

---

**FLY ASH FOR CONCRETE**





Making Better Concrete  
with Material from  
America's Coal Ash Leader.

FLY ASH: THE MODERN POZZOLAN  
IMPROVING CONCRETE PERFORMANCE  
ENHANCING OUR ENVIRONMENT

# FLY ASH: THE MODERN POZZOLAN

Power plants fueled by coal produce more than half of the electricity we consume in the United States today. But in addition to electricity, these plants produce a material that is fast becoming a vital ingredient for improving the performance of a wide range of concrete products.

That material is fly ash.

Fly ash is comprised of the non-combustible mineral portion of coal. When coal is consumed in a power plant, it is first ground to the fineness of powder. Blown into the power plant's boiler, the carbon is consumed — leaving molten particles rich in silica, alumina and calcium. These particles solidify as microscopic, glassy spheres that are collected from the power plant's exhaust before they can “fly” away — hence the product's name: Fly Ash.

Chemically, fly ash is a pozzolan. When mixed with lime (calcium hydroxide), pozzolans combine to form cementitious compounds. Concrete containing fly ash becomes stronger, more durable, and more resistant to chemical attack.

Mechanically, fly ash also pays dividends for concrete production. Because fly ash particles are small, they effectively fill voids. Because fly ash particles are hard and round, they have a “ball bearing” effect that allows concrete to be produced using less water. Both characteristics contribute to enhanced concrete workability and durability.

Finally, fly ash use creates significant benefits for our environment. Fly ash use conserves natural resources and avoids landfill disposal of ash products. By making concrete more durable, life cycle costs of roads and structures are reduced. Furthermore, fly ash use partially displaces production of other concrete ingredients, resulting in significant energy savings and reductions in greenhouse gas emissions.

## poz·zo·lan

*n.*

*A siliceous, or siliceous and aluminous, material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.*

– ASTM C125

## Modern Technology Rooted in Ancient Art

Long before modern power plants began producing coal fly ash, Roman builders turned to volcanic ash to harness the power of pozzolans.

In fact, the term “pozzolan” is derived from the name of an Italian city — Pozzuoli — that is regarded as the birthplace of ash concrete technologies. Famed Roman structures such as the Pantheon and Colosseum, as well as many roads and aqueducts, are still standing over 2,000 years after their construction — in part because of the durability of their ash-based concrete.



# IMPROVING CONCRETE PERFORMANCE

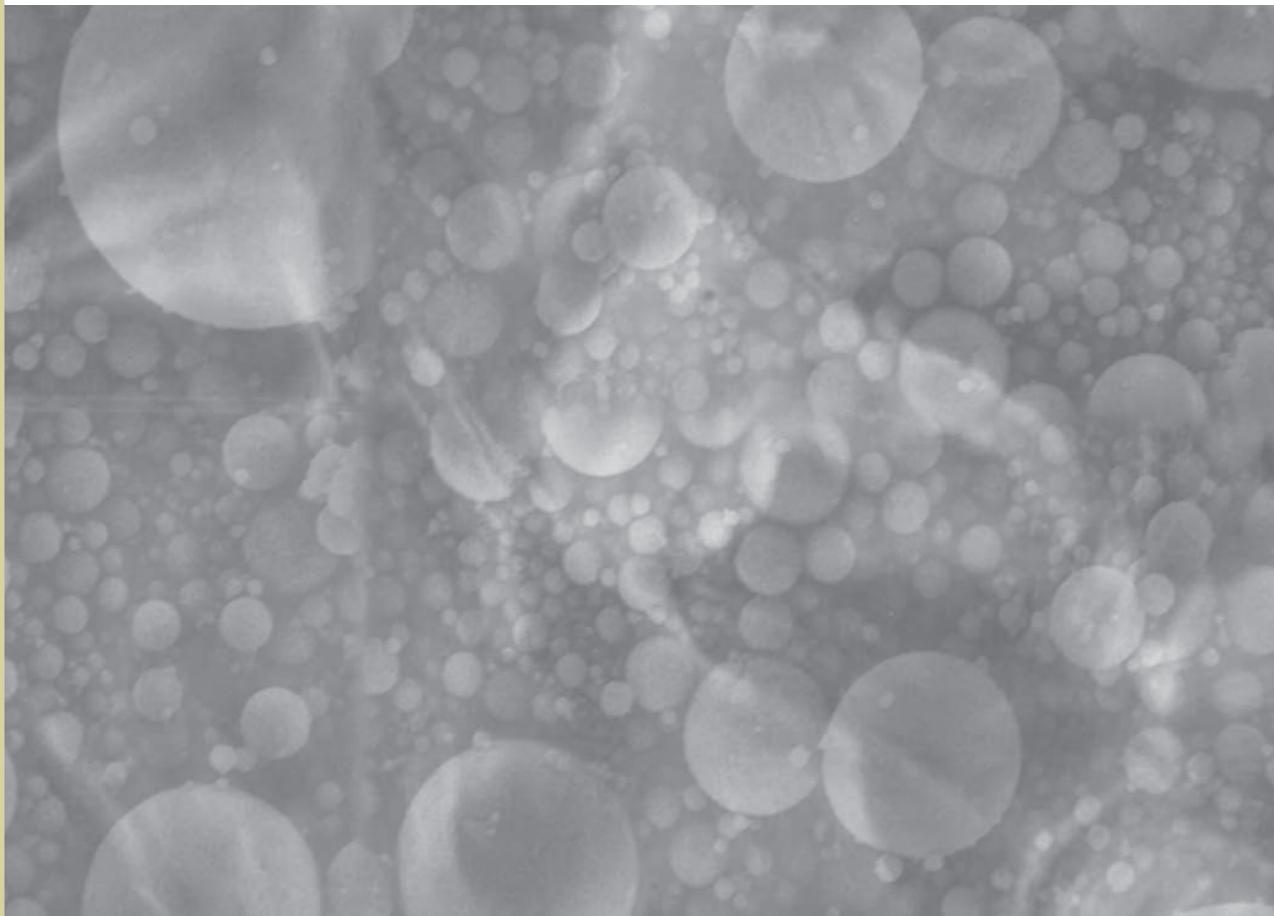
## A Short Course In Fly Ash Technology

### Fly Ash and Its Classification

Fly ash is comprised of the non-combustible mineral portion of coal consumed in a coal fueled power plant. Fly ash particles are glassy, spherical shaped “ball bearings” — typically finer than cement particles — that are collected from the combustion air-stream exiting the power plant.

There are two basic types of fly ash: Class F and Class C. Both types react in concrete in similar ways. Both Class F and Class C fly ashes undergo a “pozzolanic reaction” with the lime (calcium hydroxide) created by the hydration (chemical reaction) of cement and water, to create the same binder (calcium silicate hydrate) as cement. In addition, some Class C fly ashes may possess enough lime to be self-cementing, in addition to the pozzolanic reaction with lime from cement hydration.

The main benefit of fly ash in concrete is that it not only reduces the amount of non-durable calcium hydroxide (lime), but in the process converts it into calcium silicate hydrate (CSH), which is the strongest and most durable portion of the paste in concrete. Fly ash also makes substantial contributions to workability, chemical resistance and the environment.



### What Is Quality Concrete?

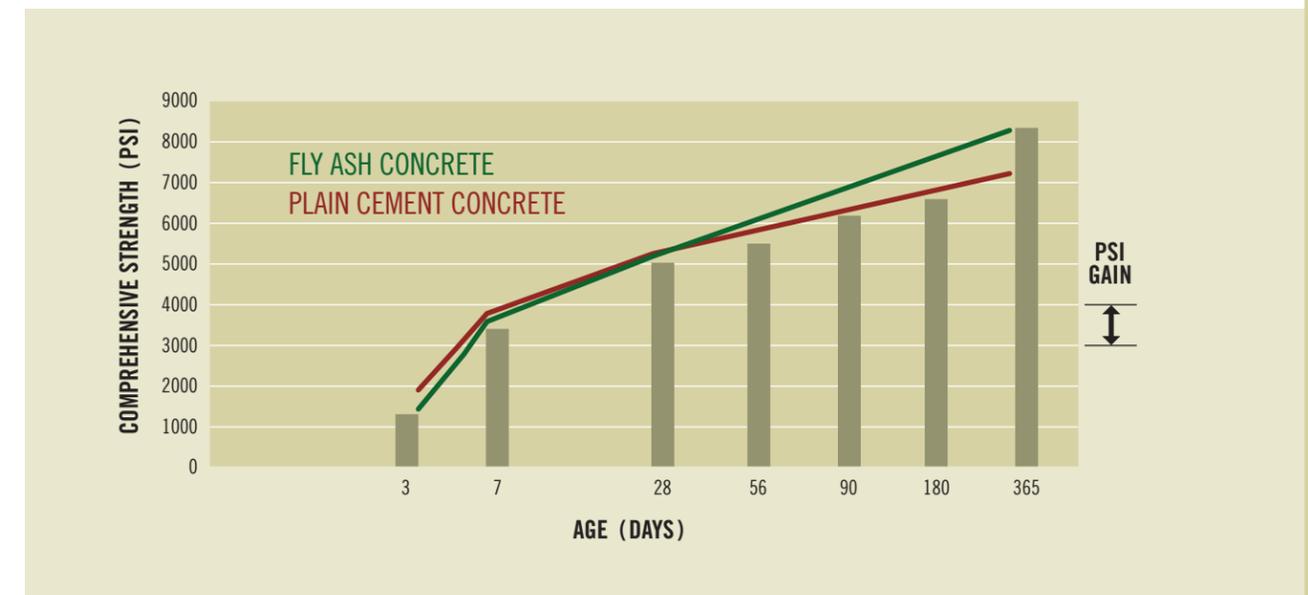
To fully appreciate the benefits of fly ash in concrete, the basics of producing exceptional concrete must be understood. Concrete is a composite material, which essentially consists of two components: aggregates and cementitious paste. To produce exceptional concrete, it is extremely important to have a smooth gradation of material from rock down to the finest particles (in other words, a good mix of particle sizes, so that the largest practicable rock fills the majority of the volume, while the progressively smaller rock and sand fill the voids left between the larger particles). Ideally, it is best to have as much volume as possible filled with strong, durable aggregate particles, with enough paste (comprised of as much CSH and as little lime as possible) to coat every particle. Also, voids should not be present in the paste unless they are specifically provided as microscopic entrained air bubbles to provide durability in freeze-thaw environments.

In real life, though, economics and local aggregate sources dictate the quality of materials used. The result is that excess voids often exist between the aggregate particles that must now be filled by paste and air. The challenge becomes producing an appropriate amount of the best possible quality paste, so that the resulting hardened paste will fill the excess voids with durability and strength approaching that of the aggregates.

### How Fly Ash Contributes to Concrete Durability and Strength

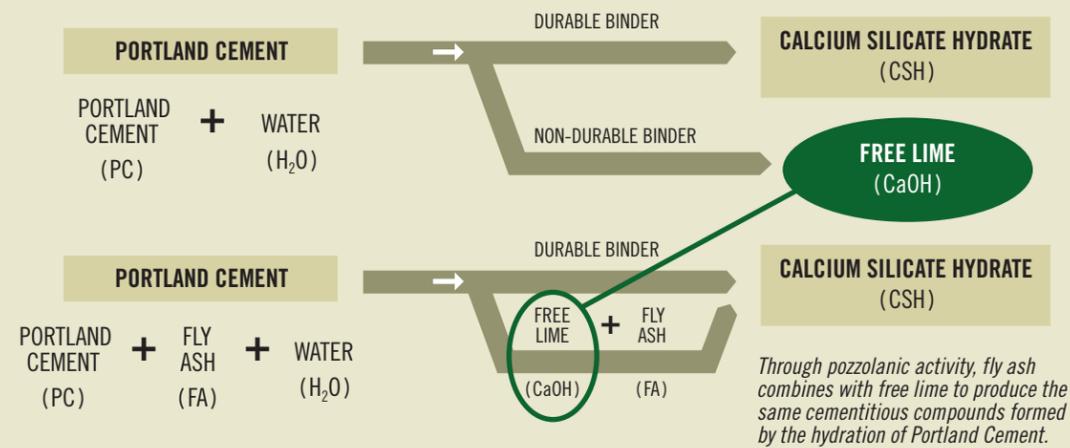
Most people don't realize that durability and strength are not synonymous when talking about concrete. Durability is the ability to maintain integrity and strength over time. Strength is only a measure of the ability to sustain loads at a given point in time. Two concrete mixes with equal cylinder breaks of 4,000 psi at 28 days can vary widely in their permeability, resistance to chemical attack, resistance to cracking and general deterioration over time — all of which are important to durability.

Cement normally gains the great majority of its strength within 28 days, thus the reasoning behind specifications normally requiring determination of 28-day strengths as a standard. As lime from cement hydration becomes available (cements tend to vary widely in their reactivity), it reacts with fly ash. Typically, concrete made with fly ash will be slightly lower in strength than straight cement concrete up to 28 days, equal strength at 28 days, and substantially higher strength within a year's time. Conversely, in straight cement concrete, this lime would remain intact and over time it would be susceptible to the effects of weathering and loss of strength and durability.



As previously described, the paste is the key to durable and strong concrete, assuming average quality aggregates are used. At full hydration, concrete made with typical cements produces approximately 1/4 pound of non-durable lime per pound of cement in the mix. Most people have seen concrete or masonry walls or slabs with the white, chalky surface coating or streaks called efflorescence. Efflorescence is caused by the face of the concrete being wetted and dried repeatedly, or by the movement of water vapor from the damp side of the concrete to the dry side through the capillaries (voids), drawing out the water soluble lime from the concrete, block or mortar. A typical 5 sack concrete mix having 470 pounds of cement per cubic yard has the potential of producing 118 pounds of lime. Fly ash chemically reacts with this lime to create more CSH, the same “glue” produced by the hydration of cement and water, thereby closing off the capillaries that allow the movement of moisture through the concrete. The result is concrete that is less permeable, as witnessed by the reduction in efflorescence.

#### HYDRATION PRODUCTS OF CEMENTING BINDERS



Other evidence of the contribution fly ash makes to strength and durability includes:

- Cement has an upper limit of roughly 7.5 sacks (7.5 x 94# sack = 705#) when using 1" maximum size aggregate, above which the psi per pound of cement strength contribution in a concrete mix diminishes rapidly. The tallest concrete structures in the world are made with concrete where fly ash is a necessary component. Its ability to contribute to additional CSH, lower water demand, reduced heat of hydration and its fine particle size are crucial to making high-strength concrete (8,000 psi to over 20,000 psi).
- Cement was invented in 1824, over 170 years ago. There are examples on the west coast of Italy, in a town named Cosa, where a mixture of natural pozzolans (volcanic) were combined with lime to produce concrete that has withstood waves and attack from seawater for over 2,000 years and is still intact.
- The Pantheon in Rome is a pozzolan and lime concrete structure built around 300 B.C. and still stands today. It features a cast concrete dome 124 feet in diameter and was the world's largest domed structure until modern times.

#### How Fly Ash Contributes to Concrete Workability

First, fly ash produces more cementitious paste. It has a lower unit weight, which means that on a pound for pound basis, fly ash contributes roughly 30% more volume of cementitious material per pound versus cement. The greater the percentage of fly ash “ball bearings” in the paste, the better lubricated the aggregates are and the better concrete flows.

Second, fly ash reduces the amount of water needed to produce a given slump. The spherical shape of fly ash particles and its dispersive ability provide water-reducing characteristics similar to a water-reducing admixture. Typically, water demand of a concrete mix with fly ash is reduced by 2% to 10%, depending on a number of factors including the amount used and class of fly ash.

Third, fly ash reduces the amount of sand needed in the mix to produce workability. Because fly ash creates more paste, and by its shape and dispersive action makes the paste more “slippery”, the amount of sand proportioned into the mix can be reduced. Since sand has a much greater surface area than larger aggregates and therefore requires more paste, reducing the sand means the paste available can more efficiently coat the surface area of the aggregates that remain.

Evidence of the contribution fly ash makes to workability includes:

- Lightweight concrete including fly ash is much easier to pump.
- Finishers notice the “creamier” texture when working. They also see reduced “bug holes” and segregation when stripping forms. Slip form pavers eliminate rock pockets and voids in an otherwise harsh, no-slump paving mix.



## How Fly Ash Protects Concrete

An extremely important aspect of the durability of concrete is its permeability. Fly ash concrete is less permeable because fly ash reduces the amount of water needed to produce a given slump, and through pozzolanic activity, creates more durable CSH as it fills capillaries and bleed water channels occupied by water-soluble lime (calcium hydroxide).

Fly ash improves corrosion protection. By decreasing concrete permeability, fly ash can reduce the rate of ingress of water, corrosive chemicals and oxygen — thus protecting steel reinforcement from corrosion and its subsequent expansive result.

Fly ash also increases sulfate resistance and reduces alkali-silica reactivity. At this point a distinction between Class C and Class F fly ashes needs to be made. While both improve the permeability and general durability of concrete, the chemistry of Class F ashes has proven to be more effective in mitigating sulfate and alkali-silica expansion and deterioration in concrete. Some Class C fly ashes have been used to mitigate these reactions, but must be used at higher rates of cement replacement.

Fly Ash in concrete can reduce sulfate attack in two additional ways:

- Fly ash reduces calcium hydroxide, which combines with sulfates to produce gypsum. Gypsum is a material that has greater volume than the calcium hydroxide and sulfates that combine to form it, causing damaging expansion.
- Aluminates in the cement also combine with sulfates to form expansive compounds. By replacing cement, the amount of available aluminates is reduced, thereby lowering the potential for this type of expansive reaction.

In reducing alkali-silica reactivity, fly ash has the ability to react with the alkali hydroxides in portland cement paste, making them unavailable for reaction with reactive silica in certain aggregates. Certain studies suggest that greater than 30% replacement with fly ash for cement has a dramatic effect in combating this expansive reaction.

## How Fly Ash Reduces Heat of Hydration in Concrete

The hydration of cement is an exothermic reaction. Heat is generated very quickly, causing the concrete temperature to rise and accelerating the setting time and strength gain of the concrete. For most concrete installations, the heat generation is not detrimental to its long-term strength and durability. However, many applications exist where the rapid heat gain of cement increases the chances of thermal cracking, leading to reduced concrete strength and durability. In these applications, replacing large percentages of cement with fly ash (fly ash generates only 15 to 35 percent as much heat as compared to cement at early ages) can reduce the damaging effects of thermal cracking.

While the first structures to apply this concept in earnest were hydroelectric dams built in the 1930s and 1940s with 40% to 50% cement replacement, warm weather concreting and the risk of thermal cracking is a problem that exists today for all concrete. Warm weather will naturally raise the temperature of concrete aggregates, which make up the majority of the mass in concrete. This natural heating of the aggregates, coupled with solar heating at the construction site, can cause even thin concrete slabs to suffer the damaging effects of thermal cracking, along with finishing difficulties caused by rapid uncontrolled setting. Replacing 20% to 35% of the cement for “everyday” concrete in warm conditions will help reduce thermal cracking and provide the time needed to obtain the desired finish.

## Who Supports Fly Ash Use?

**U.S. Bureau of Reclamation** – Has used fly ash extensively on dam projects.

**U.S. Army Corps of Engineers** – Specifies fly ash in roughly 95% of projects.

**U.S. Environmental Protection Agency** – Requires that fly ash must be allowed on federally funded projects and promotes fly ash utilization through its Coal Combustion Products Partnership (C<sup>2</sup>P<sup>2</sup>) program.

**U.S. Department of Energy** – Has reported to Congress that “[T]he increased utilization of coal combustion byproducts could provide numerous environmental and economic benefits to the United States. Positive environmental effects include (1) reduced solid waste, (2) reduced use of natural resources, and (3) reduced energy consumption and CO<sub>2</sub> emissions from the reduced use of natural resources and the production of cement.”

**U.S. Federal Highway Administration** – Supports fly ash use and publishes information in its “Fly Ash Facts for Highway Engineers” guide.

**American Concrete Institute** – Allows use of “water to cement plus pozzolan” ratio in lieu of “water to cement” ratio. Has no limit on the amount of fly ash used in concrete that will not be exposed to deicing chemicals.

**All 50 U.S. States** – Allow or mandate use of fly ash in state-funded projects.

## FLY ASH CHECKLIST: Enhancing Concrete Workability

The “ball-bearing” effect of fly ash particles creates a lubricating action when concrete is in its plastic state. This creates benefits in:

- ☒ **Workability**  
Concrete is easier to place with less effort, responding better to vibration to fill forms more completely.
- ☒ **Ease of Pumping**  
Pumping requires less energy and longer pumping distances are possible.
- ☒ **Improved Finishing**  
Sharp, clear architectural definition is easier to achieve, with less worry about in-place integrity.
- ☒ **Reduced Bleeding**  
Fewer bleed channels decrease permeability and chemical attack. Bleed streaking is reduced for architectural finishes.
- ☒ **Reduced Segregation**  
Improved cohesiveness of fly ash concrete reduces segregation that can lead to rock pockets and blemishes.

## FLY ASH CHECKLIST: Increasing Concrete Performance

In its hardened state, fly ash creates additional benefits for concrete, including:

- ☒ **Higher Strength**  
Fly ash continues to combine with free lime, increasing compressive strength over time.
- ☒ **Decreased Permeability**  
Increased density and long term pozzolanic action of fly ash, which ties up free lime, results in fewer bleed channels and decreases permeability.
- ☒ **Increased Durability**  
Dense fly ash concrete helps keep aggressive compounds on the surface, where destructive action is lessened. Fly ash concrete is also more resistant to attack by sulfate, mild acid, soft (lime hungry) water, and seawater.
- ☒ **Reduced Sulfate Attack**  
Fly ash ties up free lime that can combine with sulfates to create destructive expansion.
- ☒ **Reduced Efflorescence**  
Fly ash chemically binds free lime and salts that can create efflorescence, and dense concrete holds efflorescence producing compounds on the inside.
- ☒ **Reduced Shrinkage**  
The largest contributor to drying shrinkage is water content. The lubricating action of fly ash reduces water content and drying shrinkage.
- ☒ **Reduced Heat of Hydration**  
The pozzolanic reaction between fly ash and lime generates less heat, resulting in reduced thermal cracking when fly ash is used to reduce portland cement.
- ☒ **Reduced Alkali Silica Reactivity**  
Fly ash combines with alkalis from cement that might otherwise combine with silica from aggregates, causing destructive expansion.

## FLY ASH FACTS: Just One Ton

### ***Just one ton of fly ash use equals:***

#### **Conserved Landfill Space**

Enough for 455 days of solid waste produced by an average American.

#### **Reduced CO<sub>2</sub> Emissions**

Equal to two months of emissions from an automobile.

#### **Saved Energy**

Enough to provide electricity to an average American home for 24 days.

## ENHANCING OUR ENVIRONMENT Green Building Using a Gray Product

More than 12 million tons of coal fly ash are used in concrete products each year in America. That's more than 16 times the volume of aluminum cans that are recycled.

Over the past 30 years, electric utilities and specialized companies like Headwaters Resources have steadily increased the amount of coal combustion products that are recovered for productive uses. In addition to the 12 million tons of fly ash used in concrete products, another 34 million tons of coal combustion products are used in applications such as manufacturing gypsum wallboard, stabilizing soils or wastes, for structural fill or road base materials, or even for agricultural uses.

Because of efforts of environmentally conscious companies, use of coal combustion products has increased more than 50 percent in the past decade. And there are plenty of good reasons to use even more.

Conserving landfill space is an important consideration. Every ton of coal combustion products that is used to improve our nation's highways and buildings is a ton that is not deposited in a landfill, saving the same amount of space that the average American uses over 455 days.

Concrete itself is an environmentally sound building material. Roads and structures built from concrete last longer and require less maintenance than other materials. When used in freeways, concrete can result in less vehicle fuel consumption. Because concrete reflects light, less energy is needed to illuminate the roadway. Concrete is recyclable, with 45 to 80 percent of crushed concrete usable as aggregate in new construction.

Additionally, recent studies conducted by the Environmental Council of Concrete Organizations have determined certain metropolitan areas experience higher overall temperatures than surrounding less-developed areas. Using lighter colored concrete products instead of asphalt pavement can help reduce excessive temperature, further conserving energy.

Use of fly ash — a recovered resource — reduces depletion of natural resources. It also reduces the energy-intensive manufacturing of other concrete ingredients, leading to savings in both energy usage and emissions of greenhouse gases. Use of a ton of fly ash to replace a ton of other manufactured materials saves enough electricity to power an average American home for 24 days, and reduces carbon dioxide emissions equal to two months' use of an automobile.

Fly ash use in concrete qualifies for credit under the U.S. Green Building Council's popular LEED™ rating system for sustainable construction. The environmental benefits of fly ash use are frequently cited by numerous government agencies, including the U.S. Department of Energy and U.S. Environmental Protection Agency.

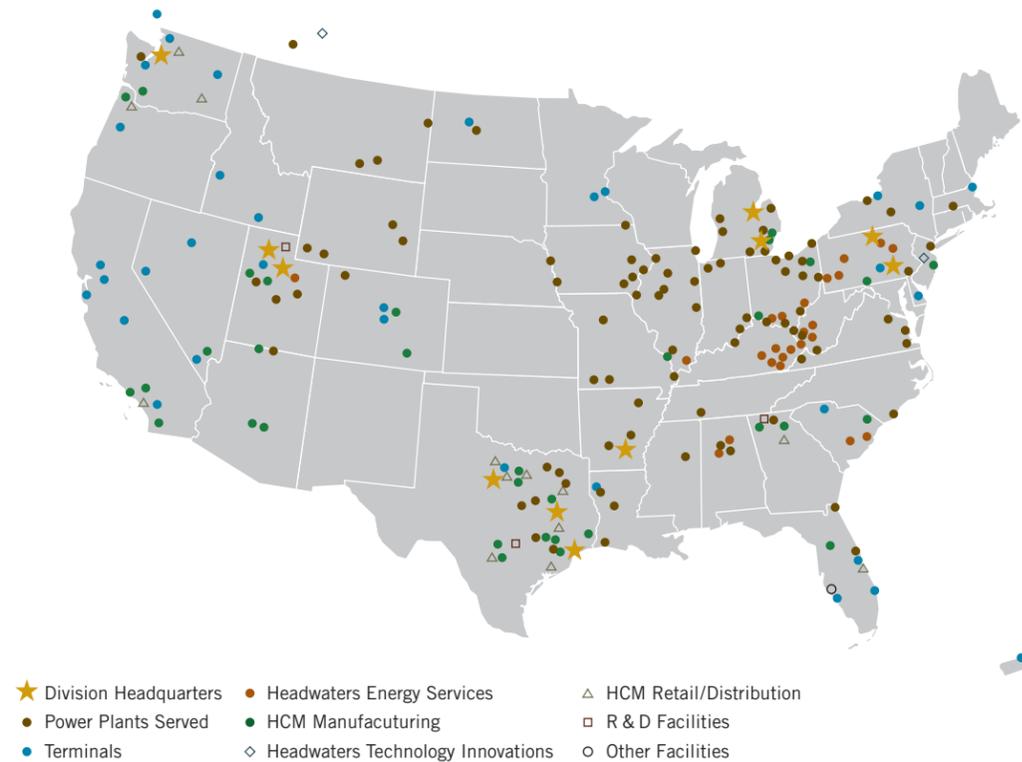
# Headwaters: America's Coal Ash Leader

From ready mixed concrete construction to precast concrete fabrication — from engineered structural fills to soil stabilization technologies — Headwaters Resources supplies materials that make building products perform better.

Operating coast to coast, Headwaters Resources is the leader in supplying materials derived from coal combustion products, including fly ash.

With fly ash sources located across the nation, Headwaters Resources operates an extensive network of terminals and transportation equipment — all designed to ensure concrete producers receive quality material when they need it. In addition to unparalleled customer service, Headwaters Resources maintains its own extensive laboratory and engineering capabilities. Highly qualified chemists, materials scientists and engineers are on hand to ensure product quality and assist in solving challenges faced by individual customers.

For in-depth technical information about coal fly ash and its use, visit our on-line information resource library at [www.flyash.com](http://www.flyash.com).





Formerly ISG Resources  
Formerly VFL Technology

## **CORPORATE OFFICES**

10701 S. River Front Parkway  
Suite 300  
South Jordan, Utah 84095-3527

PHONE 801.984.9400  
FAX 801.984.9410  
1-888-236-6236

[www.flyash.com](http://www.flyash.com)