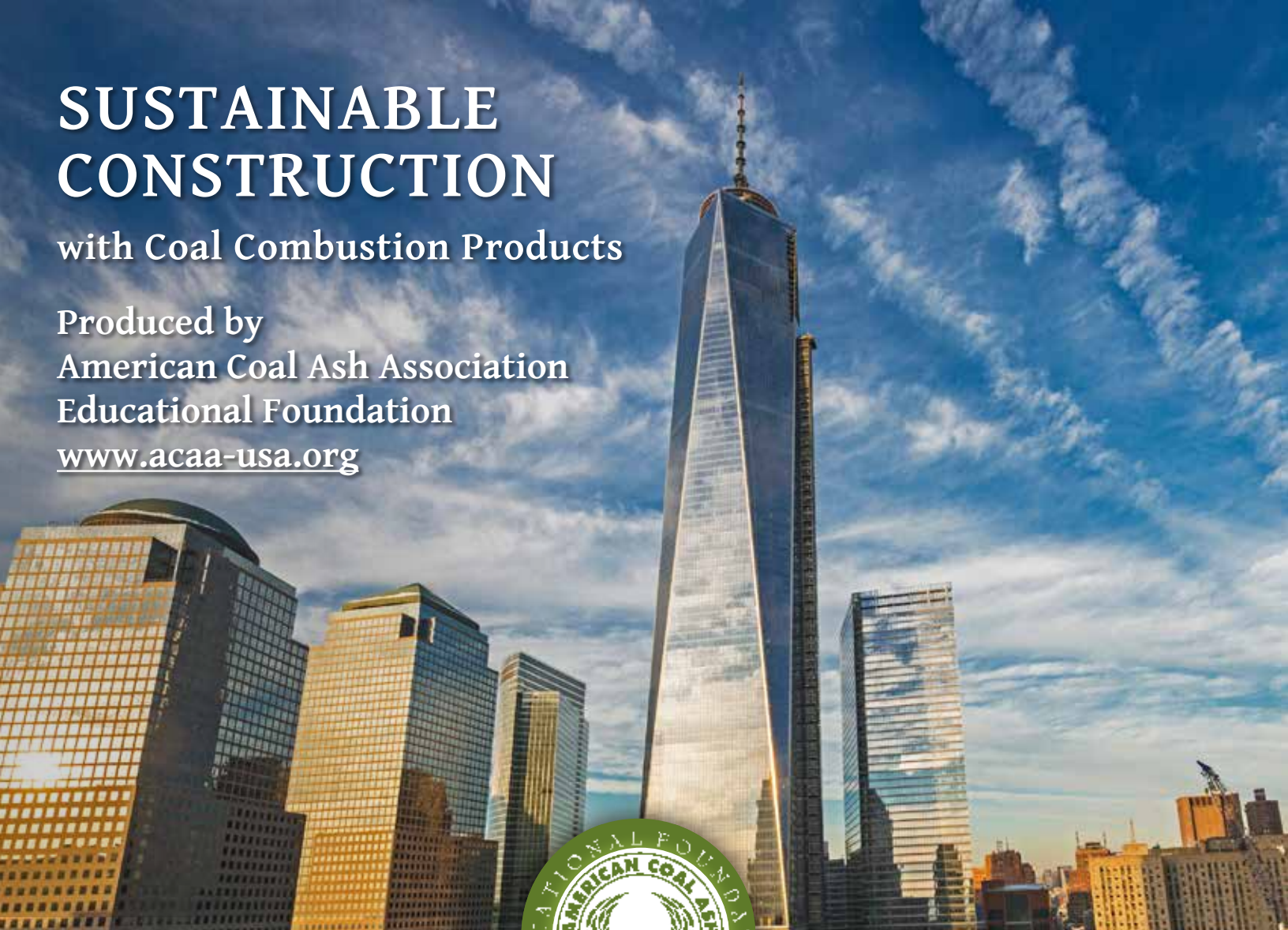


SUSTAINABLE CONSTRUCTION

with Coal Combustion Products

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



Building a Sustainable Future

Our built environment has implications for the sustainable use of natural resources, energy consumption and carbon dioxide emissions. Over half of the world's population now lives in urban areas, and by 2050 over two-thirds of the global population will be urban. Sustainable building practices are vital for protecting the natural environment while supporting livable cities and long-term economic viability.

Substituting recycled industrial materials for conventional products in construction results in tremendous environmental and economic benefits including lower construction costs; decreased water and energy use; reduced emissions; and improved technical performance and longevity. One such recycling success story is coal combustion products.

Coal combustion products (CCPs) are materials produced when coal is burned to

generate electricity. Each year in the United States, coal-fueled power plants produce over 110 million tons of CCPs. Currently, about 40% of CCPs are recycled annually into concrete and a variety of green building products.

Products made with CCPs in place of mined or manufactured materials perform better, cost less, and decrease environmental impacts. Concrete made with coal fly ash is stronger and more durable than concrete made with portland cement alone.

The environmental benefits of CCP recycling are huge: for every ton of coal fly ash used as a replacement for portland cement, approximately one ton of greenhouse gas emissions are avoided. Annually, this reduces carbon emissions by 13 million tons—the equivalent to taking 2.5 million cars off the road.



Fly Ash - Improving Strength and Durability



Fly ash is a powdery material that is captured by emissions control equipment before it can “fly” up the power plant stack. Mostly comprised of silica, alumina, iron and calcium compounds, fly ash has mechanical and chemical properties that make it a valuable ingredient in concrete, providing long-term structural strength. Fly ash concrete is less permeable and more resistant to acid, sulfates and other destructive chemical reactions than concrete made with cement alone. Fly ash lowers the heat of hydration, improves workability, and reduces shrinkage and cracking. More than half of the concrete produced in the U.S. contains fly ash, used in roads, bridges, buildings and concrete blocks. Concrete mixtures routinely use 20 to 35 percent fly ash, with the optimum specification depending on ash composition, application and exposure conditions, such as freeze/thaw cycles. High volume applications for unique projects have utilized up to about 65% fly ash to extend service life and meet sustainability objectives.

Synthetic Gypsum - from Floor to Ceilings



Power plants equipped with flue gas desulfurization (FGD) emissions control systems, also known as scrubbers, create byproducts that include synthetic gypsum. Scrubbers utilize high-calcium reagents, such as lime or limestone, to capture sulfur from the flue gases. Although not technically “ash,” synthetic gypsum is a type of CCP. Synthetic gypsum is used in 50% of the gypsum panel products (known as wallboard or drywall) manufactured in the U.S. Synthetic gypsum has numerous construction uses beyond walls, including ceilings and self-leveling flooring underlayments. The use of synthetic gypsum avoids the mining of virgin gypsum, yielding water, energy and emissions reductions.

Boiler Slag - Lasting Durability



Boiler slag is molten ash collected at the base of cyclone boilers that is quenched with water and shatters into black, angular pieces having a smooth, glassy appearance. Boiler slag is typically used for roofing granules, asphalt coatings and blasting grit because of its durability and resistance to wear.



Bottom Ash - Filling Many Needs

Bottom ash is a heavier, granular material that is collected from the bottom of coal-fueled boilers. Bottom ash is often used as an aggregate to replace sand and gravel, and as an ingredient in masonry products including concrete blocks. Bottom ash has also been identified as an excellent growing medium for green roofs, providing water retention benefits.

Reaching New Heights with CCPs



One World Trade Center

At 1,776 feet high, One World Trade Center in New York City is one of the greenest super-tall buildings in the U.S. The design had unique durability and sustainability requirements, including using high-strength “green concrete” utilizing fly ash and slag. The concrete mix tripled the compressive strength of conventional concrete, up to 14,000 pounds per square inch. The green concrete saved about 6000 tons of carbon dioxide emissions, 8 million kWh of energy and 30,000 gallons of fresh water. The high-strength fly ash concrete enabled the design to use smaller structural supports in columns and walls, yielding more livable floor area.



Wilshire Grand Center

The foundation for the 73-story Wilshire Grand tower in Los Angeles was designed to absorb ground movement during earthquakes and enable the building to withstand severe windstorms. The tower’s foundation is a concrete slab utilizing high quality fly ash as a 25% substitution for portland cement to improve structural strength and durability. The foundation for the Wilshire Grand set a world record for the largest continuous concrete pour of 21,200 cubic yards. Fly ash was essential to the project’s success because it mitigates the heat of cement hydration in such a large-scale pour.



Burj Khalifa Tower

The tallest man-made structure in the world, Burj Khalifa towers 2,722 feet above Dubai, United Arab Emirates (UAE). To achieve the structural strength needed to withstand high winds and support the building’s massive weight, the tower was designed with a “Y” shaped buttressed core constructed with high performance fly ash concrete. The concrete mix was designed to provide low permeability and high durability. Two of the largest concrete pumps in the world delivered the concrete mix to heights over 2000 feet. Over 330,000 cubic yards of concrete was used in the construction of Burj Khalifa.

Beauty in Sustainable Design with CCPs



Oakland Cathedral

To create lightness and space, the Cathedral of Christ the Light in Oakland, California used architecturally-exposed reinforced concrete made with fly ash. A main design objective of the cathedral was to have the smallest environmental footprint possible, so the use of fly ash achieved both strength and sustainability objectives.



Aqua Tower

The design inspiration for the 82-story Aqua Tower in Chicago was eroded rocks found around the Great Lakes. The wave-like balconies were created by unevenly pouring different mixtures of concrete, with the gray concrete containing more fly ash while the lighter concrete contains more portland cement.



Arizona Residence

This residence designed by Arizona architect Michael Frerking was constructed using “poured earth” made with 67 percent fly ash to substantially reduce the building’s carbon footprint and minimize energy use.



Shri Swaminarayan Mandir (12) by 4nitsirk/CC 4.0

BAPS Temple

The BAPS Hindu Temple in Chicago was built with high-volume (65%) fly ash concrete for the reinforced foundation, beams and shear walls to achieve a 1,000 year service life.



Milwaukee Art Museum

The Milwaukee Art Museum was constructed with high volume fly ash to achieve a variety of important design objectives. To create the unique sculptural Quadracci Pavilion, concrete was poured into one-of-a-kind wooden forms.

Wall-Form Products

Insulating concrete forms combine framing, insulation, sheeting and sheer wall strength into one building system. These wall-form products have hollow interiors and are stacked or set in place and can be filled with steel-reinforced high-volume fly ash concrete. The fly ash concrete provides structural integrity, energy conservation and sound proofing.

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. Overlayments are sometimes specified to correct defective flooring issues prior to installation of carpeting, tile, wood or other surfaces. These applications also can provide sound insulating features. Fly ash and synthetic gypsum are used widely in commercial applications, and can be used in single-family and multi-family homes to support credits toward LEED or Green Globes certification in the categories of indoor environmental quality, low emitting materials, recycled content, regional materials and innovation in design. For examples of these applications see www.maxxon.com/go_green.

Masonry Products

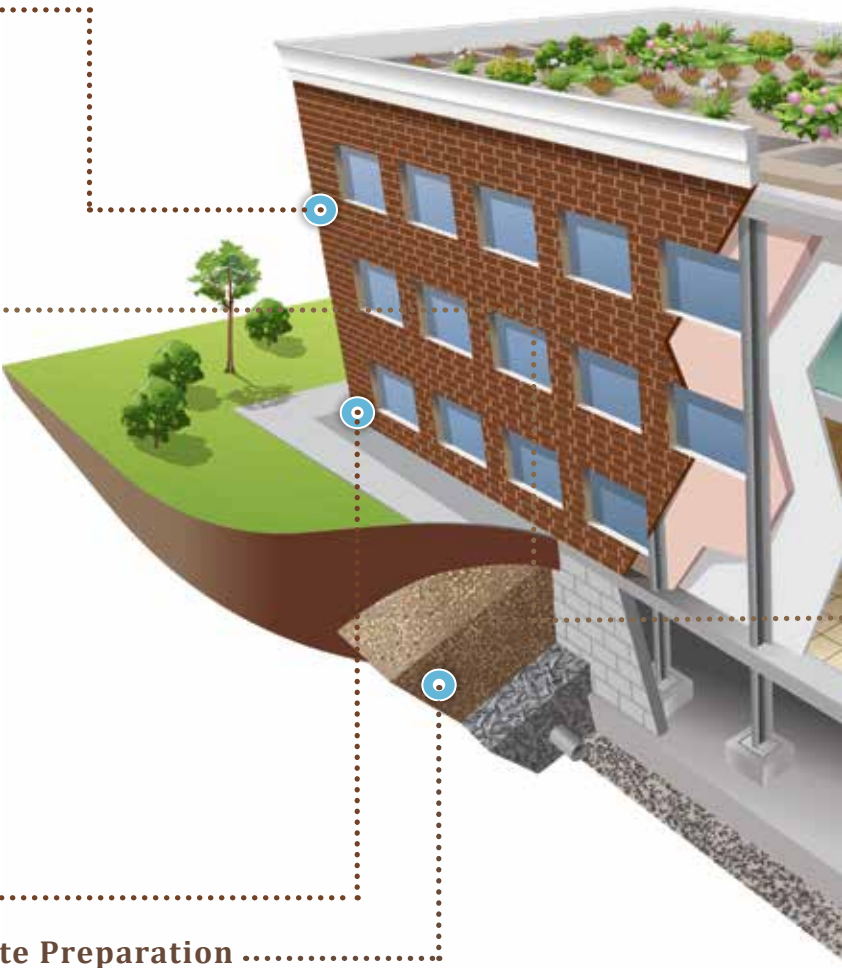
Fly ash and bottom ash are used extensively in grouts and masonry products, including concrete bricks and architectural veneer stone, available in a wide range of color options.

Site Preparation

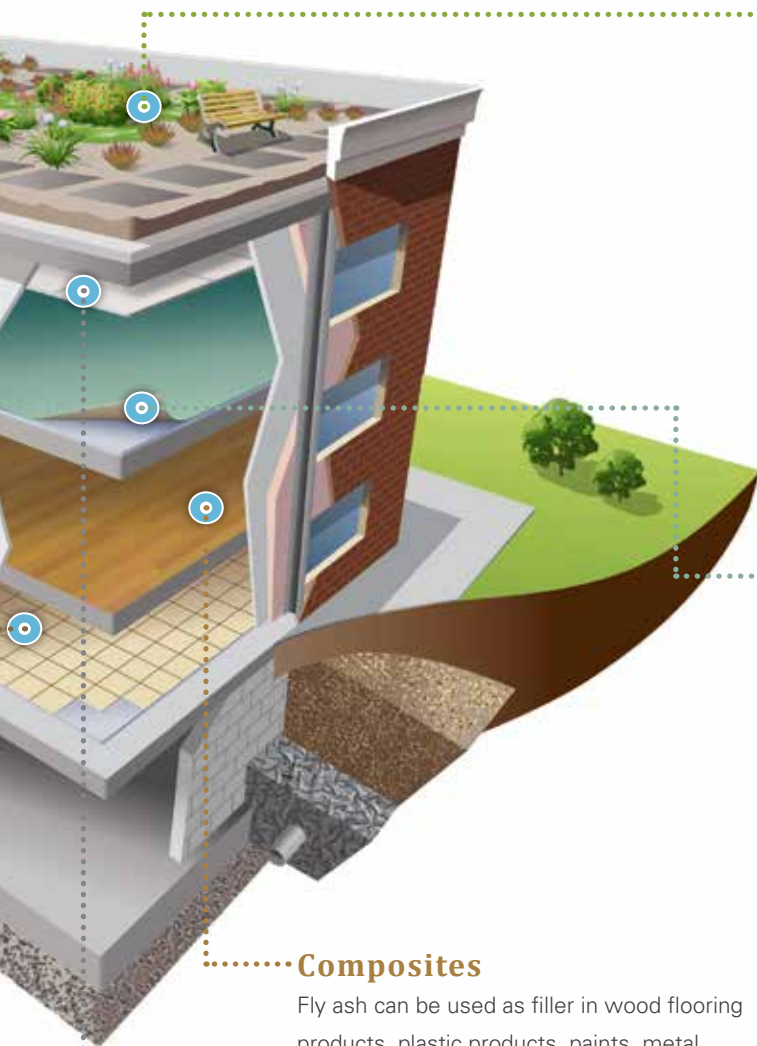
CCPs have many uses when preparing a project site for development. Fly ash can be used to stabilize and solidify soils at Brownfield sites or in construction areas. If rains have made work areas difficult to access by vehicular traffic, self-cementing fly ash or fly ash combined with portland cement, 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 geotechnical considerations.

Ceiling ... Tiles & Pa Products

Ceiling tiles and with fly ash and can be textured with a wide range of different archite



n Sustainable Construction



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 benefits including aesthetic appeal, energy conservation, noise reduction, preventing water runoff, and improved air quality. Green roofs typically require less maintenance and are longer lasting than conventional roofs, and help reduce carbon emissions. Because of its lightweight, granular characteristics, bottom ash is an ideal material for part of the growing media. For more information, visit: www.greenroofs.com and www.greenroofs.org

Carpet Backing

Carpet 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 qualify for LEED and Green Globes credits for recycled content, and under NSF/ANSI 140 standards for sustainability. Visit: <http://www.nsf.org/services/by-industry/sustainability-environment/sustainability-standards-protocols/carpet/>

Composites

Fly ash can be used as filler in wood flooring products, plastic products, paints, metal casings, and decorative composite countertops made with concrete, glass and other recycled materials.



Geotechnical

Geotechnical applications include soil stabilization, road base, engineered 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 completed. 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 the fill materials, as no compaction is needed. Large quantities can be placed in a matter of minutes, allowing the surface to be finished rapidly.

Certifying the Safety and Benefits of CCPs



LEED Platinum Bardessono hotel



*LEED Platinum home in Mill Valley, California.
Image credit: Mariko Reed Photography*

LEED v4

Leadership in Energy and Environmental Design (LEED) is a green building certification program developed by the U.S. Green Building Council (USGBC) that recognizes best-in-class building strategies and practices. LEED v4 is the newest version of this global benchmark for high-performance green buildings. In order to receive LEED certification, a building must attain a specific number of credits, with Silver, Gold and Platinum levels representing advanced certification.

Using CCPs in construction can earn credits toward certification in the categories of Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR),

Indoor Environmental Quality (EQ), Location and Transportation (LT), Regional Priority (RP) and Innovation (IN).

Materials that limit the extraction of virgin resources, such as synthetic gypsum wallboard as a replacement for mined gypsum products, earn credits. Concrete containing at least 25% fly ash is considered by LEED as an environmentally preferable product in the MR category. CCPs have also been used in brownfield redevelopment (SS) projects. And because CCPs are usually sourced locally, they can contribute toward RP credit. The heat island reduction from using fly ash concrete contributes toward LT credits. Using CCPs in pervious pavements, which reduces the

rate and quantity of storm water runoff, can contribute to earning LEED credits in the SS, LT, WE and MR categories. Buildings constructed with fly ash concrete moderate indoor temperatures and reduce energy consumption, earning credits in EA and MR categories. Green roofs earn credits in a number of categories, including SS, WE, EA and MR.

Innovative design strategies can garner additional credits, including reducing carbon emissions through the use of high volume fly ash concrete, fly ash bricks and other recycled products made with CCPs. For information on LEED, please visit: www.usgbc.org/v4.

Standards for CCP Use

Numerous technical and engineering standards have been developed for specifying and using CCPs to ensure performance objectives. In the U.S., specifications are published by ASTM International, the American Concrete Institute (ACI), National Ready Mixed Concrete Association (NRMCA), Federal Highway Administration, Army Corps of Engineers and several other federal and state agencies. These standards specify the characteristics and technical details that must be met by CCP products and applications. Similarly, standards for demonstrating environmental attributes (called product category rules) provide a consistent approach for assessing sustainability benefits.

Demonstrating Safety

The U.S. Environmental Protection Agency (EPA) “encourages the beneficial use of coal ash in an appropriate and protective manner, because this practice can produce positive environmental, economic and product benefits” including reduced use of virgin resources, lower greenhouse gas emissions and improved strength and durability of materials. Beneficially-used CCPs are exempt from federal regulation.

In 2014, EPA conducted a scientific evaluation of the safety of using fly ash in concrete and synthetic (FGD) gypsum in wallboard, finding that releases of constituents of potential concern are comparable to or lower than those from analogous products made without CCPs, or are at or below relevant health-based benchmarks, concluding that “beneficial uses provide significant opportunities to advance Sustainable Materials Management.” See: http://www.epa.gov/waste/conserve/imr/ccps/pdfs/ccr_bu_eval.pdf.



The Reagan Building in Washington D.C., headquarters for EPA, was constructed with fly ash concrete.

Green Globes

The Green Globes building rating and certification program was developed by the Green Building Initiative and is accredited by the American National Standards Institute (ANSI). Green Globes evaluates the environmental friendliness and sustainability of building projects.

As with LEED, Green Globes promotes green building practices that yield energy efficiency, emissions reductions, water savings, use of recycled and reclaimed materials, healthier indoor environments, and reduced ecological footprint. Green Globes assesses building environmental impacts on a 1,000-point scale in seven categories: Materials & Resources, Energy, Water, Emissions, Indoor

Environment, Site, and Project Management. Utilization of CCPs in building construction can help score points related to materials and resources, energy consumption, water use, emissions, indoor environment and site development.

Green Globes utilizes independent, third-party assessors to rate projects. Green Globes has been recommended by the U.S. General Services Administration (GSA) as one of two certifications (with LEED being the other) for evaluating the performance of federal government agency buildings. For more information on Green Globes, please visit: www.greenglobes.com.



Perot Museum in Dallas holds the highest Green Globes certification

The Future of CCPs in Sustainable Construction

Coal combustion products are projected to continue to play a major role in sustainable construction over the next 20 years. Utilization of CCPs in major markets has grown by an average 5.1 percent annually since 1974, increasing to over 51 million tons beneficially used during 2013. CCP utilization has increased during three of the last five U.S. recessions since 1974 as markets have taken advantage of the lower cost of CCPs compared with alternative materials.

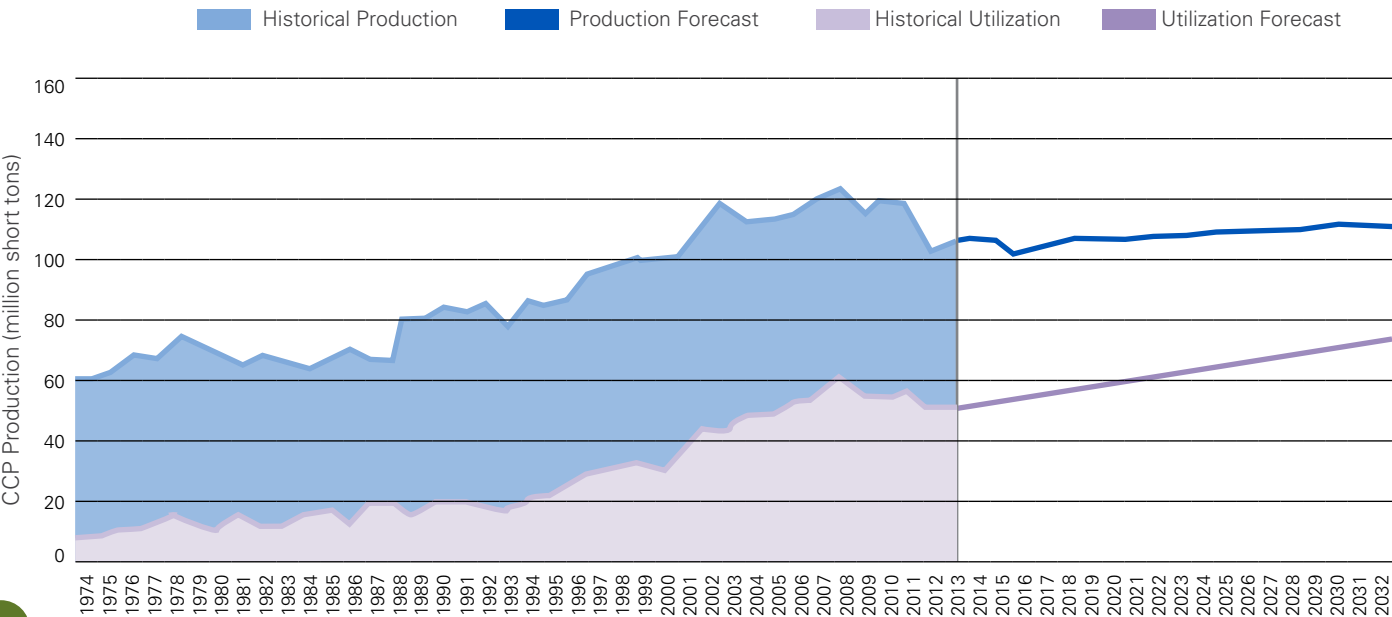
Despite retirements of coal-fueled power plants over the last few years, coal is expected to remain a primary energy source in the U.S. for decades to come, according to U.S. Energy Information Administration (EIA). As a result, overall production of CCPs are forecast to grow from 114.7 million tons in 2013 to 120.6 million tons in 2033. Fly ash production is forecast to grow from 53.4 million tons in 2013 to 54.6 million tons in 2033, and production of synthetic gypsum is projected to grow from 35.2 million tons in 2013 to 38.8 million tons in 2033. CCP utilization is forecast to

increase 48 percent over the next two decades due to growth in the U.S. economy, new housing starts, and increasing demand for ready mixed concrete. Historical CCP production and utilization over the last four decades is shown in the figure below, along with forecasts for future production and use.

Ash beneficiation and other emerging technologies are expanding the use of CCPs into new markets and products. Producers and marketers are working together to ensure CCPs will continue to comply with applicable construction standards and specifications. Architects are using CCPs in new and innovative designs, leveraging the strength, durability and environmental benefits to attain green credentials under LEED and Green Globes.

More and more architects, construction firms and consumers have come to recognize the environmental, economic and sustainability benefits that CCPs deliver. Science, engineering standards and practical experience has transformed the perception of fly ash and other CCPs from waste into valuable product.

Production and Utilization of CCPs



Sustainable Building 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 supportive of a sustainable global environment. 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**, **ACI 232.2** and **ACI 232.3**. 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. Visit: www.astm.org/Standards/C618.htm and www.concrete.org for more information on the standards.

BEES: Building for Environmental and Economic Sustainability Software developed by the National Institute of Standards and Technology (NIST) brings to your fingertips a powerful technique for selecting cost-effective, environmentally preferable building products. Visit: www.nist.gov/el/economics/BEESSoftware.cfm

Best Practices Guide for High-Volume Fly Ash Concretes: Assuring Properties and Performance is published by NIST. The best practices guide considers all aspects of high volume fly ash (HVFA) concrete production from materials characterization through curing to long-term performance. NIST Technical Note 1812 is available at <http://concrete.nist.gov/~bentz/NIST.TN.1812.pdf>

Green Globes is an online green building rating and certification tool licensed for use in the U.S. by the Green Building Initiative. The Green Globes New Construction assessment can be used for a wide range of commercial, institutional and multi-residential building types to advance sustainability and environmental goals. Visit: www.greenglobes.com or www.thegbi.org

Specific guidance on the use of high volume fly ash can be found in a book by V.M. Malhotra and P.K. Mehta, **High-Performance, High-Volume Fly Ash Concrete, 3rd Ed.** This book contains mix designs, recommendations, precautions and examples of high volume fly ash concrete placement and applications.

The **Industrial Resources Council (IRC)** is a collaboration of non-profit industry associations working together to promote the appropriate use of industrial materials, including coal combustion products. Visit: www.industrialresourcescouncil.org

LEED green building certification program, administered by the U.S. Green Building Council (USGBC), is the premier benchmark recognizing best-in-class sustainable building strategies and practices. Building projects can earn points to achieve different levels of LEED certification. LEED v4 is the newest version of the certification program with ratings systems for Building Design and Construction, Interior Design and Construction, Building Operations and Maintenance, Neighborhood Development and Homes. Visit: www.usgbc.org/leed

The **National Association of Home Builders (NAHB)** provides a variety of resources for green building certification, construction codes and standards, and valuation of green homes. The ICC 700 National Green Building Standard is an ANSI-approved residential green building rating system that guides the construction of safe, sustainable and affordable homes. Visit: <http://www.nahb.org/en/research/nahb-priorities/green-building-remodeling-and-development.aspx>

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

The **Oikos** site is an online directory for sustainable building products. The Green Building Library contains resources for various building categories. Visit: www.oikos.com

Sustainable Sources is an online source for green building information, including fly ash concrete related information. Visit: www.sustainablesources.com



Coal Combustion Products Build Sustainable...



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- ▶ Stone Veneers
- ▶ Plastic and Mineral Fillers
- ▶ Wallboard Panel Products
- ▶ Museums
- ▶ Landscaping Applications
...and much more.

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All of the images contained in this document are of buildings constructed using coal combustion products

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