



Federal Highway  
Administration



# Using Coal Ash in Highway Construction: A Guide to Benefits and Impacts



USWAG

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## **Acknowledgments**

This document was prepared by the U.S. Environmental Protection Agency (EPA), in cooperation with the following agencies and associations:

Department of Energy (DOE)

Federal Highway Administration (FHWA)

The American Coal Ash Association (ACAA)

The Utility Solid Waste Activities Group (USWAG)

## Glossary

**Alkali-Silicate Reactivity:** The reaction between the alkalis (sodium and potassium) in Portland cement with certain siliceous rocks and minerals, such as opaline chert, strained quartz, and acidic volcanic glass, present in some aggregates; the products of the reaction can cause abnormal expansion and cracking of concrete in service. Class F fly ash is used in concrete to reduce the occurrence of alkali-silica reactivity.

**Attenuation:** The reduction in mass or concentration of a compound in ground water over time or distance from the source of constituents of concern due to naturally occurring physical, chemical, and biological processes, such as biodegradation, dispersion, dilution, adsorption, and volatilization.

**Beneficial Uses:** The use of byproducts in such a manner that the material serves a beneficial function, while not adversely impacting human health or the environment. Beneficial uses of byproducts include construction applications (e.g., brick and concrete products, road bed, blasting grit, wall board, insulation, roofing materials), agricultural applications (e.g., as a substitute for lime) and other applications (e.g., absorbents, filter media, paints, plastics and metals manufacture, snow and ice control, waste stabilization).

**Borrow Pit:** An area from which soil is excavated for use as a fill material in a highway application.

**Cement Clinker:** The fused particles or pellets produced from the sintering or burning zone (2200° F to 2700° F) of a rotary kiln in the cement manufacturing process. Raw materials (limestone, shale, iron ore, sand) are proportioned and ground to a powder and blended before being processed through the rotary kiln.

**Coal Combustion Products (CCPs):** Residues from coal burning, including bottom ash, fly ash, boiler slag, and flu gas desulfurization materials (FGD), which can be used beneficially. (The use of the term “coal combustion products” in this document does not change the legal definition of solid waste as defined in RCRA 42 U.S.C. 6903(27).)

**Concrete:** A construction material consisting primarily of aggregates, Portland cement, and water. Certain coal ashes can be used as a replacement for a portion of the Portland cement.

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**Engineered Application:** Use of a byproduct that has been specifically designed and engineered (for example, a road design that incorporates appropriate run-off control and provides adequate strength for the required use).

**Fill:** Material such as dirt, gravel, or coal ash used to build up an area of land.

**Flowable Fill:** A fill material that flows like a liquid, is self-leveling, requires no compaction or vibration to achieve maximum density, hardens to a predetermined strength, and is sometimes used as a controlled low-strength material.

**Flue Gas Desulfurization Materials (FGD):** The materials created during the process of removing gaseous sulfur dioxide from boiler exhaust gas. FGD materials often are used as a replacement for gypsum in wallboard.

**Heat of Hydration:** Heat evolved by chemical reactions with water such as during the setting and hardening of Portland cement.

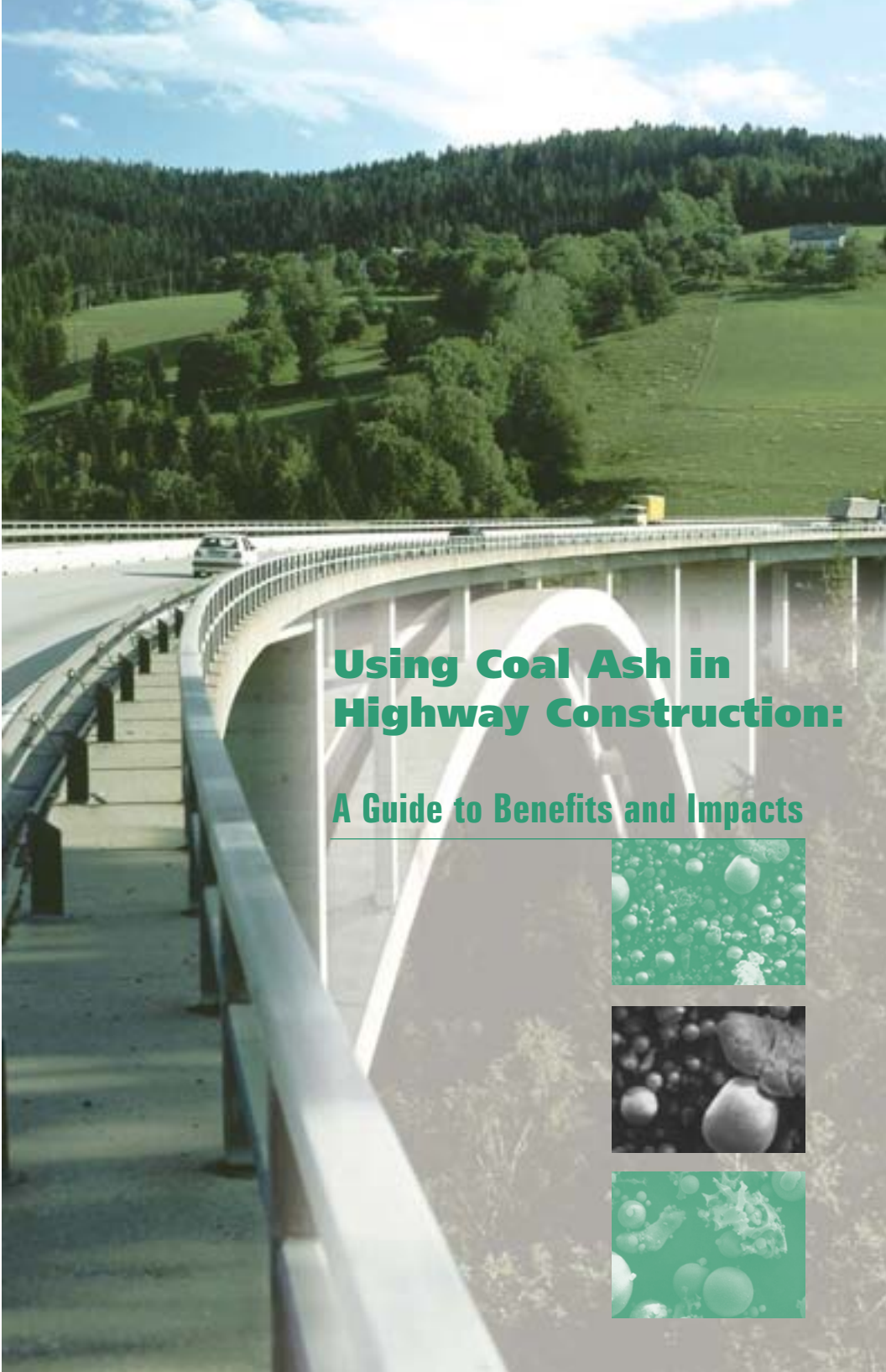
**Leachate:** The liquid, including any suspended components in the liquid, that has percolated through or drained from a pile or cell of solid materials; the liquid stream that issues from a pile or cell of solid materials and that contains water, dissolved solids, and decomposition products of the solids.

**Maximum Contaminant Level (MCL):** The highest level of a contaminant that is allowed in drinking water.

**Portland Cement:** A hydraulic cement made by heating a mixture of limestone and clay containing oxides of calcium, aluminum, iron, and silicon in a kiln and pulverizing the resulting clinker.

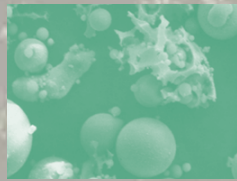
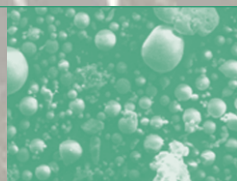
**Pozzolanic Properties:** The phenomenon of strength development that occurs when lime and certain aluminosilicates react at ambient temperatures in the presence of water.

**Sulfate Attack:** Either a chemical or physical reaction (or both) between sulfates, usually in soil or ground water, and concrete and mortar. The chemical reaction is primarily with calcium aluminate hydrates in the cement-paste matrix and can cause deterioration of the cement product.



# **Using Coal Ash in Highway Construction:**

## **A Guide to Benefits and Impacts**





## Use of Ash in Construction Through the Ages

- ❖ In ancient times, the Romans added volcanic ash to concrete to strengthen structures such as the Roman Pantheon and the Coliseum—both of which still stand today.
- ❖ The first major use of coal fly ash in concrete in the United States occurred in 1942 to repair a tunnel spillway at the Hoover Dam.
- ❖ One of the most impressive concrete structures in the country, the Hungry Horse Dam near Glacier National Park in Montana, was constructed from 1948 to 1952, with concrete containing coal fly ash.





- ❖ In Washington, DC, both the metropolitan area subway system (Metro) and the new Ronald Reagan Building and International Trade Center were built with concrete containing coal fly ash.
- ❖ Other significant structures utilizing coal fly ash in concrete include the "Big Dig" in Boston and the decks and piers of Tampa Bay's Sunshine Skyway Bridge.



## Using Coal Ash in Highway Construction

### A Guide to Benefits and Impacts

**T**he U.S. Environmental Protection Agency (EPA) encourages the use of coal combustion products (CCPs) in highway construction projects such as in concrete, road base, embankments, flowable fill, and other beneficial applications. The increased use of these materials, which would otherwise be discarded as waste, can reduce greenhouse gases in the atmosphere, reduce energy consumption, and conserve natural resources. Some applications, such as road embankments and other non-encapsulated (loose) uses, may require the evaluation of local hydrogeological conditions to ensure protection of human health and the environment.

To encourage the increased use of coal combustion products, EPA, the Department of Energy, and the Federal Highway Administration, along with the American Coal Ash Association and the Utility Solid Waste Activities Group, are co-sponsoring the Coal Combustion Products Partnership (C<sup>2</sup>P<sup>2</sup>). The purpose of C<sup>2</sup>P<sup>2</sup> is to foster the beneficial uses of coal combustion products. This booklet is intended to help users and the public understand both the environmental benefits and potential impacts of using coal combustion products in various applications. EPA and the National Academy of Sciences are evaluating the use of coal combustion products as mine-fill and will address this issue separately.





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# Background Basics

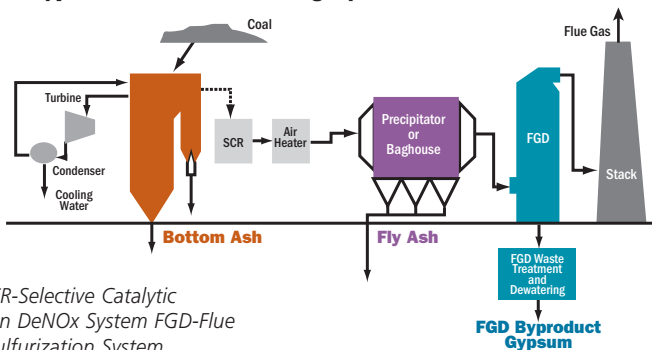
## What Are Coal Combustion Products?

**W**hen coal is burned in a power plant to generate electricity, it leaves behind residues that can be used as products or raw materials, primarily in the construction industry. These materials are known as coal combustion products, or CCPs. Power plants generate a variety of CCPs, namely bottom ash, fly ash, boiler slag, and flue gas desulfurization (FGD) materials. EPA and industry refer to the larger ash particles that fall to the bottom of a furnace as bottom ash, and ash that is carried upward by the hot combustion gases of the furnace as fly ash. Boiler slag is formed instead of bottom ash when combustion occurs in a wet boiler, and FGD materials are produced from scrubbers used to remove sulfur from air emissions.

**The concentrations of naturally occurring elements found in many fly ashes are similar to those found in naturally occurring soil.**

The concentrations of naturally occurring elements found in many fly ashes are similar to those found in naturally occurring soil. A mineral analysis of coal combustion products from coal-fired power plants indicates that they are composed of 95 percent iron oxides, aluminum, and silica. They also contain oxidized forms of other naturally occurring elements found in coal, such as arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. The exact chemical composition of coal combustion products varies depending on the type of coal burned, the extent to which the coal is prepared before it is burned, and the operating conditions for combustion.

**Figure 1: Typical Steam Generating System**

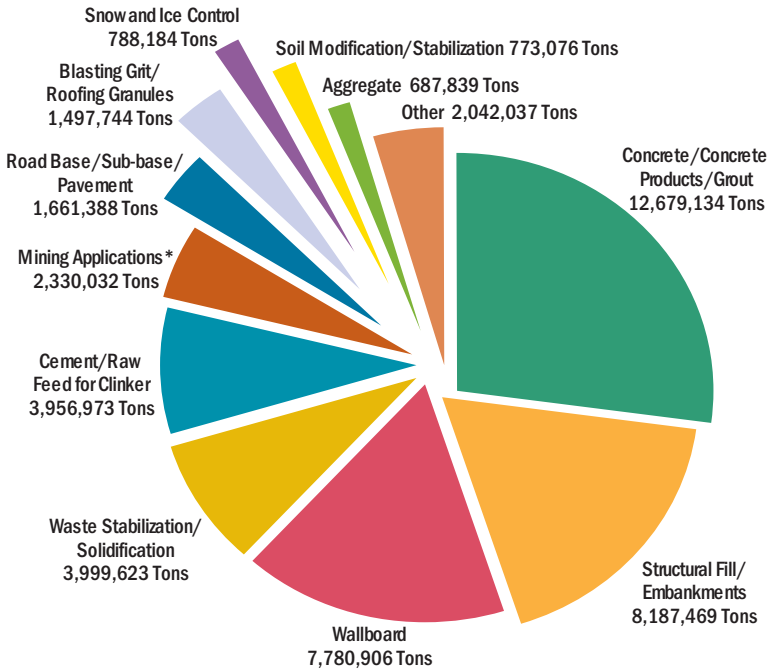


Note: SCR-Selective Catalytic Reduction DeNOx System FGD-Flue Gas Desulfurization System

## How Are Coal Combustion Products Used?

According to the American Coal Ash Association’s annual coal combustion product survey, almost 122 million tons of coal combustion residues were generated in 2003, and more than 46 million tons were used as products in such beneficial applications as concrete, roofing tiles and shingles, bricks and blocks for building construction, wallboard, and specialty uses such as filler in carpet and bowling balls. Figure 2 shows the top uses of coal combustion products, and Figure 3 shows the top uses of coal fly ash specifically for the reporting year 2003. These figures show that the number one use of coal combustion products collectively, and coal fly ash specifically, is in cement, concrete products, and grout. Figure 4 presents the total coal combustion product generation and use in 2003 by type of material. This figure shows

**Figure 2: Top Uses of Coal Combustion Products, 2003**



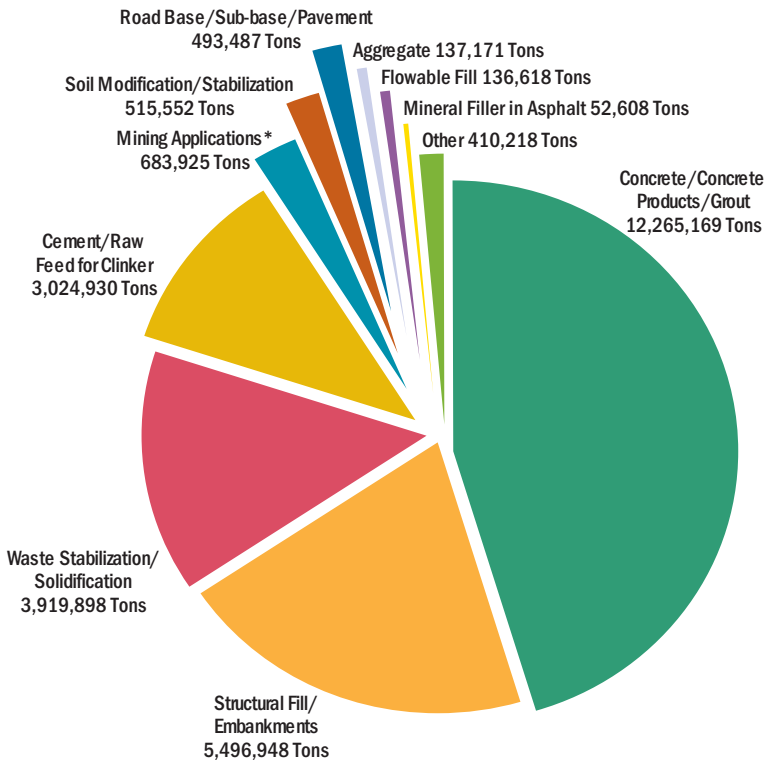
\* EPA and the National Academy of Sciences are evaluating the use of coal combustion products as minefill and will address this issue separately.

Source: American Coal Ash Association. 2004.

that for most coal combustion materials, the United States is beneficially using only about a third of the material generated, with the exception of boiler slag, which shows a 95 percent usage rate.

Coal combustion products have also been used as minefill material. EPA and the National Academy of Sciences are evaluating the use of these materials as minefill.

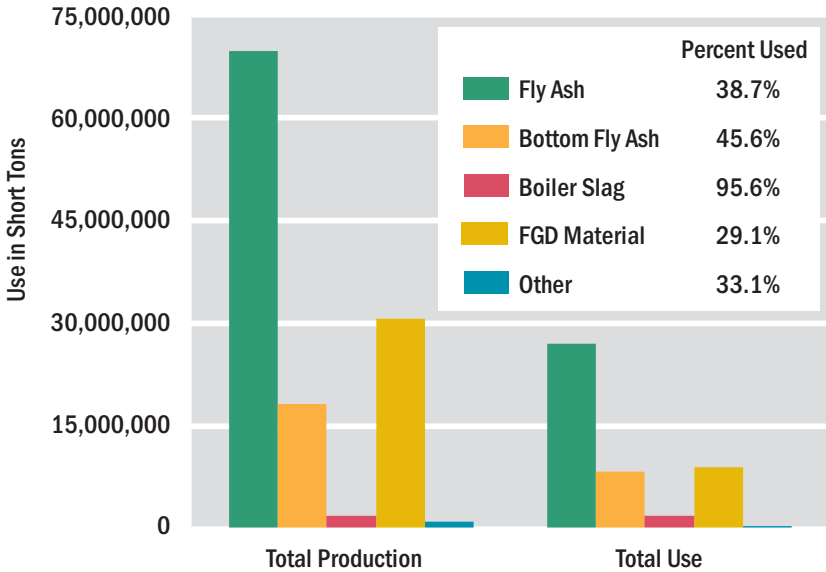
**Figure 3: Top Uses of Coal Fly Ash, 2003**



\* EPA and the National Academy of Sciences are evaluating the use of coal combustion products as minefill and will address this issue separately.

Source: American Coal Ash Association. 2004.

**Figure 4: Coal Combustion Product Generation and Use (Short Tons), 2003**



Source: American Coal Ash Association. 2004.

## How Are Coal Combustion Products Used in Highway Applications?

The two types of coal combustion products used most often in highway construction are fly ash and bottom ash. Fly ash can be used as a replacement for Portland cement in concrete and grout, as a fill material in embankments, as aggregate for highway subgrades and road base, and in flowable fill. Bottom ash can be used as aggregate in concrete and in cold mixed asphalt, and as a structural fill for embankments and cement stabilized bases for highway construction. Figure 5 presents details on coal combustion product use for the 2003 year, with highway applications shaded.

**Figure 5: Details of Coal Combustion Product Use (Short Tons), 2003**

*Highway Applications are shaded.*

Uses of CCPs	Fly Ash	Bottom Ash	Boiler Slag	FGD Material*
Concrete/concrete products/grout	12,265,169	298,181	15,907	99,877
Structural fills/embankments	5,496,948	2,443,206	11,074	236,241
Cement/raw feed for cement clinker	3,024,930	493,765	15,766	422,512
Road base/sub-base/pavement	493,487	1,138,101	29,800	0
Snow and ice control	1,928	683,556	102,700	0
Aggregate	137,171	512,769	31,600	6,299
Flowable Fill	136,618	20,327	0	9,184
Mineral filler in asphalt	52,608	0	31,402	0
Wall board	0	0	0	7,780,906
Waste stabilization/solidification	3,919,898	30,508	0	0
Mining applications**	683,925	1,184,927	59,800	390,331
Blasting grit/roofing granules	0	42,604	1,455,140	0
Soil modification/stabilization	515,552	67,998	0	818
Miscellaneous/other	408,290	1,331,331	2,815	34,813
Total	27,136,524	8,247,273	1,756,004	8,980,981

Source: American Coal Ash Association. 2004.

\* Flue gas desulfurization materials include FGD gypsum, FGD material wet scrubbers, FGD material dry scrubbers and FGD other.

\*\* EPA and the National Academy of Sciences are evaluating the use of coal combustion products as minefill and will address this issue separately.

# What Are the Engineering Performance Standards for Using Coal Ash in Highway Construction?

The American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) have issued numerous standards that describe the proper use of bottom and fly ash in engineering activities.

The standard for using fly ash in Portland cement concrete—the most common type of coal combustion product used in highway construction and the most common usage—is ASTM C 618, or the very similar AASHTO M 295. Two classes of fly ash are defined in ASTM C618: Class F and Class C. These classifications are related to the amount of free lime or calcium oxide in the ash and the grade of coal. Both Class F and Class C fly ash have pozzolanic properties—in other words, they react with water and free lime (calcium oxide) to produce a cement-like compound. Class F fly ash typically contains from 2 to 6 percent calcium oxide and requires additional lime to obtain self-hardening properties. Class C fly ash typically contains between 15 and 35 percent calcium oxide and does not require additional lime for self-hardening properties.





The *Standard Guide for Design and Construction of Coal Ash Structural Fills*, ASTM E2277-03, addresses the second largest use of coal fly ash. This document includes guidelines on using coal ash for structural fill applications (road embankments and other uses), site characterization considerations such as geologic and hydrologic investigations, laboratory test procedures, design considerations and methods, and construction considerations. This guide replaces ASTM E 1861-97. For more information concerning the ASTM and AASHTO standards that apply to coal ash use in highway construction see the Federal Highway Administration's June 2003 document, *Fly Ash Facts for Highway Engineers*.

## Are There State Requirements for Using Coal Ash in Highway Construction?

Many states have laws, regulations, policies, or guidance authorizing or allowing at least limited use of coal combustion products in highway construction. For instance, Wisconsin's Department of Natural Resources has developed a largely self-implementing regulation (NR 538 Wis. Adm. Code), which includes a five-category system to allow for beneficial use of industrial byproduct material, including coal ash.<sup>1</sup> (See sidebar on page 10.) The Texas Natural Resource Conservation Commission issued guidance in 1995 that defined coal combustion products as "co-products" instead of waste when used in certain applications in accordance with industry standards. Many other state regulations adopt by reference the federal regulation, which exempts coal combustion products from classification as hazardous waste. For additional information on applicable regulations, contact your local and state authorities.

### States with CCP Laws, Regulations, Policies, or Guidance

Alabama	Nebraska
Alaska	New Hampshire
Arkansas	New Jersey
California	New Mexico
Connecticut	New York
Colorado	North Carolina
Delaware	North Dakota
Florida	Ohio
Georgia	Oklahoma
Illinois	Pennsylvania
Iowa	Tennessee
Kentucky	Texas
Maine	Utah
Maryland	Vermont
Massachusetts	Virginia
Michigan	West Virginia
Missouri	Wisconsin

<sup>1</sup> See <[www.dnr.state.wi.us/org/law/wm/solid/beneficial/index.html](http://www.dnr.state.wi.us/org/law/wm/solid/beneficial/index.html)>.

## Wisconsin's Beneficial Use of Industrial Byproducts Waste Management Program

**W**isconsin's Beneficial Use of Industrial Byproducts Program is a state-authorized voluntary environmental program that encourages the beneficial use of coal ash, boiler slag, paper mill sludge, foundry sand, and foundry slag as alternatives to placing these materials in the state's solid waste landfills. For the reporting year 2000, the Wisconsin Department of Natural Resources (WDNR) showed that participating generators generated more than 1.4 million tons of coal ash and boiler slag and beneficially used more than 1.1 million tons (81 percent). WDNR also estimated that, statewide (including facilities not participating in the program), nearly 72 percent of coal ash and boiler slag generated in the state is beneficially used. In contrast, the American Coal Ash Association reported that only 29 percent of the coal ash generated nationally in 2000 was beneficially used.

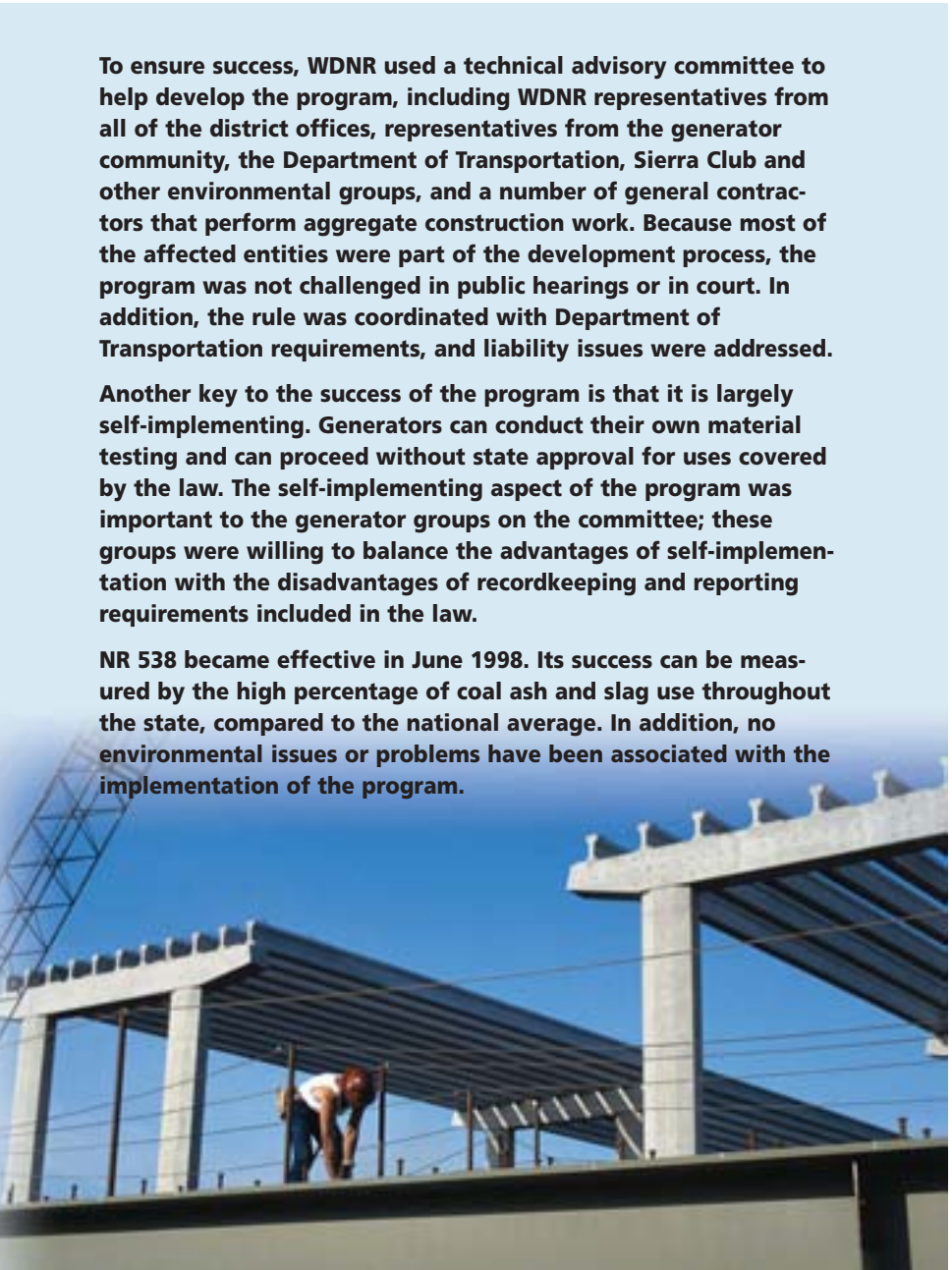
Wisconsin's beneficial use program began in 1985 when the state legislature gave WDNR authority to issue landfill exemptions for low-hazard wastes. In 1995, this authority was expanded to allow WDNR to develop a program and rule for certain industrial byproducts. The result was enactment of State Law NR 538, "Beneficial Use of Industrial Byproducts." The law includes five different categories of industrial byproducts, determined by the chemical characteristics of the materials, defines acceptable end uses for each category, and provides 12 pre-approved beneficial uses for the materials.

For small private projects (<5,000 cu. yds. of material), generators may use their byproducts in a pre-approved beneficial use without contacting WDNR. For large private or public projects, generators must notify WDNR of the nature of the project and provide information about the material characteristics. WDNR reserves the right to review any of these projects, but no permit process beyond notification is required.

To ensure success, WDNR used a technical advisory committee to help develop the program, including WDNR representatives from all of the district offices, representatives from the generator community, the Department of Transportation, Sierra Club and other environmental groups, and a number of general contractors that perform aggregate construction work. Because most of the affected entities were part of the development process, the program was not challenged in public hearings or in court. In addition, the rule was coordinated with Department of Transportation requirements, and liability issues were addressed.

Another key to the success of the program is that it is largely self-implementing. Generators can conduct their own material testing and can proceed without state approval for uses covered by the law. The self-implementing aspect of the program was important to the generator groups on the committee; these groups were willing to balance the advantages of self-implementation with the disadvantages of recordkeeping and reporting requirements included in the law.

NR 538 became effective in June 1998. Its success can be measured by the high percentage of coal ash and slag use throughout the state, compared to the national average. In addition, no environmental issues or problems have been associated with the implementation of the program.



### Performance and Cost Benefits

Using coal combustion products in highway construction yields a number of performance and cost benefits, which can lead to environmental benefits as well. Performance benefits can be realized from the use of coal ash in concrete mixtures, embankments, in flowable fill, as a stabilized base course, in asphalt pavements, and in grouts for pavement subsealing.

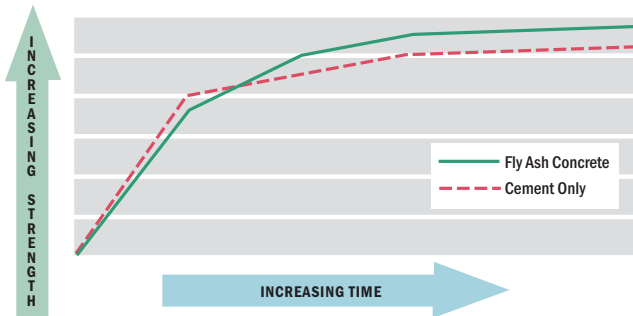
#### Why Is Coal Fly Ash Useful?

The physical properties of coal fly ash—specifically, the unique spherical shape and particle size distribution—make it a good mineral filler in hot-mix asphalt applications, improve the fluidity of flowable fill and grout, and reduce the permeability of concrete.

### In Concrete

Coal ash can be used to create superior products because of its inherent cementitious properties. Mixing fly ash with Portland cement mixtures can produce stronger and longer lasting roads and bridges than concrete made with only Portland cement as the binder (glue). The following are notable performance benefits from using coal fly ash in concrete:

**Figure 6: Strength Gain of Fly Ash Concrete**



- ❖ Improved workability of concrete due to the nature and shape of the ash particles
- ❖ Reduced water demand
- ❖ Reduced bleeding at the edges of pavement
- ❖ Increased ultimate strength of the concrete
- ❖ Reduced permeability to moisture, improving long-term durability of the concrete

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## Performance and Cost Benefits

- ❖ Decreased heat of hydration during concrete curing
- ❖ Greater concrete resistance to various forms of deterioration
- ❖ Reduced concrete shrinkage

## In Embankments

Fly ash can be used as a borrow material for highway embankments. When fly ash is compacted, a structural fill can be constructed that can support highways. The performance benefits associated with this use include:

- ❖ Elimination of the need to purchase, permit, and operate a borrow pit
- ❖ Placement over low-bearing-strength soils
- ❖ Ease of handling and compaction, which reduces construction time and equipment costs



## In Flowable Fill

Flowable fill made with coal fly ash can be used in place of conventional backfill materials and alleviates problems and restrictions generally associated with the placement of those materials. Benefits include:

- ❖ Placement in any weather, including under freezing conditions
- ❖ 100 percent density with no compactive effort
- ❖ Ability to fill around and under structures inaccessible to conventional fill placement techniques
- ❖ Increased soil-bearing capacity
- ❖ Prevention of post-fill settlement problems
- ❖ Increased speed and ease of backfilling operations
- ❖ Decreased variability in the density of backfilled materials
- ❖ Improved on-the-job safety and reduced labor and excavation costs
- ❖ Easy excavation later when properly designed



### In Stabilized Base Course

Fly ash and lime can be combined with aggregate to produce a quality stabilized base course. These road bases are referred to as pozzolanic-stabilized mixtures and are advantageous over other base materials because they provide:

- ❖ A strong durable mixture
- ❖ Reduced costs
- ❖ Autogenous healing
- ❖ Increased energy efficiency

### In Asphalt Pavements

Fly ash also can be used as a mineral filler in asphalt pavements. Mineral fillers increase the stiffness of the asphalt mortar mix, improve the rutting resistance of pavements, and improve the durability of the mix. Other benefits include:

- ❖ Reduced potential for asphalt stripping
- ❖ Reduced cost compared to other mineral fillers



### In Grouts for Pavement Subsealing

Grouts for pavement subsealing are proportioned mixtures of fly ash, water, and other materials used to fill voids under a pavement system without raising the slabs by drilling and injecting grout under specified areas of the pavement. In these applications, the performance benefits include:

- ❖ Quick correction of concrete pavements
- ❖ Minimal traffic disturbance
- ❖ Development of high ultimate strength

## Performance and Cost Benefits

In addition to these performance benefits, many coal combustion products are less costly to use than the materials they replace. At the same time, the durability benefits from using coal ash concrete can reduce the cost of maintaining the nation's road systems. This

**The California Department of Transportation requires the use of concrete containing fly ash in all of its roadways to improve durability.**

enhanced performance also provides additional environmental benefits by reducing the need for new concrete to replace aging roads and bridges, thereby significantly reducing future energy consumption and greenhouse gas emissions.

### A New Era of Pavement Technology

Over the past 15 years, the Federal Highway Administration (FHWA) and its partners in state highway agencies, universities, and the pavement industry have achieved tremendous advances in pavement technology. The FHWA's Office of Pavement Technology has been focusing on combining recent technical advances to develop long-life pavement systems that can last up to 50 years for roads—twice the lifetime of conventional pavements. These long-life pavements will reduce the costs of maintaining the nation's highway systems and also result in decreased material needs. Coal fly ash and other recycled materials are common components of these high-performance Portland cement pavements.



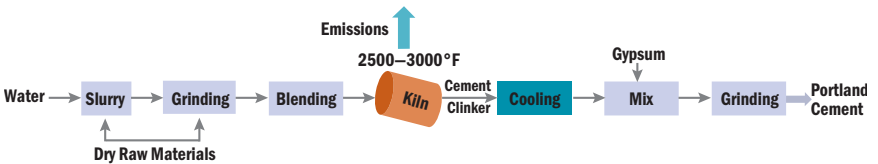
### Environmental Benefits

The use of coal combustion products in highway construction provides significant short- and long-term environmental benefits. Specifically, using coal combustion products in lieu of other materials, such as Portland cement, reduces energy use and greenhouse gas emissions and conserves natural resources. In addition, it prevents the disposal of a valuable resource, reducing the need for landfills and surface impoundments. Finally, the inherent performance benefits of concrete made from coal ash actually leads to additional environmental benefits. Highways and bridges made with coal ash concrete are more durable than those made without it and, therefore, do not need to be repaired and replaced as often.

### Greenhouse Gas Emissions and Energy Reductions

Producing cement involves many steps, including grinding and blending raw ingredients (such as limestone, shells or chalk, and shale, clay, sand, or iron ore), heating those ingredients to very high temperatures in a kiln, cooling and mixing those ingredients with gypsum, then grinding down the mixture to form cement powder.

Figure 7: Generic Cement Production Process



This energy-intensive process typically emits nearly one ton of greenhouse gases for each ton of cement created and requires the equivalent of a barrel of oil per





## Environmental Benefits

ton. Using fly ash—which would otherwise be disposed of—in concrete has the potential to significantly reduce the quantity of greenhouse gases emitted and the amount of fuel used. Typically, between 15 to 30 percent of Portland cement in concrete can be replaced with fly ash.

The Federal Highway Administration reports that roads and bridges made with high-performance coal ash concrete can last years longer than those made with Portland cement as the only binding agent. Thus, using coal ash concrete reduces the need to produce new concrete, which consequently means further reductions in future greenhouse gas emissions, energy use, and natural resources. For some locations, coal combustion products are a locally available construction material that requires less transportation costs and fuel usage for trucking the material to the construction site.

In 2002, the American Coal Ash Association estimated that 12.6 million tons of fly ash were used as a substitute for Portland cement in the United States. The industry set a goal to increase its use to 20 million tons by 2010. EPA estimates that this would reduce the future generation of greenhouse gasses by more than 6.5 million tons a year.<sup>2</sup>

### What Are Greenhouse Gas Emissions?

The Earth's atmosphere acts like an immense greenhouse, trapping heat from the sun to warm the planet to create habitable conditions. This "greenhouse effect" occurs when solar radiation is absorbed by greenhouse gases in the atmosphere. Most greenhouse gases, such as carbon dioxide, nitrous oxide, and other trace gases like methane, occur naturally. Human activities may intensify this natural phenomenon. Burning fossil fuels to power cars, homes, and industry releases carbon dioxide and increases concentrations of other greenhouse gases in the atmosphere.

### One ton of fly ash used as a replacement for cement:

- Conserves enough landfill space to hold about 1,200 pounds of waste, or the amount of solid waste produced by one American over 270 days.
- Reduces the equivalent of two months of an automobile's carbon dioxide emissions.
- Saves enough energy to provide electricity to an average American home for 19 days.

<sup>2</sup> *Estimated using EPA's Waste Reduction Model, Solid Waste Management and Greenhouse Gases, Second Edition, EPA 530-R-02-006, Office of Solid Waste, June 2002.*



## Resource Conservation

Because coal ash can be used as a replacement for many materials in highway construction, its use reduces the need to quarry or excavate virgin materials and therefore helps to reduce the environmental impacts associated with these activities. Reducing these operations helps prevent habitat destruction, protect scenic waterways, reduce water runoff and air emissions, and reduce energy use. In addition, each ton of coal ash used beneficially reduces the need for one ton of virgin resources.

### Examples of Virgin Materials That Can Be Replaced with Coal Ash

Coal combustion products can be substituted for many virgin resources that would otherwise have to be quarried or excavated, such as:

- Limestone and clay to make concrete
- Gypsum to make wallboard
- Sand and gravel to make road beds
- Soil for road embankments

## Solid Waste Reduction

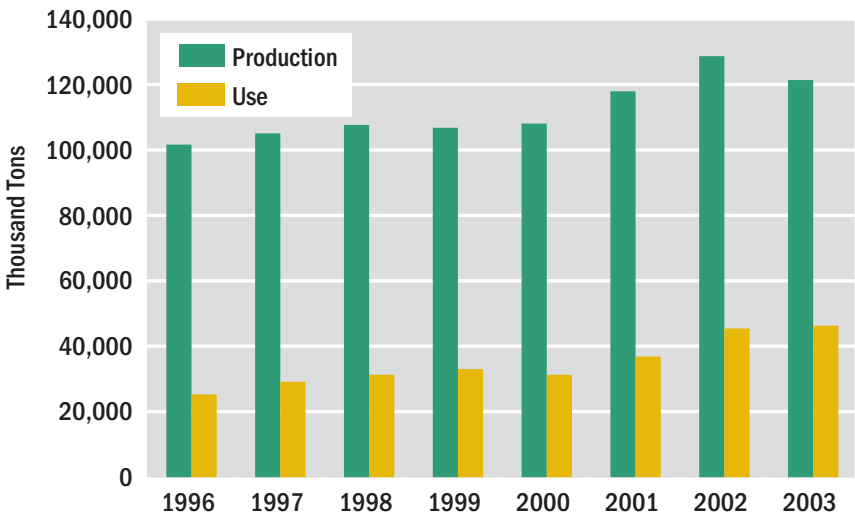
Although many U.S. industries are using coal combustion products, the United States continues to dispose of more than 80 million tons of this material in landfills and surface impoundments annually.

Using coal ash as a substitute for cement in highway construction and other applications could reduce this waste. Typically, a ton of coal ash compacted to 70 pounds per cubic foot takes up approximately 28 cubic feet of landfill space. Every million tons of coal combustion products beneficially used instead of disposed of reduces the need for 656 acre-feet of landfill space.



Figure 8 shows U.S. trends in the generation and use of coal combustion products over the past several years. These data indicate that while the beneficial use of coal combustion products is increasing slowly, so has the generation of these materials.

**Figure 8. Production and Use of Coal Combustion Products, 1996-2003**



Usage Percentage	24.9%	27.8%	29.0%	30.8%	29.1%	31.5%	35.4%	38.1%
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## Environmental and Health Cautions Associated with Concrete (Encapsulated) Uses

**W**hen coal ash is used in concrete for building roads and bridges, its constituents—such as heavy metals—are bound (encapsulated) in the matrix of the concrete and are very stable. Leaching of these constituents for all practical purposes does not occur.<sup>3</sup>

Occupational issues associated with coal ash use in concrete include the handling of dry coal ash prior to or during its inclusion in a concrete mix or exposures during demolition of concrete structures. In these cases, work inhalation and skin contact precautions should be observed, as described on page 27 in the section called Occupational Issues: Inhalation and Skin Contact.



<sup>3</sup> U.S. Environmental Protection Agency, March 1999.

## **Environmental and Health Cautions Associated with Unencapsulated Uses**

**S**tudies and research conducted or supported by Electric Power and Research Institute (EPRI), government agencies, and universities<sup>4</sup> indicates that the beneficial uses of coal combustion products in highway construction have not been shown to present significant risks to human health or the environment. But, as with many other common substances, precautions and sound management practices should be applied when using coal ash in unencapsulated uses. Water and air are the two media most likely to be affected by coal ash or coal ash constituents.

Ingestion, inhalation, and skin contact are the ways that humans and other living things could be exposed to coal ash. Other issues that may need to be addressed are leaching of elements such as mercury and metals into ground water, contamination of vegetation and the impact of other elements on the food chain, and airborne dust. In most cases, however, the way that coal ash is used, the engineering requirements for that use, and the handling and management methods applied minimizes exposure to the ash.



<sup>4</sup> EPRI. May 1990, December 1990, February 1991, November 1993, June 1995, March 1998, and 1998; Hassett, David J., et al 2001; Pflughoseft-Hassett, D.F., et al. 1993; U.S. Environmental Protection Agency. August 9, 1993.

#### Mercury

Although mercury in coal ash can potentially be released into the environment through leachate in water or as emissions to the ambient air, studies conducted by the University of North Dakota Energy and Environmental Research Center and the University of Nevada, which tested bituminous, subbituminous, and lignite coals, have shown that mercury releases from coal ash to the environment are negligible.<sup>5</sup> Results from water leachate tests showed that mercury was very stable in coal fly ash and leached less than 1 percent of the initial mercury concentrations. Studies on the release of mercury from coal ash to the ambient air show only minute losses to the environment.

EPA has proposed a new regulation, called the Clean Air Mercury Rule (CAMR), that would require reductions in mercury emissions from coal-fired power plants. This proposed regulation might affect the amount of mercury found in coal ash, but whether this regulation will increase mercury concentrations in coal ash or not is not clear at this time because this is the first time ever that EPA has regulated mercury emissions from power plants. EPA's conclusions in this document are based on the regulations currently affecting power plants. EPA will reassess its position, if it appears that there is a significant increase in the level of mercury in coal ash, when the CAMR is promulgated.

## Water Issues: Groundwater/Surface Water Health and Human Ingestion

Several studies<sup>6</sup> over the past 10 years have shown that the use of coal ash in highway construction projects has resulted in little to no impact on groundwater and surface water quality, but some precautions are necessary.



**Road Beds and Embankments:** Coal ash used as a fill for road beds and embankments, unlike that used in concrete, requires greater care to ensure its safe use. The use of engineering standards and guidelines pertaining to coal ash will help ensure that the use of these materials will not negatively impact the environment.

<sup>5</sup> Hassett, David J., et al. 1999.

<sup>6</sup> EPRI. May 1990, December 1990, February 1991, November 1993, June 1995, March 1998, 1998; Hassett, David J., et al 2001; Pflughoseft-Hassett, D.F., et al. 1993; U.S. Environmental Protection Agency. August 9, 1993.

## Environmental and Health Cautions For Unencapsulated Uses

Environmental issues in these cases are largely determined by local circumstances, such as groundwater depth and proximity to drinking water wells. The studies mentioned above show that while leaching of coal ash constituents is possible from unencapsulated uses, it does not occur in practice at high concentrations and has not been shown to migrate far from the site when appropriate engineering practices are followed.

Despite the relative safety of using coal combustion products in unencapsulated highway construction projects, some preventive and cautionary measures should be taken (See Town of Pines case study on page 24):

### Precautionary Measures Associated with Unencapsulated CCP Use

- Assess hydrogeologic characteristics of the site.
- Mitigate leaching through engineering and design practices and follow proper construction techniques.
- Unencapsulated coal ash can be used when an assessment indicates it will not affect ground or surface waters. An assessment is particularly important in areas with sandy soils, shallow ground water or in close proximity to drinking water aquifers

- 1) Conduct an evaluation of local groundwater conditions prior to using coal combustion products as a fill material. Numerous groundwater models are available, such as EPA's Industrial Waste Evaluation Model (IWEM), a groundwater fate and transport risk assessment model in EPA's *Guide for Industrial Waste Management*, and HYDRUS 2D.<sup>7</sup>
- 2) Consult with your state regulatory agency for information on the applicable test procedures, water quality standards, and other requirements.
- 3) Once you determine that a site is appropriate for coal ash use, mitigate the leaching of coal ash constituents by assuring adequate compaction and grading to promote surface water runoff, and daily proof-rolling of the finished subgrade to impede infiltration. When construction is finished, a properly seeded soil cover will also help. Two helpful sources of construction information are state highway departments and the Federal Highway Administration's June 2003 document, *Fly Ash Facts for Highway Engineers*.

<sup>7</sup> IWEM model available at [www.epa.gov/epaoswer/non-hw/indusd/iwem.htm](http://www.epa.gov/epaoswer/non-hw/indusd/iwem.htm); HYDRUS 2D model available at [www.hydrus2d.com](http://www.hydrus2d.com).

## Case Study: Town of Pines, Indiana

### History

The Town of Pines, Indiana, provides a cautionary lesson on waste disposal and the use of coal ash as general fill in vulnerable areas. It is primarily a story about the groundwater contamination that arose because of poor early disposal practices. It demonstrates several lessons on the need for good coal combustion product construction practices and site characterization when the material is not encapsulated—specifically, assessing potential groundwater impacts.

### Background

Pines is located about two miles south of Lake Michigan, adjacent to Dunes National Lakeshore. The town's drinking water comes from shallow residential wells typically drawing ground water from 25 to 50 feet below ground level. The native soils are sandy, unconsolidated, and highly acidic, with a high organic content overlying a less permeable clay-rich layer.

Since 1983, more than a million tons of coal ash and other materials have been disposed of at a local landfill or used around town as a fill material. The landfill was originally located in a swampy area only 300 feet from the nearest drinking water well and has recently closed. The direction of groundwater flow is to the east/northeast with a small northerly component that affected the main portion of the Town of Pines. Coal ash was also used throughout the town to fill in low lying areas—up to eight feet in some places—and to build roads that were often left uncovered and exposed to the elements. The shallowness of Pines's drinking water aquifer makes it susceptible to contamination of all types.

In May 2000, the Indiana Department of Environmental Management (IDEM) began an investigation of the town's water after a resident complained that it tasted foul. IDEM found several volatile organic compounds (VOCs) in the water, including



benzene. In January 2001, IDEM also found elevated levels of methyl-tertiary-butyl-ether (MTBE). Both benzene and MTBE are associated with gasoline and are not associated with the landfill or coal ash. Later investigations discovered high levels of boron, manganese, and molybdenum in the drinking water, which are associated with coal ash. In short, the shallowness of the drinking water wells, the porosity of the overlying sands, the location of the landfill, and the improper use of coal ash all contributed to the contamination of the town's drinking water.

### Lessons Learned

Several important lessons can be learned from Pines:

- Take care when using or disposing of any material in a hydrogeologically vulnerable area.
- Before using coal ash as a fill material, conduct an assessment of its potential groundwater impacts.
- Follow proper engineering requirements when using unencapsulated coal ash.

The environmental problems in the Town of Pines should not discourage the beneficial use of fly ash at other locations for fill, road base, or embankments. But, these problems do highlight the need for properly assessing and addressing potential groundwater impacts.



## Vegetation and Food Chain Issues

EPA, in 2000, determined that the use of coal ash as a highway fill material or even as a substitute for lime in agricultural applications did not pose a risk of concern. In addition, several EPRI (Electric Power Research Institute) studies<sup>8</sup> have shown that the use of coal ash in unencapsulated highway construction projects poses limited risk to roadside vegetation. Studies of road construction projects in Arizona, Arkansas, Georgia, Illinois, and Kansas indicate that while metal constituents from coal fly ash and bottom ash might enter plant tissues through absorption, the concentrations of these elements are found to be well below the toxic limits.



In addition, studies examining the effects of ingestion of fly ash constituents by animals have not suggested any associated health problems.<sup>9</sup> Some tests showed slightly elevated levels of some elements in blood and various organs, while other tests found no constituent increases. These results indicate little potential for coal ash ele-

ments from highway construction projects to accumulate in soil and increase in concentration by food chain biomagnification (the process by which animals feeding on affected plants can, in turn, accumulate the same constituents and build up these constituents in their tissues).

## Air Issues: Air Quality and Inhalation

Air inhalation of coal ash dust is primarily a worker safety issue. Nevertheless, proper precautions should be taken to protect the public from dusting during delivery and construction, when coal ash is first laid down. Dust is not an issue when coal ash is used in concrete or in a slurry form.

Coal ash can become airborne during storage and processing of ash, from traffic on roads, and through wind erosion during ash placement. Like other nuisance dust, however, specific controls can address these exposure methods to prevent air pollution and inhalation:



<sup>8</sup> Electric Power Research Institute. June 1995.

<sup>9</sup> Electric Power Research Institute. 1998.

## Environmental and Health Cautions Occupational Issues

- ❖ High-calcium, self-hardening ash should be stored dry in silos, while low-calcium ash can be stockpiled onsite if the ash is kept moist and covered to prevent dusting and erosion.
- ❖ Dry fly ash should be transported in covered or pneumatic tanker trucks.
- ❖ Wind erosion of coal ash should be mitigated in highway construction application by moistening the ash during the construction phase or by using the material in slurry form.
- ❖ Coal ash used in road construction should be compacted and covered to minimize dusting.



## Occupational Issues: Inhalation and Skin Contact

### Inhalation

Workers involved with dry ash handling, concrete grinding, or demolition activities can come in contact with fugitive dust containing coal ash. Health risks associated with the inhalation of these fugitive dusts in occupational settings can be limited by following Occupational Safety and Health Administration (OSHA) standards and practices. These standards and practices are applicable whether or not coal ash is used in concrete. Workers should request Material Safety Data Sheets (MSDS) from coal combustion product suppliers when they are not sure of the proper precautions.

In addition, workers can minimize inhalation through a number of actions:

- ❖ Cleaning work areas regularly by wet sweeping or vacuuming.
- ❖ Wearing basic personal protection such as safety goggles with side shields to protect the eyes from dust.



- ❖ Wearing a suitable particulate respirator (i.e., approved for particulates by the National Institute for Occupational Safety and Health—NIOSH) to prevent particulate inhalation.
- ❖ Adding water to the ash to prevent fly ash from blowing during handling.
- ❖ Using standard dust filters on vehicles and silos.
- ❖ Using mechanical ventilation or extraction in areas where dust could escape into the work environment.
- ❖ Using closed pumping systems for bulk deliveries.

An EPRI study to determine potential health effects of workers in frequent contact with coal fly ash concluded that routine operating activities did not produce hazardous exposures.<sup>10</sup> In addition, occupational health records for these types of workers do not show a higher incidence of respiratory problems than those of power plant workers who do not work as closely with fly ash. In some occupational settings, however,

### Radioactivity and Radon

Coal contains naturally occurring radioactive elements. After combustion, these elements and their decay products can remain in coal combustion ash. EPA has classified coal fly ash as a diffuse, naturally occurring radioactive material, which is EPA's most benign radioactive classification.

Studies have shown that the level of radioactivity in coal combustion products is about the same as the level found in surface rocks and soil.\* A long-term Tennessee Valley Authority study of a 42-acre site that used more than 1 million cubic yards of fly ash in structural fill indicated that ambient radon levels measured directly over the fly ash fill were comparable to the levels measured in control areas without fly ash.

Studies have also shown that radon releases from concrete blocks manufactured using coal fly ash are well below EPA's radon action levels.\*\*

\* *Electric Power Research Institute. 1998.*

\*\* *U.S. Environmental Protection Agency. October 1998.*

<sup>10</sup> *Electric Power Research Institute. 1998.*

## Environmental and Health Cautions Occupational Issues

such as maintenance activities or in an accident, some power plant workers can be exposed to higher concentrations of fly ash particles. In these cases, potential health problems related to either the presence of particles in the lungs or to specific substances in the ash (e.g., metals or quartz) can occur from direct inhalation of higher concentrations of coal fly ash.

Another study<sup>11</sup> reviewed the toxicity and health hazards of coal fly ash compared to coal mine dust, which is known to cause pneumoconiosis and emphysema. Researchers concluded that exposure to high concentrations of coal fly ash can cause chronic bronchitis and air flow obstruction—typical of the common effects seen after inhaling a variety of different types of dusts. However, the study found no evidence that coal fly ash can induce pneumoconiosis and emphysema. Exposures to high concentrations of coal fly ash can be minimized or prevented by following the guidelines presented earlier in this section and by observing OSHA requirements regarding nuisance dust.

### Skin Contact

Power plant workers and people involved in producing cement, concrete, or other ash-based products can have skin contact with coal fly ash. In highway applications, skin contact is likely limited to construction workers working with dry ash. When construction is finished, the road bed and a properly seeded soil cover will reduce any chance of skin contact. While most contact with coal ash can be controlled by proper handling and construction safety practices, if contact does occur, coal ash can cause skin irritation or contact dermatitis.

Workers can minimize skin contact through a number of specific actions:

- ❖ Wearing gloves or applying a barrier hand cream.
- ❖ Wearing loose, comfortable clothing that protects the skin and washing work clothes regularly.
- ❖ Washing any exposed skin thoroughly with mild soap and water prior to eating and at the end of work activities.

Others exposed to coal ash should wash exposed skin with mild soap and water and launder soiled clothing.



<sup>11</sup> Borm, P.J.A., December 1997.

# EPA's Position on the Use of Coal Combustion Products

**E**PA supports and encourages the beneficial use of coal combustion products in highway construction applications for several reasons. First, coal combustion products are a significant component of the U.S. solid waste stream. The United States produced over 121 million tons of this material in 2003. Second, coal combustion products can be beneficially used in highway applications instead of being land disposed. This beneficial use has many environmental benefits, including reduced energy consumption, greenhouse gases, need for additional landfill space, and raw material consumption. Third, using coal combustion products in highway construction applications does not result in environmental harm or human health problems if proper management practices are followed.



## Regulatory Determinations

EPA conducted two regulatory determinations on the management and use of coal combustion products, in 1993 and in 2000. As part of these regulatory determinations, EPA evaluated the following eight factors:

- ❖ The source and volume of coal combustion products generated per year.
- ❖ Current disposal practices.
- ❖ Potential danger, if any, to human health or the environment from the disposal of coal combustion products.
- ❖ Documented cases in which danger to human health or the environment has been proved.
- ❖ Alternatives to current disposal methods.
- ❖ The costs of such alternatives.
- ❖ The impact of those alternatives on the use of natural resources.

## EPA's Position on the Use of Coal Combustion Products

- ❖ The current and potential utilization of coal combustion products.

In conducting these two regulatory determinations, EPA did not identify any environmental harm associated with the beneficial use of coal combustion products in high-way construction applications and concluded in both determinations that these materials did not warrant regulation as a hazardous waste. The beneficial use of coal combustion products can include both encapsulated and unencapsulated applications. EPA recognizes that unencapsulated uses of coal combustion product require proper hydrogeologic evaluation to ensure adequate groundwater protection.

The 2000 regulatory determination recommended a separate review addressing the use of coal combustion wastes as fill for surface or underground mines, which is currently underway.



## Procurement Policy

EPA also has provided guidelines to the federal government for purchasing cement and concrete products containing fly ash.<sup>12</sup> In 1983, EPA promulgated the first federal procurement guideline that required agencies using federal funds to implement a preference program favoring the purchase of cement and concrete containing fly ash. EPA also endorses the use of pozzolans, such as coal ash, as the preferred method for stabilizing certain metal-bearing wastes. EPA published a summary of information pertaining to coal combustion products use in an environmental fact sheet, *Guideline for Purchasing Cement and Concrete Containing Fly Ash* (EPA530-SW-91-086, January 1992).

In addition, Executive Order 12873, *Federal Acquisition, Recycling, and Waste Prevention*, signed on October 20, 1993, directs federal agencies to develop affirmative procurement programs for environmentally preferable products. It also requires EPA to issue guidance on principles that agencies should follow in making determinations for the preference and purchase of these products. In 1995, EPA issued the Comprehensive Procurement Guideline, designating items that can be made with recovered materials, including coal fly ash. EPA also further clarified that flowable fill from the combustion of coal can be used as a recovered material.

<sup>12</sup> U.S. Environmental Protection Agency. January 28, 1983.

## Case Studies

The following case studies provide examples of how coal combustion products have been used successfully in a variety of highway construction applications nationwide over the past few decades.

### Concrete Pavement:

#### Cold In-Place Recycling of Asphalt Pavement, Jackson County, Missouri

A Jackson County, Missouri innovative partnership rehabilitated 2.36 miles of deteriorating rural roads, resulting in an environmentally sound and superior road surface at significant cost savings to the County.



The “Jackson County Partnership” included the County’s Department of Public Works, Lafarge-North America, Kansas City Power & Light and the University of Missouri-Kansas City (UMKC). The partnership developed a process in which the full depth of asphalt and base material were pulverized and mixed with fly ash and water. These constituents were re-compacted to form a strong, economical sub-base and then covered with a new asphalt wear surface.

In this project, an independent researcher and students from UMKC assisted in the development of County specifications and evaluated the finished product. The removal of the old asphalt and processing on site minimized the environmental impact of the project including use of nearly 1,700 tons of Class C fly ash donated by KCP&L and Lafarge-NA. The project to rehabilitate the road with fly ash cost about one-third less than it would have to remove and replace the entire road. California Bearing Ratio values, a measurement of strength, averaged 52 after 24 to 48 hours of curing. This stronger road base permitted a thinner (less expensive) layer of asphalt to be applied as the final wear surface.

On-site recycling of the old pulverized pavement with locally provided fly ash, reduced overall energy consumption, equipment and hauling costs and emission pollution, as well as truck traffic. This project also eliminated landfill requirements, excavation, and depletion of newly quarried rock and dredged sand. The partnership demonstrates not only the value of innovative cooperation among organizations, but also exemplifies the goals of the Coal Combustion Products Partnership.





## Concrete Pavement:

### Boston Central Artery/Tunnel Project, Massachusetts

Approximately 3.8 million yards of concrete containing a 30 percent coal fly ash mix is being used in the sprawling Boston Central Artery/Tunnel project—one of the largest and most technologically challenging highway projects in the United States. Coal fly ash is being used as part of the concrete design and specification because of its resistance to alkali reactivity and low heat of hydration. At the same time, the fly ash used in place of cement will prevent approximately 335,000 tons of greenhouse gases from being released.



*Storrow Drive Connector*

The project has two major components:

1. The replacement of a six-lane elevated highway with an eight- to 10-lane underground expressway directly beneath the existing road, culminating in a two-bridge crossing of the Charles River (the Cable Stayed Bridge and the Storrow Drive Connector).
2. The extension of I-90 (the Massachusetts Turnpike) from its current terminus south of downtown Boston through a tunnel beneath South Boston and Boston Harbor to Logan Airport. The first link in this new connection—the four-lane Ted Williams Tunnel under the harbor—was finished in December 1995.



*Ted Williams Tunnel*

The concrete mixes used on the project were designed to meet rigid project specifications. Using these mix-designs allows for the elimination of construction joints, which in turn helps the construction schedule, saves on labor-intensive costs, and allows for very large placements—up to 1,400 cubic yards in a single pour.

## Road Base:

### State Route 22 Project, Georgia

Post-construction environmental and performance testing determined that using coal fly ash as a base course along part of Georgia State Route 22 has resulted in negligible environmental impacts and has shown sustainable high performance.

This test project was a joint venture of the Georgia Department of Transportation (GDOT), Southern Company Services, and the Georgia Power Company, with funding from the Electric Power Research Institute, which promotes ash utilization in large volume applications. The testing area was constructed along a two-lane bypass section of Route 22, near Crawfordville, Georgia, approximately 90 miles east of Atlanta. Both coarse and fine ash were used to compare with the typical construction materials replaced by fly ash. Site preparations began in fall 1984, and construction of the ash layers was completed in July 1985.



Class F fly ash supplied from Southern Electric System was used in three applications: 1) a lime-fly ash (LFA) stabilized sub-base, 2) a cement-stabilized fly ash (CFA) base course, and 3) a cement stabilized pond ash (CPA) base course, each of which were each placed in 1,000-foot-long test sections.

Post-construction monitoring evaluated strength, road surface conditions, pavement deflections, groundwater quality from four groundwater monitoring wells and multiple leachate collection pipes, and environmental effects resulting from the use of fly ash. Results indicate that the performance of all test sections surpassed that of the control section and exceeded GDOT requirements. Environmental monitoring results indicate that the environmental impact of the test sections has been negligible.

## Embankments:

### Route 213/301 Overpass Project, Maryland

Sixty thousand tons of Class F fly ash from the Baltimore Gas and Electric and the Delmarva Power plant were provided to the Maryland State Highway Administration in 1993 and 1994 to create the highway embankments for the Route 213 overpass over Route 301 on Maryland's eastern shore. A study of the

overpass was initiated in March 1999 by the Maryland Department of Natural Resources Power Plant Research Program to assess groundwater quality impacts and promote the beneficial use of coal combustion products generated in Maryland. Groundwater data collected during May, June, and July of 1999 indicate that the leachate from the fly ash has had no discernable impact on the groundwater quality at the site.

The site embankments were constructed using a base layer of silty sand, with the placement of sandy clay berms to contain the sides of the fly ash, and placement and compaction of fly ash in 8-inch lifts. The fly ash was moistened to about 20 percent prior to compaction and covered with 2 feet of sandy clay. The portions beneath the road were covered with a stone base and asphalt pavement.

The groundwater study for this site involved using lysimeters, monitoring wells, and soil moisture probes in and through the fly ash fill on the shoulder of Route 213. Samples were collected to provide information on the embankment material's physical and chemical properties and were used to assess the factors impacting the attenuation of constituents. Pore and groundwater samples collected at the site were analyzed for dissolved trace elements, major cations and anions, and alkalinity. Water quality results indicated elevated concentrations of several trace elements and major ions in the fly ash pore water, indicating that leachate is forming within the fly ash fill. The data also indicate, however, that these constituents are being attenuated in underlying soils and ground water beneath the embankments. The water quality data indicate that the use of fly ash for highway embankments can adequately protect groundwater quality.



### **Access Ramp Project, Delaware**

Nearly 10,000 tons of stockpiled fly ash from Delmarva Power and Light Company's Edge Moor Station were used to construct the main access ramps for a new interchange to Interstate 495 near Wilmington, Delaware. This project was conducted during June 1987 and, during the two-year monitoring period that followed, showed no significant environmental effects, but did show high performance characteristics.

Environmental analysts studied the short-term effects of the project on local groundwater quality by evaluating four monitoring wells and four permeate collection drains, and by collecting and analyzing runoff and leachate in the vicinity of the ash fill area. In addition, monitoring of post-construction performance showed that in-place soil had the same characteristics as a well-compacted granular soil. Less than one-eighth of an inch of settlement was measured at each of the settlement plate locations, indicating that the fly ash fill performed as well as conventional materials.

## Flowable Fill:

### McGee Creek Aqueduct Pipe Bedding Project, Oklahoma

Not only did the use of fly ash allow the entire McGee Creek Aqueduct Pipe Bedding project to proceed on a faster schedule, but it also resulted in a 40 percent cost savings. The 1984 construction of this 16.6-mile aqueduct near Ferris, Oklahoma, by the U.S. Bureau of Land Reclamation reused 8,000 tons of fly ash. This ash was used to make a flowable fly ash grout mix, which was used instead of compacted crushed stone for the pipe bedding.

The pipeline contractor selected flowable fly ash grout for bedding to increase the speed of bedding placement, reduce labor and equipment costs, and provide a more uniform bedding. The flowable grout mix contained 11 percent Class C fly ash by weight, as well as sand, water, and R-7 chemical retarder. The fly ash, supplied by Oklahoma Gas and Electric Company, had self-cementing and flash-setting properties, and the chemical retarding agent was used to control the flash-setting characteristics.

The performance of both the fly ash grout and a Portland cement grout, which was also used on the project, was compared by visual inspection. The fly ash grout exhibited the least amount of segregation, bleeding, and shrinkage. The fly ash grout also set up in the trench faster than the cement grout, allowing the second lift to be placed sooner and the entire operation to proceed more quickly than if conventional cement grout had been used. The material cost analysis indicated that the use of Class C fly ash and retarder in place of Portland cement resulted in the significant cost savings. In addition, the use of the fly ash grout for this project resulted in a reduced need for crushed stone.

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U.S. Environmental Protection Agency. February 2003. Guide for Industrial Waste Management, EPA 530-R-03-001. Office of Solid Waste.



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## For More Information

U.S. Environmental Protection Agency, Coal Combustion Products Partnership  
[www.epa.gov/c2p2/index.htm](http://www.epa.gov/c2p2/index.htm)

American Coal Ash Association  
[www.acaa-usa.org](http://www.acaa-usa.org)

Utility Solid Waste Activities Group  
[www.uswag.org](http://www.uswag.org)

Federal Highway Administration, Pavement Technology  
[www.fhwa.dot.gov/pavement/](http://www.fhwa.dot.gov/pavement/)

Department of Energy  
[www.doe.gov](http://www.doe.gov)

The Fly Ash Resource Center  
[www.geocities.com/CapeCanaveral/Launchpad/2095/flyash.html](http://www.geocities.com/CapeCanaveral/Launchpad/2095/flyash.html)

Electric Power Research Institute (EPRI)  
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U.S. Environmental Protection Agency, Comprehensive Procurement Guidelines,  
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University of New Hampshire, Recycled Materials Research Center  
[www.rmrc.unh.edu/](http://www.rmrc.unh.edu/)

EERC/University of North Dakota, Coal Ash Resource Center  
[www.eerc.und.nodak.edu/carrc/index.html](http://www.eerc.und.nodak.edu/carrc/index.html)

UWMilwaukee, Center for By-Products Utilization  
[ww.uwm.edu/Dept/CBU](http://ww.uwm.edu/Dept/CBU)

Center for Applied Energy Research at the University of Kentucky  
[www.flyash.org](http://www.flyash.org)

Ohio State University, Coal Combustion Product Extension Program  
[ccpohio.eng.ohio-state.edu/ccpohio](http://ccpohio.eng.ohio-state.edu/ccpohio)

West Virginia University, Combustion Byproducts Recycling Consortium  
[wvri.nrcce.wvu.edu/programs/cbrc/index.cfm](http://wvri.nrcce.wvu.edu/programs/cbrc/index.cfm)



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