Recycled Materials in European Highway Environments

Uses, Technologies, and Policies

International Technology Exchange Program

U.S. Department of Transportation
Federal Highway Administration

October 2000

NOTICE

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Technical Report Documentation Page

1. Report No. FHWA-PL-00-025	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Recycled Materials in European Highway Environments: Uses, Technologies, and Policies		5. Report Date October 2000 6. Performing Organization Code
7. Author(s) Vincent E. Schimmoller, Katherine Holtz, Dr. T. Taylor Eighmy, Carlton Wiles, Michael Smith, Gerald Malasheskie, Gerald J. Rohrbach, Shari Schaftlein, Greg Helms, Robert D. Campbell, Charles H. Van Deusen, Bob Ford, John A. Almborg		8. Performing Organization Report No.
9. Performing Organization Name and Address American Trade Initiatives P.O. Box 8228 Alexandria, VA 22306-8228		10. Work Unit No.(TRAIS) 11. Contract or Grant No. DTFH61-99-C-0005
12. Sponsoring Agency Name and Address Office of International Programs Office of Policy Federal Highway Administration U.S. Department of Transportation		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes FHWA COTR: Donald W. Symmes, Office of International Programs		

16. Abstract

The objective of this scanning tour was to review and document innovative policies, programs, and techniques that promote the use of recycled materials in the highway environment. The U.S. delegation met with more than 100 representatives from transportation and environmental ministries, research organizations, and industries in Sweden, Denmark, Germany, the Netherlands, and France.

The European countries visited all had recycling policies promoting sustainability as well as a pervasive public culture about recycling. Many of the countries use an effective stakeholder process to develop engineering and environmental specifications. Generally, recycling occurs when it is economical to do so. Factors in the marketplace are dominant, but are supported by government policies and regulations such as bans on landfilling, landfill taxes, natural aggregate taxes, and, in some cases, subsidies to assist recycling efforts.

The U.S. delegation made a number of recommendations to encourage increased awareness of the benefits of using recycled materials in road construction, and the report includes specific actions for transferring findings from the scanning tour to various stakeholders. The delegation believes it is particularly important to adopt aspects of the Dutch sustainability model.

17. Key Words	18. Distribution Statement
Leaching test, waste-to-energy, municipal solid waste, coal fly ash, slag, valorization, construction and demolition, recycled asphalt pavement, subbase	No restrictions. This document is available to the public from the Office of International Programs FHWA-HPIP, Room 3325 US Dept. of Transportation Washington, DC 20590 international@fhwa.dot.gov www.international.fhwa.dot.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	132	Free

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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October 2000

ACKNOWLEDGMENTS

The trip described in this report would not have been successful without the contributions of many individuals. Most of all, the team members thank the officials, engineers, scientists, and other people in the countries that we visited. These individuals and their organizations contributed significant time and resources to prepare and make presentations, provide the team with the latest information, and make us comfortable. There are too many to list here; please see Appendix A for their names and affiliations. The delegation also wishes to recognize all those who worked behind the scenes to make us comfortable during our stay in their country.

Contributions from the staff of the American Trade Initiatives, Inc. (ATI) were essential to the organization, start, and completion of the trip. This organization, working as a contractor to the Federal Highway Administration (FHWA), managed the pre-trip logistics, escorted the team throughout the trip, and provided support to prepare and publish the report. Team members would like to recognize the following ATI staff:

- Joe Conn for his guidance and assistance in organizing the trip.
- Jake Almborg for organizing pre-trip meetings and teleconference calls. His guidance, counsel, and leadership as our escort enabled us to maintain a hectic schedule in as comfortable a manner as possible.
- Alexandra Doumani for her assistance in making trip arrangements and in other aspects of the trip.

In addition to coordinating arrangements in Paris, Ms. Marie-Dominique Gorrigan acted as an interpreter in France and translated several papers for use in the final report. We gratefully acknowledge her contributions.

The scanning trip was sponsored by the FHWA Office of International Programs, the American Association of State Highway and Transportation Officials (AASHTO) through the National Cooperative Highway Research Program (NCHRP) administered by the National Academy of Sciences, and the Recycled Materials Resource Center (RMRC) of the University of New Hampshire.

FHWA INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAMS

The FHWA's international programs focus on meeting the growing demands of its partners at the Federal, state, and local levels for access to information on state-of-the-art technology and the best practices used worldwide. While the FHWA is considered a world leader in highway transportation, the domestic highway community is very interested in the advanced technologies being developed by other countries, as well as innovative organizational and financing techniques used by the FHWA's international counterparts.

INTERNATIONAL TECHNOLOGY SCANNING PROGRAM

The International Technology Scanning Program accesses and evaluates foreign technologies and innovations that could significantly benefit U.S. highway transportation systems. Access to foreign innovations is strengthened by U.S. participation in the technical committees of international highway organizations and through bilateral technical exchange agreements with selected nations. The program has undertaken cooperatives with the American Association of State Highway Transportation Officials and its Select Committee on International Activities, and the Transportation Research Board's National Highway Research Cooperative Program (Panel 20-36), the private sector, and academia.

Priority topic areas are jointly determined by the FHWA and its partners. Teams of specialists in the specific areas of expertise being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Teams usually include Federal and state highway officials, private sector and industry association representatives, as well as members of the academic community.

The FHWA has organized more than 35 of these reviews and disseminated results nationwide. Topics have encompassed pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, safety, intelligent transportation systems, planning, and policy. Findings are recommended for follow-up with further research and pilot or demonstration projects to verify adaptability to the United States. Information about the scan findings and results of pilot programs are then disseminated nationally to state and local highway transportation officials and the private sector for implementation.

This program has resulted in significant improvements and savings in road program technologies and practices throughout the United States, particularly in the areas of structures, pavements, safety, and winter road maintenance. Joint research and technology-sharing projects have also been launched with international counterparts, further conserving resources and advancing the state of the art.

For a complete list of International Technology Scanning topics, and to order free copies of the reports, please see the last page of this publication.

Website: www.international.fhwa.dot.gov
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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACEC	American Consulting Engineers Council
ACPA	American Concrete Paving Association
ALT-MAT	Alternative Materials Program
APC	air pollution control
APWA	American Public Works Association
ARRA	Asphalt Recycling and Reclamation Association
ASTM	American Society for Testing and Materials
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
ATI	American Trade Initiatives, Inc.
BUD	beneficial use determination
C&D	construction and demolition
CERCLA	Comprehensive Response, Compensation and Liability Act of 1980 (Superfund)
CMRA	Construction Materials Recycling Association
DOT	department of transportation
ECOS	Environmental Councils of States
EPA	Environmental Protection Agency
EU	European Union
FHWA	Federal Highway Administration
GIS	geographic information system
HSWA	Hazardous and Solid Waste Amendments
LCCA	life-cycle cost analyses
LTAP	Local Technical Assistance Program
MACT	maximum achievable control technology
MSW	municipal solid waste
NAA	National Aggregates Association
NAPA	National Asphalt Pavement Association
NCHRP	National Cooperative Highway Research Program
NGO	non-governmental organization

NSA	National Stone Association
OECD	Organization for Economic Cooperation and Development
PAH	polycyclic aromatic hydrocarbons
PCA	Portland Cement Association
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RAP	recycled asphalt pavement
RCRA	Resource Recovery and Conservation Act of 1976
RMRC	Recycled Materials Resource Center
SMA	stone mastic asphalt
TAA	tar amended asphalt
TEA-21	Transportation Equity Act for the 21st Century
TRB	Transportation Research Board
UNH	University of New Hampshire
WTE	waste-to-energy

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EXECUTIVE SUMMARY

BACKGROUND

Use of recycled materials in the highway environment has been occurring with varying degrees of success in the United States for the past 20 years, notably with recycled asphalt pavement (RAP), reclaimed concrete pavement, coal fly ash, and blast furnace slag. In the 1998 Transportation Equity Act for the 21st Century (TEA-21), the U.S. Congress established the Recycled Materials Resource Center (RMRC) at the University of New Hampshire (UNH) to use research and outreach to reduce barriers to recycling in the highway environment. Congress also stipulated research into recycled materials to improve the durability of the surface transportation infrastructure. A number of states (e.g., Pennsylvania) and local governments have passed legislation to promote recycling in road construction. The private sector is developing innovations in materials processing and in new applications, particularly in appurtenances. Some states have beneficial use determination (BUD) processes to evaluate uses; however, there is no uniformity among states. State departments of transportation (DOTs) and state environmental protection agencies (State EPAs) are trying to balance the desire for increased use of recycled materials with concerns about potential environmental impacts. Interest is increasing within all levels of the highway community to learn about advances in the use of recycled materials in the highway environment and how they relate to sustainability initiatives within the transportation sector.

OBJECTIVES AND PANEL COMPOSITION

The objective of this scanning tour was to review and document innovative policies, programs, and techniques in Europe. Recommendations would be made that would lead to reduced barriers to recycled material use in the United States. Sweden, Denmark, Germany, the Netherlands, and France were identified as nations that have active research, policies, and programs promoting the use of recycled materials in the highway environment. The U.S. delegation met with more than 100 representatives from transportation and environmental ministries, research organizations, contractors, and producers involved with recycled materials in the five countries.

The U.S. delegation was assembled under the Federal Highway Administration's (FHWA) International Technology Scanning Program. The panel was sponsored by FHWA, the American Association of State Highway and Transportation Officials (AASHTO) through the National Cooperative Highway Research Program (NCHRP), and the Recycled Materials Resource Center (RMRC) at the UNH. The panel included members with expertise in materials, pavement engineering, pavement construction and recycling, beneficial use determinations, and environmental evaluation. Panel members represented FHWA, U.S. EPA, State DOTs, the American Public Works Association (APWA), the National Asphalt Pavement Association (NAPA), and academia.

Interest is increasing within all levels of the highway community to learn about advances in the use of recycled materials in the highway environment and how they relate to sustainability initiatives within the transportation sector.

GENERAL CONCLUSIONS

Recycling for Sustainable Road Construction

All the countries visited had recycling policies specifically or generally promoting sustainability as well as a pervasive public culture about recycling and social democracy that promotes national behavior change. Many of the countries use an effective stakeholder consensus process to develop engineering and environmental specifications. A wide variety of factors influence recycling success – from national values to practical considerations at the regional level. Some of these drivers are a lack of virgin material, public opposition to aggregate mining, high transportation costs, opposition to landfilling, and high population densities. In areas of the United States where similar drivers are present, European experiences may be relevant and solutions transferred. In the Netherlands, for example, the Dutch have a formal policy for sustainable development in highway construction that embraces the use of recycled materials. There is public opposition to landfills and the excavation of natural materials. The government has a policy that minimizes the use of natural materials and promotes the use of recycled materials within a market system. The government cooperates with industry by sharing risk and profit and providing unambiguous technical and environmental standards. High degrees of recycling are seen, especially for construction and demolition (C&D) aggregates, blast furnace slags, recycled asphalt pavements (RAP), coal fly ashes, steel slags, and municipal solid waste waste-to-energy bottom ash. The government has helped to start companies specialized in the marketing of lightly contaminated soils for use in sound barriers adjacent to highways, fills, and embankments. The success seen in the Netherlands is related to advances in all aspects of the sustainability model: a robust market, clear policy, economics, appropriate technical and environmental standards, and innovative technical processes that involve the private sector. The Dutch sustainability model has elements that should be considered in the U.S. transportation community's overall goals for transportation sustainability.

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Economics

Engineering and environmental life cycle costs and benefits are the basis for many of the recycling initiatives in Europe. The free market generally plays a central role in all aspects of the highway recycling industry. Where this is not the case, government acts as a catalyst to establish a market. Tax structures (both incentives and disincentives) have played a large role in promoting recycling in the highway environment in Sweden, Denmark, the Netherlands, and Sweden. There are taxes on the use of natural materials in Sweden and Denmark, and such taxes also are being considered in the Netherlands. Restrictive landfill taxes and policies in the Netherlands, Denmark, France, and Sweden also are promoting recycling; in these countries, the landfills are frequently government owned. A pending European Union (EU) landfill directive for 2002, designed to limit the landfilling of inert materials, also is influencing recycled material flow; many contractors in the five countries are positioning themselves to use more recycled materials. A number of materials like RAP, blast furnace slag, crushed concrete, and high quality C&D aggregates are of high engineering and environmental quality and compete favorably with natural materials. Demand for some of these materials in the Netherlands is so high that shortages are anticipated. Engineering and, in some cases, environmental warranties that reduce government or owner liability are widely used and provide flexibility for the greater use of recycled materials. These warranties also drive innovative public sector research. Widespread sentiments were expressed in many of the countries that recycled materials should be evaluated on their technical merits for their highest possible use and not because of direct governmental mandates.

As in the United States, there is still concern that many engineering test methods used for traditional materials do not predict true field performance of recycled materials.

Engineering

Recycling is generally encouraged at the national level by transportation ministries that provide standardization, specialized testing, and performance evaluation. A number of countries require that recycled materials meet the same specifications as natural materials and provide equal performance. An approved product list is generally not used in the host countries, but rather ultimate performance is more of a driver to promote recycled materials use. There is a general sense that recycled materials should be used in an application to return the highest possible value. As in the United States, there is still concern that many engineering test methods used for traditional materials do not predict true field performance of recycled materials. Research in Germany, Sweden, and the Netherlands is addressing this issue using equipment that simulates the loaded wheel test on site. In Europe, priority is given to performance-related tests such as cyclic load triaxial and gyratory compaction. In Germany, the team visited an accelerated testing facility using an impulse loader. Road test sections can be placed and subjected to variable water table levels and freeze-thaw cycling. The impulse loader permits 25 years of vehicle loading over short time frames. The Netherlands uses performance-related test methods, both in the laboratory and in accelerated loading tests. Researchers then examine the price-performance ratio of the investigated materials to determine a market-oriented application. In the Netherlands, an innovative, Swiss-designed double drum hot-mix plant capable of recycling up to 70 percent RAP was observed. This Ammonn Plant operates with two drums, one installed above the other. The bottom drum is a parallel flow drum that operates as a dryer and heats the RAP. Exhaust air from this drum is used as burner air for the counter flow top drum, which dries and heats the virgin aggregate. Output from both drums is mixed with asphalt cement in a mixing chamber. The mixed product is conveyed to silos. The stack from this plant had very little visual emissions. In Denmark, Tarco Construction operates a traveling combination drum mixer and paver. A cross section of existing asphalt is placed in windrows after cold milling. This material is picked up by the travel plant and transferred to a drum mixer where asphalt cement is added. The new asphalt mix is then transferred to the screed section of the plant. The newly placed mix is compacted using conventional rollers. Traffic can use the pavement when it is cool.

Companies that supply natural materials also supply recycled materials. Many countries utilize technical and environmental quality assurance/quality control (QA/QC) programs so that recycled materials have the same level of quality as natural materials. Frequently, the material processor or supplier is the certifying organization.

Environment

Recycling at the national level is accomplished by environmental ministries that develop laws and compliance structure. National environmental research laboratories are developing test methods and approaches to evaluate environmental performance and assist in setting standards. Implementation and regulation are occurring at the regional and local level. There is consistent agreement to move from laboratory work to performance modeling based on field validation. An EU 4th Framework Program project called Alternative Materials (ALT-MAT) illustrates this approach and is a model for U.S. consideration. The Dutch use mechanistic leaching tests for specific utilization applications (e.g., road base, embankments, etc.) in the environmental approval process. They use this approach to determine adverse environmental impacts to background soils and ground waters, and will permit a small incremental impact over a 100-year period. A large leaching database is also maintained at the Energieonderzoek Centrum Nederland (Netherlands Energy Research Foundation - ECN). Within the EU, efforts are under way to standardize an approach for evaluating the environmental performance of products, including highway materials. Lessons also have been learned from isolated examples of environmental problems created from storage, processing, transport, or use of some materials. In some cases, public awareness and education efforts have been needed to overcome perceived environmental risks.

The countries that were visited publish annual reports that are either devoted entirely to environmental issues or contain information concerning environmental issues. These reports include information on the country's environmental goals, strategies, and programs to meet their goals. Progress toward meeting the goals is presented. An example is the Annual Environmental Report published by the Swedish National Road Administration (Vägverket - SRA). This report details the goals for air emissions, impacts on health from air emissions, noise, material recycling, consumption of natural aggregate and other materials, and similar topics associated with the environment as it relates to the road transportation sector. The Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (Dutch Ministry of Housing, Spatial Planning and the Environment - VROM) published a report, *Environmental Policy of the Netherlands (April 1999)*, that provides an excellent summary of the main elements of the Dutch environmental policy. This report summarizes improvements made in the environment (e.g., climate change, waste disposal, etc.) from 1980 to 1997 and lists the objectives for year 2000.

Within the EU, efforts are under way to standardize an approach for evaluating the environmental performance of products, including highway materials.

FINDINGS AND RECOMMENDATIONS

In the European countries visited, recycling occurs when it is economical to do so. Factors in the marketplace are dominant, but are generally supported by government policies and regulations such as bans on landfilling, landfill taxes, natural aggregate taxes and, in some cases, subsidies to assist recycling efforts. Generally, clear and unambiguous engineering and environmental test methods and performance standards help to reduce uncertainty and allow recycled materials to compete with natural materials. Where tests and standards do not exist, governments often support recycling by sharing risk. Informing and educating the public about government policies and programs to promote recycling is a key element in each country's efforts to implement successful recycling and sustainable development programs. Public information transfer campaigns are used by the governments and industry to inform the public about their respective programs and products.

The European situation is in some contrast to the U.S. situation. Some recycled materials such as RAP, coal fly ash, and blast furnace slag are widely used in a true free market situation because of their excellent performance and competitive costs. Other materials (e.g., foundry sands, steel slags) are used more locally in response to specific local market forces. There is little Federal government involvement, except for construction procurement guidelines that require use of materials such as coal fly ash when federal funds support road construction. Rather, the situation is driven at the state level. For example, the State of Pennsylvania has adopted legislation to promote recycling in the highway environment. However, there is a wide range of engineering and environmental approaches to BUDs, the process used by the states to evaluate and permit materials utilization. California, Illinois, Massachusetts, New Jersey, and Pennsylvania are working to standardize the BUD process and create reciprocity. There are widespread needs for clear engineering and environmental test methods and performance standards. The owner or contractor generally assumes risk. The states, academia, and the private sector are conducting significant research.

The U.S. delegation made a number of recommendations to encourage increased awareness of the benefits of using recycling in the construction of roads in the United States. These recommendations include establishing a recycling strategy in the FWHA's sustainability strategic plans, creating a framework for state DOTs to consider using recycled materials, taking actions to involve private contractors in promoting the use of recycled materials, conducting demonstrations of various recycling technologies, and engaging in follow-up activities with the countries that were visited. The delegation believes it is particularly important to adopt aspects of the Dutch sustainability model as a means to promote recycling in the highway environment. Recommendations also included actions for transferring findings from the scanning tour to various stakeholders in the United States. Specific findings and recommendations are detailed in Chapter 7.

Chapter One
OVERVIEW

REASON FOR SCANNING TRIP

The main objectives for the scanning tour were to review and document innovative policies, programs, and techniques used in several European countries to promote recycling in sustainable road construction. The team also wanted to identify barriers to, and the roles that non-governmental organizations and private entities played in, implementing the policies and programs, and the degree of government support and cooperation in assisting industry. Using this and other information gathered, the U.S. delegation would make recommendations that, if implemented, would reduce barriers to increased use of recycled materials in the highway environment in the United States. Sweden, Denmark, Germany, the Netherlands, and France were identified as nations that have active research and development programs, policies, and other activities that promote recycling in general, and the use of recycled materials in road environments. In the five countries visited, the U.S. delegation met with more than 100 representatives from transportation and environmental ministries, research organizations, private contractors, and producers involved with recycled materials.

U.S. PERSPECTIVE

The delegation noted several differences between the United States and the countries visited. Differences noted include country size and population density, cultural attitudes and behavior of the public, the political process, environmental practices, and engineering and technical factors such as the industrial base, the types and quantities of waste generated, and others. These differences have influenced the degree of recycling for sustainable road construction observed in these countries.

Country Size and Population Density

The countries visited are much smaller than the United States and population densities are generally high. Thus, conservation of land space and other resources are critical and help drive development of polices to conserve, reuse, and recycle energy and materials and other resources. As an example, there is plenty of land in the United States for landfills (except in areas such as New York City), but landfill space in these countries is very scarce, with Sweden perhaps being an exception. Hence, they have restrictions and taxes on landfilling of waste. In some cases, there are taxes on mining of natural aggregates.

Cultural Aspects

From a cultural and human behavior perspective, the European public generally has a long history of recycling. They strongly support waste prevention, reuse, and recycling of energy and material resources, far more so than in the United States. What might seem inconvenient to many Americans is accepted by the public in these countries as necessary to maintain a high level of recycling. Contrast the recycling rate of more than 70 percent in the Netherlands with one that is less than 30 percent in the United States. Such cultural attitudes and behavior make it much easier for the national governments to implement regulatory and economic policies to promote recycling for sustainable road construction.

Political Process

The pervasive public culture about recycling is also directly related to a form of social democracy that promotes national behavior change. In many of the countries, an effective stakeholder consensus process is used by regional and national governments for developing engineering and environmental specifications. In the Netherlands, the Dutch political process has resulted in a formal policy for sustainable development in highway construction that embraces the use of recycled materials. The government has a policy that minimizes the use of natural materials and promotes the use of recycled materials within a market system. The government also cooperates with industry by sharing risk and profit and providing unambiguous technical and environmental standards. The government also helps to start companies specialized in the collection, processing, marketing, and sales of recycled materials.

Environment

All the countries visited have strong environmental protection rules and regulations, as does the United States. There are differences, however, in the approaches used to determine what materials can be recycled and how they are used. A notable example is that for some materials, several countries are not concerned about the concentrations of constituents in a material, but rather the total amount that will be emitted over the life of its use. An example is municipal solid waste waste-to-energy bottom ash, which is used extensively in Denmark, Germany, the Netherlands, and France. One specific difference was the Dutch approach to permit a small increase in the environmental burden to soil and water over a 100-year time frame. There are also differences in the approaches to evaluate the environmental behavior of materials. The United States generally relies on a single regulatory leaching test; the countries visited usually use several leaching tests and other factors to evaluate potential utilization options and best management requirements for residuals and other materials.

The degree of cooperation between government organizations and industry to conduct research on recycled materials and develop consensus specifications for their use is probably unique.

Engineering

The team members were very impressed with the level of technical talent, experience, and professionalism of each of the host country's representatives. A large amount of quality research is being conducted on the mechanical properties, functional requirements, and environmental characteristics of recycled materials. Some of the research is in conjunction with the European Union's 4th Framework Alternative Materials Program (ALT-MAT), but a large amount is conducted within each country. The degree of cooperation between government organizations and industry to conduct research on recycled materials and develop consensus specifications for their use is probably unique.

Waste-to-energy (WTE) is used as a major technology to recover energy from municipal solid waste (MSW), as landfilling is being phased out. The use of this technology is increasing in these European countries. In the United States, the use of this technology has decreased and the majority (60 percent) of our waste is landfilled. A large amount of landfilled material in the United States is either biodegradable or can be incinerated for energy recovery. Most of the countries would use the residues generated from this process.

GENERAL AMPLIFYING QUESTIONS

To assist our European hosts in understanding the topics of interest to the U.S. team and to help them prepare for discussions, the team prepared a series of amplifying questions, which focused on eight major topics:

- Engineering practices for recycled materials in the highway environment.
- Environmental practices for recycled materials use in the highway environment.
- Emerging technologies.
- Policies, market forces, and interest groups that drive recycled materials use.
- Barriers to recycled materials use and means to overcome them.
- Long-term monitoring and performance measures.
- Perspectives of materials suppliers and contractors.
- Other topics.

Each topic included specific questions intended to provide the U.S. delegation with a better understanding of each country's activities concerned with recycling for sustainable road construction. The amplifying questions are listed in Appendix B.

SCANNING TEAM COMPOSITION

U.S. delegation members had expertise in materials engineering; pavement design, construction, and recycling; BUDs; and environmental evaluations. They represented FHWA, U.S. EPA, state DOTs, the APWA, and academia.

PLANNING AND MEETINGS

Team members met several times during the course of trip planning and actual travel. These meetings are listed in Table 1. In addition to these meetings, several group meetings were held during train and bus rides to discuss various aspects of the summary report.

GENERAL ITINERARY

The scanning tour took place from September 10 through September 26, 1999, including travel dates. Table 2 lists the countries and cities visited during the trip. Appendix C lists the officials visited, their affiliations, and contact information.

Table 1. U.S. delegation meetings.

Location	Date	Purpose
National Academy of Sciences/ Transportation Research Board; Washington, D.C.	May 6, 1999	Scanning trip organization.
Team member local sites	September 6, 1999	Teleconference; final trip itinerary, review report outline, amplifying questions, etc.
Stockholm, Sweden	September 12, 1999 (Beginning of tour)	Review any travel changes; finalize trip actions and areas for emphasis.
The Hague, The Netherlands	September 22, 1999 (Mid-tour)	Comments for organization and content of summary report and review findings to date.
Paris, France	September 25, 1999 (End of tour)	Review and modify summary report; discuss implementation issues and further team actions.

Table 2. Countries and cities visited.

Dates	Country	Cities
September 12-13, 1999	Sweden	Stockholm, Linköping, and vicinity
September 14-16, 1999	Denmark	Copenhagen, Hörsholm, and vicinity
September 16-17, 1999	Germany	Cologne, Gladbach Bergisch, Marl, and vicinity
September 18-22, 1999	The Netherlands	The Hague, Hoofddorp, and Amsterdam vicinity
September 23-26, 1999	France	Paris and suburbs

Chapter Two
OVERVIEW OF RECYCLING WITHIN THE HIGHWAY ENVIRONMENT IN THE HOST COUNTRIES AND IN THE UNITED STATES

SWEDEN

Solid Waste Management

In Sweden, waste is generally classified into three categories: domestic or household waste, industrial waste, and hazardous waste. Some categories of waste fall under special regulations or require special planning. Municipalities are responsible for developing comprehensive waste management plans, including waste that is treated elsewhere. Under Swedish law, waste from industries, shops, and public services that is comparable to household waste is included in that category. This also includes bulky waste and yard waste generated by these sources.

The Swedish Public Cleansing Law and the Public Cleansing Regulations make municipalities responsible for collection and ultimate disposal of their waste. Although more than two thirds of Sweden's municipalities use private contractors, 50 percent of Sweden's domestic waste is collected by the municipalities. Domestic waste management is supervised at the local level by the Environmental and Health Board, regionally by the County Council and, nationally, by the Swedish National Environmental Protection Board (Naturvårdsverket - NV).

Sweden refers to industrial waste as branch specific-waste, e.g., forestry waste. Each company is responsible for treating its own waste. Environmental requirements are regulated by the Environmental Protection Act and applicable regulations. Permits are issued by the National Franchise Board for Environmental Protection. Industrial wastes that have general characteristics (e.g., different types of packaging waste) can occur in any industry. These are referred to as non-branch specific industrial waste. Building and demolition waste is also classified as non-branch specific industrial waste.

Hazardous waste is the responsibility of the industrial generator, which must be permitted according to provisions of the Environmental Protection Act. Handling of hazardous waste is regulated under the authority of the Ordinance on Hazardous Waste.

Sweden requires that producers be responsible for managing their waste. Producers' responsibility for packaging materials came into force in October 1994 under the Swedish Code of Statutes (SFS 1994:1235). The objective was to have all packaging in Sweden recycled or reused by January 1997. The producers' responsibility is to ensure that this objective is implemented for waste they generate. For newspapers, magazines, and similar materials, the goal is to reuse 75 percent by weight of this material by the year 2000 (SFS 1994:1236). For waste tires, the goal was disposal by environmentally responsible methods after September 1996. By December 31, 1998, the goal was to have 60 percent of waste tires managed by methods other than landfilling. After December 31, 1998, the goal was 80 percent (SFS 1994:1236). Most waste tires in Sweden are incinerated; none are used in asphalt pavements.

For discarded nickel-cadmium batteries, there is a voluntary agreement among the importers and manufacturers (the Foundation for the Collection of Hazardous Batteries) and the government. Under this agreement, 90 percent of discarded batteries were to be collected during the second year of the agreement.

Sweden generates about 3.2 million metric tons of domestic waste each year. Of this amount, approximately 1.3 million metric tons are landfilled, including ash and slag from WTE plants. The remaining waste has been separated out and consists of white goods, paper and glass, compost and fuel from composting plants, and waste that is converted to energy at WTE plants.

WTE and landfilling are Sweden's two predominant methods for waste disposal. Twenty-one WTE plants process approximately 1.7 million metric tons of waste. Five of these plants process 70 percent of this amount. The plants generate energy equivalent to 500,000 metric tons of oil each year. Landfills in Sweden receive about 5.5 million metric tons of waste each year. Of this, domestic waste amounts to about 1.3 million metric tons. Landfill gas is sometimes recovered and used as an energy source. Sweden's landfill regulations will be modified where needed to meet pending EU requirements.

Composting plants process only about 0.13 metric tons of domestic waste annually. About 0.06 million metric tons of compost are produced. About 0.02 million metric tons of this compost are sold and the remaining is used as landfill cover.

Recycling in the Highway Environment

Information on the use of recycled materials in road construction in Sweden was provided by two sources. Data in Table 3 are from the Swedish National Road and Transport Research Institute (Statens väg-och transportforskningsinstitut - VTI); additional information was provided by research personnel from the Swedish Geotechnical Institute (Statens Geotekniska Institut - SGI). SGI reported that about 0.15 million metric tons of ferrochrome slag is produced and sold annually (after crushing) in fractions between 0 and 100 mm. Almost all of the 250,000 m^3 of copper slag produced each year is used in road construction. Under a general permit, coal bottom ash has been used in the Norköping area since 1982. About 525,000 m^3 have been used since that time.

DENMARK

Solid Waste Management

Waste management in Denmark is regulated by the Environmental Protection Act. The Act emphasizes protection of the environment in ways that will permit sustainable development. The Act establishes the legal framework, but Danish waste legislation and policy are contained in various statutory orders. EU waste management directives will be implemented as they are adopted by the Council of Ministers and the European Parliament.

Table 3. Use of recycled materials in roads in Sweden (million metric tons).

Material	Annual Production	Amount Used	Applications
Old asphalt pavement	0.8 (1999)	0.76	In new asphalt (cold or hot recycling)
Blast furnace slag	1.0 (1999)	0.7	As aggregate in unbound layers (crushed, air-cooled)
Mining waste (rock without usable metals)	27.0 (1994)	0.1-0.3	Crushed aggregate in unbound layers
Unsorted building and road demolition waste	1.5-2.0	Small quantities	As fill material; some test sections/ subbase
Steel slag	0.2	0.2	Some in demonstrations/research
WTE bottom ash	0.34	0.34	Subbase and base in roads within facility boundary; some in demonstrations

The Government Action Plan on Waste and Recycling (1993-1997) established a preferred hierarchy of waste management alternatives. These are in order of preference:

- The minimization of waste production and energy consumption through substitution and cleaner technologies.
- The recycling or utilization of materials.
- The use of WTE technology to produce electricity and energy for district heating.
- The controlled landfilling of waste.

By the year 2000, the goal is to recycle 54 percent, incinerate 25 percent, and landfill 21 percent of the waste.

Administrative and economic tools are used in Denmark to implement waste management objectives. These include the following:

- Local authorities must conduct waste surveys and design and implement appropriate plans to manage their waste.
- Regional authorities are responsible for locating landfill sites, cleaning contaminated soils, and similar activities. They also must ensure that necessary capacity is in place and that the waste actually reaches these facilities.
- The Miljø-og Energiministeriet (The Danish Ministry of the Environment and Energy) in the Miljøstyrelsen (The Danish Environmental Protection Agency - MS) enters into voluntary agreements with industry for specific waste management actions [e.g., reducing use of PVC (polyvinyl chloride), taking back nickel/cadmium batteries]. The Minister also may order producers to take back their products and assume responsibility for their disposal.
- The Danes also use financial incentives to implement waste management strategies and goals. These include taxes, fees, and subsidies. As an example, a waste tax is levied in different amounts to support the chosen waste

management method. The waste taxes are discussed in Chapter 4. Grants, provided in the Finance Act, are used to promote the use of cleaner technologies or the recycling of products, materials, or waste residues.

Municipalities are responsible for collection and disposal of household and commercial wastes. Some collect their waste and others use private contractors for this service. Most commercial waste is collected by private contractors. Municipalities also are responsible for collecting paper and cardboard from wholesalers and retailers, and industrial food waste, and oil and chemical wastes. Although some existing landfills are privately operated, future landfills in Denmark will be owned and operated by local authorities. All municipal solid waste incinerators are publicly owned and operated. However, Danish society's preference for recycling rather than disposal has resulted in the establishment, with government aid, of private sector facilities to process waste materials into usable products.

Waste generated in Denmark in 1997 is shown in Table 4. About 0.4 million metric tons of bottom ash and 0.06 million metric tons of air pollution control residues are produced from the combustion of MSW and similar waste. The bottom ash is processed to remove metals and prepare it for use. About 80 percent is used in civil engineering applications, while metals recovered for recycling account for 10 percent, and 10 percent is landfilled.

Table 4. Solid waste generation in Denmark in 1997.

Type of Waste	Amount Produced (million metric tons)
Household waste	2.8
Waste from manufacturing industries, trade, and offices	2.6
Construction waste (building rubble)	3.4
Sewage sludge	1.2
Residues from energy production (primarily from coal-fired power plants)	1.8
Total amount	11.8

Approximately 23 to 26 percent (2.8 million metric tons) of the waste is landfilled. Denmark's goal is to reduce this to 21 percent by the year 2000. Denmark has three types of landfills: inert landfills, controlled landfills, and mono-landfills. Inert landfills receive unpolluted waste (e.g., plastics, timber, etc.) and unpolluted soil. They are not lined and leachate is permitted to seep into the ground water below the site. Controlled landfills receive municipal solid waste, sewage sludge, and non-hazardous waste. These landfills are lined with synthetic, clay, or composite liners and have leachate collection systems. Mono-landfills receive incinerator ash and similar types of waste. New guidelines in Denmark require that landfills be designed and operated to reach a steady state (i.e., when biological activity and leachate generation have ceased or are no longer a threat to the environment) in 30 to 50 years. These guidelines will result in new types of landfills.

Recycling in the Highway Environment

Tables 5 and 6 provide an overview of the production of non-road wastes in Denmark and their application in Danish roads.

Table 5. Production and utilization of waste in Danish roads (million metric tons).

Material	Total Production	Unbound Material Recycled	Material to Paving Industry (Asphalt and Portland Cement)	Landfilled
Steel slag	0.058	0	0.058	0
Rolling mill	0.013	0	0	0.013
Casting sand	0.045	0	0.005	0.040
Blasting materials	0.035	0	0.009	0.026
Crushed concrete	1.060	0.763	0.096	0.157
Waste-to-energy bottom ash	0.420	0.380	0	0.040
Rockwool slag	0.010	0	0.007	0.003
Coal bottom ash	0.184	0.184	0	0
Coal fly ash	1.060	0.556	0.504	0
Crushed asphalt	0.824	0.509	0.315	0
Crushed bricks	0.484	0.322	0.005	0.157
Road cleaning waste	0.113	0	0	0.113
Total	4.262	3.772	0.941	0.549

GERMANY

Solid Waste Management

The Law on the Prevention and Disposal of Waste (AbfG) is the basis for German regulations on waste management. Waste prevention and recycling are given preference in the law. It also grants authority to the Federal government to issue directives that encourage prevention and recycling of special waste types, such as waste oil, batteries, and similar wastes. The Technical Directive of Waste (TA Abfall) defines waste that requires special handling and supervision. The second directive is the Technical Directive Residential Waste (TA Siedlungsabfall), which regulates municipal and similar wastes.

Table 6. Applications for non-road materials in Danish roads.

Materials	Applications								
	PCC	HMA	CM/ST	GB	EMB	FILL	STR	APP	LS
Steel slag	2	4	2	2	0	0	0	0	0
Coal fly ash	2	3	2	0	4	2	3	3	0
Coal bottom ash	0	0	0	0	4	0	0	0	4
Casting sand	2	2	2	0	1	1	2	2	1
Cement kiln dust	2	2	2	0	2	1	0	0	2
Blasting product	2	3	2	3	2	2	1	1	2
MSWI ash	0	2	2	4	3	3	1	1	1
Concrete	1	1	1	4	2	2	2	2	0
Tile/bricks	0	1	1	0	0	4	1	1	0
Tile/concrete	0	0	0	2	3	4	0	0	3
Harbor dredged material	0	1	1	0	2	2	0	0	2

PCC = portland cement concrete pavement (wearing surface), HMA = hot mix asphalt pavement, CM/ST = cold mix or surface treatment, GB = granular unbound base, EMB = embankment, FILL = fill (e.g., backfill, subgrade, flowable fill), STR = structures (e.g., bridges, culverts, drain inlets, pipes), APP = safety-related items (e.g., guardrails, light post), APP = appurtenances (e.g., curbs, gutters, sidewalks), LS = landscaping (e.g., mulch, picnic benches, etc). MSWI = municipal solid waste incinerator. 4 = occurs generally, 3 = limited use, 2 = does not occur, but is considered possible, 1 = does not occur, but might be possible, and 0 = considered impossible to use. MSW WTE bottom ash can only be used as a subbase in roads.

All the regulations have the objective to generate closed cycles of materials to establish a society where the environment and a sustainable economy are compatible. In 1997, a new law was enacted that makes producers responsible for the disposal of their products. The Law on Prevention, Utilization and Disposal of Waste is also referred to as the Closed Cycle Economy Law (KrW-/AbfG). Under this law, the management of waste materials must follow a strict hierarchy:

- First, to prevent wastes, especially by reducing the amounts and their toxicity.

- Second, to recover the material or energy value in the waste generated.

This hierarchy essentially places materials recovery and energy recovery on an equal basis and will permit energy recovery where it makes technical and economic sense.

MSW in Germany includes residential waste, bulky waste, commercial waste, light industrial waste, and yard and garden waste. In 1993, approximately 44 million metric tons of MSW were generated. Approximately 11 million metric tons were collected and separated for sorting and recycling. Only about 3 million metric tons were composted. In 1995, Germany had 52 incinerators and one pyrolysis plant. These plants processed about 11 million metric tons of waste for energy recovery. About 60 percent (1.8 million metric tons) of the bottom ash produced from WTE facilities is used after aging for 3 months. The air pollution control residues are disposed into mined cavities to help prevent subsidence. All materials designated for landfilling must be made inert and cannot contain substantial amounts of salt. By the year 2006, at the latest, Germany will have only two classes of landfills. Concentrations of heavy metals in the waste, as determined by the German DEV S4 leaching test, will be limited, as well as other characteristics. This information is presented in Chapter 6. These limits were established by the Technical Directive Residential Waste. The requirements to make waste inert prior to landfilling will probably result in an increase in WTE facilities because biological processes (e.g., composting) cannot meet these requirements.

Recycling in the Highway Environment

Tables 7 and 8 summarize the production of residues and their application in Germany's roads. The tables are adopted from *Roads in Germany* by the Bundesministerium für Verker (German Federal Ministry of Transport - BMV).

Table 7. Quantities and utilization of industrial by-products and recycled construction materials in Germany (million metric tons).

Type of Residue	Production	Use in Roads	Percent Used
Slag			
- Blast furnace slag	8.3	8.3	100.0
- Steel slag	4.8	4.4	92.0
Coal mining spoils	64.8	13.6	21.0
Power plant residues			
- Boiler slag	2.8	2.7	98.0
- Coarse ash	0.4	0.3	74.0
- Coal fly ash	3.1	2.7	86.0
- Brown coal fly ash	6.1	0.0	0.0
- Gypsum (coal furnace)	1.8	1.8	100.0
Refuse waste-to-energy ash	2.6	1.8	68.0
Construction materials (estimated recycling rate)			
- Recovered asphalt	12.0	6.0	50.0
- Crushed road materials	20.0	11.0	55.0
- Rubble	23.0	4.0	17.0
- Mixed construction waste	10.0	0.0	0.0
Total (rounded)	160.0	57.0	35.0

Table 8. Materials used in German roads and their applications.

Materials	A	B	C1	C2	D1	D3	E	F	G1	G2	H
	Applications										
Asphalt	1	1	2	2	2	2	2	2	1	1	
Concrete, concrete blocks	2	2	2	2	2	2	2	2	1		1
Other hydraulically bound materials (e.g., blast-furnace slag)	1	1	1	1	1	1	1	1	2		1
Natural stone, crushed and uncrushed materials, ballast	1	1	1	1	1	1	1	1	1	1	1
Gravel, sand	1	1	1	1	1	1	1	1	1	2	1
Other mineral materials	1	2	1	2	2	2					
Bricks, masonry, stoneware	1	1	1	2	1	1	2	2			2

A = acoustical barriers, B = unbound traffic areas and roads, C1 = embankments, C2 = backfilling and covering, D1 = backfilling and trenches, D2 = soil stabilization and subsoil improvement, E = bases without binders, F = bases with hydraulic binders, G1 = bases with bitumen binders, G2 = bituminous wearing and binder courses, and H = concrete bases. 1 = feasible, 2 = feasible under certain conditions.

THE NETHERLANDS

Solid Waste Management

In 1989, the Netherlands implemented a comprehensive National Environmental Plan. Waste management is covered in the Ordinance of Waste Prevention and Recycling. The ordinance established strict goals that must be met for a variety of waste streams, which resulted in significant participation by the public and industry to recover and reuse materials, and the source separation of glass, paper, putrescibles, and household and similar small quantities of chemicals.

The Dutch strictly regulate air emissions from WTE plants. The Air Emissions from Incinerators Regulation includes provisions on waste that may be accepted, as well as guidelines for emissions of metals, dioxins, and acid gases (NO_x). For landfilling, the Disposal Regulation applies and regulates the conditions for disposing waste into three different categories of landfills. These are: landfills for non-hazardous waste with and without leachate recovery, and landfills for hazardous waste. A column leaching test is used to determine in which landfill a waste may be disposed. As of 1997, no organic waste may be landfilled; the intent is to restrict landfills to only inorganic waste and to force increased composting. The ban encompasses any waste that can be recycled, including WTE residues. Demolition and construction waste also is included in the ban to encourage beneficial use of this material.

The Dutch government's objective is to decrease waste generation and increase recycling and utilization. The environmental aspects of this policy are covered in the Regulation for Construction Materials. This regulation permits a marginal impact to soil quality over a 100-year period. There are criteria that must be met under this scheme. WTE bottom ash does not meet all of these criteria, but the Dutch desire to promote use of this material has resulted in the ash being placed in a special category. It may be used in embankments and in road base provided measures are implemented to minimize rain water infiltration.

The Ministry of Housing, Spatial Planning and the Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer - VROM) issued an action plan for the reuse, treatment, and disposal of the different residue streams generated by WTE plants. The plan provides management guidelines for bottom ash, fly ash, and flue gas cleaning residues. The criteria for the controlled use of bottom ash come under the Regulation for Construction Materials. As of January 1998, fly ash cannot be landfilled without prior treatment. Investigations are ongoing to develop methods for valorizing air pollution control (APC) residues. They are currently being temporarily stored.

Hazardous wastes in the Netherlands are covered under the Hazardous Waste Designation Decree, which contains provisions for classifying waste as hazardous or non-hazardous. Provinces have the primary responsibility for the permitting of both hazardous and non-hazardous waste facilities. The central government, however, maintains a coordinating role for these activities. Contaminated soil is regulated under the Soil Protection Act and its Ordinance for Soil Clean-up. Soil is classified into three categories depending on the level of contamination. In the case where soils are used as construction materials, they come under the Regulation for Construction Materials.

In 1995, the Dutch recycled or reused 73 percent of their generated waste; about 8 percent was incinerated, about 16 percent was landfilled, and about 3 percent was discharged to the ocean by industry. In 1999, the recycling rate was still 73 percent.

The Dutch Ministry of Transports, Public Works and Water Management (Ministerie van Verkeer en Waterstaat - V&W) is responsible for the policy on mineral aggregates. One of the policy lines is to promote the use of secondary materials to diminish the use of natural aggregates. The Public Works Department (Rijkswaterstaat, RWS) within the Ministry is also the biggest client for infrastructure work. This means that implementation of policy can be done within the same ministry. This approach and the fact that recycling is a main topic within the two ministries (VROM, V&W) account for the success of recycling in the Netherlands.

In 1995, the Dutch recycled or reused 73 percent of their generated waste; about 8 percent was incinerated, about 16 percent was landfilled, and about 3 percent was discharged to the ocean by industry. In 1999, the recycling rate was still 73 percent.

As shown in Table 9, in 1996, 0.895 metric tons of bottom ash were produced by WTE plants. In 1999, this reached about 1.0 million metric tons. Almost 100 percent of the ash was used.

Table 9. Profile of waste management in the Netherlands (million metric tons).

Year	Generation*	Landfill	WTE	Recycled (percent)	Prevention (percent)
1996	N/A**	7+	5	73++	N/A
2000	51	4***	6	76	15
2010	56	2***	9	N/A	N/A

* Does not include dredge spoils, contaminated soils, manure, and radioactive waste.
** N/A: not available.
\+ An additional 0.48 million metric tons went to private disposal.
++ The target was 67 percent.
*** Amounts stipulated by the Environmental Policy Plan.

Fly ash production was 0.054 million metric tons; 40 percent was recycled as an asphalt filler. Before this material can be landfilled, it must be treated. Residues from flue gas cleaning amounted to 0.032 million metric tons; none is recycled. Recycling options are being investigated. Projected figures for 2000 and 2010 also are shown.

Recycling in the Highway Environment

Table 10 summarizes the production and applications of recovered materials used in road construction in the Netherlands. The Dutch also noted that about 0.4 million metric tons of sand are produced from processing plants. They were uncertain as to the fate of this material, but believe that some is being used without meeting environmental requirements. The market for phosphorous slag is decreasing; its radioactivity prevents its use in buildings and surrounding environments. Also, the Dutch noted that investigations are ongoing to find more uses of steel slag in concrete and asphalt applications. Some tar amended asphalt (TAA) has been recycled in the past under strict environmental and occupational health conditions only in cold bound asphalt pavement applications. After January 1, 2001, this will not be allowed. New thermal techniques are being investigated to combust recycled asphalt that contains tar.

Table 10. Recovered materials used in Dutch roads (million metric tons).

Material	Produced	Used	Applications
Asphalt concrete	7.7	7.7	Hot mix asphalt
Asphalt rubble	3.0	3.0	1.8 in hot mix asphalt; 1,200 mostly in cement bound
Municipal waste bottom ash	0.8	0.8	Unbound base course and embankments
Municipal waste incinerator fly ash	0.08	0.02-0.03	Concrete filler
Blast furnace slag	1.2	1.2	All used in cement production; about 1 million tons imported for road base
Steel slag	0.5	0.5	Used in hydraulic works and base course; some as sand
Electric coal fly ash	0.85	0.85	Used in cement, concrete and asphalt filler, and as aggregate
Electric coal bottom ash	0.08	0.08	Lightweight aggregate; some exported to Belgium for use in concrete blocks
Soil and contaminated soil	Est. 0.016	0.157	7.0 of clean soil; 7.0 slightly contaminated soils; 1.7 of heavily contaminated soil after cleaning; 1 million tons dumped at sea.
Dredge spoils	0.023	Small amounts	Highly contaminated spoils stored; by 2000, 20 percent cleaned and used.
Phosphorous slag	0.6	0.6	Base courses and asphalt
Building and demolition waste	9.2	9.2	9.0 concrete and masonry granulates used in base course; 2.0 in concrete
Concrete crusher sand	0.3	0.3	Used as sand in subbase layers

FRANCE

Solid Waste Management

In 1992, an older law about waste disposal was amended to include materials recovery. The main objective of the modification was to promote valorization (increase its value) of waste through reuse, recycling, or treatment by methods that would permit their use as materials or as an energy source. The amended law specifies that waste disposal also means (in addition to collection, transport, and storage) the necessary operations required for recovery of usable elements and materials. The law delegated the responsibility for domestic waste disposal to local authorities. After July 1, 2002, waste disposal facilities will only be able to receive waste that cannot be technically and economically treated for recycling. The law created increasing taxes on the landfilling and WTE of municipal solid waste, until the 2002 landfill ban takes affect. The types and amounts of waste generated and the methods used to manage them in 1995 are listed in Table 11.

Table 11. Waste generation and management in France in 1995 (million metric tons).

Waste Category	Produced (million metric tons)	Recycled (%)	Incinerated (%)	Composted (%)	Landfilled (%)
Municipal waste	46	6.2	47.7	6.5	39.6
Industrial waste	148				
- Ordinary	30	10	15	10	65
- Hazardous	16	0	40	0	60
- Inert waste	100*	30	5	5	60
Agricultural waste	388	20	5	40	35

* Good estimates not available; could range from 100 to 600 million metric tons.

Recycling in the Highway Environment

Table 12 lists the materials used in highway construction in France. Chapter 6 provides additional information about the use of some of these materials.

Table 12. Use of recycled materials in French roads (million metric tons).

Material	Production	Amounts Used	Use Application
Blast furnace slag	5.0	1.1	Aggregates; remaining used as hydraulic binders
- crystalized form		0.5	
- granulated form		0.6	
Steel slag	1.3	0.2	Bituminous mixes, surface dressings
Coal fly ash (silico-aluminius)	1.0	0.25	Hydraulic binders, concrete filler, embankments
Coal mining wastes	50*	3.0	Black shale in embankments; red shale in pavements
Demolition materials	5.0	Not provided	Aggregates; used primarily near cities
Old pavements	Not provided	1-2	Wearing courses and base, depending on source
MSWI bottom ash	1.5	1.0	Aggregates
Foundry sands	Not provided	Small amount	Aggregates
Tires	Not provided	Not provided	Earthworks (e.g., embankments)
Plastics	Not provided	Not provided	Asphalt binders, lightweight fill, etc.

* Estimated 50 million metric tons available in pits around France.

UNITED STATES

Solid Waste Management

U.S. waste laws and regulations classify waste into two broad categories: hazardous and non-hazardous. There also are a number of smaller categories of special wastes. The principal law that regulates these wastes is the Resource Recovery and Conservation Act of 1976 (RCRA). RCRA was amended by the Solid Waste Disposal Act of 1980 and the Hazardous and Solid Waste Amendments (HSWA) in 1984.

Subtitle D of RCRA deals with non-hazardous waste and require states to develop comprehensive solid waste management plans. Once approved, the U.S. EPA delegates the implementation and enforcement of the plans to the states. The Federal regulations provide minimum standards for the treatment and disposal of non-hazardous waste. Many states, however, have enacted more stringent standards and regulations.

In 1989, the U.S. EPA published *The Solid Waste Dilemma: An Agenda for Action*. This document promoted a preferred hierarchy for municipal solid waste management: source reduction, recycling (including composting), waste combustion (with energy recovery), and landfilling.

Hazardous wastes are regulated under RCRA Subtitle C, which contains provisions for characterizing, testing, treating, storing, and disposing of these waste materials. RCRA also requires that these wastes be supervised (manifested) from “cradle to grave” (i.e., from generation until ultimate disposal). The Comprehensive Response, Compensation and Liability Act of 1980 (CERCLA) or “Superfund” and its amendments deal with the remediation of abandoned contaminated sites that pose hazards to the public and the environment. The Act provides for the assignment of liability for the contamination at the site and the costs to clean it up.

In 1990, the U.S. Congress enacted the Pollution Prevention Act to encourage waste minimization through input substitution, product reformulation, industrial process redesign, and similar actions to reduce the quantity and toxicity of waste.

Emissions from WTE plants are regulated under the Clean Air Act. In 1995, the U.S. EPA issued new rules covering these plants. These rules are referred to as the *Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Municipal Waste Combustors*. Also known as the maximum achievable control technology (MACT), they impose strict new limits on emissions of metals and dioxin.

The design, construction, operation, maintenance, and post-closure care of landfills are regulated under RCRA. The requirements for liner and cover designs using clay, geotextiles, flexible membranes (plastic), combinations of clay and plastic, and similar materials vary depending on location and the waste (hazardous or non-hazardous). There are also requirements for leachate collection and treatment and ground water monitoring. The Federal requirements are more stringent for hazardous waste landfills than for non-hazardous landfills. As noted earlier, some states have implemented more strict requirements than the minimum technology standards required at the Federal level.

MSW includes wastes such as durable goods, non-durable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic waste from residential, commercial, institutional, and industrial sources. Examples include appliances, automobile tires, newspapers, clothing, boxes, office and classroom paper, cafeteria waste, wood pallets and similar waste. MSW does not include waste from construction and demolition activities, combustion ash, automobile bodies, municipal sludges, and some industrial process waste that might also be landfilled or combusted in municipal solid waste landfills and incinerators. In 1997, 197 million metric tons of MSW were generated in the United States. This was an increase of 7.3 million metric tons over 1996. Recycling (including composting) recovered 28 percent (55 million metric tons) of the waste, 17 percent (34 million metric tons) were combusted mostly for energy recovery, and 55 percent (109 million metric tons) were landfilled. Table 13 summarizes the MSW generation, recovery, composting, combustion, and discards to landfills in the United States for years 1960 through 1997.

Table 13. Generation and disposal of municipal solid waste in the United States, 1960 to 1997 (in million metric tons and percent of total generation).

	1960	1970	1980	1990	1995	1996	1997
Generation	79.9	109.8	137.5	186.1	191.7	189.7	196.8
Recovery for recycling	5.1 6.4%	7.3 6.6%	13.2 9.6%	26.3 14.2%	41.1 21.5%	42.1 22.2%	44.1 22.4%
Recovery for composting	neg.	neg.	neg.	3.8 2.0%	8.7 4.5%	9.6 5.2%	10.9 5.6%
Total materials recovery	5.1 6.4%	7.3 6.6%	13.2 9.6%	30.1 16.2%	49.8 26.0%	52.0 27.4%	55.1 28.0%
Discards after recovery	74.8 93.6%	102.5 93.4%	124.3 90.4%	156.0 83.8%	141.9 74.%	137.8 72.6%	141.8 72.0%
Combustion	24.5 30.6%	22.8 20.7%	12.4 9.0%	28.9 15.5%	32.2 16.8%	32.7 17.3%	33.3 16.9%
Discards to landfills and other disposal	50.3 63.0%	79.7 72.6%	111.9 81.4%	127.1 58.3%	109.7 57.3%	105.0 55.4%	141.8 55.1%

Recycling in the Highway Environment

The FHWA published a document in April 1998 entitled *User Guidelines for Waste and By-product Materials in Pavement Construction* (Publication No. FHWA-RD-97-148). Table 14 presents some of the data extracted from that report; unfortunately, complete data on the quantities produced and used each year are not available. The document listed 19 materials and 6 major application categories for a total of 55 potential applications for using the recycled materials. Table 14 discusses some of these materials.

Table 14. Use of recycled materials in roads in the United States (million metric tons).

Material	Production (million metric tons)	Used (million metric tons)	Applications
Blast furnace slag	14	12.6	Aggregate in concrete
Coal bottom ash	14.5	4.4	Asphalt aggregate, granular base, etc.
Boiler slag	2.3	2.1	
Coal fly ash	53.5	14.6	Cement production, structural fills, etc.
Foundry sands	9 to 13.6	-	Most reclaimed and used in process
Cement kiln dust	12.9	8.3	Most used on site; some use as stabilizer; estimated 90 million metric tons stockpiled
Lime kiln dust	1.8 to 13.6		
Mineral waste	1.6 billion	N/A	34 states reported use in roads
WTE ash	8.0	Small amounts	Some in asphalt, most on landfill roads and landfill cover
Non-ferrous slags	8.1	Not available	Granular base, hot mix asphalt, etc.
Steel slag	Not available	7.0 to 7.5	Aggregate, granular base
RAP	41.0	33.0	Aggregate in hot and cold mix asphalt, asphalt cement binder, etc.
Reclaimed concrete	Not available	Not available	Aggregate for cement-treated or lean concrete; aggregate for flowable fill, etc.

Chapter Three
RECYCLING FOR SUSTAINABLE ROAD CONSTRUCTION

INTRODUCTION OF PERTINENT TOPICS

Protecting the environment, limiting waste generation, and recycling and reusing materials are all key elements needed for sustainable development. As is the case in the countries visited, these elements must be properly integrated with government policies, regulations, economics, and cultural aspects for sustainable development to be successful. This is also true for sustainable road construction. The U.S. delegation observed that recycling of materials and the reuse of by-products, waste, and other non-virgin materials are critical elements in successful sustainable road construction in several of the countries visited, particularly in the Netherlands and Denmark. In these countries, governmental policies and specific sustainability initiatives support recycling in road construction. The consensus of stakeholders and each country's cultural attitudes toward recycling also are extremely important.

SWEDEN

Sweden is progressing toward using recycled materials for sustainable road construction, but the country has not advanced as far as some of the other countries in actual implementation. Swedish road contractors want to use more recycled materials; however, use of many potentially candidate materials is not widespread. As examples, general use of WTE bottom ash and steel slag is limited to applications within the boundaries of the production facilities. These materials have only been used in Sweden's roads in demonstration projects. On the other hand, air-cooled blast furnace slag has been used in several road constructions and even as subbase in highway construction.

Sweden's *Road 94* contains specifications for constructing roads. *Road 94* permits the use of recycled materials. The Executive Summary states that:

- "Residual products such as slag may be used if they are accepted by the client and:
  - Are acceptable from an environmental point of view.
  - Do not cause problems during reuse, landfill or destruction.
  - Can be shown to possess at least as good bearing capacity, stability, and durability properties as the materials they replace.
- Residual products shall be analyzed as regards chemical composition and the risk of leaching. Requirements on disposition and any safety measures shall be investigated. Consultations shall be held with the nature conservancy unit of the county administrative board."

These provisions have not been a driver for increased use of recycled materials in road construction. Barriers cited for this circumstance include the following:

- The fact that Sweden has plentiful supplies of gravel and sand, as well as bedrock that can be crushed and used.
- Sweden has sufficient land for disposal of waste materials in comparison with several of the other countries visited.
- Lack of clear guidelines at the national level for using recycled materials.
- Swedish legislation that directs that each candidate project must abide by site-specific permitting requirements.
- Length of time for obtaining permit approval.
- Lack of knowledge about recycled materials engineering and environmental characteristics.
- Lack of knowledge by the general public about the use of recycled materials in road construction.

Swedish codes require that contractors document why they are not using recycled materials. At this time, however, this requirement does not appear to be a strong driving force for using recycled materials. Until very recently, the contractor was required to have a recycled material tested to show that it was at least as good as the traditional material. Since no such preapproval process exists for natural aggregates, it is easier for the contractors to use them. The Vägverket (Swedish Road Administration - SNRA) does not require that aggregate producers be ISO 9000 certified. Most, however, are certified. ISO 9000 concerns data quality issues; therefore, certification does not guarantee that the aggregate produced by certified producers will be quality material on the basis of mechanical properties and performance.

NV does not issue permits; this is the responsibility of the local government authorities. NV does, however, require that site-specific factors be considered in the permitting process. Information on the exact location of the project, material engineering and environmental properties, environmental protection methods to be used, and similar factors are required. There is a general lack of knowledge about the engineering and environmental properties of recycled materials and how to implement the legislation. Consequently, regional and local governments want national guidelines to support implementation. The local authorities often do not have the technical and other resources needed to evaluate the permit application. Producers of recycled materials also want guidelines. These factors result in long delays in getting permits. Complicating the process is the right of non-governmental organizations (NGOs) to provide significant input into the permitting process. They can appeal decisions by local authorities to award a permit. The appeal to an environmental court can lead to reversal of the local authorities' approval. The possibility that a permit approval will be reversed by the environmental court is an added deterrent to contractors attempting to use recycled materials.

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NV has issued guidelines in other areas, but is not doing so for the use of recycled materials in road construction. Although it would like to shorten the time for permit approvals, it maintains that the users of recycled materials have the responsibility and need to take the lead in doing so.

Since 1995, Sweden has employed a tax on virgin materials of 5 Swedish kroner (Sk) (~US$0.57) for each metric ton used. Starting January 2000 there is a tax on waste of Sk 250 (~US$28.53) for each metric ton disposed into landfills. This may help to increase the use of recycled materials in road construction, though many believe the lack of national guidelines and other factors will need to be addressed first. A project being supported by the Swedish National Sand, Gravel and Crushed Stone Association is the development of guidelines for using crushed concrete from construction demolition and debris in road construction. The guidelines will cover aggregate producers, contractors, and commissioners. In developing these guidelines, the aggregate producers believe they are positioning themselves to process recycled materials. These guidelines will probably be approved by the SNRA.

Research being conducted by VTI and SGI in conjunction with the EU 4th Framework Alternative Materials (ALT-MAT) program should help increase the use of recycled materials in road construction. The ALT-MAT program is a very large, comprehensive research program involving Great Britain, Denmark, Sweden, France, Finland, Austria, and Switzerland. This research is addressing issues that will remove and reduce uncertainties associated with using recycled materials. The ultimate objective is to define methods by which the suitability of alternative materials for use in road construction can be evaluated under appropriate climatic conditions. Methods being investigated cover mechanical properties, functional requirements, leaching characteristics, and long-term stability. Secondary objectives include determining the mechanisms and rates of release of contaminants from selected alternative materials, including use of climate control chambers and lysimeter tests. Also included are inspections of existing roads, preparation of specifications for conducting full-scale trials on embankments, and comparison of the pollution potential with that from sources such as road traffic. The program also will develop recommendations for mitigation measures that can be used to enable the use of alternative materials. Better correlation of laboratory test results to performance in the field is an important goal. Sweden's role in ALT-MAT includes investigation of leaching behavior of the recycled materials and also evaluating a 15-year-old motorway and a 5-year-old highway constructed with air-cooled blast furnace slag. Two test sections with crushed concrete in the subbase have been investigated too. Information about ALT-MAT can be obtained at http://www.trl.co.uk/altmat/index.htm.

Dr. Jan Hartlén of Lund University reported on the project Utilization of Secondary Materials in Infrastructure Projects – A Regional Approach. The project report, due soon, contains information on:

- Methodology for investigating and characterizing materials.
- Crushing and sampling materials on site.
- Crushed concrete as granular base and subbase.
- Crushed concrete, bricks, and WTE ash as subbase material.

- Environmental impacts from concrete, bricks, and MSWI ash compared with natural aggregates.
- Reuse of cold asphalt, gypsum, and excavated soils after stabilization.

The report will, among other topics, discuss risk assessments and markets for these materials. A major point that Dr. Hartlén made was that under new rules, natural rock may exceed leaching requirements. He also made the point that, when proposing the use of recycled materials, one must educate officials and provide them data. He stated that it is very important to show officials that some processing (treatment), even if only a small amount, has taken place.

While at VTI, the U.S. team also heard a presentation from Dr. Andrew Dawson, from the University of Nottingham, Nottingham, England, about some experiences in the United Kingdom (U.K.). He reported on an EU project (under the 4th Framework Transport RTD Programme) called Construction with Unbound Road Aggregates in Europe (COURAGE). The program is being managed in the U.K.

COURAGE involves participants from the U.K., Portugal, Finland, France, Iceland, Germany, and Greece. The project is investigating the mechanical characterization of a range of crushed rock materials, measuring and monitoring the variability of in-situ moisture conditions in granular materials in road pavements, and modeling of the elastic and plastic behavior of unbound materials.

Dr. Dawson reported that the U.K. formerly widely used alternative materials for pavement construction. The use, however, has been significantly reduced principally because of engineering quality assurance difficulties and requirements for accountability and warranties. Contractors now bid the road project and own it for 30 years for a fee. The government will pay the contractor to build, operate, and maintain the road over its design life, but requires adherence to performance measures. Most road construction projects in the U.K. are for widening and upgrading purposes. Specifications are being driven by performance requirements rather than the characteristics of the materials. Contractors will bid the road project using natural materials and then substitute recycled materials if they believe the materials will perform satisfactorily. There are site-specific environmental requirements; the contractor is responsible for these. The project cannot affect the ground water.

Research by the U.K. and others has shown that recycled materials can be made to work. Economics, however, may be affected by the processing and management required. The U.K. now has a landfill tax (equivalent to US$3 to $4 per ton for clean industrial waste and $10 per ton for hazardous waste) that will help this situation. Dr. Dawson also reported studies at the University of Nottingham that indicate that contaminates in most recycled materials are not an issue, although pH may be important for some. In this regard, natural limestone is sometimes worse than the recycled material. University of Nottingham researchers as well as Swedish researchers are moving toward using triaxial testing to develop methods for comparing strength with stiffness. Crushed concrete is being investigated in both the ALT-MAT program and the COURAGE studies. Information about the studies at The University of Nottingham and COURAGE can be obtained at www.nottingham.ac.uk/p&g.

DENMARK

Waste management in Denmark is governed by rules and regulations ensuring that waste is collected and managed in ways that are protective of the environment and natural resources. One of the most important measures for facilitating good management is the tax on waste that is landfilled and incinerated. Local authorities have overall administrative authority for waste management and are responsible for ensuring that sufficient waste treatment capacity exists. Therefore, except in a few special cases, the local authorities determine how wastes will be disposed. Traditionally, the public sector assumed the responsibility for treating the waste. This was done by one or more local authorities establishing corporations to treat the waste. The local authorities maintained control over waste management planning and ensured the adequate flow of waste to the treatment facilities. However, Danish society's strong preference for recycling has resulted in the establishment of private sector facilities for processing waste. Most of these have been established since 1990.

The Danish government has created an atmosphere where road contractors, producers of waste materials, and suppliers are motivated to work together to assist the use of recycled materials.

The Danish government plays a key role in driving recycling in Denmark. This was also a conclusion of the Organization for Economic Co-Operation and Development (OECD) 1997 report titled *Recycling Strategies for Road Works* (OECD study), which gave Denmark very high marks for its influence in promoting the use of recyclables in road construction. The Danish government has created an atmosphere where road contractors, producers of waste materials, and suppliers are motivated to work together to assist the use of recycled materials. This effort is achieved by supporting research investigations and demonstrations, tax policies on waste disposal, and issuing recommendations, guidance, and requirements for recycling. The government's general policy is that recycling should be done at the highest level that is technically and economically feasible. An example of this is the reuse of old asphalt concrete in new asphaltic pavements. If this is not technically feasible or economic, then use as fill or road base is acceptable. The government has provided grants to assist in the startup of private sector companies to process recyclable materials. Its efforts to educate the public about using recycled materials and the general public's very positive attitude about recycling are strong drivers for using recycled materials in road construction. In 1999, the tax for using a cubic meter (M^3) of virgin materials was 5 Danish kroner (Dkr) (~US$0.65). The tax for landfilling was Dkr 375 (~US$49). Incinerating waste to recover energy for heat and power was Dkr 280 (~US$36); for energy recovery for heat only, it was Dkr 330 (~US$43). These taxes are per metric ton of material and are in addition to the operating and other costs associated with the facilities.

The Danish government also supports research for the use of recycled materials in road construction. The Vejteknisk Institut (Danish Road Institute - DRI) involves all the partners concerned with construction to develop specifications, standards, and guidelines for using recycled materials in road construction. Specifications are developed using the consensus approach similar to that used by the American Society for Testing and Materials (ASTM). Participants include the material suppliers, environmental authorities, the Vejdirektorafet (the Danish Road Directorate - VD) (for engineering aspects), the owner agency, and the contractors. An overall committee determines the need for new standards and then establishes working groups to begin the process. All interested parties are invited to participate. All participants must agree before a standard can be adopted. The process is administered by the Secretariat under the VD. This consensus approach essentially guarantees that the standards will be implemented. While the ASTM consensus approach can take many years for a standard to pass, the process in Denmark is usually completed in 3 to 4 years. The U.S. delegation considered this consensus approach a unique method for developing standards for using recycled materials in road construction.

The Danish Agency for the Development of Trade and Industry established in 1999 the Center for Restproduckter (C-RES). The C-RES's overall objective is to develop environmentally acceptable and economically sustainable methods, concepts, and technologies for characterizing and treating industrial residues, waste materials, and other by-products for better recycling and utilization. For materials that cannot be recycled, C-RES also evaluates methods to ensure that waste is landfilled properly. Cooperating and supporting partners in the Center include industry, research organizations, academia, and others concerned with the processing and utilization of waste materials. The Center is also involved in developing methods and techniques for the safe landfilling of residues. Research findings from the Center will be used to assist in the development of standards as well as to better understand the environmental and engineering behavior of recycled materials.

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Denmark participates in the ALT-MAT program and is investigating an existing road subbase containing WTE bottom ash, as discussed in Chapter 5. The ALT-MAT program primary objective for Denmark is to define methods by which the suitability of using alternative materials can be evaluated under appropriate climatic conditions. Methods will cover the mechanical properties of the materials, their functional requirements, their leaching potential and their long-term stability. The program is also determining the mechanisms and rates of release of constituents from the materials. This includes lysimeter studies, evaluations of existing road construction, development of specifications for full-scale demonstrations, and development of methods to control contaminate release that could be used to enable the use of recycled materials.

GERMANY

Since 1972, Germany has passed several laws dealing with waste management. As is the case in some other countries, the Federal government enacts the legislation, but delegates implementation and enforcement to the individual states. The Waste Management Act of 1972 established standards for the collection, treatment, and disposal of waste. The act did not address waste prevention or recycling. As improved technologies emerged, the act was amended. In 1975, the Waste Management Program was initiated and evaluated specific waste types to determine the amounts of waste materials that could be recycled and what methods were available for recycling them. Then in 1986, Germany defined a preferred order of priorities for managing waste: avoidance, recycling, and disposal. The law established a 90 percent recycling rate as a target for road construction. This Law on Waste Disposal also stated that recycled materials must meet all the requirements placed on traditional aggregates and mixes.

Germany's Closed Substance Cycle and Waste Management Act (1996) established the fundamental philosophy that producers have responsibility for the entire life cycle of the products they manufacture.

The Closed Substance Cycle and Waste Management Act (1996) established the fundamental philosophy that producers have responsibility for the entire life cycle of the products they manufacture. This only ends with the recycling or disposal of the product. As far as possible all residues generated during this life cycle must be fed back into the closed substance cycle. Only waste that cannot be recovered and recycled may be disposed of using methods protective of human health and the environment. In 1999, companies larger than a certain size must submit waste life-cycle plans. The objective of these requirements is to help increase recycling within and among companies.

Today, Germany's waste management polices are also being affected by actions of the EU. Some of these may act as a deterrent to increased recycling in road construction in Germany and other countries. As an example, the EU classifies 8 to 10 materials from construction demolition as "waste." Germany considers these "secondary materials." The EU classifies scrap tires as waste for energy recovery, while Germany refers to them as raw materials to be used in production. As in the United States and other countries, the terms "raw materials" and "secondary materials" are perceived more favorably than "waste." The EU terminology is considered problematic.

The Industry Association for Recycling (Bundeaverband der Deutschen Recycling-Bastoff-Industrie e.V.) was established in 1983 to encourage increased use of recycled materials. The association works with end users to improve the quality of recycled materials and to eliminate all environmental effects from their use. It now has more than 200 company members. More than 55,000 jobs and an estimated 35 billion Euros (~US$35 billion) have been created by its activities.

Although Germany strongly encourages industry to recycle in-house, the 1996 legislation has not resulted in large increases in the use of recycled materials in road construction. Only selected materials such as asphalt and concrete are enjoying economic success. The government does not play a strong role in the marketing of recycled materials and leaves this primarily to industry.

Factors for increased recycling in roads and other sectors include the lack of landfill space and the concern for drinking water protection. Germany has placed strict requirements on what waste can be landfilled on the basis of concentrations of selected constituents and organic content. Also, before generators of construction demolition waste can dispose of it into a landfill, they must first get a written specification from a recycling processing facility that the waste cannot be recycled.

Economics is another major factor in the use of recycled materials in road construction. No provisions in the contract bidding process give prospective contractors credit for using recycled materials. Consequently, recycled materials will only be used if they are cheaper and will perform equally as well as natural materials. Some Germans noted that because virgin materials in Germany are cheap, it is difficult for secondary materials to compete with virgin materials in the free market system. Other Germans expressed the opinion that the Federal government will need to participate in marketing and education (which it does not currently do) to help spur increased use of recycled materials. In addition, even though landfill space is limited and there are strict requirements, land disposal costs of 20 deutschemarks (DM)/metric ton (~US$9) are still low compared with some of the other countries. This fact would tend to discourage expenditures that might be required to process materials that currently are not judged to be recyclable.

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Standards govern the general requirement for materials (e.g., cement, sand, bitumen) used in Germany's roads. There are requirements for special applications and these explicitly permit the use of recycled materials and industrial by-products. Recycled materials must, however, fulfill the same requirements as natural materials. Special conditions for using recycled materials include proving that they are environmentally acceptable. The lack of specifications and guidelines for using recycled materials was seen as a barrier.

THE NETHERLANDS

The Netherlands is far advanced as far as developing and integrating policies, economic tools, regulations, and other factors needed for increased recycling and the use of recyclables for sustainable road construction. Along with Denmark, the OECD study gave the Netherlands very high marks for increased use of recycled materials. To put this into proper perspective, it is necessary to review Dutch policy concerned with economic growth and the environment. This policy was formalized in a 1997 document issued by the Dutch government. Based on the concept that economic policy, spatial planning policy, and environmental policy must be developed together, the underlying principle is that economic growth should occur only if pollution declines at the same time. This principle, referred to as "absolute delinking," requires that significant changes be made in production, prices, taxes, and government policy. It involves a long-term process that must involve all segments of society, and called for new, sustainable forms of economic activities such as:

- Manufacturing of environmentally friendly products and services that meet the needs of consumers, who place great importance on environmental quality.

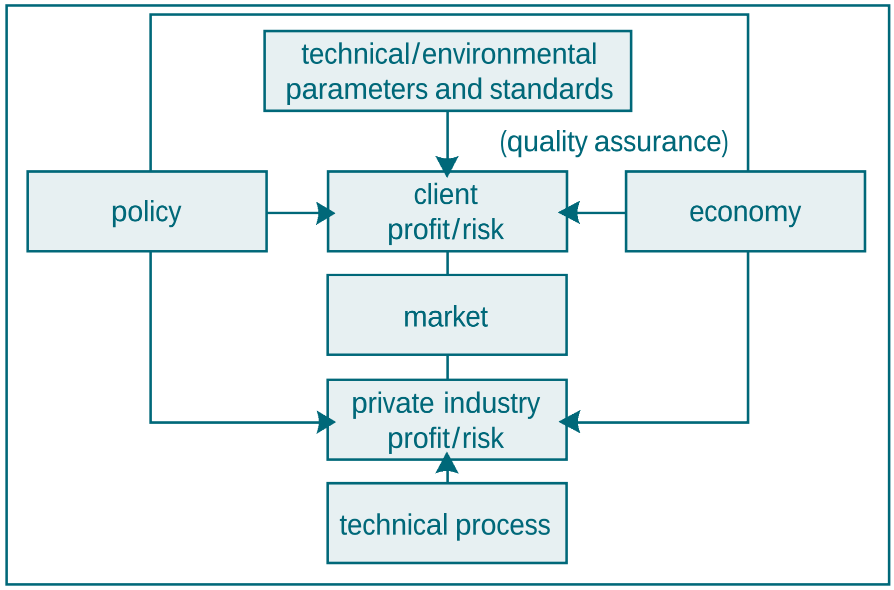
- Attainment of sustainability in all business sectors.
- Use of environmentally efficient technologies.
- Efficient use of space, spatial quality, and investments in the infrastructure to aid sustainable economic development.
- Incorporation of environmental factors in prices of goods and services.

From an environmental perspective, sustainable development involves three main policies: the Waste Materials Policy, the Soil Protection Policy, and the Surface Mineral Policy. The Waste Materials Policy is based on the "Lansink Ladder" for waste management: prevention, recycling, burning, and dumping. Among the provisions of the Soil Protection Policy is the concept of permitting a marginal environmental burdening of soil when using secondary materials. This policy permits an increase (up to 1 percent) of contamination above background levels in the top layer of soil over a 100-year period. Objectives of the Surface Mineral Policy are to encourage the conservation of raw materials, stimulate the use of secondary materials as much as possible, support the use of renewable raw materials, and ensure that adequate supplies of raw materials are available for construction.

Consistent with the Lansink Ladder, the Netherlands has a hierarchy of preferred options for managing waste. In the Environmental Management Act, in the chapter on waste (Jan. 1994), the order of preferences is: prevention, reuse and recycling, waste-to-energy, and landfilling. The Act also established rules and regulations for preventing waste; discarding and collecting waste; and treating, processing, destroying, and landfilling waste. Several instruments have been effective in making the Netherlands a leader in recycling and reuse of materials. In addition to the Environmental Management Act, and the subsequent chapter on waste, the taxes on waste disposal, voluntary agreements with industry, public campaigns, and support of research, demonstrations, and implementation by the government have all played major roles.

The Dutch embraced a market philosophy for promoting the concept of using recycled materials in sustainable highway construction. As shown in Figure 1, the market philosophy involves numerous interactive components:

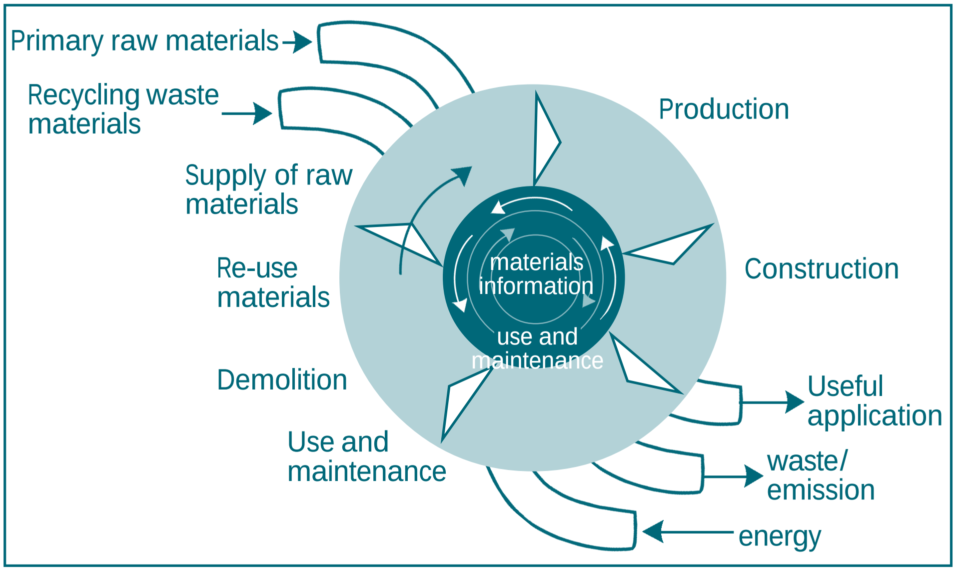
- The government provides clear and unequivocal standards for all recycled materials. The standards are usually developed through governmental research and public or industry working groups.
- Recycled materials producers treat their materials like a "product," using certified QA/QC programs so it can compete against natural materials.
- There is clear policy planning and implementation, which allows producers and contractors to prepare for this new market.
- There are incentives from the government (e.g., substantial landfill disposal taxes on materials that can be recycled and modest taxes on the use of natural aggregates) that act as stimulants.
- When these initiatives, as well as others shown in Figure 1, are combined, a mature recycling market can develop over time.



Courtesy of Jan van der Zwan

Figure 1. Market elements for a sustainable recycling strategy cycle in the Netherlands.

The Dutch sustainability model emphasizes that products should be manufactured for future recycling. This and other concepts are depicted in Figure 2. The supply of primary and recycled materials and their engineering and environmental behavior in products are critical factors. Construction should consider future maintenance and demolition requirements. Furthermore, demolition should be done using methods that enhance recovery and utilization of the materials (e.g., dismantling a building rather than using a wrecking ball). As depicted in the figure, some materials enter the closed cycled of use and maintenance; others do not. However, some materials that do not enter this closed cycle may still be utilized. Waste and emissions leave the chain and must be properly managed. An objective of following this philosophy is to avoid designing a recycling scheme for a by-product material without evaluating all the potential options and future consequences, including its engineering and environmental behavior. One must consider the future reuse of the same product, or how it can be recycled into a different product or use. An example is that the use of tar in Dutch roads appeared to be a good recycling strategy at one time. It now causes considerable problems for recycling old asphalt pavements.



Courtesy of Jan van der Zwan

Figure 2. The cyclical nature of a sustainable recycling market.

The Dutch government determined that more space would be needed for residential housing, agriculture, industrial development, and similar uses; therefore, space for landfills is being strictly controlled and mining for natural aggregates is being curtailed. Protecting the environment is a high national priority. Imposing high taxes on landfilling and the high cost for waste-to-energy because of flue gas cleaning requirements are examples of actions being used to implement environmental policies and help increase recycling. Landfill fees range from 80 to 800 Dutch guilders (f.) (~US$35 to $352) per metric ton depending on the type of waste being landfilled. These fees will increase in 2000. In 1995, the Dutch began a phased ban on landfilling of 32 wastes; construction and demolition wastes were included in 1997. This ban has helped to increase recycling of these materials.

In 1972, the Standard Specification System for Works of Civil Engineering Construction (RAW Systematiek) was established by the Dutch Ministry of Transport and Water Management (Nederlandse Ministerie van Verkeer en Waterstaat - V&W) and the Dutch Road Building Association (Nederlandse Vereniging van Wegenbouwers - NVWB) with the objective of developing standard civil engineering specifications. The Information and Technology Center for Transport and Infrastructure (Stichting Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek - CROW) was formed in 1987 to consolidate overlapping research and standardization activities. The RAW Systematiek was also incorporated into CROW. CROW acts as a knowledge broker. Its main objectives are to develop guidelines, specifications, and research on civil engineering, traffic and transport, and technology transfer. It is a non-profit organization through which the national government, provinces, municipalities, contractors, consulting organizations, public transport, and educational institutions cooperate in the design, construction, and management of road and traffic transport facilities. Research is funded by all parties and knowledge is provided by all parties involved in the specification development process. CROW has a Board of Directors with members from these groups. CROW does not conduct research directly but does formulate and supervise needed research. In this role, it is responsible for research and standards development involved in all phases of the construction process, including maintenance and demolition.

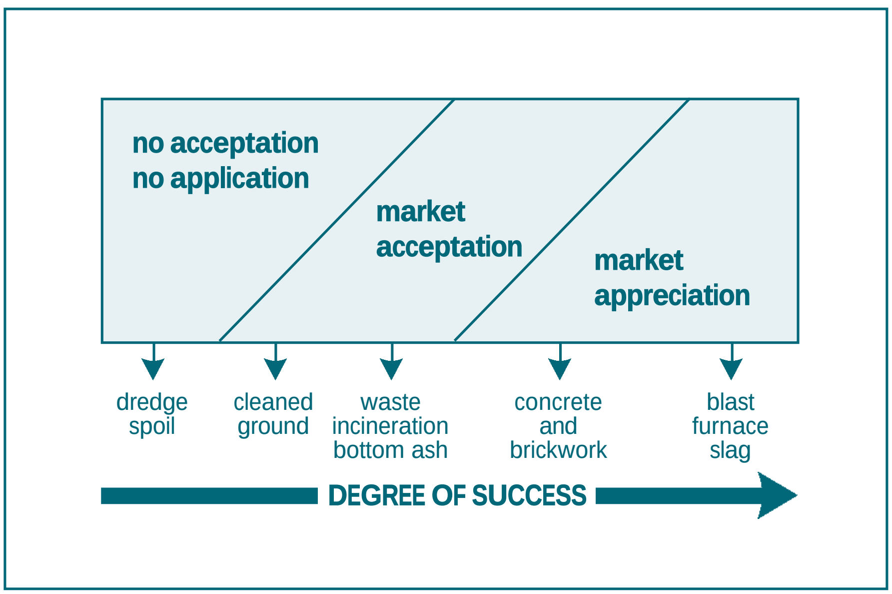
CROW publishes the civil engineering specifications referred to as the "RAW Systematiek." The RAW Systematiek is determined by the partners involved in the construction process. CROW serves in a planning and supervisory role and ensures coherence among the various parts of the standard specifications. Parties participating in the CROW standardization work include:

- V&W.
- NVWB.
- Provincial Transport and Environmental Services (Provinciale Waterstaat).
- Dutch Association of Municipalities (Vereniging van Nederlandse gemeenten - VNG).
- Government Service for Land and Water Management (Dienst Landelijk Gebied - DLG).
- Civil Engineering Contractors Association (Vereniging Aannemers Grond-, Water- en Wegenbouw - VAGWW).
- Dutch Central Dredges Association (Vereniging Centraal Baggerbedrijf - CB).
- Dutch Association of National Building Contractors (Vereniging Grootbedrijf Bouw - VGBouw).
- Dutch Association of Consulting Engineers (Orde van Nederlandse Raadgevende Ingenieurs - ONRI).
- The Association for the Promotion of Asphalt Works (de Vereniging tot Bevordering van Werken in Asfalt - VBW Asfalt).

Work is carried out in working groups and committees with all parties equally represented. The results of the work are included in the civil engineering standard specifications and are made available to the users of the RAW Systematiek. Because of the selection procedures and requirements of the process used to develop the specifications, there is a high level of quality and acceptance of the specifications. Because of the Dutch economic and environmental policies, and the strong desire of the partners involved in the RAW Systematiek, the use of recycled materials is included. This helps stimulate their use in construction. There are standard environmental specifications that do not distinguish secondary materials from natural materials. As long as they meet the specifications, they can be used.

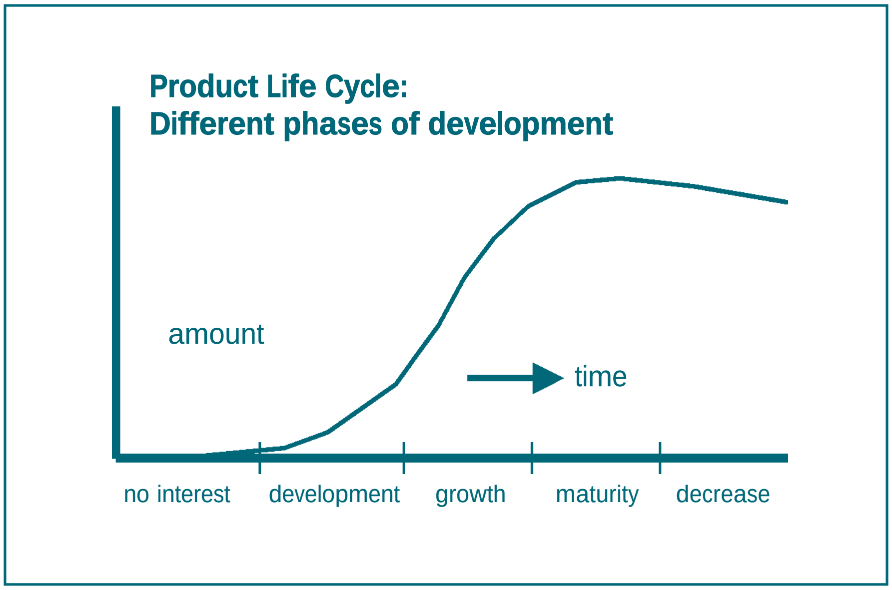
The Dutch Poldermodel is a model for cooperation between the government and industry and has been instrumental in implementation of the Dutch Building Materials Decree (DBMD), which in turn has promoted the use of waste materials in road construction. This model resulted from 15 years of many changes, developments, and rule making. Industry found it difficult to move quickly enough to adjust to the new developments and rules. The DBMD was cited as an example of a complex rule that was difficult to implement (see Chapter 6). A working group was formed to address this issue. A result was the Dutch Poldermodel, which is basically a model for democratic consensus building to find solutions to complex problems of regulations development, implementation, and associated factors. In this case, the goal was to find ways to implement the DBMD so that it would meet the needs of the secondary materials industry, and at the same time meet the needs for environmental protection. The objective was to not destroy the industry in order to protect the environment. There was a need for functional regulations with detailed standards, open communication and transfer of information, environmental quality, and operational recycling systems. The government agreed that it would not change the rules or formulate new rules to replace ones already in force during the Poldermodel development. Industry agreed that, in order to meet the conditions for environmental protection and increased recycling, it was necessary to improve the quality of secondary materials. These actions led to the development of a process used to approve materials, certify companies, and ensure quality control. A statistical approach is used for quality control to reduce costs associated with analysis of samples. Also important to the industry is that approved materials are no longer considered "waste," which helps to establish markets for the recycled products. There are provisions for taking actions against companies that do not comply with the agreement. An interesting note was that for several years, producers of natural materials were against this move to assist the establishment of a secondary materials industry, but they now are producing them in addition to their core business. At present, discussions are being held to determine necessary actions to maintain the viability of small companies that will have financial difficulties implementing certification steps related to the DBMD.

The market concept mentioned earlier, as applied to sustainable recycling initiatives, has matured to the point that there are now concrete examples of products that can compete in the marketplace while promoting sustainability. The Dutch Water Works Department (Rijkswaterstaat - RWS) has used two product life-cycle models to illustrate the degree of market success and the development phases for using recycled materials, which are shown in Figures 3 and 4.



Courtesy of Jan van der Zwan

Figure 3. Degree of success for use of recycled materials in the Netherlands.



Courtesy of Jan van der Zwan

Figure 4. Different phases of development of recycled materials.

The Dutch cited several reasons for the high level of recycling in the Netherlands:

- Space requirements in a small country with a high population density.
- Need for long-term care of landfills and the desire to minimize this burden.
- Avoidance of WTE where feasible.
- Use of financial incentives (e.g., high landfill costs, subsidies, etc.) to promote recycling. One example is that certified companies receive a fee for dismantling cars for recycling.
- A ban on landfilling of recyclable waste (e.g., C&D).

Dutch industry identified five factors for the success in recycling:

- Development of recycling technology.
- A well-defined technical program.
- A clear and unambiguous policy regarding engineering and environmental requirements.
- Government policies that restrict landfilling.
- The fact that the owner of the construction project is the responsible party if problems occur.

Dutch industry also identified the following factors for successfully creating private markets for recycled materials:

- Industry has an active selling policy.
- Industry invests in facilities for processing waste into useful materials.
- Industry improves the quality of recycled materials and uses high volumes of materials.

- Government acts to solve any social problems that arise.

As an independent verification of the success of the Dutch sustainability model, an official of a WTE bottom ash processing plant attributed the high level of recycling of the bottom ash to the following factors:

- Having clear, concise regulations that everyone understands.
- Establishing and maintaining a high level of quality control over the process.
- Having a high level of cooperation between government and industry.

Based on these discussions, there is no doubt that the Dutch government's policies and actions have significantly affected recycling in the Netherlands and led to their impressive recycling rates.

FRANCE

The team noted that France has very similar barriers to the use of recycled materials to those in the United States. These barriers, which include economics, public relations, an undefined role of the Federal government, and a lack of strong incentives, affect the degree of recycling for sustainable road construction. The U.S. delegation did, however, observe some programs and initiatives in France that may be transferable to the United States.

French delegates indicated that there are increasing environmental pressures to use recycled materials, and they expect expanded efforts in the year 2002. They also stated that France has a long history of using waste materials, especially during the period of heavy infrastructure building. During this period (1955-1975), blast furnace slag, coal fly ash, coal mining wastes, and other industrial wastes were recycled into construction. Since 1975 to the present, the responsibility to eliminate waste is that of the producer. When wastes are produced, they are expected to be used within their own industry. This method was intended to encourage industry to find better solutions for reducing and using waste.

A 1992 law requires a landfill ban in place as of 2002 that will restrict landfilling to only those wastes that cannot be recycled. Other parts of the policy involve the need to increase the quantities and quality of secondary materials and to improve the quality of household waste.

As in other countries, France has standards, specifications, guidance documents, and technical references for use in road construction; however, there are no standards that are specific to recycled materials. If one wishes to use a recycled material as an aggregate, for example, then one must go to the standards that deal with natural aggregates. Also, the same testing procedures used for traditional materials are used for recycled materials. Some view this situation as a barrier against use of recycled materials, particularly since research has shown that, in some cases, the traditional tests do not apply; that is, the tests do not adequately evaluate the properties of recycled materials in specific applications.

French policy promoting use of recycled materials in roads is only a few years old, and has concentrated on the use of WTE bottom ash and construction demolition waste. In only a few cases have other materials been used. The policy to use recycled materials was the result of the strong political will of the Environmental Ministers. Others, however, also supported the policy. The Ministère de Equipment, du Logement, des Transport et du Tourisme (Ministry for Public Works, Housing, Transportation and Tourism) was faced with shortages of natural materials in some areas of France, particularly in Paris. In these areas, the road construction industry also supported the policy. Concurrently, a portion of the public with strong environmental ethics helped push the policy.

The French use two main ways to implement increased use of recyclables in road construction:

- The Directorate for the national road network and the local authorities responsible for their roads can use the technical references for a construction project to permit the use of recycled materials.
- The contractor can develop bids in response to contract proposal requests that include the use of recycled materials in place of traditional materials, even if the contract request does not include this provision.

It is unclear how effective these methods are in encouraging use of recyclables in road construction, particularly in areas where natural materials are plentiful.

The Ministry of Public Works facilitates research to encourage increased use of recycled materials in the industry. The research is conducted by public technical research organizations such as Service d'Etudes Techniques des Route et Autoroutes (SETRA) and Laboratoire Central des Ponts et Chaussées (Central Bridge and Road Laboratory - LCPC). Research generated by these organizations is used to develop regulations, specifications, and codes of practices for using recycled materials. A major objective for supporting this research is to help assure road authorities, consulting engineers, and others that the candidate recycled materials will meet performance requirements.

With respect to NGOs, the role has been to advocate reuse and recycling. Although the informed public strongly supports recycling, the general public has not participated in pushing for the increased use of recycled materials in roads.

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The French discussed several barriers, including:

- The added cost of processing recycled materials makes them more expensive to use. Construction demolition waste is a good example.
- The low cost of landfilling inert waste. Some concern was expressed about how well the 2002 landfill ban will be enforced.

- Concerns about who will pay the added cost of using recycled materials. Although taxes on using virgin materials are being considered, no one likes taxes.
- Although grants have been used to help start recycling companies, these grants are being reduced.
- The lack of standard regulations on the national level and the differences that exist among the various regions and local states. Desires were expressed for a stronger Federal role.
- Questions and concerns remain about the long-term performance and containment of recycled materials used in the road environment. There is an interest in obtaining such data.
- The fact that there are large quantities of natural materials available in most of France. Natural aggregate shortages exist in only a few areas.

The French delegates also identified initiatives and programs that are being implemented or that are needed to overcome some of these barriers:

- Development of technical engineering and environmental guidelines to assist local and regional stakeholders in using recycled materials.
- Development of technical requirements for public works professionals and consultants.
- Availability of assistance to aid innovation in the processing and use of recycled materials.
- Support to conduct pilot and demonstration projects and testing of procedures for selective deconstruction and demolition.
- Development of quality control procedures for processing recycled materials.
- Proper characterization of new products.
- Placement of production restrictions on quarry authorities.
- Establishment of requirements that a minimum percentage of recycled materials be used in selected construction activities.
- Resurgence of the 1975 law that mandates no discrimination against recycled materials.
- France is obligated under EU provisions to use recyclable materials in construction applications.
- An increase, rather than decrease, in grants and investments in recycling facilities.
- Development of methods for better communication and exchange of information among professionals and with the public to help alleviate fears about the use of recycled materials in the highway infrastructure.

Uncertainties were expressed about the ultimate responsibility for recycled materials in the event of problems, (e.g., mechanical failure, environmental, etc.), that the definition of waste is too broad, and about the necessity for specific and precise contracts and controls. As was the case in Germany, France also has concerns about the EU's definition that a recyclable material is still a waste, which has resulted in an unclear definition of a material that has been processed through a recycling facility. Is this material a "product" or a "waste"?

Suppliers and contractors emphasized several points about the use of recycled materials in their construction projects. Twenty million metric tons per year of recycled materials are used, the market for which was developed purely on economics. Industry did not rely on government support or intervention in developing the market. Working groups were formed to exchange knowledge and establish rules. Performance standards and environmental guidelines were developed on the basis of the concentrations of sulfate, phenols, and heavy metals. These activities resulted in published guidelines and rules for using recycled materials. Quality assurance plans are important, and adopted use must not compromise quality of the final product. The overriding theme is that in using recycled materials, there can be no compromise regarding quality. The recycled aggregate has to be at least the same quality as the virgin material.

Industry representatives stated that, in their opinion, there were differences between the government's talk about increasing the use of recycled materials and the reality industry experiences. Examples of this disconnect included the fact that companies are expected to use any waste they generate within their own company, which creates a barrier for one industry to use the waste from another. Industry representatives also cited the problem of the low bid process. Because using recycled materials usually costs more, it results in higher bids. Another example cited was that contractors have been given permission to use only 10 percent of old asphalt in new mixes. France produces about 5 to 6 million metric tons of RAP each year. Contractors want to use greater amounts of RAP in the mixes because they believe it can be done easily. They stated that if they were permitted to use 15 to 20 percent in the mixes, they would consume all that is produced.

The Technical Road Committee in France is working with the highway industry to develop protocols for valorizing new products. Based on data gathered, it has published a document providing a "Charter for Innovation." It offers a framework for companies to valorize their own products. Each company agrees to a protocol specific to its product. To date, more than 100 companies have done so, and it has resulted in the use of recycled materials in new projects. It was noted that even though recycled materials often cost more, some users are willing to pay the added cost because of increased performance. However, French representatives also stated that some government subsidies may be needed for significant increases in the use of recycled materials to take place.

SUMMARY OF OBSERVATIONS

All the countries that were visited had recycling policies specifically or generally promoting sustainability. There also is a pervasive public culture about recycling and social democracy that allows national behavior change. Many of the countries have an effective stakeholder consensus process that is used for developing engineering and environmental specifications. A wide variety of drivers influence recycling success, from national values to practical considerations at the regional level, many of which are common to the United States. For instance, in the Netherlands, the Dutch have a formal policy for sustainable development in highway and other construction that embraces the use of recycled materials. There is public opposition to the landfilling of waste materials and to the excavation of natural materials. The government has a policy that minimizes the use of natural materials and promotes the use of recycled materials within a market system supported by government policies. The government cooperates with industry by sharing risk and profit and providing unambiguous technical and environmental standards. High degrees of recycling are seen, especially for construction and demolition aggregates, blast furnace slags, asphalt pavements, coal fly ashes, and steel slags. The government has helped to start companies specialized in the brokering of lightly contaminated soils for use in sound barriers adjacent to highways. The successes seen in the Netherlands are related to advances in all aspects of the sustainability model: a robust market, clear policy, economics, appropriate technical and environmental standards, and innovative technical processes. The Dutch sustainability model has recycling elements that should be included in the U.S. transportation community's overall goals for transportation sustainability.

Chapter Four
ECONOMICS

INTRODUCTION OF PERTINENT TOPICS

Economics plays a critical role in the use of recycled materials in road construction in all the countries visited. Economics affects all aspects of recycling for sustainable road building: engineering, environmental issues, testing regimes, markets, specifications, and all the other factors necessary for success in using recycled materials for sustainable road building. Because recycled materials can often be more expensive than traditional materials, government policies and incentives to develop favorable economics and markets for using recycled materials are critical to increased use of recycled materials. Key elements relating to the economic forces affecting the use of recycled products in road construction in the countries visited include the use of life-cycle analyses, free market systems, national and local governments policies, regulations, taxes, and EU directives regarding the free flow of materials. The degree to which each of these applies varies from country to country. As an example, the Dutch government's involvement and support are playing a significant role in establishing markets and the infrastructure needed for successful increased use of recycled materials in road construction. In Sweden, this is not yet the case. This difference is evident when one compares the level of recycling in road construction taking place in the Netherlands compared with that in Sweden.

This chapter describes prevalent economic factors in each of the countries visited.

SWEDEN

As noted earlier, Sweden is not as advanced as some other countries in their use of recycled materials in roads. For some materials (e.g., WTE bottom ash) Sweden's experience is limited to experimental demonstration projects. However, because of the year 2000 legislation requiring a tax of Sk 250 (~US$28) per metric ton for landfilling, plus an Sk 5 (~US$0.57) per metric ton tax on virgin materials, contractors want to use recycled materials. They believe that secondary materials can work or be engineered to work. On the other hand, contractors also realize that processing these materials will make them more expensive to use. Other factors exacerbating the economics include the lack of national engineering and environmental guidelines for these materials, the permitting process at local levels, Sweden's plentiful supply of natural materials, and concern about the environment.

Permitting for projects is done at the local level, and the process usually requires many resources from both the local government and the contractor. Although the Swedish EPA has developed national environmental regulations and policies, it has not developed guidance on how to apply these to the use of recycled materials. Local governments, contractors, and others want these guidelines, but the Swedish EPA has not yet shown an active interest in developing them. Furthermore, the Swedish Road Administration has no economic interest in developing guidelines, since its general attitude is that roads should not be a dumping place for waste. Having local decision authority without national guidance prevents the implementation of many projects.

Sweden interacts with the NORDIC and the Council, European Commissions of Transportation Ministries. It has working agreements with the U.S. FHWA and the Minnesota Department of Transportation. Sweden is participating in the ALT-MAT program, conducting research on candidate recycled materials. VTI and SGI are cooperating in doing the ALT-MAT research. Drivers for this research include the EU directives and polices concerned with the environment and increased recycling goals, as well as Sweden's geographical position in relation to other countries. The Swedes believe they need to be much more active in order to remain competitive. They hope that ongoing research will help remove some barriers impeding the use of recycled materials and will provide information to valorize some of the materials and help reduce the permitting costs, to make recycled materials more competitive in the marketplace.

... the key to future success will be the price for conventional primary materials compared with candidate recycled materials.

Sweden acknowledges in the OECD study that it has been out-distanced by many countries with respect to having strategies for increasing the use of recycled materials in road construction. The OECD noted that, in order for Sweden to reach the goals established by several other countries, the Swedish government will have to be a major influence in establishing markets. To date this has not happened, and the key to future success will be the price for conventional primary materials compared with candidate recycled materials. The upcoming taxes on landfilling and virgin materials may begin to support increased recycling; however, the Swedish government does not yet have programs in place to help establish markets for recycled materials or for educating the public about the benefits of increased recycling in road construction. Even though the new environmental law requires contractors to document why they are not using recycled materials, it is not seen as a strong market driver because the added cost of using recycled materials can be a valid reason for not using them.

DENMARK

Perhaps the key observation that the U.S. delegation made in Denmark was the strong influence of the Danish government in the establishment of market forces favorable to the use of recycled materials in road construction. Taxes are an example. Presently, the tax for landfilling each metric ton of waste is Dkr 375 (~US$49). Virgin materials are taxed at Dkr 5 (~US$0.66) for each cubic meter used. The high cost of WTE, which ranges from Dkr 280 (~US$36) per metric ton to Dkr 330 (~US$43) per metric ton, depending on how the energy produced is used, also is an inducement for industry to recycle as much as it possibly can.

The implementation of taxes has been gradual, but proactive. In 1987, a tax of Dkr 40 (~US$5) per metric ton was placed on incineration and landfilling. In 1990, it was increased to Dkr 130 (~US$17) per metric ton. In 1993, the taxes were raised to Dkr 160 (~US$20) per metric ton for incineration and 195 (~US$25) per metric ton for landfilling. In 1997, the taxes were raised to Dkr 210 (~US$27) per metric ton for incineration with energy recovery, Dkr 260 (~US$34) per metric ton for incineration without energy recovery, and Dkr 335 (~US$43) per metric ton for landfilling. In 1999, the taxes were raised to Dkr 280 (~US$36) per metric ton for incineration with energy recovery, Dkr 330 (~US$43) per metric ton for incineration without energy recovery, and Dkr 375 (~US$49) per metric ton for landfilling. Limited landfill space and the need to conserve natural resources are also reasons for the taxes. The combination of these factors is a compelling reason for the increased recycling in Denmark.

Government-private partnerships have been used to help private companies establish facilities for processing and producing higher value recycled materials. A good example of this is the Råstof og Genanvendelse (RGS 90) facility visited by the team (see Chapter 5). This plant was started 8 years ago in partnership with the Copenhagen municipal government. Facility personnel gave the Danish government (federal and municipal) high marks for their involvement and their programs for educating and selling the concept to the public. There are a large number of similar facilities in Denmark, and competition among them has led to innovation and the production of high-quality materials that are attractive to contractors. Producers pay for the waste to be delivered to the processing facilities. Because transportation costs are high, location is a key factor in the success of these companies. RGS 90 provides an added incentive by having supplies of virgin materials available to clients who need them; this allows a truck to transport a load in both directions, thus saving transportation costs.

The production of high-quality secondary materials is as important as the Danish philosophy to recycle to the highest use possible. Implementing this philosophy also affects the economics of recycling since processing and producing the secondary materials are more costly than traditional materials. In some cases, this added cost is justified by the improved material performance alone. Electric arc slags were shown to produce a high-quality product for use in wearing courses. While initial cost to use this material is higher, it was justified based on a longer service life. Using the results from test trials, a life-cycle cost analysis was used to document the added value of the longer life, which was then built into the bidding process for the contract. Because of its longer life, the contractor offered a 12-year warranty instead of the usual 5 years. The Road Directorate shared in the risk associated with the longer warranty, demonstrating its commitment and support for using recycled products.

GERMANY

The importance of economics in furthering the use of recycling for sustainable road construction is equally important in Germany. The 1996 Closed Substance Cycle and Waste Management Act has not resulted in significant increases in recycling. Even though the act requires that only waste that cannot be recycled may be landfilled. Under the act, companies larger than a certain size will be required to perform life-cycle analyses on their waste. This effort is expected to increase recycling within a company, but may not be very effective for increasing use of recycled products in road construction. Since no provisions in the contract bidding process provide credit or other incentives for using recycled materials, contractors will only use them if they are cheaper. The materials also must perform at least as well or better than traditional materials.

Germany has a free market system, and secondary materials have a difficult time competing with virgin materials. Virgin materials in Germany are cheap and landfilling costs are low, even though Germany has strict requirements on landfilling. German legislation requires that companies perform life-cycle analyses and develop waste economy plans. The EU also requires that member countries develop waste management plans. It is not clear how successful these plans will be in increasing recycling. Industry representatives and others expressed the opinion that the Federal government must play a major role in educating the public about recycling and in developing markets for their use.

The German Federal Association for Construction Recycling (Verband Deutscher Baustoff-Recycling-Unternehmen e.V.), consisting of contractors and suppliers, believes that there are market opportunities for recycled materials; however, there are no strong German programs to take advantages of these opportunities. The association also believes that the quality of recycled materials is the critical issue, but does not believe that establishing an artificial economy for comparing these materials with natural ones is the answer. To create ecobalance, each stage of the recycling scheme must be evaluated in comparison with the disposal options and these then are compared with virgin materials. Economics should not be considered in the ecobalance process. Although political forces in Germany have often demanded more recycling, economies of the free market system have clearly been a deterrent.

In the case of C&D waste, a processing company indicated that it must sell its product at a price lower than that for virgin materials. It operates on a very small margin, even though it gets paid for taking the waste materials. Processing this type of waste is expensive, and the economics of the situation make it difficult for these type of companies to remain competitive in Germany. A positive influence, however, is the requirement that producers of this waste get a certification from a processing facility that the waste is not recyclable before they can dispose of it in a landfill. Because of this requirement, the processing facility carefully inspects the waste before accepting it, which has resulted in cleaner C&D waste coming into the facilities, which in turn helps processing costs and the production of higher value products. Any waste left after the processing is the responsibility of processing company. Because of cheap landfill costs in nearby France, some of the waste is transported there.

Although political forces in Germany have often demanded more recycling, economies of the free market system have clearly been a deterrent.

Warranties for roads made with recycled materials in Germany are usually for 5 years, the same as for virgin materials. After the warranty period, the owner of the road is responsible for problems. This is another impediment to using recycled materials without a history of actual use. Contractors or the industry are also required to monitor roads made with recycled materials. This requirement involves frequent reporting to local and regional authorities, which can be burdensome and costly to the contractor.

Another factor pointed out as adversely affecting the increased use of recycled materials in roads is the high cost associated with German reunification and its associated economic stress.

In 1989, DEUTAG founded DEUTAG Gesellschaft remex für Baustoffaufbereitung mblt (Remex construction company). The company was founded on the basis of its engineering and marketing experiences in recycling industrial mining waste, and the expectation that the Federal government would take actions to increase recycling. The objective was for Remex to become a leader in the processing and marketing of quality materials from construction demolition waste. Today, Remex and associate companies are working in nearly all German states with more than 60 plants. They are expanding to other European countries. Remex attributes this success partly to the establishment of a working group of building industry stakeholders to voluntarily begin development of guidelines and standards in the absence of clear legislative guidelines from the Federal government. Since Remex is apparently successful, some might argue that there is no need for the Federal government to interfere with the free market system to aid the increased use of recycled materials in roads.

THE NETHERLANDS

There is no question that the Dutch government has been instrumental in creating a market for using recycled materials in road construction, and is considered a leader in Europe in this area, as was discussed in Chapter 3.

Key economic instruments that are driving recycling in the Netherlands include:

- The very active role the Dutch government takes in supporting research, demonstrations, and development of specifications and guidelines for using recycled materials.
- Federal policies regarding land use and the restrictions on mining of natural materials.
- High taxes on landfilling and the high cost of WTE.
- The ban on landfilling of construction demolition waste.
- The “delinking” of economic growth with pollution and the resulting Dutch programs and economic assistance to implement this policy.
- The requirement that producers assume the responsibility to internalize recycling and disposal costs, which means the polluter pays. This creates an economic incentive to recycle because of the high cost of disposal.
- The use of life-cycle analysis to give credit and added value to products made with recycled materials on the basis of improved environmental performance.
- The leadership role of the Dutch government, which has provided a large share of the costs associated with developing standards, guidelines, and specifications for using recycled materials.

Some consider that the Dutch have created an “artificial market” for recycled materials, but they consider this a positive action that was necessary. Quality is not compromised in this system and recycled materials must meet performance requirements. In some cases, longer life cycles help offset the higher initial cost of using recycled materials. The Dutch policy of allowing a marginal impact to the soil over a long period of time also has been a positive force for using some materials, such as slightly contaminated soil, that might normally be landfilled. The Netherlands does not permit dilution (e.g., mixing contaminated soil with clean soil), but one can mix such materials if there is a well-defined functional use and environmental performance is not compromised. WTE waste bottom ash is normally used in large quantities to make it more economical.

Dutch industry has responded positively to the partnership role of the government in recycling, which has allowed the industry to be more innovative in developing markets for recycled materials.

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FRANCE

Factors affecting the economics of recycling in France are similar to those of the other countries. Factors specific to France include the following:

- Some areas in France have shortages of virgin materials for construction. In these areas, the use of recycled materials is economical for road construction. However, in many parts of France supplies of virgin materials are abundant, which means that recycled materials will only be used if there are strong incentives to do so. Contractors stated that they want to use more recycled materials but the government has not done enough to influence the markets for these materials.
- Land disposal fees for inert waste in France are generally low, which acts as an economic deterrent to increased recycling and the use of recycled materials in roads. Costs are high for processing waste into quality secondary materials. Some expressed hope that the year 2002 landfill ban will improve this situation.
- France has provided grants for starting recycling processing facilities. These grants, however, are being reduced at a time when industry believes they should be increased.
- According to several French delegation members, France has recognized the need for taxes to support increased recycling. Among those discussed are taxes on virgin materials. No one likes taxes so this idea has not gone beyond the discussion stage. Placing restrictions on mining of virgin materials is also being considered.
- The law of supply and demand has prevented the use of more baled light plastic bottles for use as fill. Although demonstrations have proved this a good use, the rate of production requires that they be stored for several years to generate enough quantities needed for a road construction project. This is not economical for either the producer or the road contractor.

- Several large demonstration projects using waste tires, crumb rubber, and plastic bottles emphasized the need to adjust the economics, the importance of participation by the authorities, and the approval of the public. In one of the construction projects, the bid procedures were modified so that contractors could take economic credit for the environmental benefits from using the recycled material. The authorities were instrumental in persuading the public to accept the 5 percent cost differential for using recycled materials. In another project, the partnership between the contractor and the state and local authorities proved critical in getting the project approved and done.

SUMMARY OF OBSERVATIONS

Engineering and environmental life-cycle cost and benefits are a basis for many of the recycling initiatives in Europe. The free market generally plays a central role in all aspects of the processing and utilization of recycled materials in the highway construction industry. In some cases, the governments have acted to implement polices and other mechanisms, including subsidies, to establish markets. Tax policies and structures play a significant role in promoting recycling in the highway environment. This is especially true in Denmark and the Netherlands, and to a lesser extent in Sweden and France. High landfilling taxes and policies that ban or restrict waste in landfills are promoting recycling in Denmark and the Netherlands. Although landfill costs in Germany are low compared with other countries, Germany's restrictions on landfilling promote recycling. Similar instruments also are expected to increase recycling in France and Sweden. Like Sweden, Denmark and the Netherlands also place taxes or other restrictions on the mining of natural materials. Germany is considering such a tax.

A pending EU directive aimed at limiting the land disposal of inert waste in 2002 will influence the flow of recycled materials; companies are positioning themselves to process more recycled materials and contractors are doing the same to use more. The quality of recycled materials is a key issue for their successful marketing. The processing industries in several countries (e.g., Denmark, the Netherlands, Germany) are producing high-quality materials (reclaimed asphalt pavement, bast furnace slag, crushed concrete, construction and demolition aggregates) that meet strict engineering and environmental standards. They compete favorably with natural materials. Demand in the Netherlands has resulted in shortages of some recycled materials. The policy in many of the countries is that recycled materials should be used at their highest value based on technical considerations, rather than on government directives. Engineering and environmental warranties for roads constructed with recycled materials reduce the concern of responsible owners for future liabilities. Innovative public research, often in cooperation with government, has improved the quality of recycled materials and the applications for their use. In several cases, this resulted in warranties two times longer than normal. Although it will take political will and innovative approaches both in the public and private sectors, many of these market models may be applicable within state or regional economies in the United States.

Chapter Five
ENGINEERING

INTRODUCTION OF PERTINENT TOPICS

All of the countries visited use established standard engineering practices in building their roads. These practices do not change dramatically when constructing roads with recycled materials. The U.S. delegation, however, did observe several strategies and technologies relating to or affecting the engineering aspects of using recycled materials in each country's road construction operations. These include specifications for recycled materials, engineering and environmental performance characteristics, the concept of equal quality for recycled and virgin materials, testing procedures to predict long-term performance, and the use of life-cycle analyses. Although many of these subjects are not engineering issues, they do affect the final engineering parameters for a project. One of the main problems noted by several countries appears to be how to better evaluate the engineering and environmental performance over the design life of a road. Existing procedures used for virgin materials may be inadequate for recycled materials in many cases. The engineering practices of interest to the U.S. delegation are noted in the discussions that follow.

SWEDEN

Most of the innovations occurring in Sweden concern the research being jointly conducted by VTI and SGI in conjunction with the ALT-MAT program. The ALT-MAT program is concentrating on the relationship between laboratory testing and actual field performance. One of the objectives is to develop more functional tests that better relate to actual performance and thus decrease the reliance on empirical measurements that may not be satisfactory for recycled materials. Another objective is to better characterize the engineering and environmental properties of recycled materials. The link between engineering properties and environmental performance of a product is important, and not often considered in the United States. In addition to this research, SGI has proposed a procedure to conduct risk assessments for using recycled materials that it believes is better than what is currently being used in Sweden (see Chapter 6).

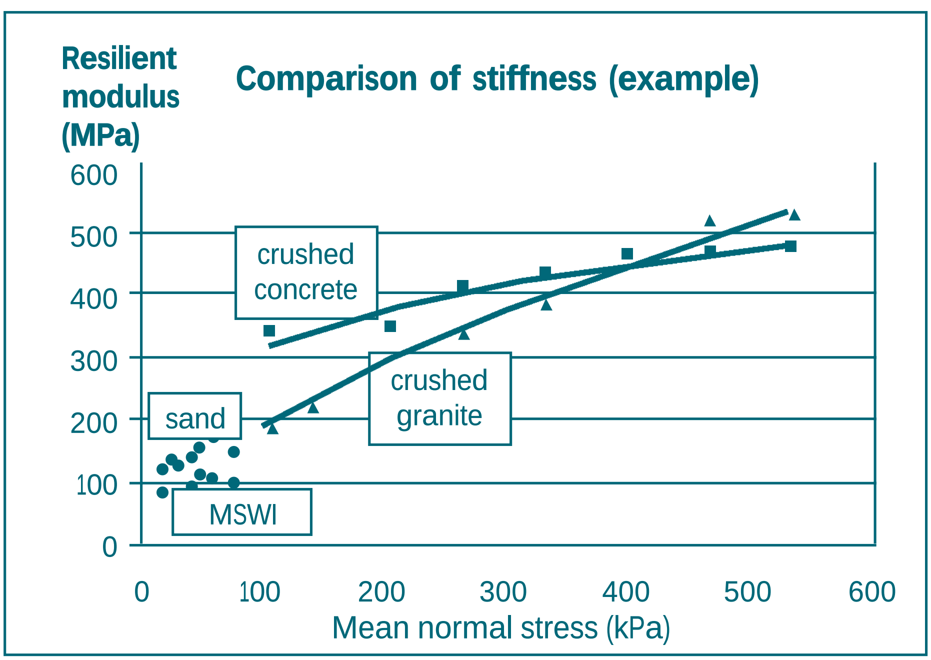
VTI's testing facilities include a road simulator, an advanced wheel-tracking machine, a Heavy Vehicle Simulator (constructed in South Africa and jointly owned by the Finnish VTT), a falling weight deflectometer, a rolling vehicle deflectometer, road surface tester using a laser technique, and other equipment. VTI has used these facilities to conduct laboratory and full-scale research on various aspects of road materials engineering and performance. The Heavy Vehicle Simulator permits full-scale testing under well-controlled climatic conditions. Figure 5 shows the Heavy Vehicle Simulator and the fully instrumented pavement test section. The simulator can be placed in one of VTI's indoor pavement bays where climatic conditions are controlled, including the alteration of the ground water table below the pavement and the influence of freezing and thawing cycles on pavement performance. The pavement layers are instrumented to measure strains, stresses, and other parameters. The heavy load simulator will be used to test pavement structures made with recycled materials. The test system is expensive to operate. There are apparently three in the United States: two in California and one at the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory in New Hampshire.

Figure 5. The (a) Heavy Vehicle Simulator and (b) a fully instrumented pavement test section in the pavement bay at VTI.

Bearing capacity is measured using a falling weight deflectometer. A rolling vehicle deflectometer permits measuring bearing capacities at normal traffic speeds. VTI uses a test it refers to as “osmotic action” using sodium chloride solutions in conjunction with freeze-thaw tests to evaluate durability of asphalt mixes under severe winter conditions. Base and binder mixes known to have poor field performance also perform poorly in this test. The test is not used for porous mixes. VTI facilities also enable testing of shear modulus and phase angle of asphalt mixes, parameters needed in a visco-elastic design system. It has conducted extensive fatigue testing using direct tensile strength tests and has developed relationships for both laboratory and field testing of typical Swedish base mixes. These efforts will help them better predict performance of recycled materials.

Dynamic triaxial testing is being done to compare secondary materials with natural materials. Figure 6 shows the triaxial test machine. Resilient modulus is plotted against measurements of stress (kPa) to compare the stiffness of one material with another. Figure 7 is an example of results from using repeated load triaxial tests to compare secondary materials with natural materials at VTI.

Figure 6. Triaxial testing machine at VTI.



Courtesy of Maria Arm

Figure 7. Triaxial testing data.

The U.S. delegation identified the following engineering practices in Sweden as also being important:

- The finding that slags used in the wearing course imparted very good skid resistance and anti-polishing characteristics.
- Engineering properties of recycled materials must meet or exceed that of virgin materials.
- Development of specifications for the use of blast furnace slag as a subbase for roads and guidelines for the use of crushed concrete in heavy load areas (e.g., parking lots, bus stops).
- An innovative triaxial test, used at VTI, in addition to the grain size distribution and durability testing of secondary materials. Sweden uses thick, unbound layers in its roads, and the testing of materials concentrated on this use.
- The fact that most of the contractors in Sweden are ISO 9000 certified.
- Development of draft guidelines for using crushed concrete in road pavements. The crushed concrete is placed into four classes based on its properties. The guidelines specify the class to use for each potential application.

Sweden's *ROAD 94* provides the general technical specifications for road construction. Although recycled materials can be used if accepted by the client, they must be at least as good as the virgin materials. These specifications are not based on performance, and the researchers and others believe that the standard tests do not apply to recycled materials. This is seen as a big barrier to the use of recycled materials in road works. Therefore, the testing program at SGI and VTI were considered very important by the U.S. delegation. VTI uses repeated load triaxial tests (60 to 120 kPa pressure depending on the material) to evaluate the engineering properties and is using the test to compare recycled materials with virgin materials. The test is not a standard one, but it is a functional test similar to the SHRP method. The test evaluates deformation as a function of repeated load (similar to the ASTM T-292 method) and gives information about the resilient modulus and permanent deformation. The U.S. test looks at continuous loads only. In plots comparing resilient modulus with mean stress, 250 kPa is the highest stress that is observed in unbound courses. Based on this comprehensive research, VTI and SGI hope that Sweden will begin to use more functional-based tests to evaluate recycled materials for road construction. In this case, the triaxial test would measure bearing capacity and stability, freeze-thaw tests would evaluate frost heaving properties and durability under different climatic conditions, and some test other than the LA abrasion test would evaluate mechanical durability characteristics.

The SGI research facilities include several large lysimeters currently being used to evaluate several different materials in the EU ALT-MAT program. These are shown in Figure 8. Although these are environmental tests, they are included here because of their relation to the ALT-MAT program and the joint research on engineering and environmental properties of materials. SGI's research includes investigations of leaching protocols for characterizing and predicting environmental behavior over the long term under field conditions. Tests being done in the ALT-MAT program include total constituent analysis, TOC, two-stage serial batch leaching test, pH static at L/S 10, availability leaching test at pH 7 and pH 4, and column leaching tests. Leachates are analyzed for alkalinity, Cl, sulfates, major constituents, trace elements, and others including non-volatile organic compounds.

Figure 8. Lysimeters used at SGI for field leaching of candidate recycled materials.

Based on these leaching studies and the engineering research, SGI and VTI hope Sweden will begin using lysimeter leaching tests and more functional tests to evaluate the environmental and engineering characteristics of recycled and traditional materials.

DENMARK

In Denmark, the U.S. delegation noted the following engineering practices:

- Denmark has abandoned the use of recycled tires because of technical and environmental problems. One host reported that crumb rubber pulled out the light oils, causing the asphaltic concrete to age prematurely. Most waste tires in Denmark are burned for energy.
- The routine use of electric arc slag in the wearing surfaces.
- The warranties on roads are normally 5 years. Some, however, are as long as 12 years. An example is for high-quality asphalt produced using electric arc furnace steel slags.
- The consensus process for developing guidelines and specifications for using recycled materials is important to the engineering of road works in Denmark (see Chapter 3). The process considers both engineering and environmental properties, again emphasizing the importance of the inter-relationship.
- The re-mixing of asphalt in hot-in-place recycling on partial or full lane applications was of interest. Selection of roadways, layer thicknesses, and mix designs appear to be subject to engineering judgment and practical experience.

- The mini-in-place travel plant for in-situ asphalt recycling may have some applications for maintenance operations in metropolitan areas in the United States. However, it only scarifies to about 1 to 1 ½ cm, which may not be sufficient for many applications. It may, however, have good application for preserving pavements over a longer life by arresting deterioration from load and environmental stresses before it becomes significant. The large asphalt traveling plant can scarify to about 12 cm.
- The U.S. delegation visited a road embankment that contained 212,000 metric tons of coal fly ash with a density of 1.1 to 1.2 metric tons/m^3. It was constructed around 1984. Figure 9 shows portions of the embankment. The U.S. delegation noted several interesting aspects about the embankment. This project was a demonstration, and the design was based on experiences in the UK. Although the ash contained 25 to 45 percent moisture, compaction was not a problem. The asphalt bicycle and pedestrian paths constructed on the site have shown no signs of cracking over the 15 years, indicating little if any settlement has occurred. Because of the highwater table at the site, a sand layer was used to break the capillary action. The site was covered with clay soil to prevent water infiltration and potentially contaminated water runoff.

Figure 9. A highway bridge embankment constructed with coal fly ash in Denmark.

- The use of field tests and trials to establish performance characteristics of candidate materials was considered by the U.S. delegation as an important factor in Denmark's successful use of recycled materials in road works. The U.S. team concluded that Denmark's continued evaluation of environmental performance is more advanced than that in the United States.
- The Danes indicated that they have had no problems with asphaltic recycling pavements. Asphalt recycling was a standard practice in Denmark even before taxes were imposed on disposal. There is a network of asphalt plants that receive and reuse old asphalt. Specifications are the same for new pavements and for those containing recycled asphalt products, since the performance is the same. Pavement design is based on the Marshall method. Different plants use RAP to produce the mixes; the parallel drum system prepares mixes with 50 percent RAP for base courses and 30 percent RAP for wearing courses. The batch plant,

which can recycle 15 percent RAP, is not widely used anymore. Up to 80 percent RAP mixes are produced using the Marini traveling drum system, which is a combination drum mixer and paver that cold mills the asphalt in situ and places it into windrows. The material is then transferred to a drum mixer and mixed with asphalt cement. The new mix is transferred to the paver. The newly placed material is compacted using conventional rolling equipment. Recycling in cold mixes also takes place. Emulsion stabilizers, foam bitumen, and rejuvenators are not used in Denmark.

The RGS 90 A/S plant processes 95 percent of the incoming recovered waste materials to higher value products. In 1998, the plant received 660,000 metric tons of construction waste, 120,000 metric tons of industrial residues and sewage sludge, and 35,000 metric tons of garden and park waste. C&D materials processed at the plant include asphalt, concrete, tile, and mixtures of these materials. Products produced include screened soil, screened top soil, crushed concrete (0/30 mm), crushed concrete-tile mixture (0/32 mm), crushed tile (0/32 mm), and metals. Prices received for these materials range from Dkr 56 (~US$7) per metric ton of crushed concrete to Dkr 28 (~US$3) for a metric ton of crushed tile-concrete mix. The plant also produces several compost products. The 5 percent of incoming material that cannot be recycled is either incinerated or landfilled. The plant maintains supplies of virgin aggregates so that clients can transport materials in both directions, thus saving transportation costs. The facility processing equipment includes an electronic weighing station, automatic and manual sorting, crushing machines, screening equipment, magnetic separator, storage facilities, and other materials handling equipment. Environmental protection measures and strict quality control are used throughout the facility. Figures 10 and11 show various operations of the plant.

Figure 10. The C&D crushing process at the RGS 90 A/S materials processing plant in Denmark.

Figure 11. Concrete jaw crusher at the RGS 90 A/S materials processing plant in Denmark.

As part of the EU's ALT-MAT program to investigate existing sites containing recycled materials, Denmark is evaluating a 5-year-old road with a municipal waste incinerator bottom ash subbase. The road handles heavy traffic loads. The overall objective of this portion of the ALT-MAT program is to obtain information about the functional and environmental behavior of recycled materials during actual use. This involves in-situ observations in trial pits, in addition to engineering and environmental testing of samples in the laboratory. In-situ observations include visual inspections, falling weight deflectometry, and similar testing. Intrusive testing includes digging trial pits, obtaining laboratory samples, plate bearing tests, and in-situ density tests.

GERMANY

As in the other countries, recycled products in Germany must meet all the engineering properties of virgin materials. They must also be environmentally acceptable. It appears that Germany is not implementing new techniques for recycling materials into road construction. It does, however, have a very active research program that includes monitoring and evaluation of field demonstrations to verify and support the laboratory work.

The U.S. delegation concluded that the research being conducted at the Bundesanstalt für Straßenwesen (the German Federal Highway Research Institute - BASt), which includes laboratory investigations, accelerated loading, and freeze-thaw testing, is well planned and well executed. The results of this research may have significant effects on the use of recycled materials in German road works. One significant observation was that BASt indicated that a plate bearing test can be used instead of the triaxial Proctor method as a measure of performance. This may have value and application in the United States. However, unlike Denmark, Germany appears to test mix designs that may not be representative of a uniform product from a processing plant.

In research, BASt uses a pavement testing facility that employs impulse loading to test and evaluate the suitability of recycled materials. Test sections containing different recycled materials have been constructed. Ground water can be injected and temperature varied to evaluate effects of freeze-thaw cycles. Using special equipment to simulate traffic action, pulse loading at 5.75 metric tons per m^3 is used rather than a wheel. The equipment permits 25 years of loading in six weeks. Recycled materials in two sections met current specifications; four did not. Building rubble used was mostly concrete. Density is not used as an acceptance criterion because of the variability of the materials. Stiffness measurements from the plate bearing test give reliable results compared with performance. All test sections meet these requirements. Results also showed that under certain freeze-thaw conditions, building rubble needs to be restricted. Additional evaluation is required to determine if this type testing would be useful in the United States.

The U.S. team toured the Wirtgen GmbH equipment manufacturing facilities located in Windhagen, Germany. Wirtgen GmbH is one of the largest manufacturers of road construction equipment. Wirtgen's hot recycling machine with a capability for in-situ recycling and overlaying top courses was impressive to several team members. However, some expressed concern about the potential for adverse air emissions from using this machine. Wirtgen's foamed bitumen equipment and process was considered impressive and environmentally neutral. The foamed bitumen process is a stabilization technique used in Europe. The European process is relatively new in the United States. The scanning team noted significant advances in the construction equipment used to apply the foamed asphalt. These advances allow for deep road base stabilization at low cost compared with other stabilization techniques. The European foamed asphalt process involves following:

- Pulverization of the existing road surface.
- Shaping of the surface to near final grade.
- Mixing and injection of foamed asphalt cement.
- Compaction to the final grade.

The preferred method is to pulverize the existing road bed without injection of asphalt cement. This allows the contractor the opportunity to adjust the grade to its near final profile prior to mixing and injection. During the mixing and injection, hot paving grade asphalt cement is "foamed" or expanded and injected into the chamber of the remixing unit.

Foamed asphalt can also be manufactured using a portable plant. The resultant material can be stockpiled for up to 30 days before use as a base course provided it is not compacted. This has allowed for some recycled materials to be stabilized prior to use.

Foamed asphalt depends on the forceful expansion of asphalt cement. Expansion of the asphalt is obtained by the addition of a small amount of water. Air may be used if working with harder paving grade asphalts. The hot reaction is similar to the addition of water to hot oil, but is controlled in the foamed process. In the expansion process, small droplets of asphalt are forced into the pulverized materials. As opposed to conventional paving techniques, the purpose is not to coat the particles but to bind the pulverized materials together. The process has been compared with spot welding. The foamed asphalt has an attraction to the fines because of the high surface area. This creates a mortar-like paste that provides strength and cohesion of the mix after compaction. It is important to use the correct amount of water to achieve optimum expansion into the pulverized material. Expansion of the asphalt occurs in specially designed spray nozzles.

Following the mixing process, a rubber-tired roller may be used as the breakdown roller followed by a steel wheel roller as the finish roller. The result is a cost-effective, deep strength road base.

Some of the benefits of foamed asphalt over more traditional stabilization techniques include:

- Ability to stockpile material for longer periods when a portable plant is used.
- Ability to achieve deeper road stabilization during in-place recycling (up to 14 inches).
- Permits opening of roads to traffic sooner when in-place recycling is used.

Three manufacturers have been identified that produce foamed asphalt equipment: CMI, Caterpillar Paving, and Wirtgen. Wirtgen has manufactured 147 machines in the past 5 years.

Wirtgens's mobile chip spreader may also be of interest in the United States. Figure 12 shows some Wirtgen recycling equipment.

Figure 12. Assembled reclaimers ready for shipping at the Wirtgen fabrication facilities.

Based on German work, European countries use a minimum 45 mega newtons per m^2 (MN/m^2) plate load for each lift of subgrade. Germany also uses a frost prevention layer, depending on the location of the construction project. In some mix designs, Germany uses up to 50 percent RAP. Germany is also evaluating ways to recycle coal tar roads using both cold emulsion plant mix and foamed asphalt mix. This is being done on a regional project-by-project basis.

The team toured the DEUTAG asphalt plant and its subsidiary, the Remex recycling plant. DEUTAG produces about 100,000 metric tons of asphalt each year. The plant routinely uses recycled bitumen and crushed concrete to produce asphalt products. It is currently investigating the use of foundry sand and MSWI bottom ash. Figures 13 and 14 show several operations of the plant.

Figure 13. RAP bins for use at DEUTAG hot mix asphalt plant in Germany.

Figure 14. RAP containing tar at the DEUTAG asphalt plant in Germany. The plant is experimenting with processing and use of different recycled matreials.
The RAP containing tar will be tested in a foamed bitumen application.

Remex Baustoffrecycling AG processes C&D waste and industrial residues into marketable material. The variety of material processed (e.g., excavated soils, road demolition waste, rubble containing reinforced concrete, brickwork, road demolition waste, and similar non-homogeneous materials) requires a wide range of processing equipment. The equipment includes crushers, sieving and screening equipment, magnetic separators, air classifiers, manual and mechanical sorting, and other materials handling processes. This particular plant, one of nine in the area, processes about 60,000 metric tons annually of waste materials; 25 percent is either incinerated or landfilled. The manual sorting line separates out paper, plastics, selected wood products, and some other materials. The company is paid DM 15 (~US$7) to DM 150 (~US$74) for each metric ton of material received from the waste generators. The cost of disposing waste remaining after processing is the responsibility of Remex. Because of this and other factors, Remex exercises good quality control over material coming into the plant. Figures 15, 16, and 17 show several operations of the plant.

Figure 15. C&D wastes to be processed at the Remex C&D processing plant in Germany.

Figure 16. The sorting conveyor at the Remex C&D processing plant. Hand sorting is used to recover glass, metal, wood, cardboard, and plastic that is co-mingled with the C&D waste.

Figure 17. Aggregate crushing and sorting facilities at the Remex C&D processing plant. The pile in the foreground is aggregate made from crushed C&D waste. It will be used in highway base course.

THE NETHERLANDS

The U.S. delegation was impressed with the amount of recycled materials the Dutch use in road works. Chapter 4 discusses the research being supported by the Dutch. The U.S. delegation was especially impressed with the process used to develop specifications and guidelines because it requires the participation of all interested stakeholders. The process has been very successful in establishing a sound basis for the use of recycled materials in Dutch road construction projects. The Dutch investigate the fundamental properties of materials and use this information to help determine expected performance. Traditionally, specifications have been based on the basic properties of the materials used. This information is also used to develop the quality control and quality assurance plans needed to ensure performance is as expected. As in Sweden and Denmark, the Dutch also think that the traditional tests used to evaluate virgin materials may not be appropriate for many recycled materials and products made with them. As an example, the use of Marshall testing is not good for determining the functional properties of an asphalt mix. Although it is used to design mixes using bitumen, it is inappropriate for use with recycled asphalt. The bitumen changes and the viscosity and other properties may also be different. In some cases, performance of a recycled material has been better than that indicated by standard testing. Tests are needed to measure the functionality of a mix using recycled materials. Therefore, one objective of the research is to determine which tests are appropriate and to develop new tests where needed. The Dutch use of porous asphalt surface mix to reduce noise was a significant finding. This is an example of the integration of engineering and environmental awareness into the overall design philosophy. The Dutch strongly endorse the use of full-scale field testing to verify laboratory findings and to determine the risks of using recycled materials. Field testing is done with the participation of the material producers.

The Dutch classify recycled materials into three categories based on their potential for causing contamination. The process does not rely solely on concentrations of constituents in the material, but also considers the amount of harmful constituents that might be released under a specific use situation. The classifications and requirements for using soil are controlled by the Soils Policy and Building Materials Decree (see Chapter 6). Contaminated soil is cleaned and used anywhere. Slightly contaminated soils may be used, depending on the location. This use is based on results of testing and the allowance of a marginal burdening above background to the soil over a long time period. A minimum of 10,000 metric tons must be used in a given project.

The team visited a residential housing development planned for 12,000 homes by the year 2006. Located at Ypenburg, a former airport, the site is surrounded by three busy highways. The requirement to reduce traffic noise to 55 decibels (dBA) resulted in the design of two embankments approximately 12 meters high requiring large quantities (more than 1,000,000 m^3) of fill materials. Because of this and the Dutch policy permitting a marginal impact to soil and water over a 100-year period, slightly contaminated soils are being used as fill material to construct the embankments. The soil is delivered by truck mainly from Rotterdam, Delf, and the Hague. Each delivery is inspected and samples analyzed to determine contamination levels prior to final placement. If the contamination levels do not meet requirements, the soil is moved to a soil cleaning facility or is landfilled. The location of each batch used in the embankment is being mapped. The contaminated soil is being covered with a half-meter-thick layer of clean soil. Figure 18 shows the embankment.

Figure 18. The noise control embankment at Ypenburg in the Netherlands.
The barrier is made with lightly contaminated soils.

The production, certification, and utilization of WTE bottom ash in the Netherlands involves the participation of the Waste Processing Association, Association of Road Contractors, the environmental authorities, and the agreement with the Certifying

Institute. The ash must meet specific physical and environmental requirements for certification and use. It must be free of any fly ash, be stored 6 weeks prior to use, contain less than 5 percent scrap metal, and loss on ignition cannot exceed 5.5 percent. Processed ash with a grain size distribution of 0/20 mm is used for road base; 0/40 mm is used as fill material. Ash producers must be certified and are required to perform quality control over the physical and environmental properties of their ash product. Certification provides a tool for quality control and a nationwide identification of the WTE bottom ash as a useful construction material. The ash is routinely used to construct road embankments. Because the water table is high and the embankments are raised, the bottom ash is usually encapsulated with bentonite clay soil. Regulations require that a minimum of 10,000 metric tons of ash be used in a given project. Contractors generally use much larger quantities to make it more economical. The owner of the embankment, most often a government agency, monitors the site.

The scanning team visited the Insulinde Recycling BV WTE bottom ash recycling project. Figures 19 and 20 show the bottom ash product being used in a road embankment located in the vicinity of Amsterdam. The project consists of two sections of road connecting highways A9 and A7. The embankment is being constructed with a bottom layer of sand and a 4-meter-thick layer of the bottom ash placed at least 1 meter above ground water, which is then covered with a layer of bentonite clay soil and a high-density polyethylene liner. The bottom ash is placed in lifts one-half-meter thick .

Figure 19. WTE bottom ash use in a road embankment in the Netherlands.

Figure 20. WTE bottom ash use in a road embankment in the Netherlands. The embankment will be about 3 meters high.

Other engineering and related functions of interest that the U.S. delegation observed in the Netherlands are:

- Recycled asphalt pavement is used in all mixes for roads excluding porous asphalt and stone mastic asphalt (SMA).
- The Dutch are not in favor of using modified asphalt in mixes because there is no good quality system that controls asphalt recycling with modified binders.
- Crumb rubber is not used in asphalt.
- Cellulose fibers are used in SMA.
- The Dutch are just beginning to use foamed asphalt.

The U.S. delegation was very impressed with the new double parallel drum asphalt plant, its equipment, and the overall process. The plant is of Swiss design (Ammonn) and is owned by a number of Dutch road contractors. The plant and some of its features are depicted in Figures 21, 22, 23, and 24. The plant is innovative and effective in maximizing the amount of recycled asphalt that can be used in mixes. The drum system is used in the batch plant to prepare mixes with 50 percent RAP for base courses and 30 percent RAP for wearing courses. Up to 70 percent RAP mixes are produced.

Figure 21. The Swiss-designed Ammonn double drum hot recycling asphalt plant in the Netherlands. The plant is co-owned by Vermeer. The plant uses high quantities of RAP that is added to the lower drum. The exhaust gas from the RAP drum is used as burner air for the virgin aggregate drum.

Figure 22. RAP is used at high substitution levels at the Swiss-designed Ammonn double drum hot recycling asphalt plant in the Netherlands.

Figure 23. RAP is sorted before introduction into the lower drum at the Swiss-designed Ammonn double drum asphalt plant in the Netherlands.

Figure 24. The double drums allow for high introduction of RAP at the Swiss-designed Ammonn double drum hot recycling asphalt plant in the Netherlands. RAP is heated in the lower drum and virgin aggregates are heated in the upper drum.

FRANCE

As noted in Chapter 3, France has a long history of using recycled industrial waste in construction. This history has revealed several engineering aspects of using different materials. The first recycled materials used in France were blast furnace slags, coal fly ash, and coal mining wastes. Blast furnace slag was initially used primarily as an aggregate, but now is granulated and used more as a hydraulic binder. France produces about 5 million metric tons of blast furnace slag annually. Of the 3 million metric tons granulated, 20 percent is used as aggregate in roads. The remaining 80 percent is used as a hydraulic binder. Gravel and sand slag (ground granulated blast furnace slag) are produced using 15 percent by weight of the granulated blast furnace slag. The ground granulated blast furnace slag increases the reactivity of the mix. The use of ground granulated blast furnace slag is controlled by economics. Cement producers are not willing to pay the added cost; therefore, some is used in road construction. The French delegation noted that they were behind in using granulated slags in cement production, which is considered the highest value use, when compared with other countries in Europe. In the past, steel slag was also routinely used after aging in hot water pits, but because calcium oxide hydrates and expands in wearing courses, only about 20,000 metric tons are now used each year. The steel slag is used in base courses.

Coal fly ash, at levels of 8 to 12 percent by weight, is used as a hydraulic binder to help stabilize the sand. The CaO content activates the binder. It is also used to modify the grain size distribution characteristics of the mix. Also, about 1 million metric tons of high aluminosilicate coal fly ash is produced annually; about 25 percent is used. As a binder, it can be transported long distances and is used all over France. This improves the economics of using the material.

The French have also found that they can use coal fly ash that was deposited in piles in the northern part of the country 25 to 30 years ago. Much of this fly ash has not lost its hydraulic properties. They also use hydraulic sulfur fly ash containing higher amounts of quicklime. The quicklime is used to fix the sulfites during the combustion process. The material can be used like cement, but only at about 4 to 4.5 percent by weight. If higher amounts are used, swelling becomes a problem.

Coal mining waste (colliery shales) shales have been used in both forms. The black shales, initially used as aggregates and in earthworks, are not as good as the red shales produced by burning the black shales. The red shales have better frost resistance properties and are used as subbase. Because the amount of red shales is diminishing, producers are trying to improve black shales. An estimated 50 million metric tons of black shales are in 20 heaps located around France. About 3 million metric tons are valorized each year. After 1975, phosphate gypsum was used in earth works, embankments, and in binders to accelerate setting of gravel slag mixes. There were several problems with phosphate gypsum and it is not being used today. Where it was used, embankment stability was compromised because of cracking and variable water contents from top to bottom layers. Using the material to accelerate setting of gravel slag mixes resulted in swelling of the materials. The phosphate gypsum had been used at levels up to 20 percent by weight. The French now think that it can be successfully used in some applications at about the 1 percent level. They are also investigating the use of sulfates generated during titanium oxide processing. Today, this material is not used in road works.

France has a few locations where approximately 5 million metric tons of C&D waste are processed to make quality aggregates. France has the potential to generate and use 25 million metric tons annually of these materials. Therefore, there is great interest in increasing the amount used. Using these aggregates can cause a few problems that must be considered in design and construction. The cement binder stuck to the aggregate can break loose and increase fines. This can increase surface porosity, increase the amount of water needed in the mix, and retard setting. The variability of the material coming into the facilities for processing can result in variability in the products, creating a need for close monitoring of quality. The cost of these aggregates is higher than virgin materials. However, the French indicated that one needs to consider all aspects, such as transportation costs, in determining the real cost of using the recycled aggregates compared with the natural ones.

Recycling of asphalt is an ongoing process. Not as much is recycled as the producers and contractors would like. In a Paris suburb, using 10 percent RAP in base courses is permitted. In some limited cases, up to 40 percent can be used if the local authorities determine that the material is of the highest quality. As stated in Chapter 3, contractors believe they can routinely use 15 to 20 percent, and should not be restricted to 10 percent. They indicated that such levels would consume all of France's yearly production. Today about 1 to 2 million square meters of asphalt pavements are recycled.

Because they are processed to meet engineering and environmental specifications, the French use WTE bottom ash as aggregates, particularly in the Paris area. In 1997, 60 percent (about 1.3 million metric tons) of the production was used. The ashes can be mechanically processed and aged to meet engineering specifications. Therefore, the key to using the ashes is to ensure that they will not pose any environmental problems. French legislation requires that the ash be classified into three categories based on their leaching characteristics and other properties (see Chapter 6).

The U.S. delegation toured the Jean LeFebvre recycling facilities processing C&D waste, concrete and WTE bottom ash. The C&D plant processes only concrete from construction demolition operations (approximately 250,000 to 300,000 metric tons annually). The facility does not process reclaimed asphalt pavements, bricks, and similar materials. For primary crushing, a front end loader is used to mix the concrete (pieces larger than 60 cm^3 are removed to prevent clogging) with gravel and sand. The plant uses a primary crusher, a secondary crusher, several screening devices, magnetic separators, and other materials handling equipment to produce its recycled aggregates. The recovered ferrous metals are sold to a recycler in Paris. Figure 25 shows various plant operations. The plant was conducting some experiments of mixing reclaimed asphalt with recycled concrete and processing with a foamed bitumen to provide material for base construction.

Figure 25. The concrete crushing Jean LeFebvre C&D waste recycling plant in France.

The WTE bottom ash processing plant processes about 200,000 metric tons annually of MSW incinerator bottom ash delivered from a local incinerator. The ash is aged for varying periods of time, usually around 3 months, until the pH drops from 11 down below 9. The plant uses several screening devices, air classifiers, a magnetic separator to recover ferrous metal, an eddy current separator to recover non-ferrous metals, conveyors, crushers, and similar equipment to produce several sizes (0-6 mm, 6-12 mm, and 12-30 mm) that are then mixed and stored to dry. The plant has a system to collect water runoff, which is transferred to a treatment facility. Figure 26 shows the plant.

Figure 26. The WTE bottom ash crushing and sieving process at the Jean LeFebvre MSW bottom ash recycling plant in France.

France has used scrap tires for 20 years in appurtenances, slope stabilization, and embankments. Approximately 370,000 waste tires are produced each year. Of these, 5 to

10 percent are used in road noise barriers and embankments, 5 to 10 percent are used as crumb rubber, 10 percent are used as fuels in cement kilns, 10 percent are landfilled, and 20 percent are retread. There are no good records as to what happens to the remaining 40 to 50 percent; some are exported to countries were tread depth is not important and others are probably disposed of illegally.

France has some experience with using vitrification technologies for treating hazardous waste and to produce quality products. Although it might be worthwhile for the United States to follow the progress in this area, vitrification is an expensive process that has not had success in the United States. The main use of this technology in the United States has been to treat sites contaminated with radioactivity. France is supporting research on coal tar asphalt to find methods to use it. One option being investigated is using cement and water to make an aggregate base material.

France has a comprehensive set of technical references, specifications, and standards for materials used in road construction. Since recycled materials are processed to meet these specifications and standards, they can be classified using the aggregate classification procedures. These documents have all the necessary principles and guidelines for designing mixes for pavements, embankments, and similar engineering applications used in road works. Designs using recycled materials must follow these guidelines. These standards, specifications, and guidelines are used by administrators, contractors, universities, and others involved in the industry.

Three French firms are using crumb rubber in porous asphalt for low temperature applications in wearing surfaces. The use of crumb rubber provides good ductile properties and may help reduce noise. The French reported that when the crumb rubber is introduced at different stages of the process, the noise reduction properties of the mix are improved. A maximum 1.55-mm size is used for noise reduction. Crumb rubber is also used for sealing cracks. Overall, however, the use of crumb rubber is not economically viable.

LCPC is France's representative in the ALT-MAT program. Its role involves testing fly ash, slags, and MSWI bottom ash. Laboratory testing includes evaluation of physical properties and environmental behavior using leaching tests. France is also evaluating a 20-year-old road subbase of WTE bottom ash and an 8-year-old road with a crushed concrete base.

France also routinely evaluates the mechanical properties of recycled materials in the laboratory and in the field. An objective is to standardize specifications for mix designs using recycled materials, at least on a regional basis. However, there are no specific provisions for recycled materials, and the French believe that quality must not be compromised in order to use them. Chapter 3 discusses these issues as they relate to sustainable road construction in France.

SUMMARY OF OBSERVATIONS

As expected, the countries toured use standard engineering practices for constructing roads. Some variations do exist, however, because of locations and policies. A high degree of recycling and use of recycled materials in roads are present in most of the countries. Blast furnace slag, asphalt pavements, coal fly ash, C&D aggregates, and steel slags are routinely used. The Netherlands and Denmark also use most of the municipal waste incinerator bottom ash that they produce; Germany uses about 68 percent and France also uses this material in some areas. Generally, as in the United States, recycled materials must meet the same engineering specifications and performance as natural materials and must be environmentally acceptable. The desire to use materials at their highest value may influence the final application; however, if the material cannot be used in this manner, a lower value use is acceptable. There was general agreement among the countries that many standard engineering and mechanical test methods used to characterize and measure the performance of recycled materials and their products are inadequate. They believe that more functional tests that better predict performance are needed. Also, as in the United States, many believe that current laboratory tests alone cannot adequately predict performance of materials in actual applications. All the countries are addressing these issues in cooperation with the EU ALT-MAT program and in their own research programs. There appear to be opportunities for the United States to participate in these efforts and use the information to help better evaluate recycled materials for use in U.S. roads.

In several countries, particularly Denmark and the Netherlands, companies producing natural materials also produce recycled materials. Some recycled material processing companies also supply natural materials as a service to their clients. Several countries have strong QA/QC programs to ensure that recycled materials meet specifications and quality requirements. In the Netherlands, contractors are certified once their materials are approved. This certification process is instrumental in marketing and use of the recycled materials for road construction. Some other countries have similar certifications. Regionally, in the United States, similar activities are being developed that mirror these approaches.

Chapter Six
ENVIRONMENT

INTRODUCTION OF PERTINENT TOPICS

One overriding theme in the countries visited was that all recycled materials used for sustainable road construction must be environmentally acceptable. Also, the importance of National environmental policies specific to recycled materials use was emphasized. These policies must be supported with clear implementation guidelines. Test methods for evaluating environmental characteristics varied among the countries, but there was agreement that field testing is critical to verify laboratory results and to determine the validity of using laboratory tests to predict performance in the field. The EU 4th Framework ALT-MAT project emphasizes this approach. The environmental ministries or national environmental agencies in each country generally develop the policies and regulations. These policies are, however, implemented at the regional and local levels, often creating variability in their application among local and regional jurisdictions.

National agencies support research at national environmental laboratories to develop test methods, define approaches for evaluating environmental performance (including risk assessments), and assist in developing standards, specifications, and guidelines for using recycled materials in road works.

Approvals and permitting for using recycled materials in roads are normally done at the local level. In some cases this process can be very time consuming, adversely affecting the implementation of projects. In some cases (e.g., Denmark) there are broad categorical approvals for using selected materials in specific applications. More frequently case-by-case approvals are used for specific materials on the basis of conditions at a specific utilization site. The EU is attempting to develop a standard approach to evaluate environmental performance of recycled products, including those used in road construction projects.

The following information concentrates on environmental issues such as testing, applicable laboratory and field research, approaches for predicting environmental behavior, and other important environmental issues for each country.

SWEDEN

In Sweden, environmental assessments for projects are completed and permits are approved on a site-specific basis using risk classification guidelines established for soils. These values were developed by considering the mobility or immobilization of constituents; dilution in pore water, surface water, and ground water; means of exposure; and the toxicological effects on humans and the environment. Working backwards from what was considered an acceptable dose to a receptor, Sweden established the levels deemed acceptable for soils. Guideline values have been established for a number of elements and substances. For use, soils have been classified into three categories: sensitive uses of soils (KM), less sensitive uses of soils with ground water extraction (MKMGV), and less sensitive uses of soils (MKM). These are the only guidelines available for permitting the use of recycled materials in road construction. As mentioned earlier, there are no provisions in Sweden's *ROAD 94* standards that deal with the environmental evaluations.

The need for national environmental standards and guidelines regarding the use of recycled materials is emphasized in SGI's program, Environmental Friendly Use of Secondary (Recycled) Materials. The program goal is to achieve a major breakthrough in 5 years for use of recycled materials in road construction. The program is designed to help alleviate problems caused by:

- Lack of knowledge about environmental behavior, mechanical properties, and legislation dealing with recycled materials.
- The fact that there are few established test methods to evaluate these materials.
- Lack of guidelines for using these materials.
- Lack of communication between producers and users of recycled materials.

SGI hopes that this program will help reduce the impediments to using recycled materials now caused by the site-specific environmental assessments required by Swedish legislation.

SGI researchers have proposed to the NV what they believe is a better approach to evaluate the risk associated with using recycled materials. To develop their approach, they (i) surveyed principles used to evaluate the risks of using civil engineering materials, (ii) reviewed international leaching protocols, and (iii) reviewed related procedures used in Sweden. For the leaching protocols, they focused on the Dutch and Danish systems. The approach provides structure and guidance for establishing criteria needed for the assessment. It includes formulation of the risk assessment problem and exposure assessment, risk evaluation, and completion of the risk assessment. This approach results in the listing of substances, identification and establishment of guidelines for the specific use scenario, and establishment of technical and administrative measures required for the project. Also important is the establishment of procedures for QA/QC.

SGI is using assessment values from other established systems (e.g., ground water, surface water, agricultural soils, contaminated soils, forest soils). It has provided information on where and how these values should be used for conducting risk assessments. SGI believes that the approach now in use to evaluate exposures is unsuitable. It believes that determining the source term under different conditions needs work and that decisions should be made based on an evaluation using concentrations closer to the source term (i.e., at the source of the contamination and not at the receptor). This change would reduce problems associated with using transport and fate modeling.

Sweden is conducting comprehensive research as part of the EU ALT-MAT program in an effort to increase the use of recycled materials in roads. Objectives of this research include defining the properties (environmental and engineering) of materials, establishing the relationship between laboratory testing and field behavior, developing an improved approach for assessing the risks of using recycled materials, and developing protocols for leach testing to evaluate environmental behavior of recycled materials when placed in the field. A key objective is to develop tests for characterizing the functional behavior of products made with recycled materials rather than relying strictly on standard empirical tests most often used with virgin materials.

The ALT-MAT program includes investigations using climate chambers, lysimeter leaching studies, and field testing of leaching and other characteristics of actual roads used in demonstration projects. Field studies include repeated column leaching, lysimeter leaching evaluations, and sampling and analysis of ground water beneath test roads with installed leachate collection systems. Sweden’s activities also include evaluating the leaching properties of natural materials and of new roads constructed with crushed concrete at southern and northern locations.

SGI is the lead organization for leach testing. Its strategies for investigating the leaching properties of a waste (and also natural materials) include the following:

- Analyzing the total composition of the materials.
- Determining the fraction of each constituent of concern that is available for leaching. The leaching test used is NT-ENVIR 003. (NT refers to NORDTEST or Nordic Countries Standard Test)
- Applying the oxidized availability test (NT ENVIR 006).
- Using pH static leaching tests.
- Determining the relationship of a two-step compliance test (pr EN 12457-3) to column leaching tests.

DENMARK

Three factors are essential to the Danish integrated system for successful recycling: laws, technology, and economics. Laws are needed to protect human health and the environment. Denmark’s overall environmental policy is to develop cleaner technology, increase recycling, use WTE for energy (electricity and heat) where appropriate, and landfill waste that cannot be used.

The three main objectives of its environmental regulations are protection of water resources, prevention of conflicts with respect to use of sensitive lands, and harmonization of environmental regulations with other laws and regulations. The Danes must also consider EU directives regarding environmental matters.

The MS develops national regulations. The 16 counties are responsible for developing county environmental plans and issuing permits. The 275 Danish municipalities must develop waste management plans, implement and enforce regulations, and are responsible for collecting and disposing of waste. In an application to use a waste material, the producer has the responsibility to declare to the environmental authorities and the end user, the following:

- Place of production and type of waste being used.
- Method used to treat the waste.
- Sampling methodology used to collect the waste.
- Leaching test used and the results of the analyses to evaluate the waste.
- Laboratory used for testing and analyses.

- Designation of the material into category 1, 2, or 3.

The user of recycled materials must notify the county and the municipality 4 weeks in advance of the project. The notification must include the start and end dates; the amount and type of waste; engineering drawings of the project with locations of drinking water wells, fresh water, sea water; and any direct discharge points. The county and municipality are responsible for ensuring the producer handles the material according to all rules. The municipality also conducts field inspections during the project. Environmental evaluation with respect to ground water, fresh water, and sea water is also the responsibility of the county.

Denmark's model for classifying waste materials into three categories is depicted in Table 15. A leaching test (CEN prEN 12457) is used to determine in which category a waste is placed. This test involves a 6-hour contact of the waste sample with 0.0001 molar $CaCl_2$ or HNO_3 leachate at a liquid to solids ratio of two.

Table 15. Danish model for classifying waste.

Greater excess by leaching	Category 3, specific evaluation required	Category 3, specific evaluation required
Smaller excess by leaching	Category 2b, statutory order	Category 2b, statutory order
No excess by leaching	Category 1, no regulation	Category 2a, statutory order
	Below the soil quality criteria	Exceeds the soil quality criteria

Category 1 materials cannot exceed established limits for concentrations of arsenic, barium, lead, cadmium, total chromium, chromium VI, copper, mercury, manganese, nickel, and zinc in the leachate in the material. Category 2 materials cannot exceed the concentration limits of these same substances in the leachates.

The following are additional requirements for category 2a and 2b:

- They are not hazardous.
- They are not contaminated with other materials.
- They cannot be used (or disposed of) in a gravel pit.
- They must be placed above the highest water table level.
- They cannot be used above specified amounts for the specific project.

Category 1 materials do not need permits. Category 2 materials require permits except for those that have statutory approval, including asphalt, crushed concrete and tile, coal fly ash and bottom ash, and WTE bottom ash. Category 2 materials do, however, require site-specific use permits and must meet minimum requirements. As an example, the requirements for WTE bottom ash and coal fly/bottom ash are:

- pH (1% slurry) > 9.0
- Alkalinity > 1.5 eqv/kg
- Lead < 3000 mg/kg

- Cadmium < 10 mg/kg
- Mercury < 0.5 mg/kg

In addition, Category 2 materials cannot be placed closer than 20 meters to drinking water wells and cannot be used in layers thicker than 0.3 meters for unpaved applications, or thicker than 1 to 2 meters under paved surfaces.

Category 3 materials must go through a complex permitting process, which involves application, review and permitting based on guidelines, and public notification. If the public complains, the Danish EPA reviews the application. If the public appeals the EPA's decision, it goes to a complaint board for review. If the board's decision is appealed, the courts decide. Some question the economics of a Category 3 waste permit application.

Mobile hot mix asphalt plants must also be permitted. A temporary permit is given for operations of 2 months or less. The plant must get a permanent permit for longer operations. Because permitting is difficult, and a separate one is needed for each new site, mobile hot mix plants are not widely used.

Denmark participates in the EU ALT-MAT program. A part of this program is investigating old sites that used recycled materials. Denmark is evaluating a 5-year-old road with a subbase of MSWI bottom ash. The overall objective is to obtain information about the functional and environmental behavior of recycled materials under use conditions. The investigations involve destructive and non-destructive testing both in the field and in the laboratory. Denmark's environmental testing results for the WTE bottom ash and several other materials are presented in Table 16.

Table 16. Environmental testing results for WTE bottom ash in Denmark.

Material	Environmental Results
Crushed concrete subbase	High pH and calcium in leachates; chromium and lead levels higher than natural sand
MSWI bottom ash subbase	Some migration of salts into subgrade; all samples comply with Danish water quality criteria
Natural sand subbase (reference)	Very low leachability; little or no migration into subgrade

These and similar results from other participating countries led to an overall conclusion that, although leaching of the alternative materials may affect the concentrations of certain constituents in the subgrade, they are far below national pollution limits.

C-RES's (see Chapter 3) research will further characterize the environmental behavior of a wide range of materials, including C&D wastes, slags, bottom ash, fly ash, mining wastes, and a number of organic waste materials. Participants in the Center's research include industry partners and others involved in the treatment, utilization, and disposal of waste materials; academia; and other research organizations. These participants, in addition to the steering committee, are adding credibility to the results, and should help to provide a better understanding of the environmental behavior of secondary materials. Rapid dissemination of information, a Center goal, will increase utilization of these materials in road and other construction.

GERMANY

The German Federal government establishes regulations for recycling and waste management. Under these regulations the producer of the waste is responsible for ensuring that the waste is used or disposed of properly. Verification of this requirement is covered under the Law on Waste Disposal. Industry is required to develop waste economy plans that include descriptions of how a waste will be managed, with emphasis on recycling. Waste must be analyzed before any management decisions can be made. Enforcement of Federal environmental regulations is the responsibility of regional and state governments. This has resulted in non-uniformity in application of the regulations.

Germany stresses the protection of ground water. Depending on the material, materials used are placed in a manner to ensure that ground water is protected and that infiltration of moisture to the recycled material is kept to a minimum.

The environmental aspects of using recycled materials involve the following process:

- Determining the quantity and quality of the material under consideration.
- Determining the recycling scheme or application to be used and the appropriate disposal method if the material is not used.
- Determining and comparing the emissions from the recycling scheme and disposal method.

This involves a time- and energy-intensive process, and for some materials (e.g., concrete), data are not available. In such cases, a theoretical analysis is done based on what could be inaccurate information. A working group of Federal and state officials is evaluating the use of a leaching test (DIN 38414 - S4 Batch Extraction test) to determine emissions data (concentrations of constituents in leachates) for recycled materials. Certified laboratories are doing the testing in cooperation with private companies that also have been certified. Natural materials are not being included, although some officials expressed a wish to have them in the program. Some German officials expressed the opinion that certain natural materials would not perform as well as recycled materials with respect to the environment, an opinion shared by officials in some other countries.

With respect to long-term monitoring of recycled materials in field applications, the degree of monitoring depends on the specific situation. One must evaluate the material and the use application. Test sections containing the new recycled material are evaluated with respect to engineering and environmental behavior. Ground water quality is a major concern. If, for example, a waste is potentially dangerous (e.g., containing dioxin, heavy metals, etc.), then constant monitoring is required. Because of heavy metals (e.g., lead, zinc, etc.), field monitoring of land spreading of MSW compost has been required since 1981. This is to minimize any potential soil contamination. For less sensitive situations, monitoring is left to industry with oversight by state officials. If there is a drainage layer (e.g., rubber, concrete, etc.) under the site and application, industry is required to analyze drainage water and keep the data in files for inspection on demand by state officials.

Continuous process and emission monitoring via telephone data transmission hookups with local officials is required for hazardous waste incinerators. Companies receiving waste for recycling must complete forms to document waste origin, characteristics, and processing history.

Petroleum contaminated soils are considered hazardous and must be disposed of under strict environmental controls. Contaminated soils removed from old gas stations are disposed of into salt mines. These soils can be processed to produce clean sand, but this material does not have good grain size distribution characteristics. Using contaminated soil requires that there be no connection to ground water, and that the material be placed over clay and under pavement or other engineering measures to prevent migration of contaminants.

Table 17 presents the concentrations of heavy metals and other constituents permitted in waste for disposal in landfills and in WTE bottom ash for use. The limits for wastes were established by the Technical Directive Residential Waste; the bottom ash limits were established by a memorandum of the Board of German States (Landerarbeitagemeinschaft Abfall - LAGA.) These are determined by applying the German DEV S4 leaching test.

Table 17. German limits for landfilling waste and for using bottom ash.

Parameter	Class 1 Landfill	Class 2 Landfill	Bottom Ash Use
Loss on ignition (wt%)	3	5	
Total organic carbon (wt%)	1	3	1
DEV S4 Leach Test			
Total dissolved matter (wt%)	1	6	
Electric conductivity (mS/m)	1000	5000	600
Cl (mg/l)			250
Cu (mg/l)	1	5	0.30
Zn (mg/l)	2	5	0.30
Cd (mg/l)	0.05	0.10	
			0.00
			0.30
Pb (mg/l)	0.20	1	0.05

NGOs in Germany have in the past caused considerable problems regarding environmental concerns, primarily because, according to one official, they were not knowledgeable about the issues. However, they have been credited with causing change, and the German EPA believes these NGOs are now very competent and are needed to promote and push implementation of environmental initiatives.

THE NETHERLANDS

Dutch overall environmental policy and practice are stated in the 1989 National Environmental Policy Plan, its predecessors, and a number of ordinances and regulations that have emerged as a result of the policy. The policy focuses on environmental issues, including climate change, acidification, eutrophication, toxic and hazardous pollution, soil contamination, waste disposal, ground water depletion, and resource dissipation. The Directorate-General for Environmental Protection, part of the Ministry of Housing, Spatial Planning and the Environment (VROM) has 11 policy directors who focus on these issues. To develop its policies and regulations, this organization works with other government organizations (e.g., V&W), educational institutions, environmental protection organizations, industry, and trade unions.

The various ordinances and regulations determine how waste in the Netherlands will be managed. Strict environmental engineering controls are imposed on landfills and incinerators and the wastes that can be disposed of by these technologies. Wastes are classified as hazardous or non-hazardous based on the concentration of selected constituents (e.g., Cu, Hg, Cd) in the waste (e.g., Cu > 5000 mg/kg). If the concentration of any of the constituents exceeds the limit, then the waste must be classified as a hazardous waste. However, even if classified as hazardous, the waste still falls under the hierarchy of preferred treatments. There are three classes of landfills in the Netherlands, 80 percent of which are owned by local governments. These landfills are for industrial waste, for non-hazardous waste with and without leachate recovery, and for hazardous waste. Starting in October 1995, to facilitate recycling the Netherlands initiated a ban on landfilling of 32 types of waste over several years. Banned wastes include household waste, cleanable contaminated soils, packaging, tires, wrecked automobiles, and similar wastes. As of January 1, 1997, the ban also includes reusable C&D waste, wood waste, and horticulture waste.

The Decree on Waste Disposal at Landfills (under the Soils Protection Act) requires strict environmental engineering and other controls for landfills in operation after March 1995. These controls include the installation of liners and caps, leachate collection and treatment, a system for monitoring soil and ground water, maintenance and repair of facilities, and financial security for placing the final covers. The requirements for long-term post closure care went into effect in April 1998. In a separate rule, hazardous waste is divided into categories to determine in which landfill it can be deposited.

Costs of landfills in the Netherlands range from about f. 175 (~US$75) per metric ton for non-incinerable waste to f. 800 (~US$352) per metric ton for waste disposed into the country's only category 2 landfill. Other hazardous waste landfill costs range between f. 200 (~US$88) and f. 300 (~US$132) per metric ton.

Incinerators are regulated under the Waste-to-Energy Decree (1993), which established requirements for air emissions, plant construction, the WTE process, measurement and record keeping, and calculations and actions to take when emissions standards are exceeded. For hazardous waste incinerators, the regulations were enforced starting in April 1998. There are strict emissions limits for HCl, HF, SO_2, NO_x, heavy metals, (Cd, Hg, Sb, Pb, Cr, Cu, Mn, V, Sn, Co, As, Ni, Se, and Te), dioxins/furans, CO, and organic carbon.

Costs for WTE range from f. 220 (~US$96) per metric ton for non-hazardous waste to as much as f. 10,000 (~US$4,400) per metric ton for hazardous waste. Some specific hospital waste costs f. 1000 (~US$440) per metric ton to incinerate.

The use of recycled materials in road construction is controlled by the DBMD. This decree classifies materials into two categories on the basis of emissions and the composition of selected constituents in the material. Emissions values are established based on the maximum quantity of selected inorganic constituents that may disperse into soil and surface water without increasing unacceptable burdening. Acceptable burdening has been established as 1 percent over background levels over a 100-year period. For example, in a period of 100 years, not more than 540 mg of copper from building materials used in construction works may dispense over 1 m^2 of soil. These values are calculated using results from leaching studies considering the form of the material (e.g., granular, monolithic, etc.), and how it will be used. No suitable leaching tests have been identified for organic compounds in building material. For organic compounds, total composition values are determined. As an example, a building material may not contain more than 0.5 mg PCB/kg. This information is used to determine the conditions for using recycled materials in construction, the need for and types of native soils in construction, and need for surface water protection.

Category 1 materials are those that do not exceed any of the established limits. These materials may be used without additional environmental protection measures. Category 2 materials are those that do not exceed any of the organic composition limits, but have calculated inorganic constituent emissions that would exceed the limits without additional environmental protection measures. Category 2 materials may be used, however, if engineering methods are used to isolate them, and the resulting emissions limits are acceptable. Materials that exceed these limits may be treated to fall into one of these categories. If treatment fails, they must be disposed. These materials must be removed at the end of their useful life.

There are exceptions for some materials that do not fall into these two categories. WTE bottom ash is permitted to exceed the limits, but only if special isolation measures are used. TAA, produced from older, macadam roads, exceeds the limits for polycyclic aromatic hydrocarbons (PAH). Building materials containing asphalt aggregates may be used with special isolation measures if they do not exceed any limits other than for PAH.

“Earth” is defined in the Netherlands as loose materials that can be excavated by hand or land tool from the solid soil on which one stands. In addition to the above categories, earth is also classified as “clean earth.” In classifying earth, an additional compositional value (C_e) was established. The earth is considered clean when its composition values (organic and inorganic) are less than C_e1. In this case only portions of the DBMD apply to clean earth. If the value falls between C_e1 and C_e2, then it is required that the emission values (inorganic) be determined. Earth that exceeds organic and inorganic values greater than C_e2 may not be used as a building material. The Building Material Decree also stipulates the minimum quantities of category 1 earth, category 2 material, WTE bottom ash, and TAA that may be used in a project. It also specifies the engineering and other requirements required for isolating these materials. Table 18 summarizes the regulations for building materials in the Building Materials Decree.

ECN has conducted comprehensive research on the leaching properties of materials. In cooperation with the EU, the Committee European de Normalization's (CEN's) program on the harmonization of leaching and extraction tests involves the Netherlands, the U.K., Denmark, France, and Spain. The main objective of these activities is to develop a standard approach to evaluate the leaching behavior of materials. The program was started because of the many different approaches being used, the failure of researchers and others to properly document conditions of the tests (e.g., pH), and the very limited use of the large amount of data available. The work is being conducted by technical group CEN/TC 292, which consists of seven working and three ad hoc groups. These groups are concentrating on sampling, leach test procedures, terminology, analysis, basic characterization, ecotoxicological properties, biodegradation, characterization of household waste, and validation procedures. Materials include contaminated soils, sediments, compost, sewage sludge, waste (e.g., WTE ashes, stabilized ashes), construction materials (e.g., concrete, bricks), preserved wood, and others. Data are available for more than 30 different materials.

Work also includes evaluating relationships between laboratory and field data and field validation of models used to predict behavior in field conditions. As an example, this work compared the release of copper from WTE bottom ash used as a subbase in Rotterdam. Modeling, based on laboratory test results, predicted a release of 1530 mg per m^2; the measured release was 1386 mg per m^2.

The leach testing hierarchy adopted by TC 292 is:

- Use of characterization or leaching behavior test that takes a few days to several weeks.
- Use of a compliance test that takes a maximum of 2 to 3 days.
- Verification of laboratory characterization/leaching behavior tests by on-site monitoring.

TC 292 concluded that the pH static test can be useful for:

- Comparing leaching tests within a specific class of materials.
- Modeling of geochemical phases that control leaching.
- Evaluating long-term behavior and effects of external stresses on material leaching behavior.
- Comparing data and information among different classes of materials.

The committee also indicated that the characterization test can provide the input data needed to predict long-term environmental behavior, and concluded that an understanding of the leaching behavior of materials can be used to develop protocols for quality control and regulatory compliance tests. Results from the extensive leaching tests have shown that most constituents leached contaminates at levels lower than expected.

Additional work is needed to fully document findings and generate the additional data needed for inorganic contaminants. Leaching tests for organic contaminants lag far behind, and significant work is needed to resolve this issue. Establishing a European or worldwide database on the leaching behavior of materials is considered an important need and would help prevent duplication of efforts and lead to much needed standardization of leach testing.

Table 18. Review of the regulations in the German Building Materials Decree.

Material	Removal of Building Material	Minimum Quantity	Reporting to the Competent Authority Before Use		Submit Data to Authorities on Request
			Soils	Surface Water	
Clean earth	No	No	No	Yes, > 2 days before use	Yes, until 1 year after application
Cat 1 building material (excl. earth)	Yes	No	No	Yes, > 2 days before use	Yes, until 1 year after application
Cat 1 earth	Yes	50 m^3	Yes, > 2 days before use	Yes, > 2 days before use	No, done with reporting
Cat 2 building material (including earth)	Yes	10,000 metric tons (1,000 in road base)	Yes, >1 month before use	Permit based on Pollution of Surface Waters Act	No, done with reporting
WTE bottom ash	Yes	10,000 metric tons	Yes, > 1 month before use	Permit based on Pollution of Surface Waters Act	No, done with reporting
TAA	Yes	10,000 metric tons (1,000 in road base)	Yes, > 1 month before use	Permit based on Pollution of Surface Waters Act	No, done with reporting

FRANCE

For the use of by-products in roads, France's current environmental regulations concentrate on two types of waste materials: WTE bottom ashes (Circulaire Miniistéielle du 09/05/1994) and foundry sands (Arrêté du 16/07/1994). There are no regulations dealing with recycled materials, though there are requirements for the element contents (e.g., sulfates) because of technical requirements for use. There are no environmental regulations for natural materials.

For environmental purposes, WTE bottom ashes are placed into three categories (V, M, and S) based on results of a leaching test (French standard X31-210) that uses three successive leaching extractions of the ash sample. The leachate is analyzed for heavy metals, total organic carbon, and total dissolved solids. The requirements are provided in Table 19. Category V ashes can be used in road construction and for embankments. Category M ashes must be treated before use either by stabilization or by maturation. If treatment is not successful, these ashes must be disposed of into a non-hazardous waste landfill. Category S ashes must be landfilled.

Table 19. Categories of WTE bottom ash and leach test requirements in France.

	V	M	S
Loss on ignition	<5 %	<5 %	<5 %
Mercury	<0.2 mg/kg	<0.4 mg/kg	>0.4 mg/kg
Lead	<10 mg/kg	<50 mg/kg	>50 mg/kg
Cadmium	<1 mg/kg	<2 mg/kg	>2 mg/kg
Arsenic	<2 mg/kg	<4 mg/kg	>4 mg/kg
Chromium VI	<1.5 mg/kg	<3 mg/kg	>3 mg/kg
Sulfates	<10,000 mg/kg	<15,000 mg/kg	>15,000 mg/kg
TOC	<1500 mg/kg	<2000 mg/kg	>2000 mg/kg
Total dissolved solids	<5 %	<10 %	>10 %

Facilities processing the bottom ash for use must have a quality assurance plan in place for the environmental inspector assigned to regulated facilities. For approval, facilities must take into account all environmental issues such as effluents, noise, dust, traffic, etc. At the time of receipt, the client receiving the ash must be provided a data sheet with information about the physical and environmental characteristics of the ash. The form also must stipulate lot number, truck volume, and similar data to facilitate tracking. Documentation is required that leachates from the residue meet applicable French requirements for use. Results of France's ALT-MAT program testing showed that WTE bottom ash used as base and subbase in roads leached at levels far below national standards.

The utilization application for foundry sands with organic binders depends on their leachate phenol content. They may be used in embankments if the phenol content is less than 1 mg/kg of dry sand. If the phenol content is less than 5 mg/kg dry sand, the sands are used in the manufacture of hydraulic binders. Regardless of the phenol content, these sands may be used for manufacturing cement, bricks, tiles, and similar products.

The Ministry of the Environment is working to improve environmental regulations and is concentrating on residues from thermal processes (e.g., coal fly ash, MSW bottom ash, slags). Efforts are evaluating the behavior of the materials under different utilization and disposal scenarios. This testing will be based on the environmental behavior of the materials and the transfer of pollutants to ground waters. Threshold values will be selected using different factors, including comparison with the environmental characteristics of natural materials, pollutant concentrations in soils, drinking water threshold values, and negotiations with the public. Any new rules will need to be consistent with EU directives concerning construction products.

Environmental rules will be determined by the Ministry of Land Use and the Environment (MATE), administrators, construction and public works professionals, and eventually representative associations. France is using the advice of specialized national councils (e.g., public welfare, classified industry, etc.). The Council for Waste Reuse, for example, is a participant. The development of waste plans in geographical areas also is an important component of the overall project. The plan involves informal agreements for accepting a waste family for use. The only formal agreement thus far is for WTE bottom ash. Local agreements are possible for using a single waste in a specific application. Conditions for this type of application involve a control system designed to determine potential adverse effects on the environment. Generally, an authorization is required for conducting an experimental demonstration project on a controlled site to determine these effects.

The following principles are being applied in this process:

- The waste cannot be used in a wearing surface.
- The waste cannot be used in or under drinking water sources.
- Hazardous waste is prohibited unless it has been stabilized or otherwise treated.
- Large quantities of the waste should be used to assist in future tracking.
- The waste must have a clear functional use in the product; dilution is not permitted.

The MATE is the controlling authority and is assisted by the Agence de l'Environnement et de la Maitrise de l'Energie (Agency for Environmental and Energy Management - ADEME). There are at least two levels of controls: internal and external. These include the classical geotechnical engineering test and environmental tests. Quality assurance procedures are an important part of the control process. The MATE local administration is the decision-making body regarding using waste materials within its jurisdiction. It may seek the advice of other public agencies, but there is no systematic approach or control regarding the decision-making process. The waste material should have the same functional properties and use as the natural road materials; if not, any new use application must be evaluated to ensure that the waste does have a legitimate function in the new use application.

SUMMARY OF OBSERVATIONS

Environmental ministries develop the regulations governing the use of recycled materials in highway construction. All have a similar hierarchy for waste management: prevention, reuse, recycling, WTE, and disposal. In some cases, particularly in the Netherlands and Denmark, guidelines for implementing these rules also are developed at the national level. The Swedish EPA, however, has not developed such guidelines although the secondary materials industry believes this step is necessary for establishing widespread use of recycled materials in roads. Implementation and compliance are usually left to the regional and local governments. In some cases, as in the United States, this has resulted in non-uniformity in application of the rules, which has impeded the use of recycled materials. Environmental standards vary somewhat among the countries, although EU programs and directives will tend to make minimum requirements the same among member countries. Some countries have or are implementing very strict requirements on landfilling of waste materials, limiting landfills to only very hazardous waste and inert waste that cannot be recycled or incinerated. Germany, Denmark, and the Netherlands are good examples of countries whose environmental policies are assisting the use of recycled materials in roads. Dutch environmental rules permit slight burdening of soils and waters above background levels over a 100-year time frame. This policy, and similar ones in Denmark and other countries, permits the use under specific conditions of some materials (e.g., slightly contaminated soils, WTE bottom ash) that would not meet all of the other standards. There is consistent agreement among the countries that moving from laboratory testing to performance modeling requires field validation. All the countries are conducting research and most are participating in the EU 4th Framework ALT-MAT project to address these issues. Within the EU, there are efforts to standardize an approach for evaluating the environmental behavior of recycled materials. Various approaches are being used in the countries for obtaining environmental approval and permits. There are broad categorical approvals, specific recycled materials approval in specific uses, and site-specific approvals. EU efforts also are addressing this issue. The EU 4th Framework ALT-MAT project may be a model for U.S. consideration.

Chapter Seven
RECOMMENDATIONS

CONCLUSIONS AND PRIMARY RECOMMENDATIONS

In the European countries that were visited, recycling occurs when it is economical to do so. Factors in the marketplace are dominant, but are generally supported by government policies and regulations such as bans on landfilling, landfill taxes, and natural aggregate taxes. Generally, clear and unambiguous engineering and environmental test methods and performance standards help to reduce uncertainty and allow recycled materials to compete with natural materials. Where tests and standards do not exist, governments often support recycling by sharing risk.

This is in some contrast to the U.S. situation. In the United States, some recycled materials such as RAP, coal fly ash, and blast furnace slag are widely used in a true free market situation because of their excellent performance and competitive costs. Other materials (e.g., foundry sands, steel slags) are used more locally in response to more specific local market forces. There is little Federal government involvement, except for comprehensive procurement guidelines for materials such as coal fly ash. Rather, the situation is driven at the state level. For example, the State of Pennsylvania has adopted legislation to promote recycling in the highway environment. However, there is a wide range of engineering and environmental approaches to BUDs by different states. California, Illinois, Massachusetts, New Jersey, and Pennsylvania are working to standardize the BUD process and create reciprocity. There is widespread need for clear engineering and environmental test methods and performance standards. The owner or contractor generally assumes risk. The states, academia, and the private sector are conducting significant research.

Table 20 provides a summary of specific findings and corresponding recommendations for the U.S. situation. The U.S. delegation will provide leadership in sharing these recommendations at the national level with their various constituencies. Tentative organization assignments to act on recommendations are listed in the table. The delegation believes it is particularly important to adopt aspects of the Dutch sustainability model as a means to promote recycling in the highway environment. Further implementation strategies for the U.S. delegation will include electronic and written distribution of the final report, presentations, published articles, and development of a website.

ADDITIONAL RECOMMENDATIONS

The following recommendations were made by team members on their daily report sheets:

- The U.K. concept of "privatization" of roads to 30-year ownership and maintenance should be reviewed for application in the United States.
- The United States needs to change the negative image about using recycled materials and provide incentives (or disincentives) for contractors to use recycled materials and to work with contractors. A tax on landfilling usable materials should be considered as one incentive.

Table 20. Summary of findings and recommendations.

Subject	Findings	Recommendations (Lead Organization from Scanning Team To Act on Recommendation)
Recycling for sustainable road construction	The Dutch sustainability policy centers on a *market system* where *policy* and *economy* influence the market. There are clear and unambiguous *technical* and *environmental standards.* The government promotes recycling by using *taxes* as incentives or disincentives and by *assisting* startup companies. Technical processes are developed to assist production of quality material. A high degree of *information* and *technology transfer* was seen among various ministries and agencies in each country, and among countries. The EU 4th Framework *Alternative Materials* (ALT-MAT) project is one example of such cooperation and technology transfer. There is a high degree of *public awareness* and *participation* in recycling in Europe. Federal and local governments have excellent *informational compaigns.* There can still be concern at the public level. Non-governmental organizations (NGOs) are involved in policy development in the Netherlands.	- Include a recycling strategy in the sustainability aspect of FHWA's and AASHTO's strategic plans and long-range research priorities (FHWA, AASHTO Standing Committee on Environment). - Create a framework for state DOTs to consider using recycled materials in project planning, analysis of alternatives, and mitigation analysis (AASHTO Standing Committee on Environment, Subcommittee on Materials). - Encourage state DOTs to conduct long-term materials supply plans and recycled materials availability plans (AASHTO Subcommittee on Materials). - Develop clear engineering and environmental guidelines at the state and Federal level that are available to suppliers and decision-makers (RMRC). - Prepare a briefing document for the U.S. Congress and state legislatures (FHWA, RMRC). - Prepare a briefing document for environmental foundations (RMRC). - With the new FHWA-EU partnership negotiated under the EU 5th Framework Program, explore research coordination, technology transfer, and exchange of experts [FWHA, AASHTO, Association of state and Territorial Solid Waste Management Officials (ASTSWMO), RMRC]. - Hold a special Transportation Research Board (TRB) session on recycling in the highway environment (RMRC, FHWA, AASHTO, NAPA). - Develop a National Highway Institute course on recycling (RMRC). - Conduct a public awareness program (AASHTO, FHWA).
Economics	Recycling successes in the Netherlands, Denmark, and France are based in part on *market opportunities* for materials suppliers and contractors. Life-cycle cost analyses (LCCA), some using *environmental costs*, are used.	- Encourage contractors to use their private markets as a place to innovate and develop technologies (NAPA). - Adapt current FHWA LCCA procedures to include recycled materials; it should address environmental costs (FHWA, RMRC).

Table 20. Summary of findings and recommendations (cont'd).

Subject	Findings	Recommendations (Lead Organization from Scanning Team To Act on Recommendation)
Engineering	A number of countries are moving toward *performance-based design procedures* and to *accelerated testing* to predict material performance. However, there is still concern that *test methods do not predict true field performance.*	- Conduct recycling demonstration projects about foam bitumen, hot recycling, C&D aggregate use (FHWA, AASHTO, NAPA, RMRC). - Encourage AASHTO and state DOTs to involve contractors more in committees establishing specifications (AASHTO). - Evaluate contractors with respect to use of recycled materials or environmental protection during contract performance reviews (AASHTO).
Environment	The Netherlands uses a hierarchy of *mechanistic leaching tests* of both recycled materials and their highway products to look at cumulative release of constituents and their marginal impacts to soils and waters. This also is generally the basis for an EU normalization activity to adopt this approach. Efforts are under way to create a European *database on product leaching.* There is *coordination* between transportation and environmental ministries. Many countries expressed a need to develop an approach to evaluate the *environmental behavior* of recycled and natural materials by looking at source terms, the fate and transport of their constituents, and their relation to human health and ecological risk.	- Develop and implement the use of warranty and performance-based specifications. - Make connections to the European efforts to establish a leaching database (RMRC). - Hold an AASHTO and state EPA workshop on the Dutch and EU approach to evaluate product leaching behavior (RMRC). - Include state DOT environmental staff and state EPA staff on Innovations and New Product Reviews (AASHTO). - Develop a model geographic information system (GIS) layer to track recycled materials use and aid future maintenance and management decisions. - Add an *Excellence in Recycled Materials Innovation* category in the annual FHWA Environmental Excellence Awards and the AASHTO Environmental Best Practices Award (FHWA, AASHTO). - Encourage the U.S. EPA to work more with state BUD programs to expand reciprocity (U.S. EPA). - Encourage U.S. EPA to expand the Federal procurement guidelines to recycled materials in the highway environment (U.S. EPA). - Perform long-term monitoring (AASHTO, state EPAs). - Conduct a workshop on issues related to source term description, fate and transport, and risk (RMRC).

- Consider expanding Sweden's approach or hierarchy of applications for recycled materials to other transportation uses (e.g., slopes, embankments, storm water controls, appurtenances, landscaping, etc.).
- U.S. regulatory agencies should use leaching tests to assist in determining what and how recycled materials can be used.
- Develop a table of classes of materials and suggested uses similar to that developed by VTI (Sweden) for crushed concrete.
- The United States should consider startup (demonstration) projects using donated recycled materials as a means of introducing and evaluating recycled materials in road construction. (Note: this has been done for MSW bottom ash.)
- Encourage U.S. state DOTs to have environmental staff participate in all committee work for using alternative materials (similar to Denmark's Road Directorate). They can help advocate use of recycled materials.
- Encourage and introduce legislation that provides increased grants for research and development for economical use of waste products. Increase the awareness of politicians and the public regarding the benefits of using recycled materials.
- Invite Peter Miklos (Denmark) to share his knowledge at technical asphalt training seminars in the United States.
- The United States needs to better market recycled materials that are the equivalent of virgin materials in engineering applications.
- U.S. DOTs should adopt a philosophy and consensus approach to recycled materials use similar to Denmark's.
- Begin to establish a database similar to that in the Netherlands on the environmental behavior of different materials.
- Develop cooperative/partnered research and standards development with industry technical and financial input.
- The United States should participate in the ECN and CEN standardization efforts in the Netherlands.
- The United States should consider using the Netherlands' detailed specifications on performance measures, tendering, and administration as a means of making contractors more innovative in developing and using recycled materials.
- The RMRC should coordinate a TRB session on the use of recycled materials. Speakers from Sweden, the Netherlands, Denmark, Germany, and France should be invited to participate.
- The United States should identify and develop test methods that will predict long-term mechanical (engineering) and environmental performance of recycled materials.
- Adopt warranty and performance specifications similar to those used in several of the countries visited.
- The U.S. team should follow France's progress in using incentives to support the waste plans being developed and the landfill ban.

IDENTIFIED RESEARCH NEEDS

The U.S. team members identified a number of research needs on the basis of their observations:

- Develop procedures for processing, QA/QC and routine use of C&D wastes and municipal solid waste incinerator bottom ash in U.S. transportation applications.
- Formulate and conduct a multi-county shared project to demonstrate the use of cost-benefit analysis so that all can communicate on a common basis.
- Investigate and develop methods to encourage railroads to participate and identify opportunities where they could use recycled materials. The ability of the highway sector to use recycled materials is dependent on the participation and cooperation of all public works developers to create a demand for recycled materials.
- Research how to establish an environmental evaluation system that is specific to recycled materials in transportation construction. Look at each material to determine which constituents leach and how much it leaches, rather than basing decisions on the concentrations in the material.
- Investigate the use of the triaxial test (or wheel track) to develop "quality" characteristics of a recycled material in various applications.
- Develop a database relating the performance characteristics of materials to long-term performance in the field.
- Conduct research to define and develop specifications for using WTE ash in embankments.
- Evaluate the use of a value-added performance system in the bidding process for contracts in the United States.
- Investigate modeling using leaching results to evaluate environmental behavior of recycled materials in construction applications.
- Develop any necessary safety and human health protection procedures for handling recycled materials and any training and educational materials needed to implement them.
- Investigate the use of foamed bitumen as a preventive maintenance tool.
- Evaluate the plate bearing test to determine if it gives a better correlation to performance than the density test for non-homogeneous recycled materials.
- Investigate and determine values for the environmental behavior of natural materials as a standard to compare with recycled materials.
- Investigate the applicability of using the pH stat and other tests used by the Dutch for U.S. industries.
- Identify government and private sector successes in using recycled materials. Evaluate the factors that contributed to the successes and develop models that will help determine recycled product technical and economic feasibility in various applications.
- Evaluate the Netherlands' 5-year plans for materials usage to determine if they would be feasible in the United States.

Chapter Eight
IMPLEMENTATION

Table 21 describes the immediate implementation strategy as a result of the scanning tour. The U.S. delegation will work with their respective constituencies to promote recommendations from this summary report. Specific implementation strategies include electronic and written distribution of the final report, presentations, published articles, and development of a website.

Table 21. Immediate communication strategy.

Implementation Item
Action on recommendations in Summary Report
Publication of the Final Report on the RMRC website at www.rmrc.unh.edu
Electronic announcement of Final Report availability (as downloadable pdf, Word, or WordPerfect files on the RMRC website) to the following electronic distribution lists: (i) appropriate TRB committees and subcommittees, (ii) the Local Technical Assistance Program (LTAP) list server, (iii) the Recycled Materials Resource Center list server, (iv) the AASHTO Subcommittee on Materials, and (v) the AASHTO Standing Committee on Environment.
Lists for Final Report distribution by FHWA International Programs/ATI to include: FHWA, TRB, FHWA ATLP Centers, U.S. EPA, state DOTs, AASHTO, state EPAs, Environmental Councils of States (ECOS), ASTSWMO, the NAPA, American Concrete Paving Association (ACPA), Asphalt Recycling and Reclamation Association (ARRA), Construction Materials Recycling Association (CMRA), Portland Cement Association (PCA), National Aggregates Association (NAA), National Stone Association (NSA), ASTM, the Asphalt Institute, American Consulting Engineers Council (ACEC), Association of Environmental Professionals, etc.
Prepare magazine articles to be published in *Better Roads*, the *Transporter*, *Hot Mix Asphalt Construction*, *APWA Reporter*, *Environmental Technical Assistance Program* (ETAP) *Weekly,* HMAT, NCAT, etc.
Develop presentations for use by the team at workshops, conferences, special presentations, etc., at the national, state, association, and local level. Provide Power Point presentation electronically or on diskette and provide overheads.
These are some of the presentations by team members at national venues: (i) 1999 AASHTO Meeting in Tulsa, Oklahoma, 10/99; (ii) Beneficial Use of By-Product Materials in Construction Applications Conference in Albany, New York, 11/99; (iii) NAPA Annual Meeting, Hawaii, 2/00; (iv) AASHTO Standing Committee on Environment in Gulf Shores, Alabama, 3/00; (v) PennDOT Transportation & the Environment for the 21st Century, 5/00; (vi) AASHTO Subcommittee on Materials, 8/00; (vii) the ASTSWMO Annual Meeting, 10/00; and (viii) 2001TRB Meeting in Washington, D.C., 1/01.
These are some of the intended presentations by team members at regional/state meetings: (i) Association of Pennsylvania Contractors/PennDOT Fall Workshop, 11/99; (ii) MinnDOT, 11/99; (iii) Brown Bag Lunch for Washington State Agencies, Legislators, Governor's Staff, Fall 1999; (iv) TEA-21/EPA Region 10 Meeting, Fall 1999; (v) Washington Counties Regional Maintenance Supervisors, 12/99, (Campbell); (vi) Pennsylvania Construction Industry Spring Conference, 2/00; (vii) Minnesota Transportation Conference, 2/00; (viii) Asphalt Recycling and Reclamation Association 24th Meeting, Cancun, Mexico; (ix) 2000 Southern Regional Quality Workshop for Materials and Construction, Birmingham, Alabama, 3/20; (x) Georgia Department of Environmental Services Recycling Workshop, Atlanta, Georgia, 3/00; (xi) Minnesota Transportation Conference, 5/00; (xii) Washington State University Road and Street School, 10/00 and 12/00; and (xiii) Michigan SEMCOG, MAPA, Michigan DOT Conferences, dates not provided.
Appropriate research recommendations and problem statements will be sent to the appropriate AASHTO committees and to NCHRP to encourage additional research activity.

Chapter Nine
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Appendix B
DETAILED AMPLIFYING QUESTIONS

The following eight general categories of questions have been identified as important areas of interest by the delegation. The specific questions are intended to serve as a guide for the host agencies. There is some overlap between categories and some questions could also be associated with other categories. Since the delegation members are not aware of all aspects of recycling in the host agency's country, the host agency should feel free to identify other issues that the delegation should learn about.

To help clarify our perspectives, the delegation has defined recycled materials as reclaimed highway paving materials, secondary materials, by-product materials, and waste materials. These include recycled asphalt pavement, reclaimed concrete pavement, coal fly ash, blast furnace slags, foundry sands, municipal wastewater sludge compost, glass, tires, construction and demolition debris, etc. From our perspective, the highway environment includes construction within the highway right of way (e.g., roads, shoulders, medians, bridges, culverts, swales, appurtenances), though activities associated with highway construction can also result in use of recycled materials outside the highway right of way. From our perspective, recycled materials are typically used in such applications as bituminous pavements, portland cement concrete pavements, road base, embankments and fills, flowable fills, landscaping, bike paths, parking lots, and appurtenances (signs, fencing, barriers, traffic delineators, etc.).

While our focus is directed at recycling in the highway environment, transportation is inter-modal. There can be obvious recycling connections with other transportation modes so appropriate related recycling activities are also of interest.

1. Engineering Practices for Recycled Materials Use in the Highway Environment

    1.1 What recycled materials are used in the highway environment and in what applications? Can this information be quantified for the delegation? Have some materials been used historically? Have some materials been used only recently?

    1.2 What specifications and standard engineering practices (design, construction, maintenance) are in place for these uses? Are these more stringent or less stringent than those used for natural materials?

    1.3 How do you determine that the recycled material used in highway environments equals or exceeds the engineering performance of standard or traditional materials they replace?

2. Environmental Practices for Recycled Materials Use in the Highway Environment

    2.1 What standard environmental regulations, specifications, and practices are in place for the uses and applications identified in question 1.1 above? Are these more stringent or less stringent than those used for natural materials?

    2.2 How do you determine that the recycled material used in highway environments equals or exceeds the environmental performance of standard or traditional materials they replace?

2.3 Does the public, the supplier, or the contractor get involved in environmental regulation or specification development?

2.4 Are there different types of environmental approvals, such as general, conditional, application-specific, or site-specific?

2.5 What environmental agency (e.g., Environmental Ministry) is responsible for identifying and quantifying pollutant levels released from recycled materials use and how are environmental controls established? Are there databases available?

2.6 What methods are used to determine risks to human health and the environment associated with using recycled materials in the highway environment?

2.7 From the environmental standpoint, who provides data that the use of a recycled product is not harmful to the workers and the public? Can pavement with recycled materials be later reused in another application with no adverse environmental effects?

2.8 Is tracking (documentation of application, amount used, location, etc.) of recycled materials use by a regulatory agency required?

3. Emerging Technologies

3.1 What process or path is used to implement or introduce new recycled materials (especially less traditional recycled materials) or new applications (e.g., use of recycled materials like metal or plastic in appurtenances)?

3.2 Does cost, performance, or concern for the environment drive the process?

3.3 What outreach activities are used to encourage the use of recycled materials?

3.4 Are demonstration or field trial projects crucial to new technology adoption?

3.5 Are there examples that can be highlighted of recycling successes?

3.6 Are there examples that can be highlighted of recycling failures?

3.7 What is your participation with the ALT-MAT project (under the European Union's Directorate General VII 4th Framework Program)? Can summary information from your country be shared with the delegation?

4. Policies, Market Forces, and Interest Groups That Drive Recycled Materials Usage

4.1 What is the nature of the interaction between governmental authorities (e.g., between a transportation ministry and an environmental ministry) with jurisdiction over approvals of recycled materials use?

4.2 Who within the transportation sector (e.g., Transportation Ministry) takes responsibility for advocating, leading, and responding to recycling issues?

4.3 Who generally drives recycled materials utilization? The people through referendums? The government through legislation? The private sector through market forces?

4.4 How do other local governmental agencies, research organizations, universities, highway associations, and the general public participate in this process?

4.5 What role do non-governmental organizations (NGOs) play in the process?

4.6 How active is the public in supporting or opposing recycled materials use?

4.7 After the design life of the principal reuse application is reached, how is subsequent reuse or disposal managed? Are there mechanisms in place to encourage continued reuse?

4.8 Are there taxes that drive recycling or financial incentives/disincentives used to encourage recycling in the highway environment?

4.9 Are there other types of incentives provided to incorporate recycled materials into construction products?

4.10 Have “recycling mitigation credits” been developed as a tradeoff for unavoidable transportation environmental impacts?

4.11 Are there specific cost analysis studies (e.g., by recycled material type or application) that look at planning costs, first costs, operation and maintenance costs, life-cycle costs, etc.? Can a typical one be provided?

4.12 What level of governmental support is provided for research and development in this area? Is the trend increasing or decreasing?

5. Barriers to Recycled Materials Use and Means to Overcome Such Barriers

5.1 What barriers to recycled material use in the highway environment have been identified at the national, regional, or local level?

5.2 What initiatives, programs, or activities have been developed to reduce barriers?

5.3 Are long-term legal liabilities a barrier? If these are an issue, how are they addressed?

5.4 What protection is there for the potential of future liability if recycled materials used in highways are found to be a health or pollution problem in the future?

5.5 Does your agency share technical data and project results with other organizations through databases, case study results, etc. using the Internet or other informational services (e.g., web-based databases)? If so, can these be identified?

5.6 Have centers of critical activity or expertise been established? If so, can these be identified?

5.7 In the United States, the lack of reciprocity agreements between states is seen as a significant barrier to uniform use of recycled materials in the highway environment. Within a national context, or even within a European Union context, is reciprocity for approval of recycled material use being considered?

6. Long-Term Monitoring and Performance Measures

6.1 Are there specifications or goals that address long-term engineering or environmental performance of an application using a recycled material?

6.2 Are field demonstrations considered to be the best way to look at long-term performance?

6.3 Are there laboratory methods or models developed to predict long-term performance from either a physical or environmental perspective? If so, can they be provided? Are they being used in a regulatory sense?

6.4 What long-term physical or environmental monitoring is required at utilization sites? Can examples be provided? Are there demonstration or full-scale use sites where long-term monitoring is occurring that the delegation can visit? Is there typical data that can be presented to the delegation?

6.5 Are there special maintenance activities that are used in conjunction with long-term monitoring? If so, can they be described?

7. The Perspective of Materials Suppliers and Contractors

7.1 Does the supplier or contractor get involved in engineering or environmental specification development?

7.2 How is recycled materials processing handled—at central facilities or at the job site?

7.3 Do traditional aggregate processing facilities handle recycled materials? If so, are they segregated?

7.4 Does the supplier or contractor get involved in engineering or environmental specification development?

7.5 Are there processing facilities that the delegation can visit?

7.6 Are ISO 9000 procedures used by suppliers during processing of recycled materials?

7.7 Are the same processing controls required for recycled materials as they are for natural materials?

7.8 What quality assurance/quality control procedures are used by the suppliers working with recycled materials? Are these the same as those used for natural materials?

7.9 Are ISO 9000 procedures used by contractors working with recycled materials during construction?

7.10 What construction quality assurance/quality control procedures are used by the contractors working with recycled materials? Are these the same as those used for natural materials?

7.11 What issues do contractors face when maintenance operations or procedures are conducted on infrastructure containing recycled materials?

7.12 How is the use of less-conventional recycled materials handled in the contract process? Are they specified by the owner; is the contractor allowed to be innovative in the use of these materials? If a warranty is involved, how is it affected by the presence of a recycled material?

8. Other

8.1 Are bio-materials (municipal wastewater sludge compost, municipal solid waste compost, street sweepings, storm drain wastes, wood chips, site grubbing material, native plant salvage) used in highway construction activities?

8.2 Are there any efforts to set up a bio-materials exchange for mitigation or waste reduction purposes?

8.3 Some U.S. experiences with tire chip embankments suggests that spontaneous combustion can occur. What has been your agency's experience?

8.4 What are your agency's experiences of using petroleum-contaminated soils as aggregate substitutes in asphaltic pavements?

8.5 To what extent are recycled materials used in highway appurtenances?

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Publication No. FHWA-PL-00-025
HPIP-10/00(10M)EW