PERKINS
+WILL

Fly Ash in Concrete

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PART I: Where Opinions Align on Fly Ash in Concrete

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“It’s very complicated…if fly ash is a hazardous waste and it becomes part of a concrete wall, is the wall a hazardous material?”

— Scot Horst, a senior vice president at the U.S. Green Building Council.[3]

> "Coal combustion wastes should not be able to avoid environmental regulation just because they are destined for reuse in construction; the distribution of these products in homes, schools, and roads throughout the nation should not be allowed unless adequate, independent testing is done to ensure that the increasing usage will not result in increasing exposures to building occupants or construction workers."

— Public Employees for Environmental Responsibility (PEER)[4]

> "Even though millions of tons of coal combustion products are used every year, millions more are still going to waste."

— Headwater Resources, self-proclaimed to be "America's largest manager and marketer of coal combustion products"[1]

Disclaimer

Eighty-two years after fly ash was first used in the concrete mix of the Hoover Dam, it's use concrete still has no consensus with regard to opinions on environmental harm and human safety. Our intent is not to write an endorsement or to rebuke the use of fly ash in concrete. Rather, this paper is our first attempt to better understand this very complex topic. Simply stated: there is no clear conclusion. We prepared this report to assist building owners and design professionals in their decision-making processes about the safety and ecological implications of using this building material. This paper consolidates the many diverse opinions, mutually agreed upon facts and minimal independent scientific research on this topic. For clarity, we have structured this paper into two halves. The first half delineates where there is agreement, and the second half covers areas where opinions diverge on the impact of fly ash in concrete.

The research for this paper is based on a thorough examination and consolidation of publicly available information and is not supported by original scientific research. The scope of this paper is limited to fly ash in concrete and does not address fly ash in other building products. This paper does not address other coal combustion by-products such as flue gas desulfurization or secondary cementitious materials such as blast furnace slag. While these topics are worthy of examination, we have chosen to limit our efforts to examining the impact of fly ash in concrete. The authors would like to note that while this paper covers only its origins and use as a replacement for Portland cement in concrete, a subsequent paper examining its uses in other building products is necessary.

> "There are tradeoffs to anything; there's no perfect material. Fly ash, in a way, is still solving a symptom. In one sense, yes, you're using up this waste material. In another way it's justifying the burning of coal as a fuel source. Until we find better ways to produce energy, it is a good use of the by-products."
>
> *— Daniel Hendeen, a research fellow at the University of Minnesota, Center for Sustainable Building Research.*[2]

Executive Summary

To power our world, we burn a billion tons of coal every year,[5] leaving significant quantities of coal ash. Rather than sending this ash to landfills, some is being recycled for beneficial uses, including as an additive or key component of building products. In particular, the lighter ash (the dust that rises up the flue when coal is burned – usually referred to as fly ash) is now a common ingredient in concrete, carpet backing, recycled plastic lumber, grout, acoustic ceiling tiles, and myriad of other building materials.

Though fly ash has become a ubiquitous ingredient in building materials over the last 82 years, it has been largely ignored by regulatory agencies in the United States. That changed in 2010 when the United States Environment Protection Agency (EPA) proposed to classify fly ash as a hazardous material. The EPA actions surprised many design professionals, builders, and owners because fly ash had become a common "recycled" component in buildings. Until the EPA's proposed regulations, fly ash's provenance and its life cycle impacts were largely overlooked.

Of all the building materials that have fly ash in them, concrete merits special consideration. Foremost, it is a very common beneficial use of a fly ash. Fly ash mixed into concrete accounts for approximately seven percent of the fly ash that is diverted from landfills each year. The remaining un-diverted fly ash is either sent to dry or wet disposal facilities. The disposal of fly ash places significant stress on our overtaxed waste system. In 2008, 42.3 million tons of fly ash were sent to coal ash disposal sites on top of the estimated 100 to 500 million tons that have been dumped in United States landfills since the 1920s.[6] This equates to 813,462 tons of fly ash disposed of every week. Unfortunately, this "waste" fly ash is not always contained safely. In 2010, 31 coal ash disposal sites were linked to contaminated groundwater, wetlands, creeks, and rivers in fourteen states.[7]

For the fly ash that is diverted into concrete, there is the unanswered question. Is fly ash chemically changed when it is mixed into concrete? We were unable to find any studies that prove fly ash is changed chemically when in concrete. There is not scientific consensus on this topic. This is an important question because fly ash carries the same toxic burden as the coal from which it was derived. If the harmful substances in fly ash were rendered harmless when bonded into concrete, this would be one of the most significant benefits to the use of fly ash, even exceeding the value of recycled content. The studies that we found (and are noted in this paper) have mostly focused on heavy metal leaching (mercury in particular) from the concrete, and have not addressed the other harmful substances regularly found in fly ash dust generated from modifying or demolishing fly ash concrete, or what happens at the end of its life in a building.

Since the production of Portland cement is estimated to generate between two and five percent of the world's greenhouse gas (GHG) emissions,[8] 3.4 percent according to the EPA,[9] the substitution of fly ash for cement is often cited as a means to reduce carbon footprint. However, the assertion that replacing Portland cement with fly ash in concrete reduces GHG emissions is only correct if the production of fly ash is not taken into account. The burning of coal, the source of fly ash, generates approximately twenty to thirty tons of carbon dioxide (CO_2) per ton of fly ash generated.[10] In contrast, the production of Portland cement produces approximately 1.25 tons of CO_2 per ton of ash,[11] meaning fly ash actually has a higher carbon footprint than Portland cement when CO_2 emissions are compared by weight.

The impact the EPA's classification of fly ash as a hazardous material on its use in concrete or other materials is unclear. As of the writing of this paper in the fall of 2010, the EPA regulation of fly ash is still pending. That being said, there are numerous precedents in the building industry for products that attained widespread use before they were deemed hazardous. Lead paint is the most infamous example, but asbestos and arsenic-treated wood are also relevant precedents. All these materials have proven to be expensive to remove and dispose after they had been deemed harmful by regulatory agencies.

For the building community to continue to have faith in fly ash as a good substitution for Portland cement in concrete, it must have a better understanding of the provenance and life-cycle of fly ash and its use in concrete. At a minimum, research needs to be done to address the chemistry of fly ash's toxic burden when it is in concrete and at end of its life. There also needs to be a complete and rigorous life-cycle assessment of the embodied energy of fly ash in concrete, including the initial production from coal ash. Until this work has been done, three tough questions remain unanswered about the use of fly ash in concrete:

1 What are the total GHG emissions of concrete when fly ash is used in lieu of Portland cement?

2 Is fly ash's toxic burden benign when in concrete?

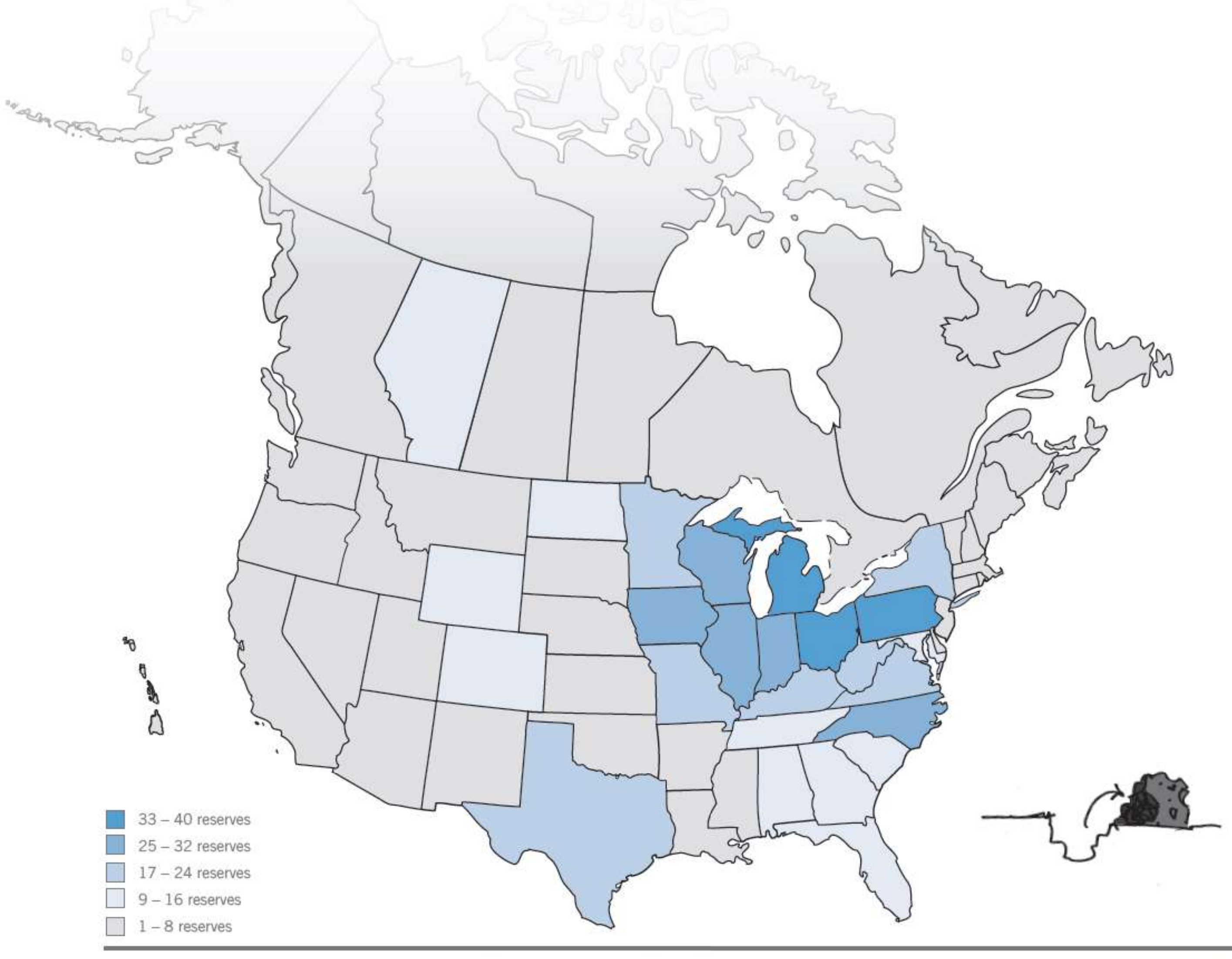
3 Is it better to send fly ash to landfills or to divert it into our homes, schools, hospitals, and offices?

Introduction to Fly Ash

The recipe for concrete is simple: a mixture of water, Portland cement, fine aggregates and course aggregates, cured for 28 days. Portland cement is the key ingredient in concrete, composing approximately twelve percent of the mix weight, acting as the binding agent that holds sand and other aggregates together in a hard, stone-like mass. This basic recipe for modern concrete has been altered countless times since Joseph Aspdin, a bricklayer, patented Portland cement in 1824. Today, the concrete mix is altered to improve compressive strength, to shorten curing time, improve workability and many other performance traits.

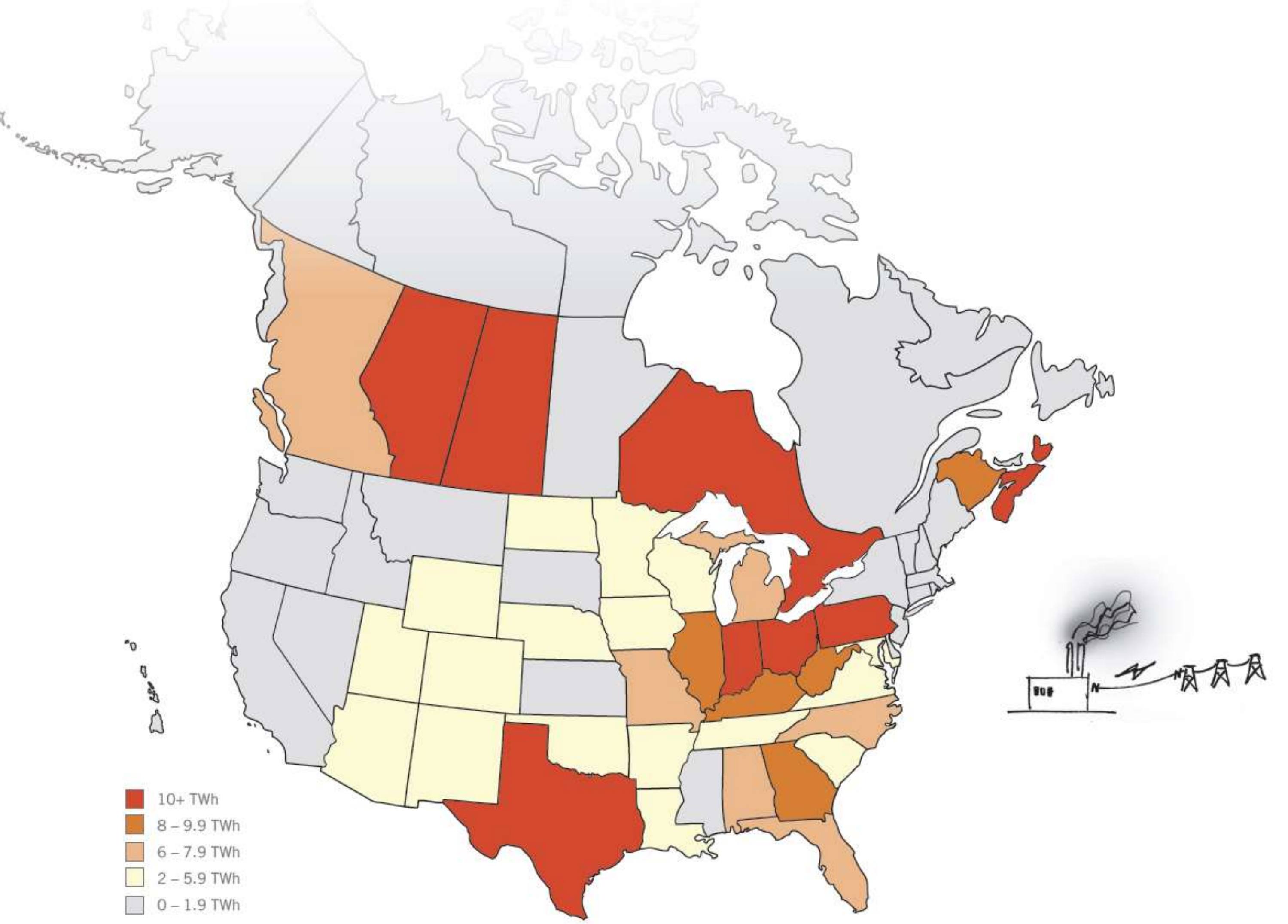
One of the most unique changes to concrete's recipe is the use of fly ash, a by-product from coal-fired power plants, in lieu of Portland cement. There are many performance reasons to use fly ash in concrete: it improves plasticity, decreases permeability, increases sulphate resistance and enhances durability. Volcanic ash was used by the ancient Romans in concrete, and fly ash has been used as a pozzolan (a material that has cementitious properties) in modern concrete since the building of the Hoover Dam in 1929.[12] Each year in North America, fly ash replaces about eight percent of Portland cement in concrete, and in some European countries the replacement rate exceeds 25 percent.[13] Reducing or eliminating Portland cement has resulted in lower levels of extraction for virgin silica and limestone as well as reducing the GHG emissions tied to the concrete itself; but, as noted previously, current calculations do not take into account the process of fly ash production and instead focus on the concrete itself. Recently, fly ash has also been used to improve the environmental footprint of concrete by lowering the

KNOWN COAL RESERVES



Sources: http://www.sourcewatch.org/index.php?title=Existing_U.S._Coal_Plants, http://www.sourcewatch.org/index.php?title=Existing_coal_plants_in_Canada

ELECTRICITY PRODUCTION BY COAL

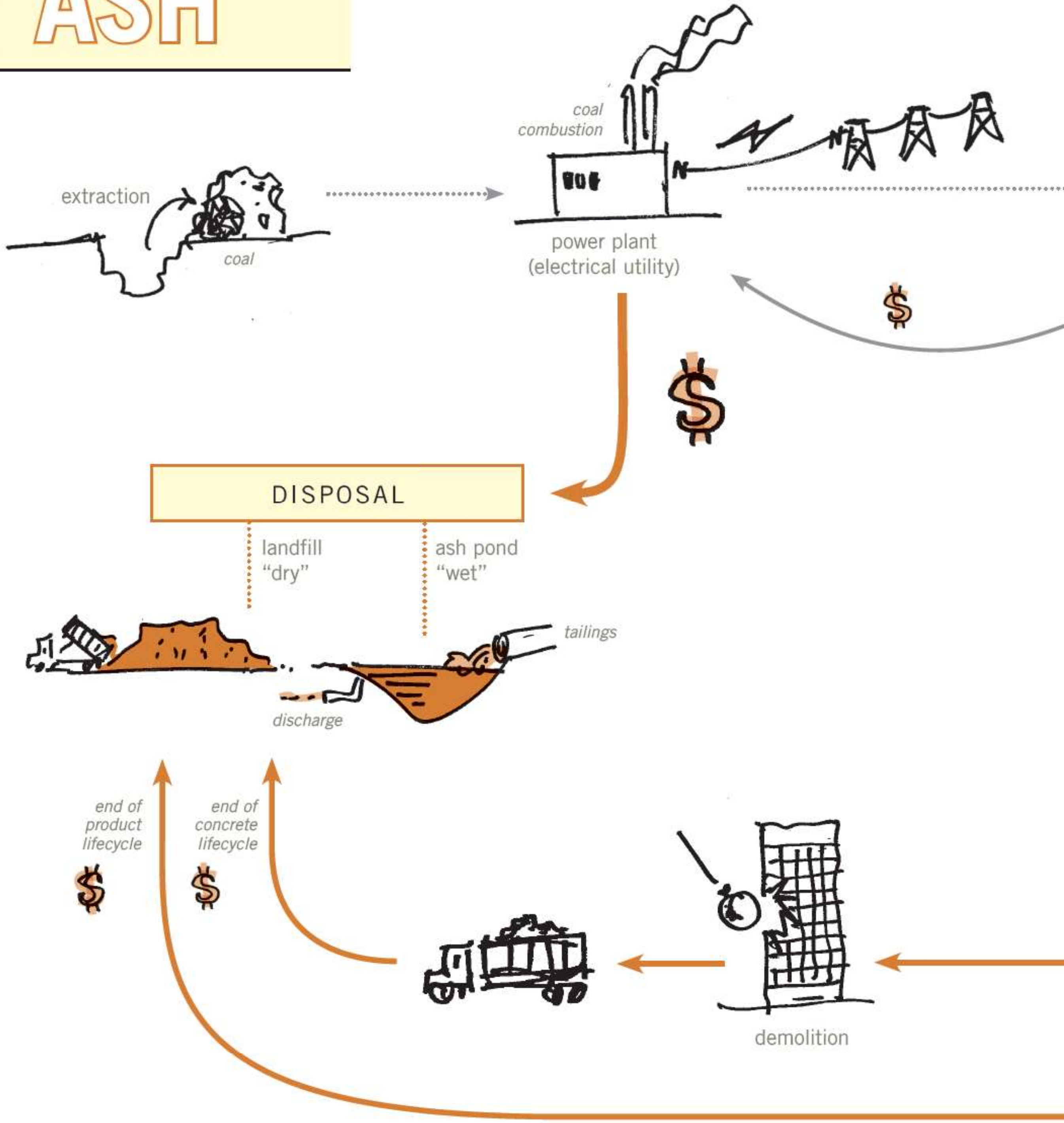


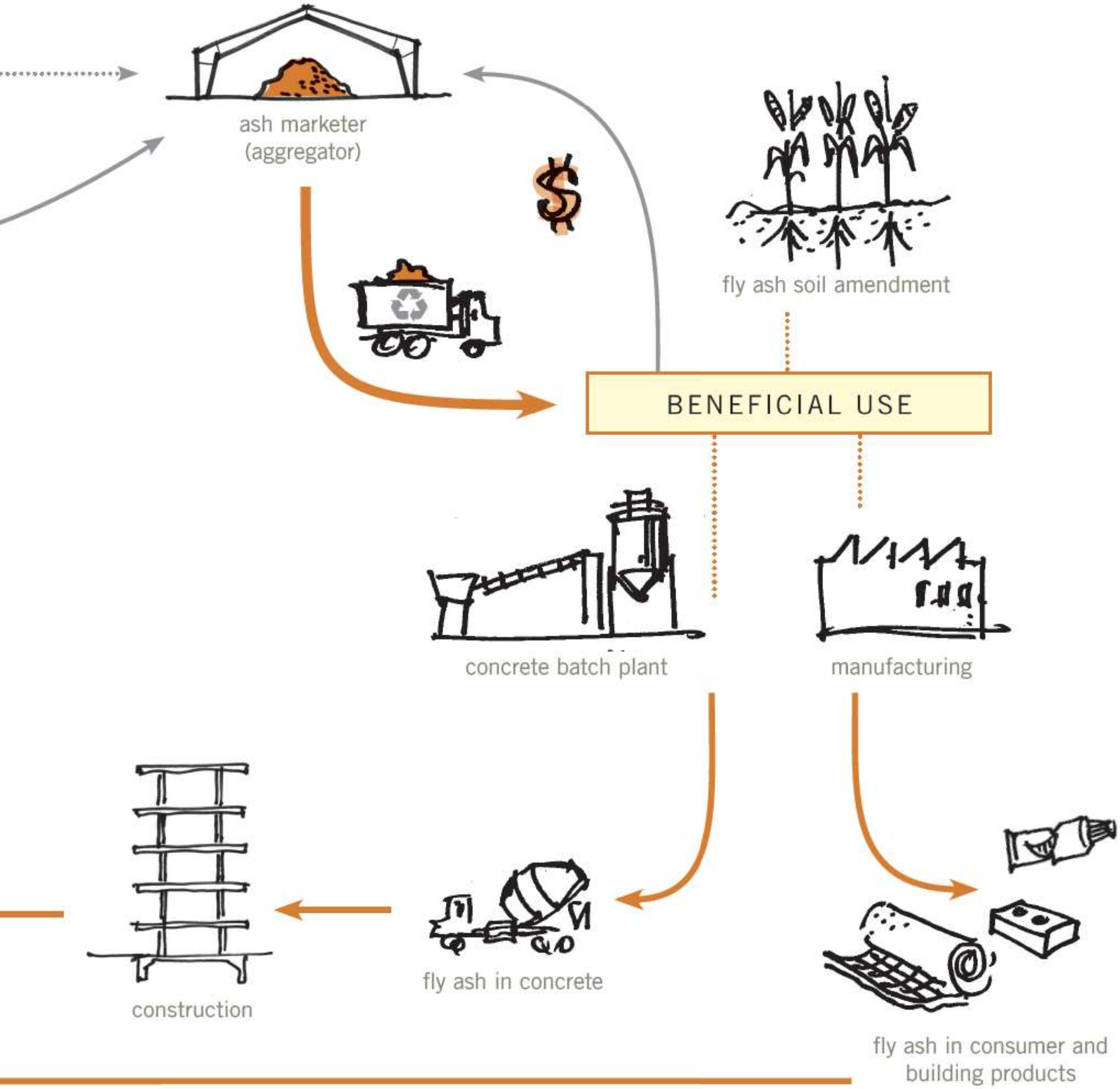
Sources: http://www.eia.gov/cneaf/coal/page/acr/table1.html, http://www.centreforenergy.com/FactsStats

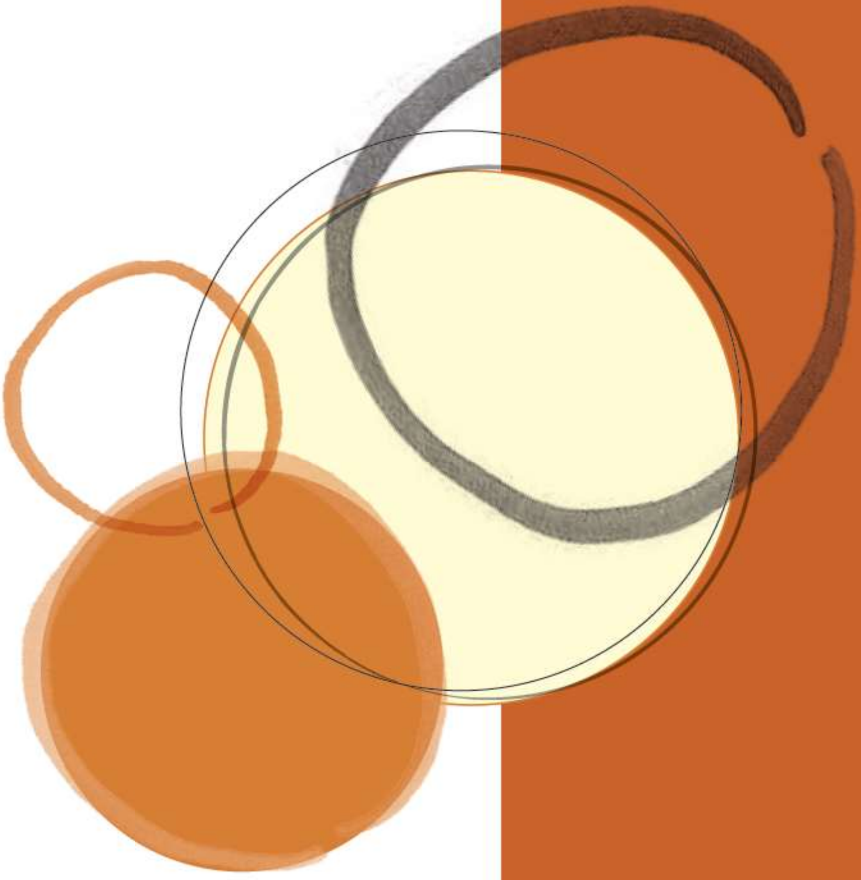
potable water content in the mix, thereby diverting fly ash from the landfill. Its use is also rewarded as recycled content in green building rating systems such as the United States Green Building Council's (USGBC) Leadership in Energy & Environmental Design (LEED™) and other green building standards.[14] Additional technical information and performance standards for fly ash concrete are included in Appendix: **"Technical Consideration: Fly Ash is a Pozzolan" on page 38**.

The fact that fly ash is not a benign material, however, raises the question of whether it truly improves the environmental performance of concrete. Since fly ash is a by-product of coal combustion, it often contains the harmful elements of the burned coal. Fly ash may have trace amounts or even higher levels of known health hazards such as lead and mercury.[15] Trade organizations such as the American Concrete Institute (ACI) and the American Coal Ash Association (ACAA) have taken the position that the environmental benefits of the "reuse" of fly ash outweigh the potential health risk of entombing toxic compounds into concrete. The pro-fly ash position has been challenged by many environmental groups. Public Employees for Environmental Responsibility (PEER) opposes the use of fly ash in concrete because there is no "demonstrated scientific support for the safety or quantifiable benefits of using coal combustion wastes in building and consumer products."[16] California's Collaborative for High-Performance Schools (CHPS) has put limits on the mercury content for fly ash in concrete under their green building rating system, and the recently released LEED™ for Healthcare also has a credit that limits mercury levels in supplemental cementitious materials (SCMs) derived from coal-fired power plants.

THE LIFECYCLE OF FLY ASH




ash marketer
(aggregator)
$
fly ash soil amendment
BENEFICIAL USE
concrete batch plant
manufacturing
construction
fly ash in concrete
fly ash in consumer and
building products



PART I:

Where Opinions Align on Fly Ash in Concrete

There Will Be More Fly Ash in Our Future

In 2006, the U.S. produced approximately 227 gigawatts of electricity from coal, about 25.7 percent of the world's supply of coal-fired electricity.[17] The majority of the 615 coal-fired power plants in the United States are clustered in parts of the Midwestern, Mid-Atlantic and Southern United States, with less than ten in New England and only five in the Pacific Northwest.[18] Pennsylvania leads the country with 40 coal plants, and Ohio is a close second with 35.

DEPENDENCE ON COAL FOR ELECTRICITY BY COUNTRY:

> The pending EPA hazardous material ruling has generated a great deal of debate on the environmental traits of fly ash. In this debate, we found that opinions are not completely divided; there is general consensus on fly ash's growing market share, chemical composition and radiological risk.

Coal Dependency

American electric utilities and other power producers generate 136 million tons of fly ash and other coal combustion residuals (CCRs), which include bottom ash, boiler slag and flue gas desulfurization (FGD) material (sulfur dioxide (SO_2)) exhaust matter. FGD is commonly used as a replacement for mined gypsum in "synthetic" gypsum wallboard).[19] Of the coal burned in United States power plants, about ten percent ends up as a combination of fly ash and bottom ash.[20] Forty percent of this ash is "re-used."[21]

Outside of the United States, coal is also a common source fuel for electrical generation. Coal-fired power plants currently fuel 41 percent of global electricity. In some countries coal is the primary source of electricity. Due to its relatively low cost, the use of coal as a source fuel for electrical generation worldwide will likely continue to grow. It is estimated that coal will fuel 44 percent of global electricity needs in 2030.[22] As coal will continue to be a global energy source for the foreseeable future, it is a safe assumption that the coal industry and others will continue to seek uses of fly ash.

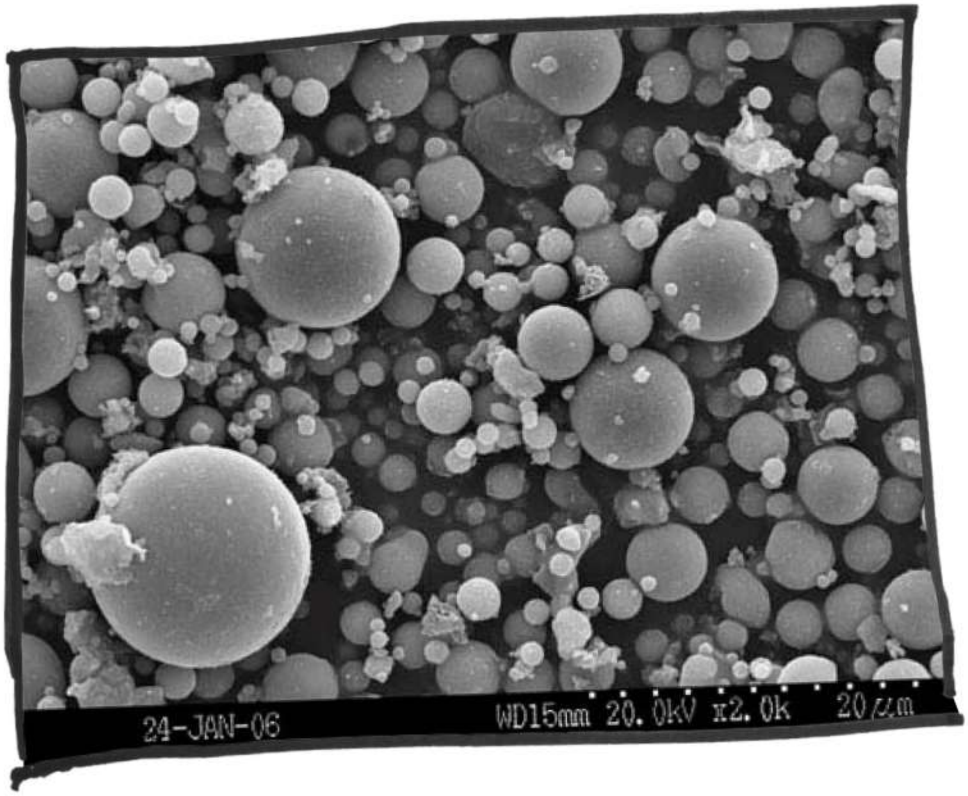
CONCRETE **WITHOUT** FLY ASH

CS	+	H	=	CSH	+	CH
calcium silicates *(Portland cement)*		hydrogen *(extracted from water)*		calcium silicate hydrate *(glue)*		calcium hydroxide *(weak lime crystals)*

CONCRETE **WITH** FLY ASH

All of the Above	+	Si	=	CSH
		silica *(fly ash)*		calcium silicate hydrate *(MORE glue)*

Source: Making Better Concrete: Guidelines to Using Fly Ash for Higher Quality, Eco-Friendly Structures by Bruce King.



Class F fly ash sample as viewed via SEM at 2000x magnification. *Copyright UK CAER.*

Source: http://www.caer.uky.edu/kyasheducation/images/ccbs/gallery-ccbs/pages/Class-F-fly-ash-1-600.html

Composition of Fly Ash

As noted earlier, fly ash is part of coal ash, or the "total residue," created during the combustion of coal in electrical power plants. The coal that is not incinerated either settles at the bottom of the boiler ("bottom ash") or rises in the flue ("fly ash"). In short, fly ash is the dust collected in the smokestacks as a result of combustion.

Depending on the source and properties of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) and calcium oxide or lime (CaO). The two types of fly ash used in concrete are categorized as either Class C or Class F by the American Society for Testing and Materials (ASTM) under their C618 standard." The primary difference between these classes is the amount of calcium, silica, alumina and iron content in the ash. The most commonly produced fly ash, Class F, exhibits calcium oxide (CaO) contents below eighteen percent and often well under ten percent. In addition to higher alkali and sulfate (SO4) contents, Class C fly ash has a lime (CaO) content of more than ten percent, and therefore is often referred to as "high calcium" fly ash. Class C fly ash has enough calcium to exhibit cementitious properties by itself, necessitating only water to hydrate and harden.

As noted in the introduction, the chemical properties of the fly ash are largely influenced by the chemical content of the type of coal burned (i.e., anthracite, bituminous, sub-bituminous and lignite). Class F fly ash is created when harder, "older" anthracite and bituminous coal is burned. Class C is produced from burning "younger" lignite, which is mostly found in the Western United States. Regional proximity is the primary reason one type of fly ash is specified over another. In general, Class F fly ash is typically used to partially replace Portland cement in concrete because it is superior to Class C in mitigating both sulfate and alkali–silica damage, but concrete can be made with Class C fly ash without any Portland cement. Additionally, it is critical to note that "because of variations in the chemical structure of coal from different regions, it's often easier to remove mercury from eastern coal than western coal. Also, because eastern coal usually has a higher heat rate, there is less mercury per unit of energy in eastern coal than from western coal." [23]

Additional information on performance and technical aspects of fly ash in concrete are included in Appendix: **"Summary of Current Regulations, Codes and Technical Standards" on page 40**.

Fly ash contains many hazardous substances within its composition in addition to substantial amounts of silicon dioxide (SiO_2) and calcium oxide (CaO). The composition of both Class C and F fly ash varies greatly, but may include "one or more of the following elements or substances in quantities from trace amounts to several percent: arsenic, beryllium, boron, cadmium, chromium, chlorine, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and Polycyclic aromatic hydrocarbons PAH compounds."[24, 25] (It is important to note the scientific community's consensus on the toxicity of fly ash as a raw material.)

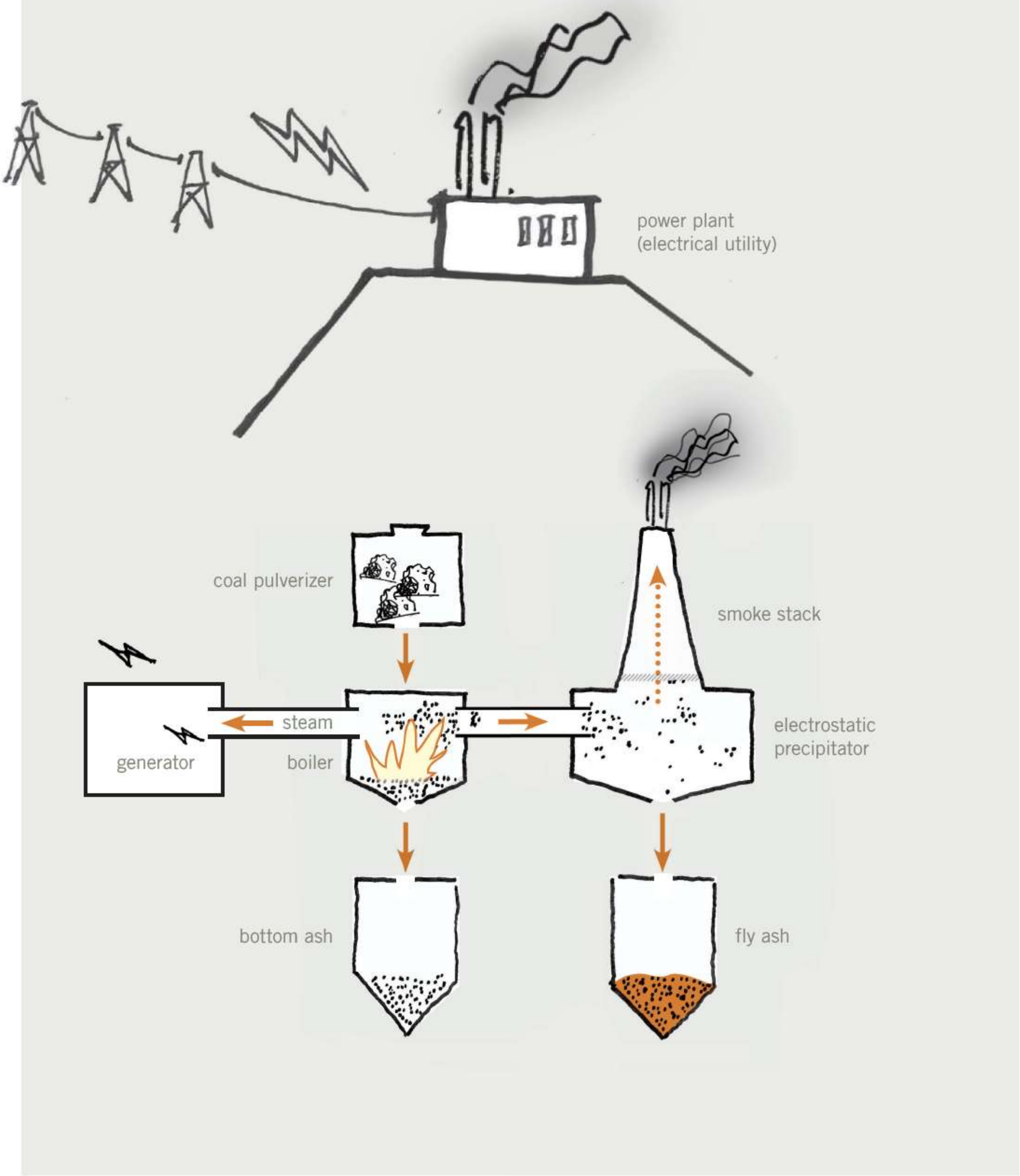
All of the chemicals listed above are cited on government watch lists as substances that have known and suspected impacts on human health. For instance, according to the EPA, mercury is a known persistent bioaccumulative toxin (PBT), and it is a developmental toxicant under California's Proposition 65.[26] **Mercury is also implicated or suspected to be the following**; the organizations or noted authors associated with these positions are listed in parentheses:[27]

- Cardiovascular or blood toxicant *(KLAA)*
- Endocrine toxicant *(IL-EPA; KEIT; WWF)*
- Gastrointestinal or liver toxicant *(RTECS; STAC)*
- Immunotoxicant *(HAZMAP; SNCI)*
- Kidney toxicant *(HAZMAP; KLAA; LAND; MERCK; STAC)*
- Neurotoxicant *(ATSDR; DAN; EPA-HEN; EPA-SARA; FELD; HAZMAP; KLAA; OEHHA-CREL; RTECS; STAC)*
- Reproductive toxicant *(EPA-SARA; FRAZIER; HAZMAP; OEHHA-AREL)*
- Respiratory toxicant *(HAZMAP; NEME)*
- Skin or sense organ toxicant *(HAZMAP; KLAA; RTECS)*

See Appendix: **"Body Burden of Substances in Fly Ash via Government Watch List" on page 44** for more information on the suspected and known health impacts of the substances found in fly ash.

Fly ash contains approximately one part per million of mercury. To put this quantity in perspective, this exceeds, by a factor of 1000, the maximum level of mercury in drinking water permitted by the EPA, which is two parts per billion. It only takes 1/70th of a teaspoon of mercury to contaminate a 20-acre body of water and make all fish within it toxic to humans. This is about the amount of mercury in a typical medical thermometer.[28]

COAL FUELED POWER PLANT PROCESS



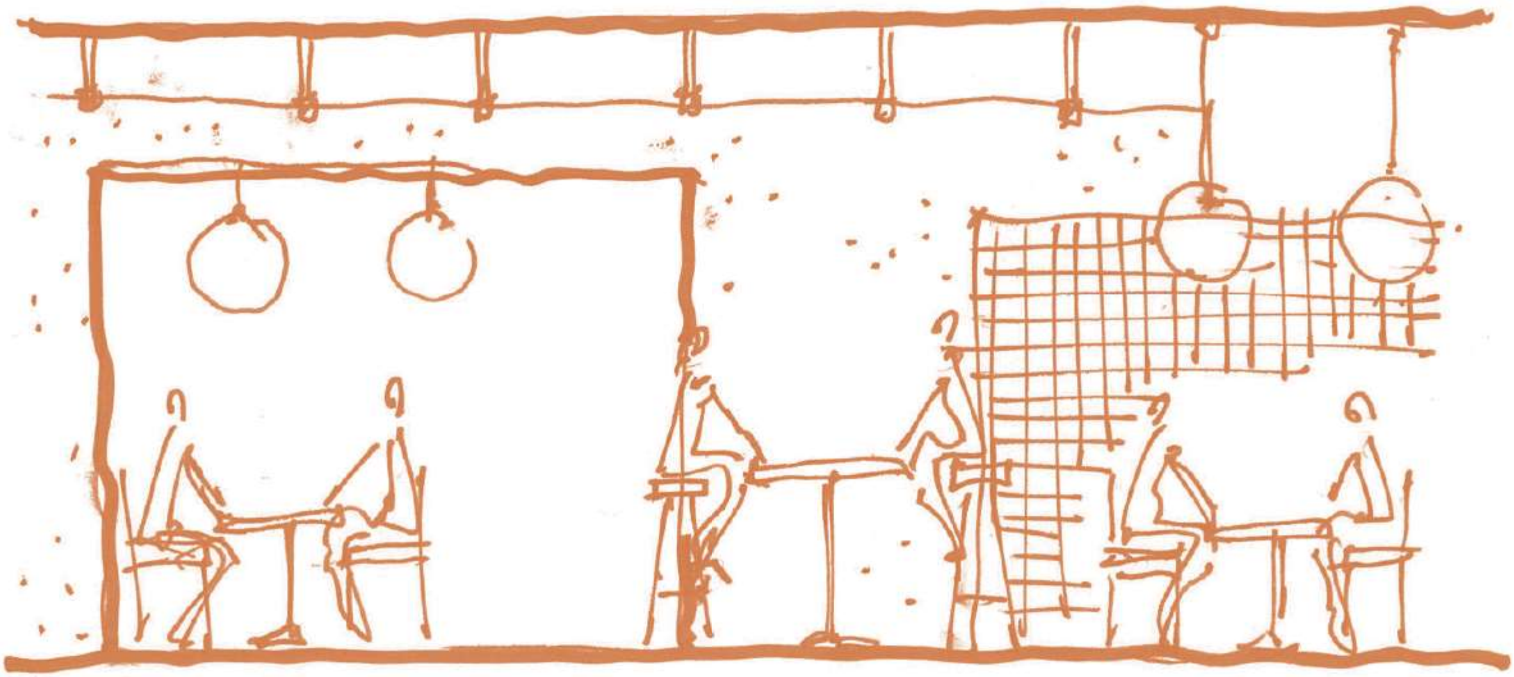
Radioactivity and Fly Ash

With a few exceptions, consensus among the scientific community says that use of fly ash in concrete does not constitute a significantly different radiation risk than the Portland cement it replaces. Both Portland cement and fly ash pose a radiation risk similar to that of common soil.

Coal is largely composed of organic matter, but some of the inorganic matter (the trace elements) in coal is radioactive. These radioactive trace elements include uranium (U), thorium (Th), and their numerous decay products, including radium (Ra) and radon (Rn). Although these elements are less chemically toxic than other coal constituents such as arsenic, selenium or mercury, questions have been raised concerning possible risk from radioactive coal's combustion by-products being used in consumer products. See graphics of consumer, building products, and agriculture applications that contain fly ash in Appendix: **"Coal Combustion Wastes in Our Lives" on page 45.**

Radioactive elements in coal remain after combustion and are held in both bottom ash and fly ash. In particular, most of the uranium and thorium are released during combustion from the original coal and are distributed between the gas and solid combustion products. The partitioning between gas and solid is controlled by the volatility and chemistry of the individual elements. For example, virtually 100 percent of radon present in coal is lost in stack emissions. In contrast, less volatile elements such as thorium, uranium, and the majority of their decay products are almost entirely retained in the solid combustion wastes.[29]

In fly ash, the uranium is more concentrated in the finer sized particles. During combustion of coal, uranium is concentrated on ash surfaces as a condensate, This surface-bound uranium is potentially more susceptible to leaching. The radioactive elements from coal and fly ash may come in contact with the general public when they are dispersed in air and water or are included in commercial products that contain fly ash.[30]

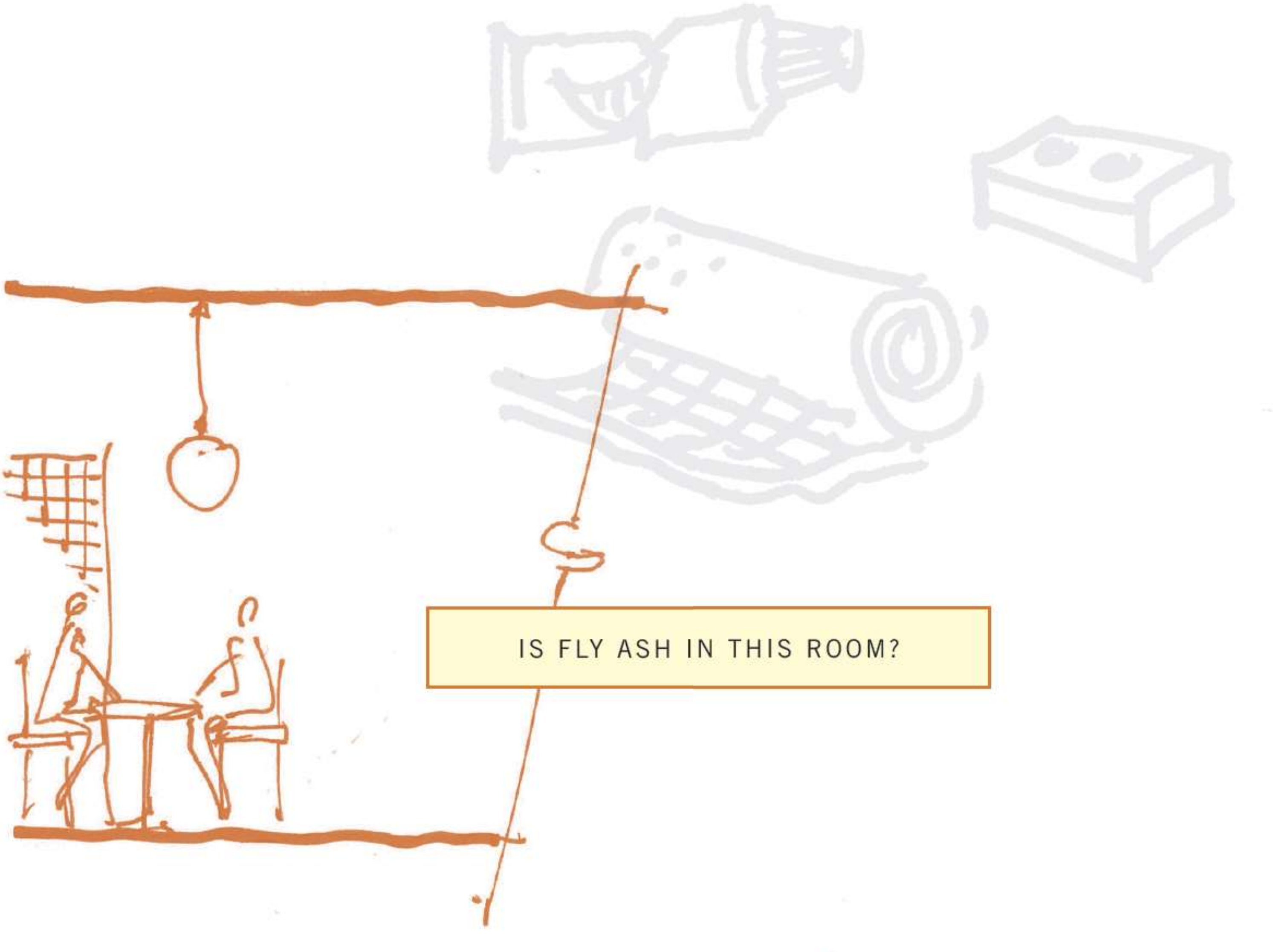


Trace amounts of uranium and thorium occur naturally in coal, but when coal is burned to create ash, the uranium and thorium are concentrated up to ten times their original levels. Nevertheless, Robert Finkelman, a former coordinator of coal quality with the United States Geological Survey (USGS) who oversaw research on uranium in fly ash in the 1990s, notes that:

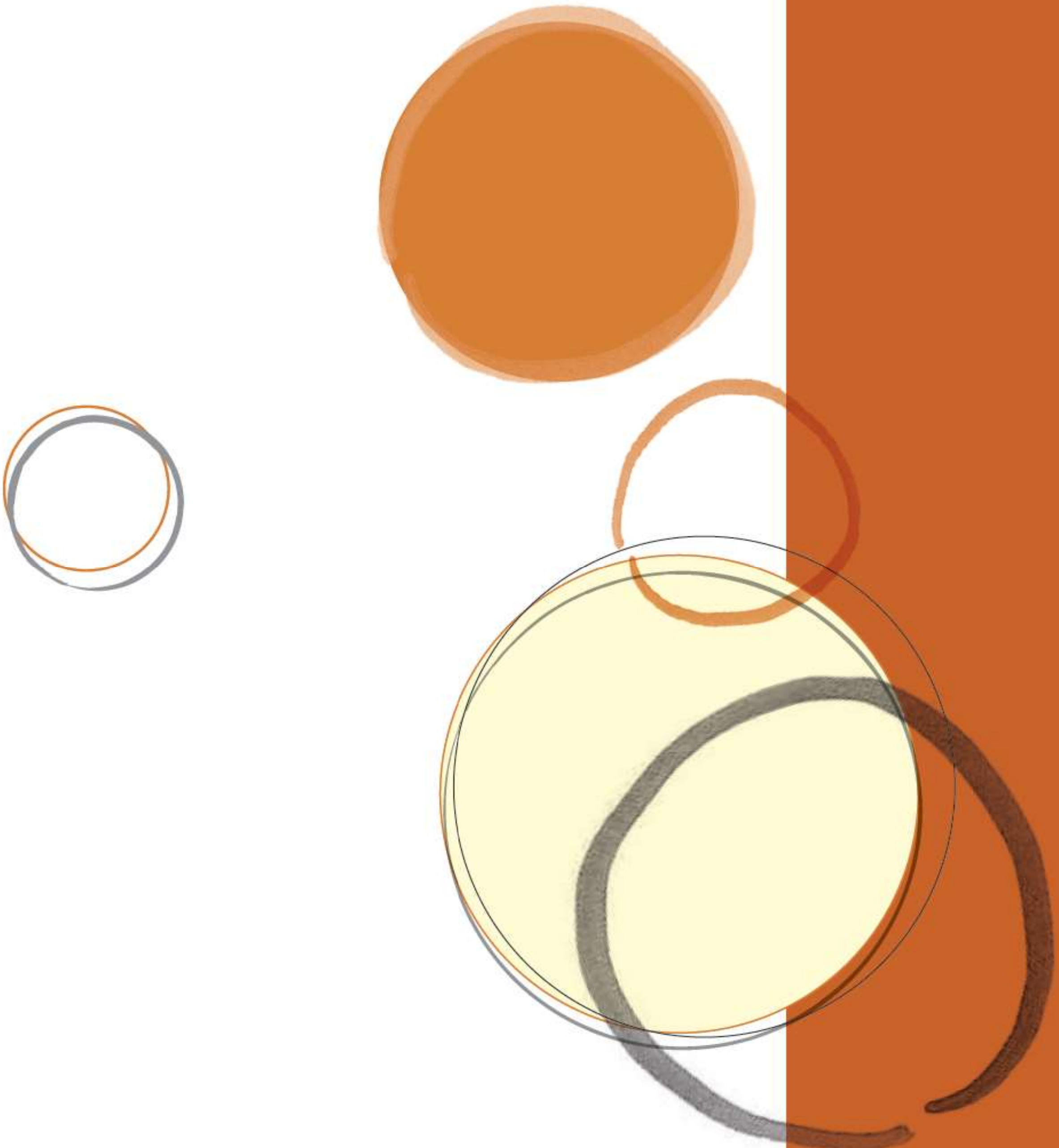
> *"[F]or the average person the by-product accounts for a miniscule amount of background radiation, probably less than 0.1 percent of total background radiation exposure. Radiation from uranium and other elements in coal might only form a genuine health risk to miners."*[31]

A 1983 EPA document, "Cement and Concrete Containing Fly Ash; Guideline for Federal Procurement," also discusses the potential radiation resulting from fly ash stating:

> *"Tests recently conducted for EPA substantiate that the radon emanation rate of fly ash in its raw state and as used in concrete is only a few percent compared to the absolute radium concentration. Thus, while fly ash use in cement would, on the average, result in a small increase in gamma radiation exposure, this small increase in gamma exposure is likely to be offset by a decreased radon exposure. In light of this, the EPA believes that the use of typically-occurring fly ash in concrete does not constitute a significantly different radiation risk than the risk from the cement it replaces and neither of these is significantly different from the radiation risk posed by common soil."*



IS FLY ASH IN THIS ROOM?



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PART II:

Where Opinions Differ on Fly Ash in Concrete

Opinions differ widely on the environmental and health impacts of using fly ash in concrete, specifically, and other building products, additionally. These debates center around the CO_2 impact of substituting fly ash for Portland cement, regional limitations and resource stewardship, whether the toxic burden of fly ash is actually "encapsulated" in the concrete mix, and the inherit risks of putting fly ash into our buildings.

Fly Ash as a Waste Product / Handling and Disposal of Fly Ash

After fly ash is produced in coal power plants, it and other Coal Combustion Residue (CCRs) await two possible fates: recycling or disposal. Only about 25 percent of all fly ash produced is diverted annually. The remainder is discarded in engineered landfills and surface impoundments or abandoned mines and quarries.[32] Not everybody believes that the redirecting of fly ash from disposal sites is beneficial. Public Employees for Environmental Responsibility (PEER) has been one of the most vocal critics of recycling. Following PEER's August 2010 statements, fly ash has no "demonstrated scientific support for the safety or quantifiable benefits of using coal combustion wastes in building and consumer products."[33]

The magnitude of the fly ash disposal issue is enormous. CCRs represent the second largest industrial waste stream in the United States after coal mining.[34]

The disposal issue cannot be ignored. Such large quantities of CCRs are generated each year in electric utility plants, they have become the third most abundant mineral resource in the United States.[35] In 2008, electric utilities and other power producers in the United States generated 136 million tons of fly ash and other CCRs, which also include bottom ash, boiler slag and flue gas desulfurization (FGD) material. Of the coal burned in United States power plants, about ten percent ends up as a combination of fly ash and bottom ash, according to the American Coal Ash Association (ACAA).[36] Of that ten percent, only about 40 percent is diverted to beneficial uses leaving 60 percent destined for disposal.[37] Globally, the utilization rate of fly ash is much lower, around 25 percent.[38]

Disposal takes place using one of two methods, and both types of facilities are typically located near electric utilities. CCRs are either dumped in dry form into one of approximately 300 landfills in the United States, or they are contained in wet form in one of approximately 580 surface impoundments, also known as "ash ponds."[39] In the wet disposal method, a slurry of CCRs mixed with water is transported to an ash pond. Many of these ash ponds are not lined, increasing the probability of seepage and leaching of contaminants into groundwater as well as runoff into surface waters.

Conversely, while more costly, the dry collection method reduces the potential for pollution while increasing the potential beneficial uses of the fly ash. Dry ash sites should also be lined--although many are not--and should be stabilized with vegetation to minimize environmental damage caused by wind erosion.

In 2008, 42.3 million tons were landfilled, compounding the estimated 100 to 500 million tons already been stockpiled in United States landfills since the 1920s.[40]

The storage and handling of fly ash became an issue of national prominence in December 2008 with the collapse of an embankment at an impoundment for wet storage of fly ash at the Tennessee Valley Authority's (TVA) Kingston Plant. The cleanup is projected to cost $268 million and take up to four years to complete. According to the EPA as of May 2010,

> *"Drinking water, river water and groundwater in the area are sampled on a routine basis and current results indicate no exceedances [SIC] of drinking water standards or surface water quality criteria. Semiannual sampling of groundwater wells indicates no contaminant plume is present under or around the site."*[41]

Fly ash exists in four primary forms based upon its intended end use: dry, conditioned, stockpiled and lagooned. When transported to project sites for use in concrete, it most often is in the dry form, whereas it is most often stored for long term in wet or moist form. Some agencies such as the TVA are moving from wet to dry storage to avoid future spillage.

This transition also has health impacts since the dry application of fly ash may pose danger prior to encapsulation in concrete. During dry storage, fly ash can be blown by the wind, become airborne and eventually be released into the greater environment. According to a 2010 Greenpeace report,

> *"about twenty percent of coal ash particles are hollow, making them easily dispersible by wind. Regardless of whether dry or wet disposal methods are used, without a properly enclosed storage*

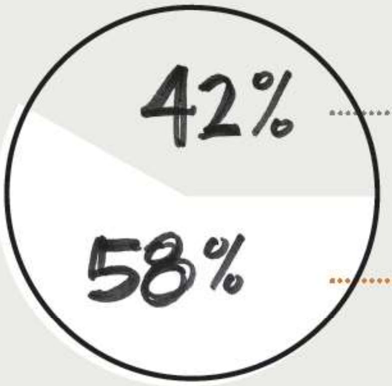
WASTE DISPOSAL VOLUME

calendar year	fly ash generated *(million tons)*	fly ash used *(%)*	fly ash disposed *(%)*
1970	26.5	8.3%	91.7%
1975	42.3	10.6%	89.4%
1980	48.3	13.3%	86.7%
1985	48.3	23.5%	76.5%
1990	49.0	25.5%	74.5%
1995	54.2	25.0%	75.0%
2000	63.0	30.8%	69.2%
2001	68.1	32.4%	67.6%
2002	76.5	34.9%	65.1%
2003	70.2	38.6%	61.4%
2004	70.8	39.7%	60.3%
2005	71.1	40.9%	59.1%
2006	72.4	44.7%	55.3%
2007	71.7	44.2%	55.8%
2008	**72.4**	**41.6%**	**58.4%**
2009	63.1	39.2%	60.8%

Source: American Coal Ash Association, annual survey data

FLY ASH USED IN THE U.S. IN 2008

30.1 MILLION TONS



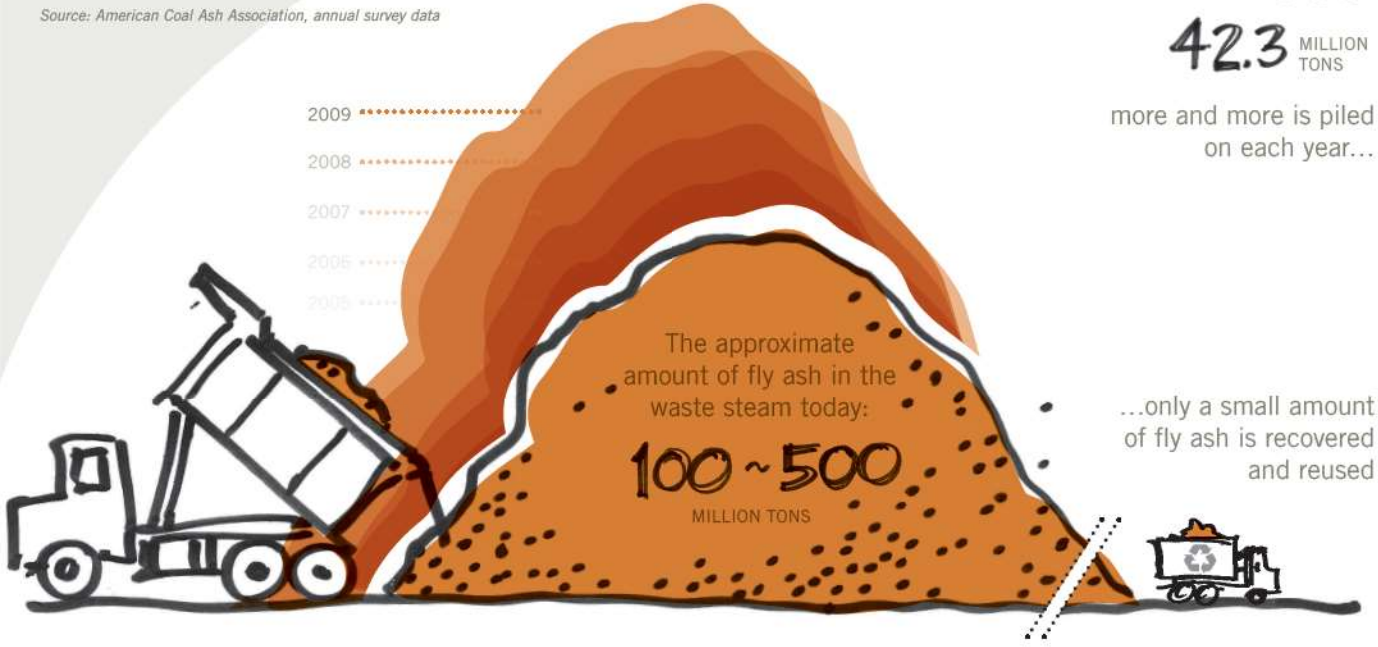
BENEFICIAL USE

DISPOSAL

FLY ASH DISPOSED IN 2008

42.3 MILLION TONS

more and more is piled on each year...



The approximate amount of fly ash in the waste steam today:

100~500 MILLION TONS

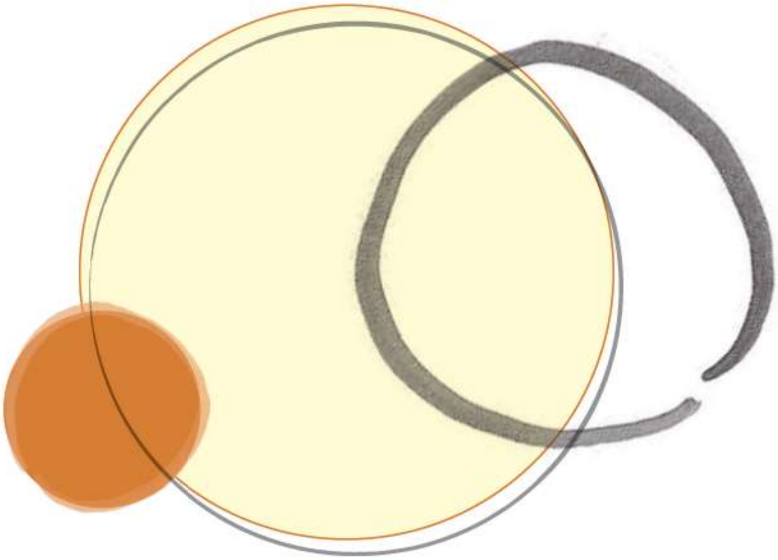
...only a small amount of fly ash is recovered and reused

> *system, coal ash can easily be scattered into the atmosphere as secondary dust pollution. This will have serious consequences for people living downwind of the coal ash impoundment."*[42]

During fabrication and construction of concrete, workers may have direct contact with the concrete mix both in the mixing plant and when concrete is poured into the formwork. This exposure takes place before any chemical binding occurs, meaning the toxic burden of the fly ash is "free" and not yet "bonded" within the concrete, an occupational exposure with significant consequences. In addition to the fly ash's harmful substances derived from the coal itself, fly ash may also absorb ammonia or ammonium sulfate compounds when the fly ash is "conditioned" in the flue. According to Paradise, Petechuk, and Mertz "during the mixing and pouring of concrete, ashes with high amounts of ammonia may create harmful odors that can affect workers' health."[43] Another time of potential exposure is during dust-generating modifications or demolition of concrete. As previously noted, in order to confirm fly ash's safe use, peer-reviewed studies are needed to prove that fly ash's toxic compounds can be trapped in the concrete matrix structure. Furthermore, encapsulation and human exposure needs scientific analysis to determine what happens with regard to polishing, drilling or chipping concrete containing fly ash. No available studies assess the potential occupational exposures in facilities or in jobs involving grinding or jack hammering concrete, or in places that crush it for recycling at the end of its lifecycle.[44] The presence of fly ash in the concrete matrix could also significantly increase the hazards posed by exposure to concrete dust.

Given the risks of disposal, inadequate precautions taken at many disposal facilities, and the potential for catastrophic failures, significant environmental benefits may be gained by diverting fly ash from disposal and using it in concrete as long as that process can be done safely, protecting both the public and the environment. Conversely, other means could achieve a similar outcome through tighter regulations and enforcement of more adequate disposal facilities; however, these require political change and the will to enforce the regulations, while the former approach is within the sphere of influence of the design and construction community.

Of the 136 million annual tons of total CCRs cited earlier, currently only 12.5 million tons (or nine percent) represent fly ash used in concrete; this total figure includes all CCRs, including bottom ash, boiler slag and FGD material. Maximizing the use of fly ash and minimizing the negative impacts of its disposal appear to have significant room for improvement.



Concern about Rebranding of a Waste Product

More than 1.1 billion tons of fly ash were produced in the last ten years, and 420 million tons have been recycled.[45] This reflects a diversion rate increase from 30 percent to 40 percent and is clear evidence of the strong growth in the green building movement in the United States and application of the LEED™ rating system.[46] The ACAA's claim that fly ash is the second largest waste stream clearly identifies the potential financial incentive for diversion, as diversion reduces the substantial costs associated with the safe storage and disposal of fly ash. In other words, producers have been able to reduce the cost of disposal by selling their waste as a "recycled" commodity. The coal industry heavily promotes fly ash as "recycled" and benign as a part of an attempt to rebrand the industry as "green." In fact, some critics allege that the use of fly ash actually supports the coal industry by partially absolving it of accountability for the coal combustion processes and outputs. This rebranding is best exemplified by the "America's Energy" website, which is a part of the coal industry's "Clean Coal" campaign. This website includes a link to a Dow Jones Newswire story quoting EPA Administrator Lisa Jackson as saying "there seems to be genuine agreement that the use of coal ash in concrete and concrete-like products does not cause a threat to human health and the environment."[47] As noted, the EPA itself remains conflicted on the environmental impact of fly ash, as indicated by their proclaimed reevaluation of the material.

In this manner, the use of fly ash in concrete has been rebranded as a sustainable building practice that is prominently supported by the LEED™ rating system. The replacement of Portland cement with fly ash in concrete is considered a post-industrial (pre-consumer) recycled material, which contributes towards achievement of LEED™ points under the Materials and Resources category. However, there are signs of changing attitudes at the USGBC. As stated earlier, LEED™ for Healthcare addresses the toxicity of fly ash and the USGBC has stated that their support for fly ash is contingent on its not being classified as a hazardous material. "We respect EPA's ability and role as a regulator ... and are quite sure there is alignment around the beneficial use of fly ash," says Scot Horst, senior vice president in charge of the LEED™ green building rating system, "however, if [the] EPA designates fly ash as a hazardous waste, LEED™ committees will take a look at (and re-evaluate) the rating system."[48] Others take a harder line than the USGBC, and have decried the use of fly ash in concrete or other building materials because of the larger environmental issues surrounding coal's use as an energy source. One of the most outspoken critics is the Executive Director Jeff Ruch of Public Employees for Environmental Responsibility (PEER). He notes "ironically, 'green' rating systems give extra credit for using coal wastes that may become a later source of pollution... the EPA should immediately halt this marketing program until it has set toxicity standards supported by peer reviewed research."[49]

Climate Change Impact

Concrete is the most ubiquitous construction material in the world; current average consumption is approximately one metric ton installed per year for every person on the planet.[50] The manufacturing of concrete is very intensive, from the extraction of all concrete's raw materials through transportation to the site. The manufacturing of Portland cement is especially energy intensive. To put this in perspective, for every 1000 kg (2205 lbs) of Portland cement produced in the United States, 927 kg (2044 lbs) of CO_2 are emitted.[51] Any action that reduces the carbon footprint of concrete, therefore, can make a real dent in overall global CO_2 emissions. Of the total CO_2 emissions related to concrete, including those from manufacturing, transportation and placement, the primary culprit is Portland cement, accounting for about 80 percent of total emissions. Production of Portland cement is especially carbon intensive because it emits CO_2 not only from burning fossil fuels to heat the kilns, but also as a direct by-product of the "calcining" process that transforms the limestone raw material into calcium oxide (lime) and CO_2. While substituting fly ash for Portland cement has a positive impact on GHG emissions in concrete production, the source emissions associated with coal combustion are not yet accounted for because they are considered external to the concrete production. This lifecycle cost analysis approach is the source of the differing opinions regarding the total climate change impacts associated with the use of fly ash.

The concrete industry and the EPA have argued that the substitution of fly ash for Portland cement can have a significant benefit in CO_2 emission reduction:

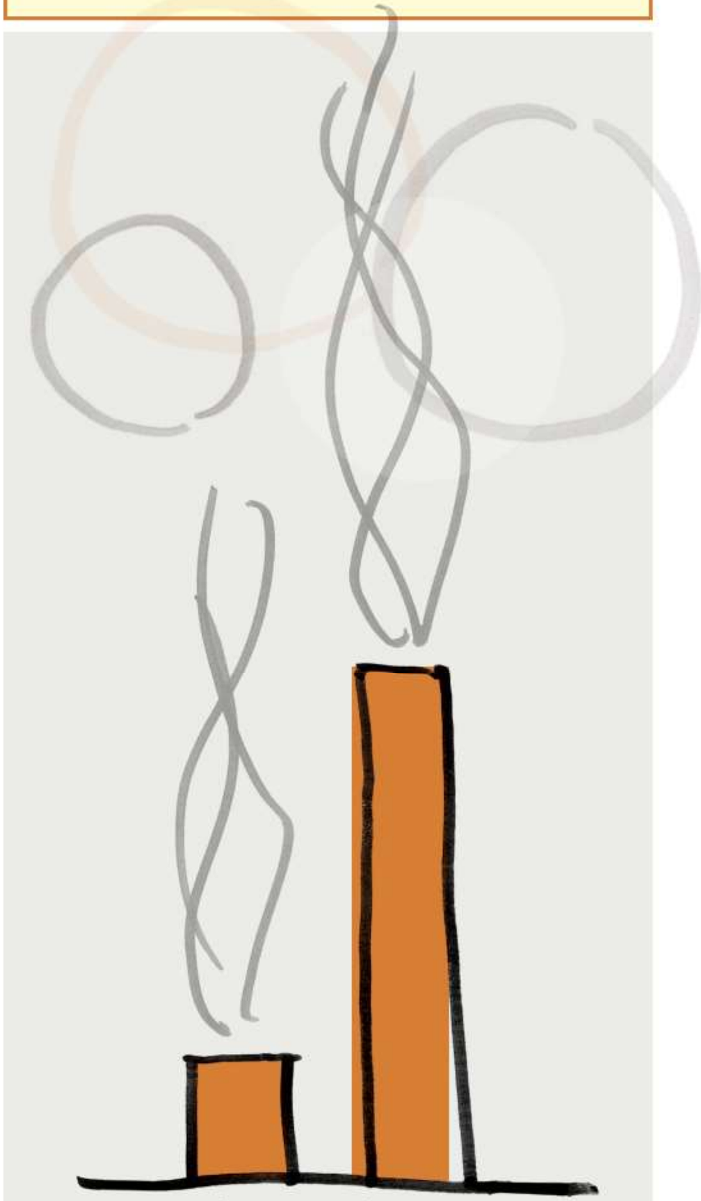
- According to the American Concrete Institute (ACI) in their analysis of CO_2 emissions for concrete that substituting fly ash for 25 percent of Portland cement in a typical concrete mix can reduce overall CO_2 emissions by thirteen to fifteen percent.[53]
- The American Coal Ash Association (ACAA) estimates that fly ash in concrete is responsible for avoiding twelve million tons of CO_2 emissions each year.[54]
- The EPA's Office of Air Quality Planning and Standards (OAQPS) estimated that recycling fly ash in cement kilns saves $4.9 billion in energy costs annually.[55]

The editors of Environmental Building News (EBN) have also suggested that significant environmental benefits can be gained by substituting fly ash for Portland cement because it reduces the overall embodied energy and carbon footprint of concrete. This endorsement does not include instances where fly ash serves only as a "filler," as in carpet backing.[56] Though somewhat self-evident, one important note is that fly ash can reduce the carbon footprint of concrete only if it displaces the Portland cement, not as an augmentation to the mix.

Environmental organizations such as the Environmental Integrity Project (EIP), Public Employees for Environmental Responsibility (PEER), Stockholm Environment Institute and Earthjustice, however, dispute the overall reduction of CO_2 emissions associated with substituting fly ash for Portland cement. Foremost, these organizations note that "creating coal ash generates huge amounts of climate altering greenhouse gases,"[57] which are not taken into account by the EPA nor by trade associations. Coal-fired power, which creates fly ash, is a main source of greenhouse gases in the United States and it is now estimated that coal accounts for approximately a fifth of global GHG emissions.[58] "If the federal government is truly going to reduce its carbon footprint, banning coal ash is an unavoidable step," according to PEER Executive Director, Jeff Ruch.[59] PEER also claims that the EPA overestimated the energy savings associated with recycling fly ash in cement kilns in the recently proposed coal ash regulations. As noted above, the EPA estimated that diverting fly ash to cement kilns saves $4.9 billion in energy costs, "but the Agency's Office of Air and Radiation, in analysis developed to support the separate and more far-reaching Clean Air Act standards, estimated total energy costs for the entire industry at no more than $1.7 billion."[60]

Amongst building materials, Portland cement has a very high embodied energy and is by far the largest single emitter of CO_2 in the U.S., responsible for two percent of total CO_2 emissions and five percent of all human-caused CO_2 emissions worldwide.[52]

GREENHOUSE GAS (GHG) EMISSIONS



Portland Cement Manufacturing is responsible for

5%

of the world's total GHG emissions

Coal Combustion is responsible for

20%

of the world's total GHG emissions

Sources: World Business Council for Sustainable Development and Pew Center on Global Climate Change.

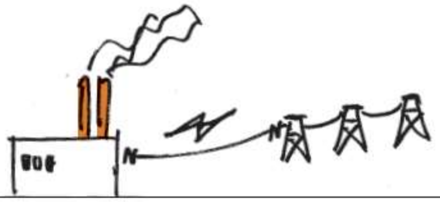
Resource Stewardship

Proponents for the use of fly ash in concrete often cite the environmental benefit of reduced impact of mining, extracting, and processing operations in the production of Portland cement as a key reason to use fly ash as a replacement. Opponents note these benefits need to be weighed against the mining, extraction and processing operations for coal. Approximately 60 percent of United States coal is extracted in surface mines; the rest comes from underground mines. In West Virginia alone, woodlands equal in size to half of the state of Rhode Island and 1,000 miles of streams have been destroyed from strip mining.[61]

Geographic Availability and Transportation Impacts

The impacts associated with storage and transportation of fly ash destined for concrete are also a matter of some debate and are often overlooked when calculating the environmental benefits of fly ash use. Forty-eight states produce at least some electricity from coal, with the exception of Rhode Island and Vermont, and such distribution of coal-burning power plants in the United States has implications on the environmental effects of fly ash for a particular project. As of 2005, Pennsylvania has been the leader with 40 coal burning power plants, while other states have much less reliance, like Nevada with only three coal power plants.[62] If a project is not located near coal-burning power plants that produce fly ash appropriate for use in concrete, then storage and transport become a larger issue. Life cycle analysis by researchers at the University of Florida found that the de facto distance from plant to project is about 50 miles, beyond which the transportation costs start to become prohibitive.[63]

Coal is not distributed evenly across the world. North America, Asia and Europe are rich in the resource, whereas the Middle East, South America and Africa have considerably fewer reserves. Geographic availability informs where the use of fly ash makes the most sense. For example, a project manager in the Middle East should understand that the fly ash he specified must travel considerable distances to the site, and the carbon dioxide reduction provided by substituting Portland cement for fly ash may be negated or outweighed by greater carbon intensity from transportation. Regional geography and economics govern the chemical content of fly ash as it varies based on the specific type of coal and the technology of a given power plant.



Toxic Burden

It is a commonly held belief that the toxic burden of fly ash is rendered "harmless" when in concrete. As Michel de Spot of the EcoSmart Foundation stated, the toxic burden "gets embedded into the concrete matrix the same way that combining two very toxic elements like sodium and chloride creates table salt."[64] The proposed 2010 EPA fly ash regulations, however, have ignited new debates around the long-term health and environmental impacts of its use in concrete.

The toxicity of fly ash while in concrete is in question, not the isolated substance prior to encapsulation; this distinction is important as the toxicity of fly ash has been scientifically proven. Coal ash includes 36 elements and a wide array of potentially toxic constituents, such as aluminum, arsenic, beryllium, cadmium, lead, manganese, nickel, sulfate and thallium, among others.[65] The vast majority of these substances have substantial negative health effects and many of them are known carcinogens according to government regulatory bodies in the US (see Appendix: **"Body Burden of Substances in Fly Ash via Government Watch List" on page 44** for additional information). Scientific analysis on the toxicity of fly ash encapsulated in concrete, however, is scant. One reason is that the chemical composition of fly ash can vary widely depending on the geological characteristics of the coal at extraction and the design of the power plant where it is burned. Another reason is the complexity of isolating a health and environmental problem back to a single building material: concrete with fly ash. Because we are exposed to so many chemicals from so many sources each day, it is nearly impossible to isolate and quantify the impact of one chemical from a building material such as mercury in a fly ash concrete mix.

The first instance of government discussion of potential health issues of fly ash is a 1983 EPA document, "*Cement and Concrete Containing Fly Ash; Guideline for Federal Procurement.*" This document recognizes the toxicity of substances contained in fly ash, but does not put forth any conclusive data that fly ash when used in concrete does not leach hazardous materials. Rather than considering the composite product's toxicity in isolation, the document considers the toxicity of fly ash by itself in relation to its encapsulation in concrete:

> *"The permeability of concrete containing fly ash is negligible compared to the permeability of fly ash as typically disposed. This reduced permeability prevents water or other liquids from penetrating concrete and providing a leaching medium through which contaminants could travel."*

The document also claims that when used in concrete, fly ash becomes an integral part of the final product:

> *"The surface area of individual fly ash particles, from which leaching of trace constituents takes place, is so greatly reduced in this application as to be almost nonexistent. It is not possible through conducting leaching tests of raw fly ash to estimate the leaching, if any, which would take place in a concrete containing fly ash."*

This is significant because it appears to be the genesis of the idea that the hazardous burden of fly ash is held in the concrete and does not pose a health hazard. We could not, however, locate any objective scientific analysis that can support any of these claims made by the EPA.

The document does not discuss the potential health impacts during all phases of the concrete life cycle, both before and after the final encapsulation of fly ash in concrete. Processes such as handling and mixing fly ash into the concrete mix, grinding, drilling or sanding of the finished concrete product, and final demolition or disposal at the end of the building life cycle are not discussed. It does not appear that any scientific analyses have been conducted on the health and environmental impacts for these instances where the final encapsulated concrete product is physically altered in some manner.

Additional studies done since the EPA released its findings in 1983 show little leaching of hazardous substances from concrete with fly ash, but the academic research is clearly nascent and, as noted prior, very limited. These early studies primarily address the leaching of heavy metals, but do not evaluate all of the toxic substances found in fly ash. In general, the key peer-reviewed studies conducted to date indicate that concrete seems to bind well with some heavy metals and that fly ash may help in that process.[66] To this point, in their 2010 report on the environmental impacts of concrete and cement, Environmental Building News cited these key studies on hazardous substances in fly ash concrete:

A 1997 study conducted in Germany by Hohberg and Schiessl indicating that leaching of heavy metals from concrete products (with or without fly ash) was not dependent of the amount of those metals in the cement.[67]

A 2008 study by researchers at Ohio State University that found when fly ash concrete is exposed to heat through steam curing it retained 99 percent of its mercury content.[68]

A 2009 follow-up study at Ohio State found gas emissions and liquid leaching of mercury from fly ash concrete was independent of the amount of mercury in the cement.[69]

In contrast to the studies above, a 2004 study by researchers from several universities in China and Japan showed that heavy metals do leach from cement mortars and solidified fly ashes.[70] Other observations from the study concluded that both Portland cement and fly ash contain a certain amount of heavy and toxic metals; leaching is also noted to intensify when the fly ash and water to cement ratio is increased. In addition, these results also show that during testing, the leaching of heavy metals only occur from the surface layers of the concrete specimens. The metals in the inner part of the concrete specimen require much more time to leach because of diffusion, the fixation effect of cement hydrates, and the reduced leachability of most heavy metals under the high pH condition of concrete.[71]

Most importantly they note "the source of coal, combustion condition of coal in furnace and capturing method of fly ash have great influence on the chemical, mineral compositions, content of crystalline phase, particle size, surface structure and reactivity of fly ash and result in different leachability of the same heavy metal, but in different fly ashes."[72] The factors that govern how heavy metals perform in concrete will differ from coal plant to coal plant.

The research to date on how toxic chemicals are "held" in concrete should be aligned with a new understanding of the true nature of concrete's complex crystalline structure. Surprisingly, the "DNA" of the cement molecule was only recently decoded in 2009 by researchers at Massachusetts Institute of Technology (MIT). Until the MIT study, it was believed that at the atomic level, cement hydrate (or calcium-silica-hydrate) resembled the structure of the rare mineral tobermorite (a calcium silicate hydrate) with its ordered geometry consisting of layers of long chains of three-armed silica molecules mixed with tidy layers of calcium oxide. The researchers at MIT found that the calcium-silica-hydrate in cement is not a crystal, but rather a hybrid that shares some characteristics with crystalline structures and some with the amorphous structure of frozen liquids such as ice. "We believe this work is a first step toward a consistent model of the molecular structure of cement hydrate and we hope the scientific community will work with it," said Professor Sidney Yip of MIT's Department of Nuclear Science and Engineering Department.[73] As Brent Ehrlich of EBN recently noted, MIT's cement "DNA" work is an important breakthrough for our understanding of chemistry of concrete.[74] This is important because this type of cystraline structure is stronger and, therefore, may have fundamentally different physical and chemical properties.

Finally, it is important to note that the recent concerns about the contamination of concrete with mercury and other toxins in coal fly ash may be a part of a larger problem: those same contaminants may also occur in Portland cement at higher levels than in fly ash.[75] More research needs to be completed surrounding the chemistry of concrete and the health impacts of using fly ash as a supplement for Portland cement.

Risk Management

Since the EPA announced that it was considering the regulation of fly ash last year, the potential risks of specifying fly ash building products has generated much discussion. The ultimate determination of risk is reliant on the future ruling by the EPA, but several historic precedents should be considered, too. For example, the EPA's own history documents

> *"'widespread acceptance' of chemicals in building products is no guarantee that toxic chemicals remain bound as predicted. In 1982, the agency exempted arsenic-treated wood from hazardous waste disposal regulations that would typically have applied to the chemicals in the product. By the mid-1990s, leaching from arsenic-treated wood in unlined landfills was threatening Florida's aquifers. It turns out that the arsenic was not as well bound to the chromium and wood as originally presumed."*[76]

Numerous other precedents in the building industry illustrate products that attained widespread use before they were deemed hazardous.

For architects and engineers, continued use of a material that may, in the near future, be considered a hazardous material raises the issue of "standard of care." According to the American Institute of Architects (AIA), the performance of a licensed design professional is measured in two ways: the professional is required to perform the services as delineated in their contract (contractual standard) and the manner in which those services are performed (standard of care). The standard of care is a part of tort law, centering on negligent performance. If fly ash is classified hazardous by the EPA, would a design professional be deemed negligent if they specified fly ash before it is classified as a hazard, especially if they were aware of the pending EPA ruling when they specified that specific concrete?

Closing Thoughts

Fly ash is a piece of the much larger environmental puzzle of using coal as a source of power. Nevertheless, the world's dependence on coal is growing. In 2009, China alone produced more than 375 million tons of coal ash (fly and bottom ash), enough to fill one average swimming pool every two and a half minutes.[77] This ugly reality forces architects to consider the options of the best way to dispose of fly ash. Unfortunately, a good, "right," or even clear answer to this question is not available. Like many ecological problems we face today, the dilemma is very complex, and the choices involve multiple trade-offs.

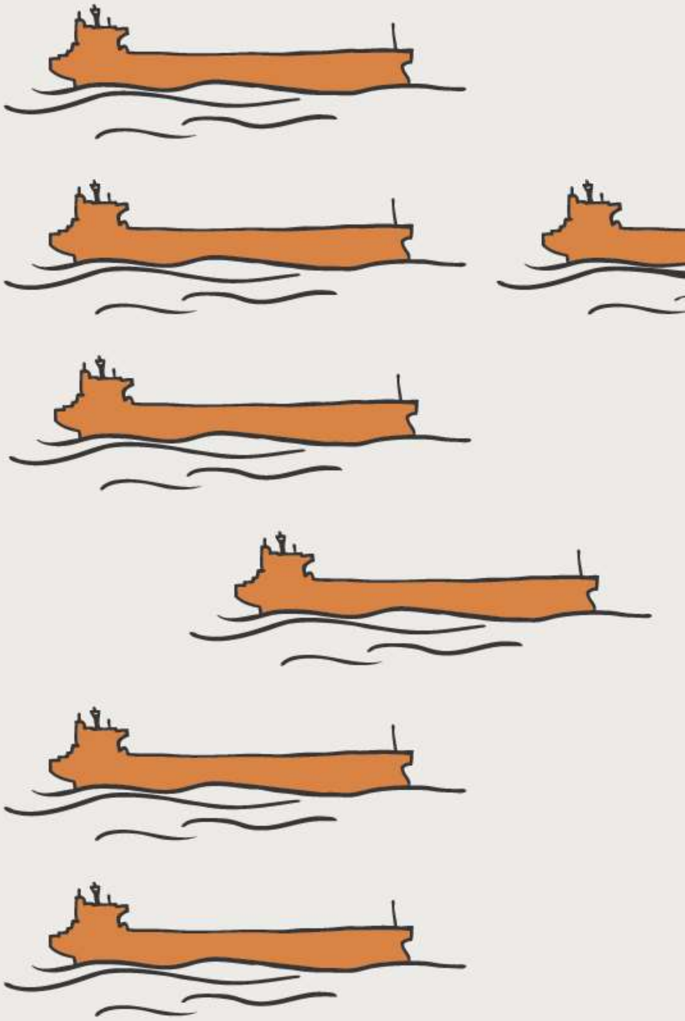
Fundamentally, the disposal of fly ash comes down to two different disposal models: dispersed versus centralized. Under a centralized disposal model, coal fly ash, scrubber sludge, bottom ash, and other coal combustion waste by-products are sent to landfills or held in large disposal ponds. Ideally, under this model, the hazards of coal ash can be regulated and controlled (or at least regulated). Unfortunately, in our current world, the disposal of coal ash is not adequately controlled. A 2010 report on 31 coal disposal sites found that coal ash had contaminated groundwater, wetlands, creeks and rivers in fourteen states including Delaware, Florida, Illinois, Indiana, Maryland, Michigan, Montana, Nevada, New Mexico, North Carolina, South Carolina, Tennessee, Pennsylvania and West Virginia.[78] Sometimes, the ecological damage is undeniably evident as seen in the 2008 collapse of one of the retaining walls at the Tennessee Valley Authority's Kingston power plant that released over 1 billion gallons (3.7 million cubic meters) of water and coal combustion, affecting an area greater than the 1989 Exxon Valdez oil spill.[79]

The second disposal approach is to redirect fly ash from disposal sites to "safer" uses, including as a substitute for Portland cement in concrete. Under this model, fly ash is "recycled" into a viable building product, thereby distributing the fly ash into our homes, schools, hospitals and office buildings and, theoretically, holding the fly ash in the concrete mix. Regrettably, our limited knowledge of how concrete binds to the toxic elements in fly ash does not empirically show that the toxic burden of fly ash can be permanently bonded in the concrete mix. This leads to a vexing question: have designers brought another hazardous material inside buildings much like they had done before with lead and asbestos?

EXXON VALDEZ OIL SPILL VS.
TVA'S KINGSTON POWER PLANT
COAL ASH POND LEVEE BREAK

Exxon Valdez Oil Spill:
11,000,000 gallons *(.13 of an oil super-tanker)*

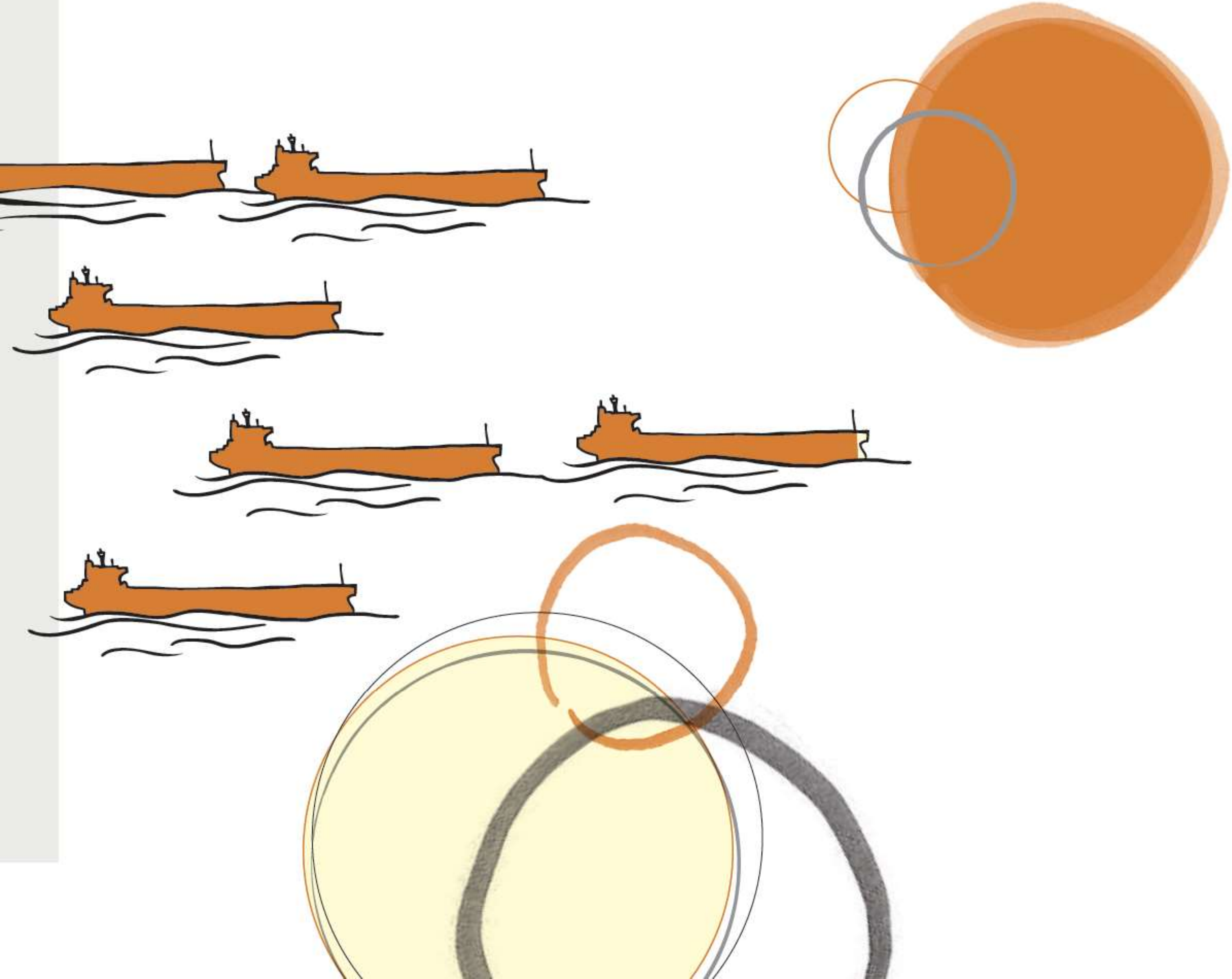
TVA Kingston Power Plant Coal Ash Spill:
1,000,000,000 gallons *(11.96 super-tankers, water and coal combustion combined)*



If fly ash in concrete is empirically proven to pose no hazard when in buildings, is it not a hazard when the building is demolished? The "diversion" of fly ash into concrete may help to solve a problem that we faced today; however, we may be just putting off the problem for 50 years, the typical building lifespan. Will future generations face a new problem of disposing potentially contaminated concrete?

We know that disposing of fly ash in landfills is problematic and has environmental consequences. We know that fly ash is not a benign material, but, when used in concrete, fly ash reduces the use of virgin materials needed for concrete. We know the CO_2 emissions of concrete are reduced when fly ash is used in lieu of Portland cement, but we also know that coal combustion (the source of fly ash) is one of the largest sources of CO_2 emissions.

We still do not know if the toxic components of fly ash are "held" safely for the life of the concrete matrix or if it will continue to pose a potential health risk when it is finished and polished, demolished, or eventually sent to a landfill. ■



APPENDIX:

Supplemental Information

Technical Consideration: Fly Ash is a Pozzolan

Fly ash is one of several supplementary cementitious materials (SCMs) that reacts with substances in the concrete mix to form cementitious compounds. As a result, fly ash can replace a portion of Portland cement in a concrete mix. Other SCMs, such as ground granulated blast furnace (GGBF) slag and silica fume, are hydraulic, meaning that they react with water in the mix. Like fly ash, GGBF slag and silica fume are by-products of industrial manufacturing processes. SCMs can also include agricultural waste products, such as rice hull ash.[80]

Some SCMs, like fly ash, are also pozzolans. ASTM standard C618 defines a pozzolan as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value, but, in finely divided form and in the presence of moisture it will chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementing properties.[81] In plain terms, this means pozzolans are not cement, but they exhibit cement-like properties and can be used as an enhancement to concrete.

Fly ash is the most commonly used pozzolan and is present in half the concrete poured in the United States.[82]

When used in concrete, fly ash typically replaces between 15% to 35% of Portland cement in the mix with substitution ratios ranging between 1:1 and 1.5:1 (fly ash: Portland cement).[83] Replacement rates exceeding 30% to 50% are considered "high-volume-fly-ash-concrete" (HVFAC). However, definitions and thresholds for HVFAC appear to vary. The Federal Government, through the EPA's CPG recommends fly ash or other SCMs in the 20% to 30% replacement range. As stated earlier, these are recommendations not requirements.[84] Fly ash can also be incorporated into concrete in a "blended cement," in which fly ash is mixed with Portland cement and other cementitious materials, such as GGBF slag, natural pozzolans or silica fume.[85]

Performance of Concrete with Fly Ash

There is generally agreement on the performance benefits of adding fly ash to concrete. For example, fly ash increases the compressive strength of concrete. Some of these performance benefits also result in tangible environmental benefits.

Foremost, when fly ash is added into the concrete, the workability of the mix is improved during pouring. This is due to the spherical shape of its particles. Fly ash in the mix allows concrete to flow and pump better than 100% Portland cement concrete. Additionally, there is the environment benefit that the improved workability can be achieved with less water. The amount of water in the mix is decreased in direct proportion to the amount of fly ash added to the mix.[86]

According to the American Concrete Institute (ACI), fly ash makes concrete less permeable, thereby reducing infiltration by water and aggressive chemicals making concrete more long-lasting.[87] In particular, fly ash increases concrete's resistance to chemical attacks including alkali-silica aggregate and sulfate reactions, which can cause expansive cracking. Fly ash also makes concrete more resistant to scaling from deicing salts.[88] The decreased permeability is the result of additional cementitious compounds and reduced water in the mix. This, in turn, reduces the chances for corrosion of steel reinforcing, which is a major source of concrete failure. All this improves the durability of concrete and increases the longevity of concrete. In other words, fly ash imparts properties that enhance the performance of the concrete itself, extending its life and keeping the fly ash concrete from becoming construction debris for longer than a standard concrete mix.

Another performance benefit of fly ash is the mitigation of heat island effect. Since fly ash imparts a lighter color to concrete, it increases the albedo or reflectance of the surface when it is used in exterior concrete flatwork.

Lessons Learned: If You Choose to Use Fly Ash in Concrete, What Are the Best Practices?

Based on our past project experiences, and discussions with structural engineers, fabricators and suppliers, we will share the following recommended applications for using or not using fly ash in concrete. Many of these are echoed in the book Making Better Concrete: Guidelines to Using Fly Ash for Higher Quality, Eco-friendly Structures by King, Bruce P.E.

Specification Requirements

Comply with the mercury limit requirements of California's Collaborative for High-Performance Schools (CHPS) for fly ash in concrete or LEED™ for Healthcare's limits on the mercury levels in supplemental cementitious materials (SCM's) derived from coal fired power plants used in concrete.

Require that chemical composition test data be submitted for review and approval. (Please note that power plants, and by extension fly ash dealers, typically tested the chemical composition of their fly ash once a year because they generally burn coal from a single source mine and the chemical composition of coal does not generally vary greatly from one mine).

Specify fly ash only when a project is within a 50 mile radius of coal power plant.

Require proof of provenance of the fly ash (to avoid the issue of the aggregation of fly ash from multiple sources, which will nullify the accurate testing data about chemical composition noted above).

Avoid fly ash for

- Elevated beams and slabs – where formwork often needs to be removed quickly.
- Cold weather pours – may not be appropriate for fly ash concrete when early strength is needed.
- Face mixes of architectural or precast concrete – due to the effect on color control and uniformity.
- Below-grade concrete support structures for utility pipes – avoid using fly ash for concrete in contact with metal or ductile iron pipes (as stated earlier, studies have shown that fly ash can be corrosive to metals).

Use fly ash for

- Poured-in-place concrete walls and columns, mat slabs and poured footings in earth.
- Lightweight concrete on metal deck – an ideal application for fly ash because the metal deck acts as permanent formwork, so late set is less of a concern.
- Drilled piers and piles – fly ash concrete can perform well in water conditions due to decreased permeability. Also building piles are often not loaded to full capacity for some time after pouring. This allows for the 56-day curing period typically required to meet strength requirements for high volume fly ash applications.[89]
- Grouting of concrete block.
- Precast concrete elements (with a few caveats) – this application is dependent on the precaster's ability and willingness to allow for early strength gain before removal of the formwork. Conversations with several fabricators yielded a range of responses:
    - Where precast units can be engineered with a face mix and a separate backup mix, fly ash is most appropriate for the backup mix or for the inner wythe of precast insulated sandwich panels.
    - Typical range of 15 - 25% replacement for Portland cement in the mix.
    - Certain fabricators were reluctant to use fly ash, citing concerns that it would change the rheological behavior of the mix (rheology is the study of the flow of matter), add cost and complicate the mix operations (which are computer controlled whereas fly ash may need to be added manually to the mix).

Summary of Current Regulations, Codes and Technical Standards

The current regulatory climate surrounding fly ash, combined with the paucity of studies regarding its potential negative impacts, has created a caveat emptor situation with little protection for the public or guidance for architects, engineers, builders and owners. The ascendance of LEED™ in the last decade has codified fly ash in concrete as a fundamental process of the green building movement to the degree that it is virtually automatically specified on many projects, often without scrutiny.

Federal Regulations

Historically, the disposal of coal combustion residual (CCR) materials including fly ash has been exempt from federal regulations covering hazardous waste, but in 1980 Congress ordered the EPA to study CCRs and to make a regulatory determination no later than 1983. However, no regulations followed.[90] In both 1993 and 2000, the EPA determined that CCRs did not warrant federal management as a hazardous waste.[91] In 2010, for the first time, the EPA proposed regulating fly ash. This was, in large part, a response to waste disposal accidents at fly ash surface impoundment facilities. The most infamous of these spills occurred on December 22, 2008, at the Tennessee Valley Authority (TVA) plant in Kingston, Tennessee. A structural failure of one of the embankments of the pond caused more than one billion gallons of water and CCR waste to flood more than 300 acres, flowing into the Emory and Clinch Rivers.[92]

The EPA has proposed to regulate fly ash under the federal Resource Conservation and Recovery Act (RCRA). The proposed rule, for which several public hearings were conducted and public comments solicited, will likely follow one of two possible paths:

- Fly ash will be regulated under Subtitle C of the RCRA and will be reclassified as "hazardous waste," for which disposal would fall under EPA enforcement. However, beneficial use of fly ash in concrete, amongst other applications, will still be permitted under a "special waste" exemption.
- Fly ash will be regulated under Subtitle D of the RCRA and would retain its current "non-hazardous" designation. Under this scenario, disposal will be enforced by individual states, not by the EPA.

Some say that by opting for the first path, the EPA will stigmatize fly ash as a hazardous material, potentially discouraging architects and engineers from specifying it even though its beneficial use would technically still be legal.[93] This possibility has made the coal ash industry nervous, leading to the formation of quasi-trade organizations with strong ties to industry. With seemingly innocuous names such as "Citizens for Recycling First," the missions of these groups include supporting the recycling of coal ash as a "safe, environmentally preferable alternative to disposal."[94] For the coal ash industry, recycling and beneficial use of fly ash are big business. To protect their interests, the "Citizens for Recycling First" group flooded the EPA with thousands of comments during the public review period, supporting the beneficial use of fly ash. According to their website, the CEO of this organization is a past president of the American Coal Council and former chairman of the Government Relations Committee of the American Coal Ash Association.[95]

Despite this reaction from the coal industry, some believe that the first regulatory path is unlikely since the EPA would not want to relinquish its enforcement authority.[96] Even some environmental advocacy organizations have concerns about regulation under Subtitle C, the foremost being whether there is sufficient existing capacity for landfilling if CCRs were to be designated as hazardous waste.[97] As of the writing of this paper, the EPA has not updated information on their website regarding the status of the proposed rule.

As an extension of its regulatory efforts, the EPA has conducted facility assessments of existing coal ash impoundments throughout the United States. The assessment reports, which are posted on the EPA website, found that most of the facilities had a "high" or "significant" hazard potential rating.[98] Note that the ratings were based on the potential for economic loss and damage to the environment and infrastructure if the impoundment were to fail (and not the structural stability of the impoundment itself). These potential environmental and health impacts include leaching of contaminants and heavy metals into ground- and surface-waters as well as the killing of aquatic life.

Separate from its regulatory role, the EPA encourages the use of fly ash and other SCMs in concrete through its Comprehensive Procurement Guidelines (CPG), which designate items that must contain recycled content when purchased with appropriated federal funds by government agencies (federal, state, or local) or contractors. For cement and concrete, the CPG recommends, but does not require minimum levels of recycled content.[99]

State and Local Regulations

To our knowledge few state or local authorities have, or are considering, rules to regulate the beneficial use of fly ash. Furthermore, state regulations covering disposal are minimal, with only four states in the United States currently requiring all landfills to be monitored and only six states requiring all ponds to be monitored for leaks.[100] The vast majority of states do not require liners to stop the migration of coal ash pollution into the environment.[101] Safeguards are also rare when it comes to leachate collection and dust controls at coal ash landfills and ponds.[102]

According to Eric Schaeffer, Director of the Environmental Integrity Project (EIP), due to inadequate state regulations every region in the United States has unlined coal ash dumps that have contaminated groundwater, amongst other environmental impacts. Currently 137 locations have been documented by the EPA to have water supplies contaminated by coal ash.[103] New York State is one of the few to address these issues to some degree. In 2009, it revoked a 20-year old beneficial use designation for fly ash used at cement kilns throughout the state.[104] This was in response to the LaFarge Ravena cement kiln, the state's largest source of mercury air pollution, which had caused elevated mercury levels in nearby soil and wildlife.[105] The issue is that many cement kilns use fly ash to manufacture Portland cement as a less expensive substitute for shale or clay, and unlike power plants, these kilns are exempt from mercury controls for smokestack emissions.[106]

International Regulations

International regulations are too vast to cover in this paper in detail. Fly ash regulations reflect the particular environmental concerns and sensitivities of each country. For example, the Dutch require all fly ash to be diverted directly into building products or the raw materials that will become building materials.[107] The rationale behind this policy may be because there are few landfills in Holland and the disposal of coal by-products in landfills is considered a greater risk. In China fly ash is almost virtually unregulated. According to Greenpeace, "China lacks effective policy to monitor coal ash once it is reutilized and recycled into other products. There is a severe lack of safeguards for public health in regards to harmful substances found in bricks and other products made from coal ash."[108]

Building Codes

In the last few years, fly ash criteria (both mandatory and voluntary) have begun to find their way into building codes throughout the United States. One example is CalGreen, the first mandatory statewide green building standards code in the United States aimed at assisting the State of California in meeting its greenhouse gas reduction goals. CalGreen, which went into effect on January 1, 2011, is a uniform regulatory code covering all residential, commercial, hospital and school building construction throughout the state.

While CalGreen does not explicitly require the use of fly ash in concrete, it does encourage its use as one of numerous voluntary measures, which allow projects to achieve higher performance (Tier 1 or Tier 2) above and beyond mandatory requirements. (These voluntary "Tiers" are akin to achieving higher certification levels under the LEED™ rating system). The voluntary criteria are as follows:[109]

- *Residential projects:* reduce cement used in foundation mix design by not less than 20% (Tier 1) or 25% (Tier 2), using fly ash, slag or other materials.

- *Non-residential projects:* use concrete manufactured with supplementary cementitious materials (SCMs) including fly ash. A mix design equation is also provided for cases where multiple SCM's are combined within a concrete mix: **Fly ash % / 25 + Ground granulated blast furnace (GGBF) slag % / 50 + Silica fume % / 12 = 1**, where % is the percent of total cementitious material in the concrete for each SCM.

In the equation above, no explanation is given as to the relative "weighting" of materials. For example, the formula would allow about twice as much fly ash as silica fume in a concrete mix. It is also noteworthy that CalGreen allows exceptions to the above formula, where high early strength concrete is required. (Delayed strength gain and delaying are some of the drawbacks of using fly ash in concrete).

While CalGreen encourages the use of fly ash, other building codes include limitations on its use for certain applications. For example, the New York City Construction Code (2008) limits the percentage of allowable fly ash (and other SCMs and pozzolans) in concrete in cases where it may be exposed to deicing chemicals.[110] For these applications, fly ash cannot exceed 25% of total cementitious materials by weight in the concrete mix. The basis of this criterion is not clear since fly ash, in general, is known to make concrete more chemical resistant.

Green Building Standards & Guidelines

Green building certification programs, such as the LEED™ rating system, typically reward projects for incorporating fly ash and other post-industrial recycled materials in a project. For example, under LEED™ 2009, fly ash can contribute towards achievement of MR Credit 4.1, however, there are no criteria covering the type or potential toxicity levels of the fly ash.

This omission is in contrast to LEED™ 2009 for Health Care, which like other LEED™ systems, rewards projects for using sustainably sourced materials (MR Credit 3), but unlike other LEED™ systems, also recognizes that all fly ash is not equal in terms of toxicity: "supplemental cementitious materials derived from coal fired power plant wastes shall not have mercury content > 5.5 ppb (0.0055 mg/L). Fly ash generated as a by-product of municipal solid waste incinerators does not qualify as a recycled-content materials for this credit."[112]

One reason for the inclusion of mercury limits in LEED™ for Health Care may be because many of the credits are established by the Green Guide for Health Care (GGHC), which strives to eliminate toxic materials and products from buildings to guard against occupant exposure. Several measures (MR Prerequisite 2, MR Credit 4.2 and EQ Prerequisite 3) address hazardous materials, such as mercury. In addition, MR Credit 3 (Sustainable Sourced Materials) will only permit fly ash with documentation that producing coal plants do not co-fire with hazardous waste, medical waste, or tire-derived fuel and that fly ash should not be generated from municipal solid waste incinerators.[112]

Fly ash is also commonly addressed in voluntary design guidelines, like the California Collaborative for High Performance Schools (CHPS), New York City's High Performance Building Guidelines (HPBG) and High Performance Infrastructure Guidelines (HPIG). Typically, these guidelines encourage the use of fly ash, but focus more on benefits such as resource efficiency, durability and maintenance issues without regard for its potential health impacts. These standards recommend use of fly ash in common applications such as building enclosures (concrete and CMU) and interior concrete floors. The NYC HPIG cites fly ash for less well-known exterior uses such as impervious pavement, flowable fill for backfilling utility trenches and below-grade concrete support structures. (Please note for the latter, it is advisable to avoid using fly ash for concrete in contact with metal or ductile iron pipes since some studies have shown fly ash to be corrosive to metals).[113] The NYC HPIG also advocates using Portland cement due to its higher albedo properties in asphalt concrete pavement.

Technical Standards

In the United States, specifications calling for fly ash in concrete typically require compliance with two reference standards, ASTM C618-08a and ASTM C311-07. These standards are also used outside of North America.

C618-08a is ASTM's "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." According to ASTM, "this specification covers coal fly ash and raw or calcined natural pozzolan for use in concrete where cementitious or pozzolanic action or both is desired or where other properties normally attributed to fly ash or pozzolans may be desired or where both objectives are to be achieved." The specification tests materials for "fineness, strength activity index, water requirement, soundness and autoclave expansion or contraction."[114]

ASTM C311-07 is the "Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete." This standard covers "procedures for sampling and testing fly ash and raw or calcined pozzolans for use as a mineral admixture in Portland-cement concrete." These chemical analyses include moisture content, available alkali, iron oxide, and silicon dioxide amongst other things and physical tests include density, fineness and water requirement. The strength test is specifically used to determine whether fly ash or natural pozzolan results in an acceptable level of strength development when used with hydraulic cement in concrete.[115]

Another standards-making body, the American Concrete Institute (ACI), has expressed concern about the EPA's proposed rule described above. Designating fly ash as hazardous waste would require rewriting standards and technical documents that currently address the use of fly ash in concrete including the following:[116]

ACI 232 - "Use of Fly Ash in Concrete." This report gives an overview of the origin and properties of fly ash, its effect on the properties of hydraulic cement concrete and the proper selection and use of fly ash in the production of hydraulic cement concrete and concrete products.

ACI 318 - "Building Code Requirements for Structural Concrete." A model concrete code, adopted and amended by state and municipal authorities for local building codes.

The technical standards above define the use of fly ash in concrete including maximum carbon content; however, they do not address potential toxicity of substances within the fly ash such as mercury. In other words, they address only structural performance, not environmental performance.

International Technical Standards

Standards outside the United States for use of fly ash in concrete vary greatly based upon region and country. In Canada, fly ash specifications commonly cite Canadian standard CAN/CSA A23.5 – "Canadian Specification for Supplementary Cementing Materials" and CAN/CSA A3001-08 – "Cementitious Materials for Use in Concrete." These standards address various aspects of cementitious materials such as the definitions, chemical, physical and uniformity requirements, required tests, procedures for inspection and sampling, units of measurement, packaging, and marking and storage.

In Europe, the primary technical standard is BS EN 450 – "European Standard for Fly Ash." This is a harmonized European standard for fly ash that replaces the former British Standard BS 3892 Part 1. The standard alternatively refers to fly ash as "Pulverized Fuel Ash" (PFA), which is the by-product of coal combustion at power stations and appears to be the equivalent of what we commonly know as fly ash.[117] BS EN 450 provides performance criteria for fly ash, such as loss of ignition, fineness, particle density and percent of chlorides. It is important to note that standards development in Europe has been influenced by the primary trade organization for European energy producers, the European Coal Combustion Products Association (ECOBA), which appears to be analogous to the ACAA in the United States. According to its website (www.ecoba.com), ECOBA was founded in

1990 to deal with matters related to the usage of construction raw materials from coal.

To summarize, in recent years, criteria relating to the use of fly ash have been written into codes, design guidelines and other building product standards. Many of these do not address the health concerns surrounding fly ash providing little protection for the public and little guidance for architects, designers, specifiers, builders, and owners. Furthermore, the current regulatory climate has created uncertainty and confusion. Only recently, progressive guidelines such as LEED™ for Health Care and Green Guide for Health Care have begun to address these public health issues.

Body Burden of Substances in Fly Ash via Government Watch List

🟧 **Known Health Effects**

🟨 **Suspected Health Effects**

Health Effects **Substances**	Asthma Trigger	Asthmagen	Asthmagen Sensitizer	Carcinogen	Cardiovascular or Blood Toxicant	Developmental Toxicant	Endocrine Toxicant	Gastrointestinal or Liver Toxicant	Hazardous Air Pollutant	Immunotoxicant	Kidney Toxicant	Musculoskeletal Toxicant	Neurotoxicant	Persistent Bioaccumulative Toxic Chemical	Reproductive Toxicant	Respiratory Toxicant	Respiratory Sensitizer	Skin or Sense Organ Toxicant
Aluminum / 7429-90-5	🟧	🟧	🟧		🟨										🟨	🟨		
Antimony / 7440-36-0		🟨			🟨								🟨		🟨	🟨		
Arsenic / 7440-38-2				🟧	🟨	🟧	🟨	🟨		🟨								
Barium / 7440-39-3		🟨				🟨							🟨		🟨	🟨		
Beryllium / 7440-41-7		🟨		🟧	🟨			🟨		🟨	🟨				🟨	🟨		🟨
Boron / 7440-42-8		🟨			🟨	🟨							🟨			🟨		
Cadmium 7440-43-9		🟨		🟧	🟨	🟧	🟨			🟨	🟨		🟨	🟧	🟧	🟨		
Calcium / 7440-70-2																		
Hexavalent Chromium (VI) / 7440-47-3		🟧	🟧	🟧												🟨	🟧	
Chloride (Chlorine) / 7782-50-5) *Chloride is more than one chlorine attached*	🟧	🟧			🟨			🟨			🟨		🟨		🟨			🟨
Cobalt / 7440-48-4	🟧	🟧	🟧	🟧	🟨	🟨				🟨	🟨		🟨		🟨	🟨	🟧	🟨
Copper / 7440-50-8					🟨	🟨		🟨			🟨				🟨	🟨		
Fluoride / 16984-48-8								🟨			🟨	🟨	🟧		🟨			
Iron / 7439-89-6		🟨			🟨			🟨			🟨		🟨		🟨	🟨		
Lead / 7439-92-1				🟧	🟨	🟧	🟨	🟨		🟨	🟨		🟨	🟧	🟨	🟨		
Lithium / 7439-93-2										🟨	🟨							
Magnesium / 7439-95-4		🟨														🟨		
Managanese / 7439-96-5		🟨						🟨					🟧		🟨	🟨		
Mercury / 7439-97-6					🟨	🟧	🟨	🟨		🟨	🟨		🟧	🟧	🟨	🟨		🟨
Molybdenum / 7439-98-7			🟨										🟨		🟨			
Nickel / 7440-02-0	🟧		🟧	🟧	🟨	🟨				🟨	🟨		🟨		🟨	🟨		🟨
Nitrate / 14797-55-8					🟨						🟨				🟨			
Phosphorus / 7723-14-0					🟨			🟨	🟧		🟨	🟨	🟧		🟨	🟨		🟨
Potassium / 7440-09-7																		
Selenium / 7782-49-2		🟨			🟨	🟨		🟨			🟨	🟨	🟨		🟨	🟨		🟨
Silver / 7440-22-4		🟨			🟨						🟨				🟨			
Sodium / 7440-23-5																		
Strontium / 7440-24-6												🟨						
Sulfate / 18785-72-3																		
Sulphide																		
Thallium / 7440-28-0					🟨			🟨			🟨		🟨		🟨			🟨
Tin / 7440-31-5					🟨					🟨			🟨		🟨	🟨		🟨
Titanium / 7440-32-6		🟨													🟨			
Vanadium / 7440-62-2	🟧	🟨								🟨	🟨					🟨		
Zinc / 7440-66-6					🟨	🟨				🟨					🟨	🟨		🟨

Coal Combustion Wastes in Our Lives

Consumer Products and Home Uses

Kitchen counter tops
Cosmetics
Toothpaste
Utensils and tool handles
Picture frames
Carpet backing
Dog houses
Auto bodies and boat hulls
Driveways
Running tracks
Bowling balls
Flotation devices

Construction and Building Materials

Synthetic gypsum
Raw feed for cement clinker (in kiln)
Cement replacement (in concrete)
Roofing granules
Carpet backing
Binding agent
Flooring and ceiling tile
Flowable fill
Asphalt roads
Slate-like roof tiles
Wood-like decking
Structural insulated housing panels
House siding and trim
Fireplace mantles
Aggregate
Soil modification & stabilization
Grout
Stucco
Cinder block
Roofing shingles
Paints and undercoatings
Acoustical ceiling tile
Road base / sub-base
Blasting grit
Recycled plastic lumber
Utility poles and crossarms
Railway sleepers
Highway sound barriers
Drywall
Roofing tiles and panels
Marine pilings
Doors
Scaffolding, non-catastrophic failure
Window frames
Sign posts
Crypts
Architectural interiors and exteriors
Columns
Rail road ties
Bricks
PVC pipe
Vinyl flooring
Paving stones
Paints and plastics filler
Shower stalls
Garage doors
Park benches
Landscape timbers
Planters
Pallet blocks
Molding
Mail boxes
Artificial reef

Agriculture

Soil amendment and fertilizer
Dairy feedlot pads
Cattle feeders
Agricultural stakes
Soil stabilization – stock feed yards
Recycled drywall soil amendment

Loose Application on Roads, Rivers, and as Fill

Dumping on rivers to melt ice
Land contour and golf course fill
Structural fills and embankments
Mining applications / minefill
Snow and ice traction on roads and parking lots

source: http://www.peer.org/campaigns/publichealth/coalash/everywhere.php

Portland Cement vs. Fly Ash Comparison Chart

PORTLAND CEMENT		FLY ASH	
PRO	CON	PRO	CON
CONCRETE • In some applications concrete takes less time to cure	**CONCRETE** • Energy use and fuel combustion during mining operations result in atmospheric emissions, like carbon dioxide (CO_2) as well as numerous other pollutants. • Great deal of energy to grind up, heat in a kiln and process into the final product • Higher embodied energy	**CONCRETE** • Improves strength, segregation, and ease of pumping of the concrete • Improved workability means less water is needed resulting in less segregation of the mixture and less likelihood of cracking • Fly ash itself is less dense than Portland cement, but the produced concrete is denser, less permeable, and results in a smoother surface with sharper detail • Lower embodied energy (when coal extraction is not included and sourced within 30 miles of the site) • Can be formulated to produce various set times, cold weather resistances, strengths and strength gains, depending on the job without additional additives • Cost effective compared to Portland cement • Improves the performance and quality of the concrete • Contains alumina and silica, which strengthens cement • Makes concrete more resistant to chemical attacks (sulphates and alkali-aggregate reaction), which protects against corrosion of reinforcing steel	**CONCRETE** • Concerns about freeze/thaw performance and a tendency to effloresce, especially when used as a complete replacement for Portland cement • Concrete mix is essentially a big chemical reaction, adding fly ash slows the curing of the concrete
	RAW MATERIAL • Water pollution from mining runoff can cause deoxygenation • Impact from mining can be significant in terms of habitat alteration and destruction and soil erosion • Great deal of energy to mine out of the Earth	**RAW MATERIAL** • Industrial by-product of coal that is otherwise waste	**RAW MATERIAL** • Energy use and fuel combustion during coal mining operations result in atmospheric emissions • Contains approximately 1 part per million of mercury and other heavy metals • Acid rain and greenhouse gases from the burning of coal

Graphics Index

Glossary of Terms

Cementitious – Having the characteristics of cement.

Coal Combustion Residue (CCR) – The coal that is not incinerated during power generation, which includes fly ash, bottom ash, boiler slag, and flue gas desulfurization material.

Class C Fly Ash – A category of fly ash by the American Society for Testing and Materials (ASTM) under their C618 standard. This class of fly ash has pozzolanic as well as cementitious properties and is produced from burning lignite or subbituminous coal. Type C fly ash has the following chemical properties:

Silicon dioxide (SiO_2) + aluminum oxide (Al_2O_3) + iron oxide (Fe_2O_3)	50.0 min. %
Sulfur trioxide (SO_3)	5.0 max. %
Moisture content	3.0 max. %
Loss on ignition	6.0 max. %

Class F Fly Ash – A category of fly ash by the American Society for Testing and Materials (ASTM) under their C618 standard. This class of fly ash has pozzolanic properties and is produced from burning anthracite or bituminous coal. Type F fly ash has the following chemical properties:

Silicon dioxide (SiO_2) + aluminum oxide (Al_2O_3) + iron oxide (Fe_2O_3)	70.0 min, %
Sulfur trioxide (SO_3)	5.0 max. %
Moisture content	3.0 max. %
Loss on ignition	6.0 max. % *

** Note: according to the ASTM, the use of Class F pozzolan containing up to 12.0 % loss on ignition may be approved by the user if either acceptable performance records or laboratory test results are made available.*

Flue Gas Desulfurization (FGD) – is a technology that removes sulfur dioxide (SO_2) from the flue gases of fossil fuel power plants.

Fly Ash – The fine particulate waste gathered from the flue gases during coal combustion, smelting, or waste incineration. For the purposes of this paper the term fly ash is only referring to ash from coal combustion.

Greenhouse Gases (GHG) – Greenhouse gases are naturally occurring as well as the result of human activities. Water vapor, carbon dioxide, methane, nitrous oxide, and ozone all are GHG found in nature. Human activities add to the levels of the naturally occurring gases: carbon dioxide is released to the atmosphere from solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned; methane is emitted during the production and transport of coal, natural gas, and oil; methane is also released from the decomposition of organic wastes in solid waste landfills, from livestock; nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels. Other human activities release powerful greenhouse gases that are not found in nature; some of these gases are: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), all of which are generated from industrial processes.[118]

Ground Granulated Blast Furnace Slag (GGBFS) – GGBFS is the non-metallic by-product of iron ore being smelted into pig iron in a blast furnace. This slag material is ground up into a powder and used as cementitious material in concrete.

High-volume-fly-ash-concrete (HVFAC) – A concrete mix that contains more than 50% fly ash by mass of the cementitious material.

Portland cement – A hydraulic cement is created when a mixture of limestone and clay are heated in a kiln and then pulverized. The name Portland originally was a reference to the stone quarried on the Isle of Portland, which has a color similar, but now is the universal name for this type of hydraulic cement.

Pozzolan – Is a material that when combined with calcium hydroxide has cementitious properties. The most common use of pozzolans is as an addition to or in lieu of Portland cement in concrete.

Silica Fume – Is a pozzolan material that is the by-product of manufacture of silicon or ferro-silicon metal.

Supplementary Cementitious Materials (SCM) – Is a material that reacts with substances in the concrete mix to form cement-like compounds.

General Web Resources

American Coal Ash Association	www.acaa-usa.org
American Coal Council	www.americancoalcouncil.org
American Society for Testing and Materials	www.astm.org
Building Green	www.buildinggreen.com
Citizens for Recycling First	www.recyclingfirst.org
Earth Justice	www.earthjustice.org
Environmental Building News	www.ebn.com
Greenpeace	www.greenpeace.org
Green Source	www.greensource.construction.com
Headwater Resources	www.flyash.com
Healthy Building Network	www.healthybuilding.net
Perkins+Will's Precautionary List	www.transparency.perkinswill.com
Pew Center on Global Climate Change	www.pewclimate.org
Portland Cement Association	www.cement.org
Public Employees for Environmental Responsibility	www.peer.org
Union of Concerned Scientists	www.ucsusa.org
United States Environmental Protection Agency	www.epa.gov
United States Green Building Council	www.usgbc.org
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