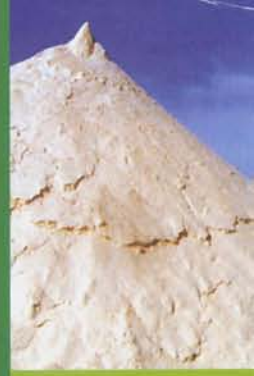
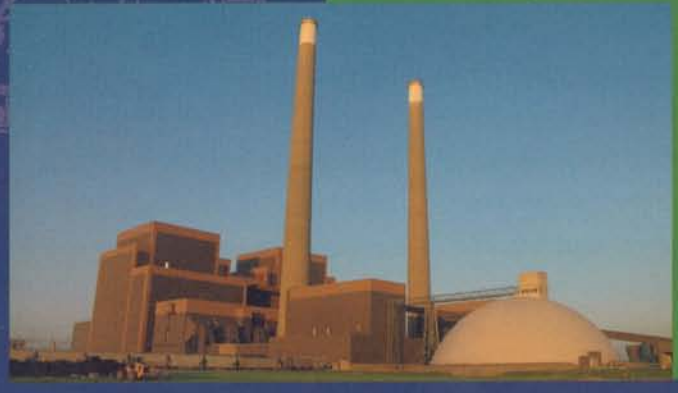


Sustainable Construction
with Coal Combustion Products

A Primer for Architects



Produced by the American Coal Ash Association Educational Foundation
www.acaa-usa.org

What are Coal Combusiton Products?

When selecting materials for construction, we have the choice of substituting recycled materials for conventional products to achieve sustainable design and significantly reduce a myriad of environmental impacts. In most cases these materials cost less, are available locally, and are technically equivalent or superior to conventional materials. They can significantly increase profitability through decreased energy, water, land, and other costs, as well as through quality and longevity.

Coal combustion products or "CCPs" are materials produced by coal-fueled power plants. They include fly ash, bottom ash, boiler slag, flue gas desulfurization materials, and other products. Most CCPs can be recycled in place of conventional materials, especially those that must be mined, using energy and other resources that degrade the quality of our environment and increase project costs. The economic, environmental and social impact of sustainable construction is profound. Each year in the U.S. coal-fueled power plants generate electricity along with more than 125 million tons of CCPs that can be used or recycled in construction and in a wide variety of other commercial or "beneficial" uses. About 40 percent of CCPs are used, while the remaining 60 percent are disposed of.

Fly Ash

Among the most common uses of CCPs is the substitution of fly ash for portland cement in concrete or the use of fly ash as an admixture in concrete. More than half of the concrete produced in the United States is blended with fly ash — a fine, powdery substance captured in emission control systems at the power plant. Annual production is about 72 million tons, with 44 percent of that amount used in various applications. Fly ash is used extensively in concrete, from lightweight to ultra high strength load bearing columns in high-rise buildings. Though the properties of fly ash vary according to coal composition and power plant operating conditions, experts can advise on quality and determine the best mix design for most any condition and project need. Builders routinely use 40 percent fly ash in mixes, but that amount can reach 70 percent or more in massive walls, girders, road bases, dams and foundations.

- Building foundations
- Exterior and interior walls
- Pavements
- Sidewalks
- Floor slabs
- Bricks
- Concrete masonry units
- Fiber cement siding
- Ceramic tiles
- Paints
- Composite materials (wood, plastic and stone)
- Soil stabilization
- Controlled low-strength materials (flowable fill)
- Carpet backing
- Floor underlayments
- Manufactured soils and composts
- Pervious concrete
- Mineral filler in asphalt, road base and pavement sub-base
- Metal castings
- Portland cement feedstock

Flue Gas Desulfurization Gypsum

The second most common use of CCPs is flue gas desulfurization (FGD) gypsum in wallboard. This material is produced by emission control systems that remove sulfur and oxides from power plant flue gas streams. Residues vary, but the most common uses in construction applications are FGD gypsum (or "synthetic" gypsum). This material is used in almost thirty percent of the gypsum panel products (wallboard) manufactured in the United States. FGD gypsum can be used in cement production and geotechnical applications. It can also be used in self-leveling floor applications. The agricultural industry also uses this material to treat undesirable soil conditions and to improve crop performance.

Boiler Slag

Boiler slag is formed in cyclone or slag tap boilers, which produce a molten ash that is cooled with water. Boiler slag is generally a black, granular material.

- Roofing shingles
- Blasting grit
- Snow and ice control
- Portland cement production
- Structural fills
- Embankments
- Road base
- Pavement sub-base
- Mineral fillers in asphalt

Bottom Ash

- Bricks
- Green roof growing media
- Aggregates
- Pervious pavements
- Pavement sub-bases
- Concrete masonry units
- Shingles
- Manufactured soils and compost
- Portland cement production
- Snow and ice control

Bottom ash is a coarse, granular material collected from the bottom of a coal furnace. It is composed of a range of fine to coarse angular particles that are generally gray to black in color. Bottom ash and boiler slag can be used as a raw feed for manufacturing portland cement clinker. The physical characteristics of bottom ash and boiler slag lend themselves as replacements for aggregate in structural concrete applications, including masonry products. These materials are also suitable for geotechnical applications, such as structural fills and land reclamation.

CCP Production and Use Statistics*

Fly Ash

Annual Production = 71,700,000 tons
Annual Use = 31,626,037 tons

Flue Gas Desulfurization Gypsum

Annual Production = 12,300,000 tons
Annual Use = 9,228,271 tons

Bottom Ash

Annual Production = 18,100,000 tons
Annual Use = 7,303,538 tons

Boiler Slag

Annual Production = 2,072,695 tons
Annual Use = 1,663,980 tons

*2007 survey results; additional CCP categories and data available at **www.acaa-usa.org**

Programs Supporting CCPs in Sustainable Architecture

U.S. Green Building Council's LEED Certification

Leadership in Energy and Environmental Design (LEED) is a suite of related, sustainable rating systems developed by the U.S. Green Building Council. To become a LEED-certified project, a building must attain a specific number of credits to achieve certification or the advanced levels of Silver, Gold, or Platinum certification.

When using concrete in construction, the use of coal combustion products (CCPs) can contribute to credits providing various benefits to many project types, including schools and university campuses, commericial interiors, and homes.

CCPs contribute under the Materials and Resources category, as well as the Green Construction and Technology categories for their recycled content and because they are locally available. Innovation in Design credits can be attained for replacing portland cement with fly ash mixes.

Fly ash concrete contributed points toward LEED Silver Certification for EPA Region 8 Headquarters in Denver, Colorado.

Using fly ash or bottom ash/ boiler slag in pervious pavements, which reduces the rate and quantity of stormwater runoff, can contribute to Stormwater Design: Quantity Control. CCPs can also be used in brownfield redevelopment (Sustainable Sites) and in concrete to reduce the heat island effect.

The thermal mass effects of concrete offer numerous energy advantages, including reductions in energy use in heating, air conditioning, and lighting. Even underground-parking garages incorporating CCPs have contributed to reducing a project's carbon footprint. Use of CCPs has contributed to all six credit categories, including: 1. Sustainable Sites, 2. Water Efficiency, 3. Energy and Atmosphere, 4. Materials and Resources, 5. Indoor Environmental Quality, and 6. Innovation and Design Process when they are included in a variety of bulidng materials and applications. Please visit: www.usg www.usgbc.org/leed

Similar to LEED, the BRE Environmental Assessment Method (BREEAM), is taking hold internationally. Please visit: www.breeam.org

Green Building Initiative

As with LEED, the Green Building Initiative (GBI) promotes the adoption of building practices that result in energy-efficient, healthier and environmentally sustainable buildings by promoting credible and practical green building approaches for residential and commercial construction. GBI uses the Green Globes management tool that includes an assessment protocol, rating system and guide for integrating environmentally friendly design into commercial buildings. Working with the American National Standards Institute, GBI has released for public comment a standard against which sustainability can be evaluated. As in the LEED process, the use of CCPs contributes points to site development, materials and resources, and building longevity. Please visit: www.thegbi.org

Greenprint: Denver, Colorado

The City and County of Denver partnered with the University of Colorado at Denver's Sustainable Urban Infrastructure Program to develop a first-of-its-kind greenhouse gas inventory at the city scale. The inventory included the embodied energy of key urban materials, including concrete, and showed that cement in concrete contributed more than 2 percent of the city's greenhouse gas footprint. The UCD team investigated alternative concrete mixes containing fly ash, and found them to be more durable than ordinary concrete. In May 2007, Greenprint Denver announced Denver's Green Concrete Policy as a part of the city's Climate Action Plan. In October that year, Mayor John Hickenlooper signed an executive order outlining the city's sustainability policy, including a requirement that construction projects use concrete with at least 20 percent fly ash. This requirement is the first of its kind in a U.S. city. http://greenprintdenver.org.

Build it Green - GreenPoint Checklist: California

Build It Green is a non-profit membership organization whose mission is to promote healthy, energy- and resource-efficient building practices in California.

The GreenPoint Checklist is the basis of GreenPoint Rated, a third-party home rating program offered by Build It Green. The program offers builders, homeowners and municipalities a tool to assess how environmentally friendly or "green" a home is. A home can be considered green if it fulfills the prerequisites, earns at least 50 points, and meets the minimum points per category: Energy (30), Indoor Air Quality/ Health (5), Resources (6), and Water (9). Coal combustion products may contribute in several categories.

For more information about GreenPoint Rated, visit www.greenpointrated.org

Sustainable specifications with fly ash concrete

Wal-Mart recently issued company-wide specifications requiring fly ash and other supplementary cementitious materials (SCMs) in all construction. The company now has specifications for the use of fly ash or CCPs for non-troweled exterior sitework, structural concrete, grout, concrete masonry units, and troweled concrete floors in amounts ranging from 12 to 25 percent. These innovative requirements placed Wal-Mart in the forefront of large retail corporations. The company has long supported using CCPs, but its past experience caused some challenges. Many of its consultants, contractors and construction managers remembered past problems, such as delayed set times and poor finishes — largely caused by inexperience with CCPs. Wal-Mart did not allow hearsay to sour them on CCPs. Continued research and expert knowledge demonstrated that CCP use can result in lower costs (or no cost increase), improved environmental performance, and material benefits. Tests of its concrete placements allowed Wal-Mart to see for itself the benefits and mitigate the concerns. Wal-Mart's dedication and innovative approach has now led to its leadership role among retailers in CCP use.

Micheal Clark, a senior architect for Wal-Mart accepts a Coal Combustion Products Partnership award from Susan Bodine, Assistant Administrator for the EPA's Office of Solid Waste and Emergency Response.

High Volume Fly Ash Concrete: Superior Sustainability & Technical Performance

Among the most significant environmental aspects of using fly ash over conventional cement is that greenhouse gas emissions can be exponentially reduced. For every ton of fly ash used for a ton of portland cement approximately one ton of carbon dioxide is prevented from entering the earth's atmosphere. Fly ash does not require the energy intensive kilning process required by portland cement.

This energy expense can also be calculated in terms of fuel use. A single ton of cement requires approximately 55 gallons of oil to produce. By using fly ash concrete instead, we prevent disposal, conserve virgin resources - by using an industrial material instead - and we prevent the energy consumption associated with mining virgin materials.

Fly ash concrete is also technically superior to conventional concrete in that it has proven more resistant to acid, sulfates, and other destructive chemical reactions that degrade and destroy structures over time. The pozzolanic properties of fly ash produce long-term strength gains and improve concrete durability by making it less permeable. Fly ash concrete lowers the heat of hydration, and reduces shrinkage and cracking. Fly ash affects the concrete's plastic properties by improving workability, reducing water demand, and reducing segregation and bleeding.

Economic gains are significant from both technical and sustainability perspectives, as well as from an aesthetic point of view. Projects that endure save taxpayers maintenance and reconstruction costs, freeing money to stimulate local economies and enhance communities. Fly ash typically costs less than portland cement, making concrete competitive with other materials such as wood and asphalt.

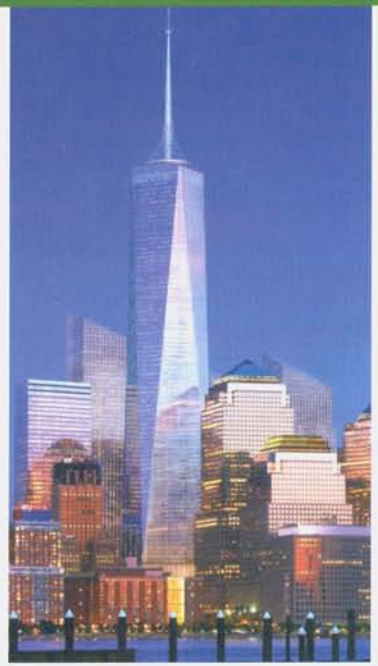
Among the many examples of high volume fly ash concrete are... the U.S. Environmental Protection Agency Headquarters, Washington, D.C. ... Northern Arizona University's Applied Research and Development Building (LEED Platinum) ... Wurster Hall Seismic Upgrate, Stanford University ... The University of Texas - Houston's School of Nursing and Student Community Center (LEED) ... Montana State University's science building ... the Milwaukee Art Museum ... the Utah state Capitol building ... Oakland-Bay Bridge ... and more...

This residence designed by Arizona architect, Michael Frerking utilizes 67 percent fly ash concrete.

The Milwaukee Art Museum incorporated high volume fly ash concrete to achieve a variety of important design objectives.

Durability & strength make fly ash concrete ideal for high-rises, skyscrapers and other large structures.

Freedom Tower, New York City



The Freedom Tower will set a record for strength with concrete including Class C fly ash in the foundation, core and support columns, and slabs. The building's engineers required 14,000 pounds per square inch of compressive strength. More than 240,000 yards of concrete will be used with mix designs of 40 percent fly ash. When complete the tower will be a 1,368-foot-tall building, topped by a 408-foot spire, for a total of 1,776 feet.

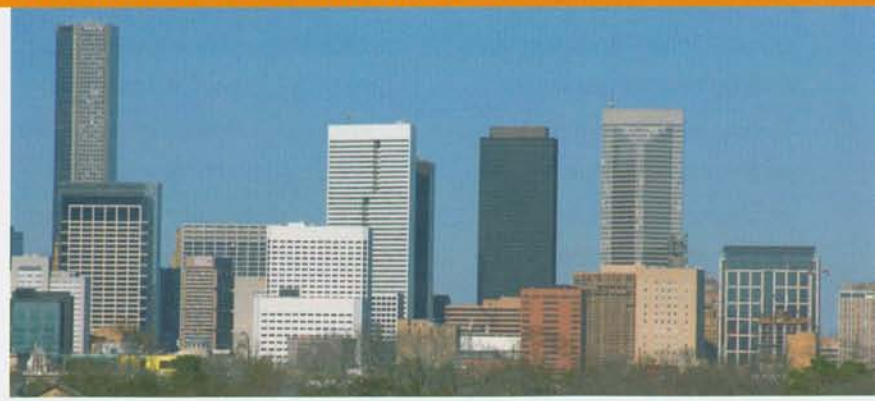
Trump International Hotel and Tower, Chicago

The Trump International Hotel and Tower in Chicago will be the Western Hemisphere's tallest reinforced concrete building. The project includes 180,000 cubic yards of high performance (fly ash) concrete and conventional concrete. Outrigger beams achieved 16,000-psi, marking the highest design strength to date for a commercial application.

BAPS Hindu Temple, Chicago

High volume fly ash was used for the reinforced foundations, beams, and shear walls of this Hindu Mandir, which is one of the largest constructed in the United States.

CEMEX U.S. Headquarters, Houston



The new CEMEX USA headquarters will be the largest green building of its kind in Houston, including concrete mixes that contain fly ash.

Much of the concrete will reflect more of the sun's energy during the day and does not radiate as much stored heat at night.

Site Preparation

CCPs have many uses when preparing a project site for development. Fly ash can be used to stabilize and solidify soils at Brownfield sites or in construction areas. If rains have made work areas difficult to access by vehicular traffic, self-cementing fly ash or fly ash combined with portland cement, cement kiln dust or lime kiln dust can dry up these areas quickly and economically. Blending self cementing fly ash with existing soils allows for the stabilization of roads and parking areas prior to paving. When embankments or structural fills are needed, fly ash, bottom ash and boiler slag can be combined with earthen materials to meet engineering specifications for compaction, compressive strength, grain size distribution and other geo-technical considerations. Large quantities of CCPs can be placed to provide economically acceptable alternatives to importing barrow materials.

Flooring Applications

Many builders are using CCP-based floor underlayments in construction, to address a variety of flooring situations and challenges. Self-leveling underlayments may be placed to aid in preparation of the floor prior to installation of the finished floor systems. On the other hand over-layments are sometimes specified to correct defective flooring issues prior to installation of carpeting, tile, wood or other surfaces. These applications also can provide sound deadening features. For examples of these applications see www.maxxon.com/go_green. Fly ash and FGD (or synthetic) gypsum are used widely in commercial applications, and can be used in single family and multi-family homes to support LEED points for indoor environmental quality, low emitting materials, recycled content, regional materials and innovation in design.

Carpet Backing

Backing comprised of recycled materials can take years of abuse without sacrificing performance. The inherent "ball-bearing" effect resulting from the spherical nature of the glass particles of fly ash contribute to better packing factors in various polymer systems. For carpet backing systems, this translates to improved flammability ratings, better tuft binds, and improved dimensional stability. As a bonus to the performance characteristics fly ash imparts to these engineered systems, carpet backings now qualify under the USGBC LEED section MR 4.1 and 4.2 for recycled content and the NSF 140 as contributing towards silver, gold and platinum levels of sustainability.

Wall-Form Products

Most of these products have hollow interiors and are stacked or set in place and can be filled with high volume fly ash steel-reinforced concrete.

CCP Building

Masonry Products

Fly ash and bottom ash are also used extensively in grouts and masonry products, including concrete veneer stone, available in a wide range of color options.

Applications

Diagram courtesy U.S. EPA

Ceiling Tiles & Panel Products

Ceiling tiles and wall products made with fly ash and FGD gypsum can be textured and pigmented with a wide range of colors.

Composites

Fly ash also serves as filler in wood, plastic products, paints, and metal castings.

A wood alternative produced by Lifetime Lumber (www.ltlumber.com) can contain up to 65 percent fly ash or more. Please see "The Buyer's Guide to Coal Ash Containing Products" under Resources (pg 10).

Green Roofs

Typically, green roofs are part of a normal roof system which involves green space on top of a building. Green roofs are usually modular in design allowing plants to be planted in movable sections or containers. A waterproof barrier separates the green roof from the structural roof. The units containing plants have a drainage system, filter cloth and lightweight growing media to allow the plants to establish their roots. Green roofs can provide a wide range of public and private benefits. They are normally longer lasting than conventional roofs, reduce heat loss dramatically, require less maintenance, absorb sound, and often provide aesthetic spaces for people to meet or congregate. Because of its lightweight, granular characteristics, bottom ash is an ideal material for part of the growing media. For more information: www.greenroofs.com and www.greenroofs.org

Geotechnical

Geotechnical applications include soil stabilization, road base, structural fill, and embankments. The use of CCPs in controlled low-strength materials (CLSM), sometimes called flowable fills, provides economic alternatives to many backfill situations. When utility trenches are constructed at a job site, often the dirt or earthen materials excavated are removed immediately. This necessitates importing fill materials once the trench work is complete. Rapid setting flowable fills made with fly ash, bottom ash and cement (if needed) can be used to efficiently close the exposed work areas. Workers are not needed in the trench to tamp or manually place fill materials and large quantities can be placed in a matter of minutes, allowing the surface to be paved or finished quickly.

Future of Coal Combustion Products in Sustainability

Coal combustion products are expected to continue to play a major role in the concrete market by replacing at least 25 to 40 percent of portland cement in most applications. Their use in other building products is also expected to grow as sustainable construction becomes more prominent, and more architects and building owners understand CCPs' many benefits.

The price of fly ash per ton is typically half to a third the price of portland cement. As portland cement increases or decreases, the prices for fly ash follow that movement.

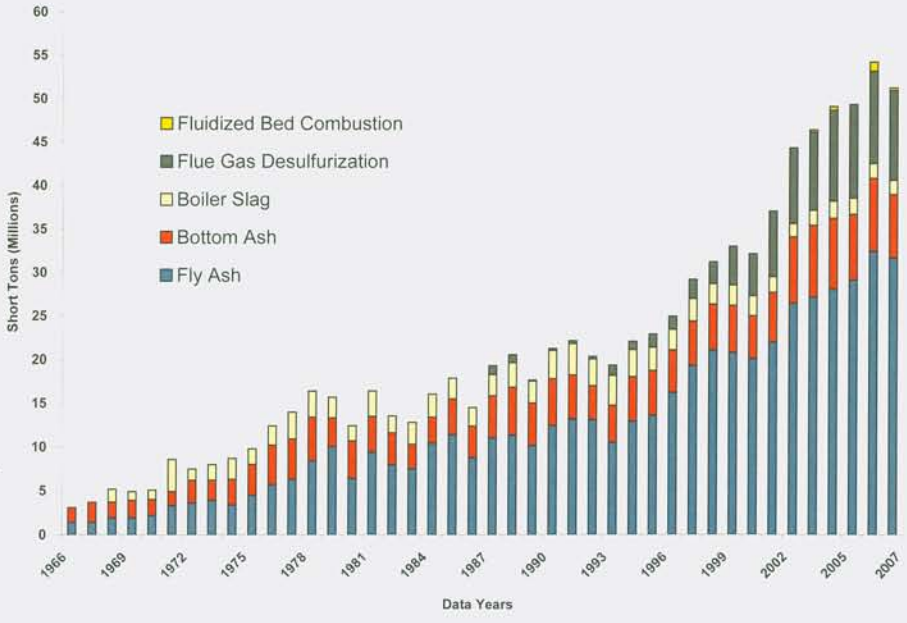
In California, fly ash is shipped in from as far away as Arizona, Texas and Oregon. On the east coast, fly ash is shipped from Baltimore to Puerto Rico to meet market needs. Like slag, fly ash is going to be available to the specifier or project owner who wants to incorporate it into a sustainable concrete design and is willing to pay for this quality and performance. It is hard to generalize where the sources of quality fly ash will be, but with power plants in 47 of the 50 states, the likelihood of adequate supplies is great.

Education and practical experience is transforming the perception of fly ash and other CCPs, from waste to valuable product. Using CCPs reduces green house gas emissions, reduces the need for landfill space, and eliminates the need to use virgin materials. These benefits result in significant positive impacts to the environment.

Though new air emission control systems threaten to affect some fly ash quality, the industry is working hard to meet this and other challenges. Beneficiation processes and emerging technologies are being developed and implemented to ensure that dependable, high quality sources of CCPs will be available to the project owner, designer and architect well into the future. Producers and marketers are working together to ensure CCPs will continue to comply with applicable standards and specifications. Adoption of performance-based specifications will further enable the CCP industry to adapt to changing production and market conditions. As is indicated in the chart below, production of CCPs will continue their upward trend.

Architects and property owners who want to create more sustainable buildings, choose coal combustion products as a way to meet a variety of objectives - aesthetic, technical, economic, social, and environmental.

U.S. Coal Combustion Products Use Trend Chart



Resources

The **American Coal Ash Association (ACAA)** advances the management and use of coal combustion products in ways that are environmentally responsible, technically sound, commercially competitive, and more supportive of a sustainable global environment. **Please visit: www.acaa-usa.org**

The quality and characteristics of fly ash as a component of concrete are defined in several standards, including **ASTM C618** and **ACI 232.2.** Marketers of fly ash will commit to the quality specified as they supply fly ash to ready mix producers, who in turn ensure the concrete will meet the designer's needs through their own quality program. **Please visit: www.astm.org/Standards/C618.htm** and **www.concrete.org/bookstorenet (Search "ACI 232.2"** and **"ACI's Sustainability Related Publications.")**

Specific guidance on the use of high volume fly ash can be found in a book recently published by Dr. P.K. Mehta and Dr. Mohan Malhotra titled, **"High-Performance, High-Volume Fly Ash Concrete for Building Sustainable and Durable Structures."** This book contains mix designs, recommendations, precautions and examples of high volume fly ash concrete placement and applications. **Please visit: www.acaa-usa.org/storeindex.cfm**

Another document, **"Optimizing the Use of Fly Ash in Concrete,"** published by the Portland Cement Association (IS548) has detailed information on mix designs, placement and finishing techniques, performance characteristics and case studies that describe in technical detail the reasons to use fly ash in concrete to improve performance. **Please visit: www.acaa-usa.org/storeindex.cfm**

"Building Green with Concrete" published by the **Portland Cement Association** offers case studies and guidance on achieving LEED certification. **Please visit: www.pca.org**

Greener Buildings is a resource for green building and development. **Please visit: www.greenerbuildings.com**

Green Globes sponsored by the Green Building Initiative is a green management tool that includes an assessment protocol, and a rating system and guide for integrating environmentally friendly design into both new and existing commercial buildings. **Please visit: www.thegbi.org**

The **National Association of Homebuilders Green Building Program** offers several resources and tools to help builders, remodelers, home building associations, and homeowners learn how to build green, and the benefits of doing so. **Please visit: www.nahbgreen.org/content/pdf/nahb_guidelines.pdf**

The **Buyer's Guide to Coal Ash Containing Products** compiled by the Energy and Environmental Research Center, University of North Dakota, Grand Forks is a catalog of products containing coal ash, including building materials, cement and concrete, and specialty products. **Please visit: www.undeerc.org/carrc/BuyersGuide**

The BEES: Building for Environmental and Economic Sustainability Software brings to your fingertips a powerful technique for selecting cost-effective, environmentally-preferable building products. **Please visit: www.bfrl.nist.gov/oae/software/bees/bees.htm**

The **Industrial Resources Council (IRC)** comprises those whose mission is market development for high volume industrial materials, including coal combustion products. **Please visit: http://industrialresourcescouncil.org**

Sustainable Industries Journal Online focuses on green building, clean energy, and sustainable farming and food production. **Please visit: www.sijournal.com**

Coal Combustion Products Partnership (C^2P^2) helps promote the beneficial use of coal combustion products and the environmental benefits that result from their use. **Please visit: www.epa.gov/epawaste/partnerships/c2p2**

The **Greenbuilder Sourcebook** offers fly ash concrete-related resources and information, including CSI numbers, considerations, commerical status, guidelines and other details. **Please visit: www.greenbuilder.com/sourcebook/Flyash**

ToolBase Resources combines product descriptions, design and construction guides, best practices, performance reports, case studies, and more. The NAHB Research Center provides this service with funding from the Department of Housing and Urban Development (HUD) through The Partnership for Advancing Technology in Housing (PATH) program, and other industry sponsors. **Please visit: www.toolbase.org/Technology-Inventory/Foundations/fly-ash concrete**

The **National Ready Mix Concrete Association (NRMCA)** has guidance documents available to its members and others that define the quality requirements for all concrete mix designs, including those using fly ash or slag. **Please visit: www.nrmca.org**

Oikos is an online directory for green building products. **Please visit: www.oikos.com**

Coal Combustion Products Build Sustainable...

- Residences
- Office Buildings
- High Rise Structures
- University Facilities
- Bridges
- Concrete Pavements
- Airport Runways
- Dams and Reservoirs
- Stadiums and Arenas
- Outdoor Sports Complexes
- Tilt-up Buildings
- Tunnels
- Monuments
- Masonry Products
- Government Structures
- Pervious and Asphaltic Pavements
- Back-Fills
- Composite Products
- Manufactured Soils
- Stone Veneers
- Plastic and Mineral Fillers
- Wallboard Panel Products
- Composts
- Landscaping Applications

...and much more.

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