COAL ASH PRIMER

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Introduction

Coal ash pollution poses grave risks to health and the environment worldwide.[1] Each year, the world's coal plants generate more than 500 million tons of coal ash.[2] Coal ash is a toxic waste product generated by burning coal, and the world extracts about 7.5 billion tons of coal each year.[3] Approximately 65.5% of the coal produced is burned globally for electricity and commercial heat.[4] Because coal supplies a third of all energy used worldwide, coal ash is one of the world's largest industrial waste streams. [5]

Since coal naturally contains trace amounts of toxic chemicals, these hazardous substances are concentrated in the ash when the coal is burned.[6] Over decades, as power plants have installed more effective pollution control devices on their smokestacks to reduce the emission of heavy metals, particulates, and other pollutants, increasing amounts of hazardous chemicals are captured in the ash. Consequently, coal ash is a deadly brew of carcinogens, neurotoxins, and poisons—including arsenic, boron, cadmium, cobalt, hexavalent chromium, lead, lithium, mercury, manganese, molybdenum, radium, selenium, and thallium.[7]

Despite the large volume and hazardous nature of coal ash, the waste has historically been disposed almost entirely without safeguards to contain its toxic contents.[8] When coal ash is improperly dumped and allowed to come in contact with water or be dispersed by wind, hazardous chemicals are released to air, groundwater, surface water, and soil, and communities and ecosystems are harmed. [9]

This primer provides an introduction to the serious threats to human health and the environment, particularly to water resources and clean air, posed by coal ash. The primer describes widespread disposal practices that have lead to contamination of water and air, and it provides suggestions for safeguards that can minimize such harm. The primer also discusses the lack of stringent regulation of coal ash disposal, and how the absence of effective and enforceable regulations have led to worldwide damage. Lastly, this primer presents legal strategies to reduce coal ash pollution, prevent spills, and force cleanup of contaminated sites.

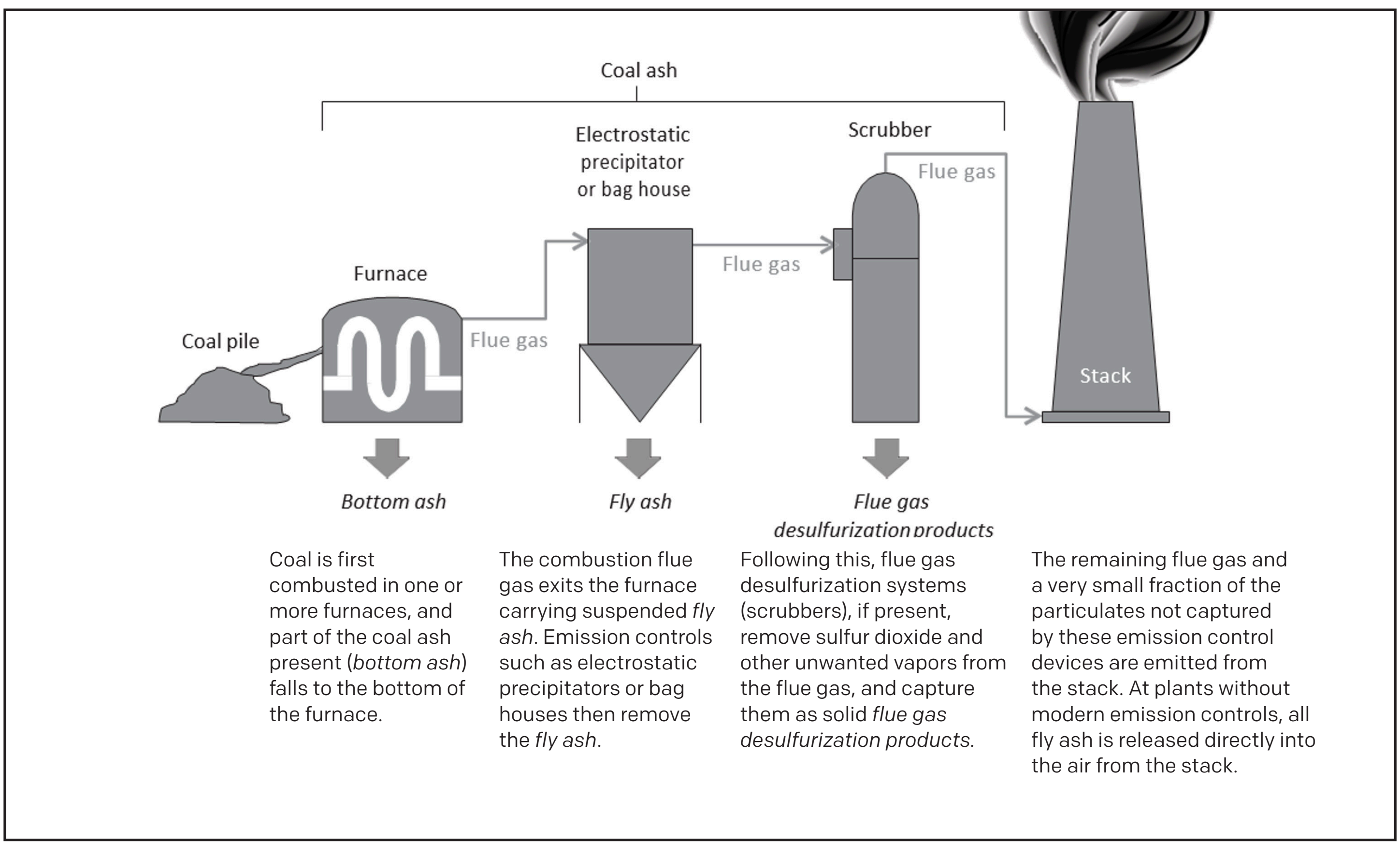

Figure 1: Diagram of coal ash generation at a coal plant with emission controls[10]

1. What is Coal Ash?

The combustion of coal in power plants generates several forms of solid waste collectively called "coal ash" or coal combustion residuals (CCR). Coal ash consists of fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) sludge.[11] *See Figure 1*. Fly ash represents the major component (62 percent) of coal ash, followed by FGD sludge (19 percent), and bottom ash and boiler slag (18 percent).[12] For coal plants that do not have scrubbers, fly ash represents roughly 80 percent of the coal ash generated. The different types of coal ash are described below.

1.1. Fly Ash

Fly ash consists of very fine powder-like particles carried out of the boiler by the flue gases. At plants with effective pollution controls, most fly ash is captured by dust-collecting systems before it escapes the boiler's stack. Particulate control devices include mechanical collectors, electrostatic precipitators, and fabric filters (baghouses). Heavy metals and other chemicals mobilized in the combustion process are captured in the fly ash, enriching the ash in arsenic, lead, boron, selenium, thallium, and other toxic pollutants.[13] Mercury adsorbs, or sticks, to fly ash unless another material, such as activated carbon, is added to the flue gas.[14] The primary component of fly ash is silica, which presents hazards to health if inhaled.[15] Fly ash is usually a light to medium gray color.

1.2. Flue Gas Desulfurization Sludge

Flue Gas Desulfurization (FGD) sludge is the waste generated by "scrubbers" used to reduce sulfur dioxide (SO2) emissions from the exhaust gas system of a coal-fired boiler. Scrubbers can use either a wet or dry process (wet scrubbers are far more common).[16] FGD waste varies from a wet sludge to a dry, powdered material, and consists primarily of gypsum and calcium sulfite hemihydrate.[17] Many pollutants end up in the FGD sludge discharged from the scrubber, including contaminants from coal, limestone, and make-up water (water added to the boiler to make up for evaporation).[18] The resulting waste stream is acidic and supersaturated with gypsum, with high concentrations of total dissolved solids (TDS), total suspended solids (TSS), heavy metals, chlorides, and, occasionally, dissolved organic compounds.[19]

1.3 Bottom Ash

Bottom ash consists of the larger and heavier ash particles that accumulate on the sides and bottom of the boiler.[20] Physically, bottom ash is coarse, with grain sizes spanning from fine sand to fine gravel. It is typically grey to black in color.

1.4. Boiler Slag

Boiler slag is a molten bottom ash collected at the bottom of the boiler and discharged into a water-filled pit, where it is cooled with water (quenched) and removed as hard, black angular particles that have a smooth, glassy appearance.[21]

1.5. The Variability Of Coal Ashes

Composition of coal ash, including toxic chemicals, varies dramatically depending on: (1) the chemical and physical characteristics of the source coal, which can vary greatly even within one mine; (2) the combustion technology; and (3) the pollution control technologies used by the power plant.[22]

1.5.1. Chemical Composition and Ash Volume

The source of the coal determines its natural metal and radioactive content, and thus coal from different countries, different basins within a country, and even different seams within the same coal mine produce coal ash with different levels of trace metals and radioactivity.[23] Both the form and the concentrations of these trace elements also vary with coal type (e.g., anthracite, bituminous, sub-bituminous, and lignite).

The source coal also determines the amount of ash that will be generated by combustion. Coal is classified into three major types: anthracite (hard coal, low ash), bituminous (soft coal), and lignite (lowest grade, brown, high ash). Low-ash coals, such as those from the U.S., Indonesia, South Africa, and China, typically contain about 5 to 15 percent ash.[24] Australian coal can fall in low or moderate categories with ash content ranging from 12 to 20 percent.[25] High-ash coals common in India contain about 25 to 45 percent ash and can contain as much as 50 percent ash.[26] Thus, the volume of ash can differ by a tenfold factor depending on the source coal burned.

Table 1: Relative amounts of coal ash generated per country[27]

COUNTRY OF ORIGIN	AVERAGE ASH CONTENT OF COAL
Australian thermal export coal (higher grade)	12-14%
Australian thermal export coal (lower grade)	20%
Indonesian thermal export coal	2-10%
South African thermal export coal	15%
Russian thermal export coal	10-25%
Indian domestic thermal coal	25-45%
United States (bituminous)[28]	12-15%
China	5-15%

1.5.2. Combustion Technology

Different combustion technologies produce different types and quantities of coal ash. For example, fluidized bed combustion (FBC), also called circulating fluidized bed (CFB), where coal is burned in a suspension with a solid sorbent (usually limestone), has a significant effect on coal ash characteristics, including the volume of ash produced. Generally, a FBC plant will generate about 6-7 times the volume of coal ash for the same amount of coal burned in a conventional pulverized coal (PC) plant, because a FBC plant often burns waste coal, which has much lower carbon content.

1.5.3. Impact of Pollution Control Technologies

The volume of coal ash generated is a function of the amount of coal burned, its ash content, and the combustion technologies used. As a rule of thumb, one can calculate the amount of coal ash generated annually at a particular plant by dividing the total amount of coal burned per year by the percentage of ash in the source coal for PC plants. For FBC or CFB plants, the average annual ash generation must be multiplied by a factor of at least five (conservatively). For plants that operate scrubbers to control SO2, the total amount of coal ash generated (including the FGD sludge) will increase an additional 10 to 25 percent.

2. Coal Ash Contamination: Human Health and Environmental Damage

2.1. Coal Ash Toxicity

Burning concentrates the metals naturally found in coal, including toxic elements such as arsenic, barium, boron, beryllium, cadmium, chromium, cobalt, lead, lithium, manganese, mercury, molybdenum, radium, selenium, thallium, and other dangerous chemicals.[29] Consequently these toxic metals are found in much higher concentrations on a per volume basis in ash compared to coal.[30] In addition, as power plants employ more and better pollution control devices to capture hazardous air pollutants, the toxicity of coal ash increases.[31] Without adequate safeguards, the chemicals that have harmed human health for decades as air pollutants now reach us through coal ash-contaminated drinking water supplies, fugitive dust, and contaminated surface waters.

The hazardous substances found in coal ash can harm every major organ in the human body.[32] *See Figure 2*. The pollutants in coal ash can cause cancer, kidney disease, and reproductive harm, and damage the nervous system, especially in children.[33] One of the most common and mobile pollutants in coal ash is arsenic. Arsenic causes multiple forms of cancer, including cancer of the liver, kidney, lung, and bladder, and an increased incidence of skin cancer in populations consuming drinking water high in inorganic arsenic.[34]

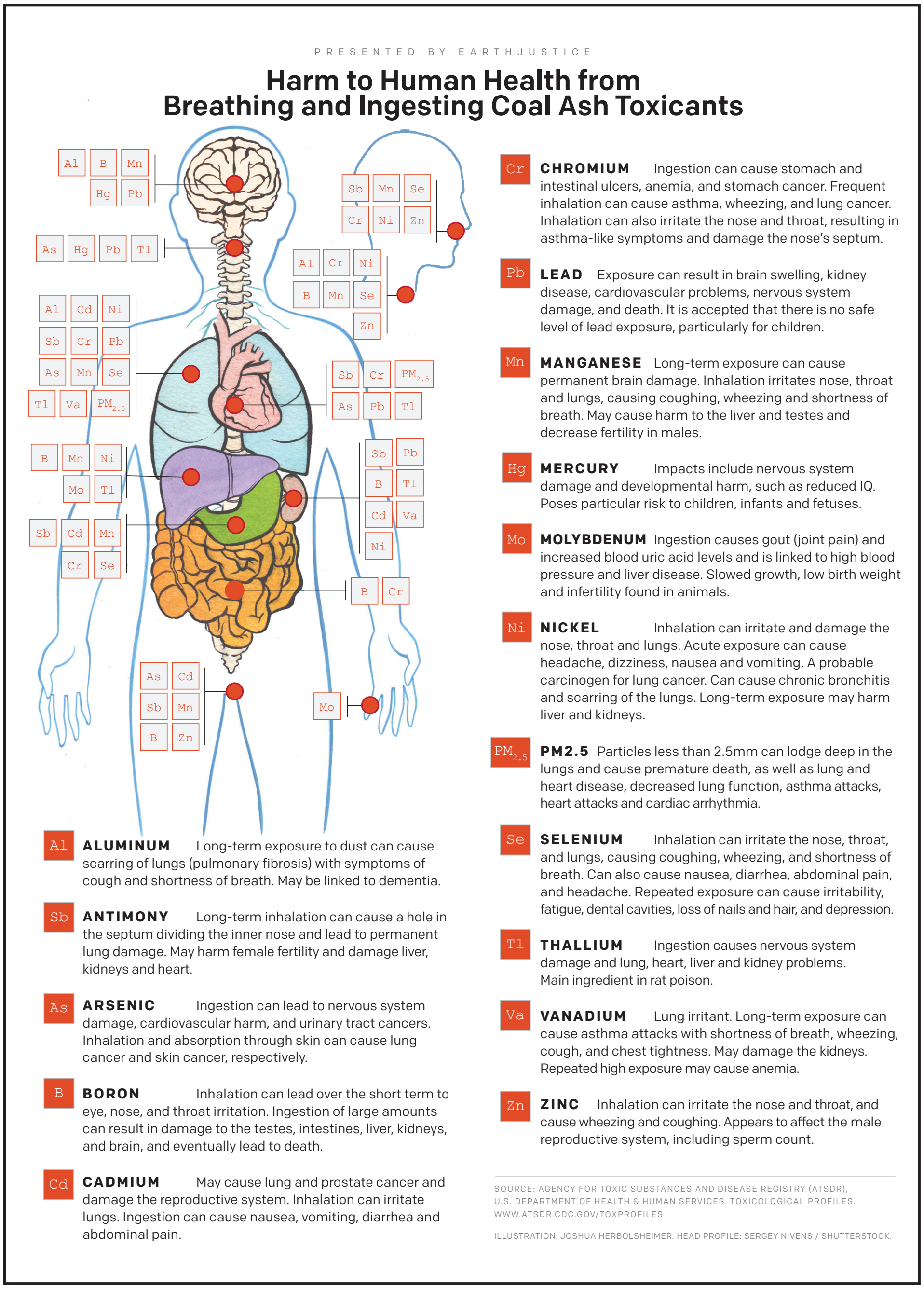

Figure 2: Human Health Impacts of Coal Ash Pollutants[35]

A United States Environmental Protection Agency (U.S. EPA) risk assessment found that living near ash ponds and unlined landfills increases the risk of damage to the liver, kidney, lungs and other organs as a result of being exposed to toxic metals like cadmium, cobalt, lead, thallium, and other pollutants at concentrations far above levels that are considered safe.[36] Another recent U.S. study found the prevalence of health and sleep problems were significantly greater in children living near coal ash dumps.[37] Further, the U.S. EPA risk assessment warns that peak pollution from coal ash dump sites occurs long after the waste is placed. For example, peak exposures from coal ash ponds are projected to occur approximately 78 to 105 years after the ponds first began operation.[38] Thus old dump sites, even if they cease receiving waste, still pose very significant heath threats.[39] Coal ash, when disposed improperly, poses a long-term and potentially deadly risk to human health and aquatic ecosystems for many generations.

Why is coal ash pollution so toxic?

Common coal ash pollutants and their adverse health and environmental impacts are listed below:

- **Aluminum (Al):** Long-term exposure to aluminium dust can cause scarring of lungs (pulmonary fibrosis) with symptoms of cough and shortness of breath.[40] High exposure may lead to dementia.[41]
- **Antimony (Sb):** Long-term inhalation can lead to permanent lung damage and also cause a hole in the septum dividing the inner nose.[42] Exposure may also cause cause developmental toxicity (reduced fetal growth), metabolic toxicity (reduced blood glucose levels), harm fertility and damage the liver, kidneys and heart.[43] Antimony can also irritate the skin.[44]
- **Arsenic (As):** Arsenic is a potent poison that can "bio-accumulate" in ecosystems.[45] Arsenic in drinking water is linked to miscarriages, stillbirths, and infants with low birth weights.[46] Arsenic can also cause multiple types of cancer, including skin tumors and internal organ tumors, and is also connected to heart problems, nervous system disorders, and intense stomach pain.[47] Inhalation and absorption through the skin can cause lung cancer[48] and skin cancer, respectively.
- **Boron (B):** Boron is rare in unpolluted water, meaning that even very small concentrations can be toxic to wildlife not usually exposed to this pollutant.[49] Coal plants discharge a large amount of boron to surface waters via coal ash wastewater,[50] converting a rare contaminant into a commonplace pollutant downstream of their discharge points. Boron's effect on people is less clear, but it can cause nausea, vomiting, diarrhea[51] and, in studies on animals, harm to male reproductive organs. Inhalation can lead over the short term to eye, nose, and throat irritation.[52] Ingestion of large amounts can result in damage to the testes, intestines, liver, kidneys and brain, and eventually lead to death.[53] Boron also poses developmental risks to humans, such as low birth weight.[54]
- **Bromides:** Coal plant waste contains bromide salts, which are very hard to remove short of evaporating wastewater to crystallize out these pollutants. Bromides interact with disinfectant processes in water treatment plants to form disinfection byproducts, including a class of chemicals called trihalomethanes, which are associated with bladder cancer.[55]
- **Cadmium (Cd):** Cadmium is yet another bio-accumulating heavy metal. Consuming water with elevated cadmium levels can cause kidney damage, fragile bones, vomiting and diarrhea — and sometimes death.[56] Cadmium also likely causes lung[57] cancer, and there is some limited evidence on its ability to cause prostate cancer.[58] Fish exposed to excess cadmium become deformed.[59] Inhalation can cause nausea, vomiting, diarrhea and abdominal pain.[60]
- **Chromium (Cr):** Ingestion can cause stomach and intestinal ulcers, anemia, and stomach cancer.[61] Frequent inhalation can cause asthma, wheezing, and lung cancer.[62] Inhalation can also irritate the nose and throat, resulting in asthma-like symptoms and damage the nose's septum.[63] Hexavalent chromium, which is commonly the form of chromium present in coal ash leachate[64] is toxic at very low doses.[65]
- **Cobalt (Co):** Ingestion harms the heart, blood, thyroid, and other parts of the body.[66]
- **Lead (Pb):** Exposure can result in brain swelling,[67] kidney disease, cardiovascular problems, nervous system damage, and death.[68] It is accepted within the medical community that there is no safe level of lead exposure, especially for children.[69] Once lead leaches out of coal ash and enters groundwater[70] or the river ecosystem, it can enter the food chain and bio-accumulate,[71] leading to serious harm to wildlife, as well as threatening people.
- **Lithium (Li):** Ingestion presents multiple health risks including neurological harm.[72]
- **Manganese (Mn):** Long-term exposure can cause permanent brain damage.[73] Inhalation irritates nose, throat and lungs, causing coughing, wheezing and shortness of breath.[74] There is "conclusive evidence from studies in humants that inhalation exposure to high levels of manganese compounds [...] can lead to a disabling syndrome of neurological effects referred to as 'manganism.'"[75]
- **Mercury (Hg):** Even though mercury concentrations in coal plant waste can be relatively low, mercury is a highly toxic compound that represents an environmental and human health risk even in small concentrations, and the conditions at the bottom of coal ash ponds are particularly likely to convert mercury into its most toxic forms.[76] Mercury is a bio-accumulating poison that impairs brain development in children and causes nervous system and kidney damage in adults.[77] Atmospheric deposition equalling only a fraction of a teaspoon of mercury per year over many years is enough to render fish unsafe in a 25-acre lake.[78] Mercury

also accumulates in fish, making them unsafe to eat.[79] Impacts include nervous system damage and developmental harm, such as reduced IQ.[80] Mercury poses particular risk to children, infants, and fetuses.[81]

- **Molybdenum (Mo):** Ingestion causes gout (joint pain) and increased blood uric acid levels and is linked to high blood pressure and liver and kidney disease.[82] In animals, molybdenum can result in slowed growth, low birth weight, and infertility.[83]
- **Nickel (Ni):** Inhalation can irritate and damage the nose, throat and lungs. Acute exposure can cause headache, dizziness, nausea and vomiting, chronic bronchitis, reduced lung function, and cancer of the lung and nasal sinus.[84] Nickel can cause chronic bronchitis and scarring of the lungs. Long-term exposure may harm liver and kidneys.
- **Nitrogen (N) and Phosphorus (P):** These nutrients are important in small quantities, but can readily overpower ecosystems in larger quantities, converting clear waters into algae-choked sumps.[85] Coal plants contribute harmful nutrient loadings in many watersheds.[86]
- **PM 2.5:** Particles less than 2.5 mm can lodge deep in the lungs and cause premature death, as well as lung and heart disease, decreased lung function, asthma attacks, heart attacks and cardiac arrhythmia.[87]
- **Radium (Ra):** Ingestion and inhalation can cause cancer.[88] Radium is a radioactive element.
- **Selenium (Se):** Coal power plants discharge a large amount of selenium resulting in severe environmental harm. High levels of selenium can kill people, and lower levels can cause nervous system problems, brittle hair, and deformed nails.[89] Selenium may take its most serious toll in rivers and streams, where it is acutely poisonous to fish and other aquatic life in even small doses. Concentrations below 3 micrograms per liter (3 parts per billion or ppb) can kill fish,[90] and lower concentrations can leave fish deformed or sterile.[91] Selenium also bio-accumulates and interferes with fish reproduction, meaning that it can permanently destroy wildlife populations in lakes and rivers as it works its way through the ecosystem over a period of years.[92]
- **Sulfate:** Ingestion can cause diarrhea and can be very dangerous to young children and the elderly.[93] Sulfate can render water undrinkable due to its "rotten egg" odor. Sulfur dioxide gas irritates the skin and mucous membranes of the eyes, nose, throat, and lungs.[94]
- **Thallium (Tl):** Ingestion causes nervous system damage and lung, heart, liver and kidney problems.[95] Thallium is the main ingredient in rat poison.[96]
- **Vanadium (V):** Long-term exposure can cause asthma attacks with shortness of breath, wheezing, cough, and chest tightness.[97] Vanadium may damage the kidneys. Repeated exposure may cause anemia.
- **Zinc (Zn):** Inhalation can irritate the nose and throat and cause wheezing, coughing, vomiting, and even anemia and damage to the pancreas.[98] Zinc appears to adversely affect the male reproductive system, including sperm count.[99]

Tragedy in the Dominican Republic: Who pays?

In 2003, US-based AES Corporation dumped more than 50,000 tons of coal ash at a port abutting homes in Arroya Barril in the Samana Province of the Dominican Republic.[100] The ash sat for four years, and residents suffered serious illnesses including miscarriages and birth defects. Babies were born with cranial deformities, organs outside their bodies, and missing limbs. The Dominican Republic eventually brought suit against AES to remove the waste and fined the company $6 million.[101] However, this meager settlement included the guarantee that the Dominican Republic would be responsible for liabilities from all future lawsuits resulting from the AES dumping, including paying AES lawyers $200-500 per hour to defend the claims. Consequently, when a civil suit was brought on behalf of injured residents, the government of the Dominican Republic paid the $37.8 million settlement.[102] Fifteen years after AES dumped coal ash in the heart of the coastal community, health consequences persist, according to local physicians. While the incidence of spontaneous abortions and birth defects is lower than the rate that occurred a decade ago, babies with malformations are still being born.

Above: Coal ash victim in Dominican Republic / **Photo Credit:** Toxic-Coal-Ash.net

2.2. Exposure Pathways

Contaminants derived from coal ash have the potential to enter drinking water supplies, surface water bodies, or biota at unacceptable concentrations, thereby creating risks to human health, aquatic life, birds, and wildlife. Release of coal ash pollutants commonly occurs from coal ash ponds, landfills, and mines or other pits where coal ash is disposed." *See Figure 3*. The extent of contaminant release from coal ash depends on the volume and characteristics of the ash and the disposal environment.

Coal ash can also enter the food chain via contaminated surface water. Coal ash contamination in lakes, rivers and streams can lead to massive extirpation (die offs) of fish and other aquatic life.[104] Because some coal ash contaminants, like selenium, bioaccumulate in benthic organisms and fish,[105] their harmful impacts are magnified and can cause harm to animals, including humans, higher up the food chain. Lastly, coal ash can create long-term ecosystem damage because ash contains persistent, bioaccumulative, and toxic (PBT) chemicals, including lead and mercury, which resist degradation and persist in the environment for extensive periods. As a result of their persistence, when these chemicals are consumed, they bioaccumulate in the fat tissues, bones, and brains of organisms.

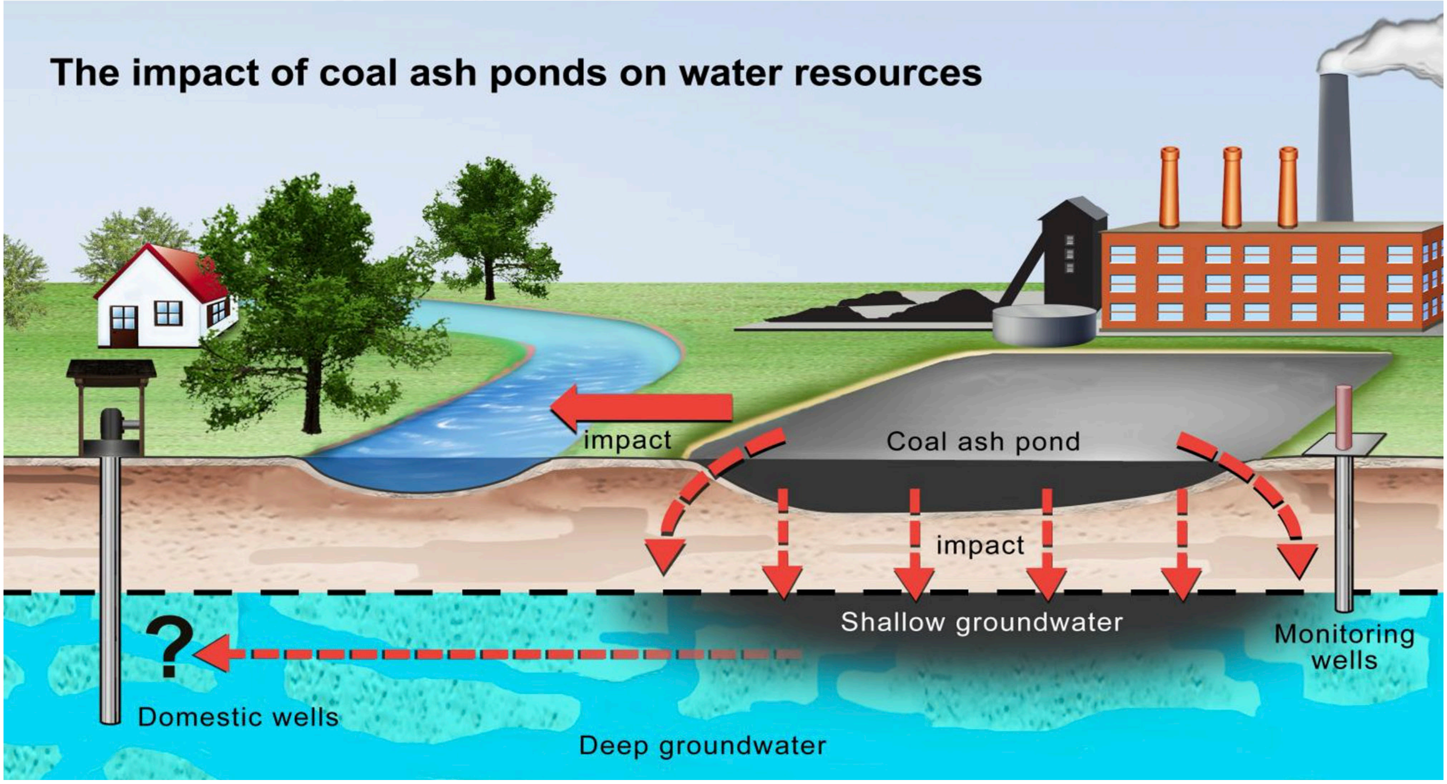

Figure 3: Leaching from Coal Ash Surface Impoundment (Pond) [103]

2.3. Surface Water Contamination

Because large volumes of water are needed to operate the turbines of steam electric plants, coal plants are almost always located very close to rivers, lakes, or other bodies of water.[106] Since coal plants usually dispose of ash very close to the plants to avoid the expense of transporting large volumes of solid waste, these water bodies are imperiled.[107] Direct discharges of leachate or wastewater from coal ash dumps and/or the migration of contaminated groundwater is likely to contaminate these lakes, rivers, and streams. Coal plant water pollution poisons waters, fouls sediment, and contributes to large-scale ecological disruption.[108]

Discharge of contaminated wastewater from coal ash ponds is a significant source of pollution to lakes and rivers. In the U.S., coal-fired power plants are the largest source of toxic water pollution based on toxicity, dumping billions of pounds of pollution into rivers, lakes, and streams each year.[109] Most countries do not adequately limit the amount of toxic chemicals that can be discharged to surface waters from coal ash ponds. Consequently, the waters near such ponds commonly receive heavy doses of arsenic, cadmium, mercury, selenium, thallium and other toxic contaminants.[110]

Even in large lakes, coal plant pollution persists and accumulates.[111] Researchers have discovered that arsenic, in particular, accumulates in the porewater (water in the sediment at the bottom of lakes), and then erupts from the porewater as water warms and stratifies in the summer, contaminating the lake during the same summer days when many people are likely to be out fishing and swimming.[112] The wastewater also contributes contaminants to the sediments of the lake floor, leading to long-term exposure and bio-magnification in aquatic life.[113]

These dangerous discharges have serious consequences for communities that live near coal-fired power plants and their dumps.[114] In the United States, approximately 70 million tons of coal ash each year is disposed at nearly a thousand sites across the nation, in all states and Puerto Rico, except Rhode Island, Vermont, and Idaho.[115] The U.S. EPA has identified more than 250 individual instances where coal plants have harmed groundwater or surface waters.[116] Because many coal power plants sit on recreational lakes and reservoirs, or upstream of drinking water supplies, the potential for harm to human health is substantial.[117] Coal water pollution raises cancer risks, makes fish unsafe to eat, and can inflict lasting brain damage on children.[118]

2.3.1. Harm to Aquatic Life

The toxic metals in coal ash do not degrade over time and many, like selenium, bio-accumulate, increasing in concentration as they travel up the food chain.[119] Harm to fish and other wildlife from coal waste discharges is widespread.[120] Scientists have documented that coal pollutants, such as selenium and arsenic, build up to "very high concentrations" in fish and wildlife exposed to coal waste discharges, and that those accumulating toxics can ultimately deform or kill animals.[121] In fact, coal ash contamination causes deformation and reproductive failure in fish so severe that entire species can be killed in an impacted water body.[122] Fish and other wildlife that do survive can have toxins so high in their bodies that human consumption is dangerous.[123]

Such damage to fish and wildlife can also cause significant economic harm. One survey in the United States focusing on reported fish and wildlife damage caused by coal waste discharges showed at least 22 such incidents over the last few decades, causing damage of more than $2.3 billion.[124]

Devastating Harm to Fish at Belews Lake, North Carolina

The Belews Lake story is the most widely recognized site in the U.S. associated with wildlife destruction caused by coal ash. It offers an example of the serious environmental harm that can occur when coal ash leaches selenium into surface water. In 1974, Duke Energy (then known as Duke Power) began discharging wastewater from fly ash settling basins into Belews Lake, a large reservoir that provided cooling water for a coal-fired power plant. By 1978, 16 of 20 fish species had disappeared completely from the reservoir. Ultimately, three additional species were rendered sterile, leaving only one species of fish in the reservoir. Intensive studies revealed that selenium, a highly mobile, bioaccumulative, and reproductively toxic element associated with coal ash, was the source of the problem. Subsequent studies revealed that female fish accumulated high concentrations of selenium in their tissues and then transferred selenium to their offspring, resulting in grotesque developmental abnormalities and high mortality rates. In 1985, after 10 years of thorough study, Duke Energy ceased discharge of coal ash into the settling basins. Subsequent monitoring has revealed slow recovery of the system. By 1996, 10 years after the cessation of the discharges, selenium levels and adverse effects on fish reproduction had decreased but were still higher than normal levels, indicating the persistence of coal ash pollution.

Above: Photo of deformed fish from Belews Lake (Lemly)
Sources: Lemly, A.D. 1985. Toxicology of selenium in a freshwater reservoir: Implications for environmental hazard evaluation and safety. Ecotoxicol. Environ. Saf. 10:314-338; Lemly, A.D. 1996. Selenium in Aquatic Organisms. In W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood (eds), Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. Boca Raton, FL: SETAC Press.

2.4. Groundwater Contamination

Groundwater contamination occurs when coal ash is inundated with water, and ash constituents leach out of the ash into the underlying aquifer.[125] Water may reach disposed ash via rain, surface run-on, disposal in a coal ash pond, or by placement of the ash directly into groundwater or mine pools. If a disposal unit is unlined or inadequately lined, the water will transport dissolved ash contaminants from the disposal area.[126] Biogeochemical processes control the rate and distance of movement of contaminants from coal ash disposal areas.[127] Under certain conditions, coal ash contamination in water can flow several miles.

Extensive groundwater monitoring data provided by U.S. utilities in March 2018 demonstrate that 91 percent of the U.S. coal plant sites have contaminated underlying groundwater with coal ash pollutants above health standards, including high levels of arsenic, boron, cadmium, chromium, cobalt, lead, lithium, molybdenum and radium 226 and 228.[128] As demonstrated by the recent groundwater data from hundreds of leaking coal ash landfills and ponds, ash disposal sites almost always cause significant and harmful groundwater contamination that threatens drinking water sources.[129]

2.5. Fugitive Dust/Air Pollution

When coal ash is disposed, dust is emitted into the air by loading and unloading, transport, and wind.[130] Once in the air, the fugitive dust can migrate off-site.[131] As a result, workers and nearby residents can be exposed to significant amounts of coarse particulate matter (PM10) and fine particulate matter (PM2.5).[132] Both have been linked to heart disease, cancer, respiratory diseases and stroke.[133]

Coal ash contains significant amounts of silica, in both crystalline and amorphous form.[134] Respirable crystalline silica in coal ash can lodge in the lungs and cause silicosis, or scarring of the lung tissue, which can result in a disabling and sometimes fatal lung disease.[135] Chronic silicosis can occur after many years of mild overexposure to silica.[136] While the damage may at first go undetected, irreversible damage can occur to the lungs from chronic exposure.[137] Such exposure can result in fever, shortness of breath, loss of appetite, and cyanosis (blue skin).[138] In addition, the International Agency for Research on Cancer has determined that silica causes lung cancer in humans.[139]

Inhalation of coal ash also poses significant health threats because of the toxic metals present in the ash, such as arsenic, chromium (including the highly toxic and carcinogenic chromium VI), lead, manganese, mercury, radium and others.[140] When inhaled, these toxic metals can cause a wide array of serious health impacts, ranging from cancer to neurological damage.[141] Following the cleanup of a massive coal ash spill in the U.S. in 2008, more than 50 cleanup workers died and over 200 were sickened by the inhalation of coal ash, according to a lawsuit filed after the spill.[142]

Air polluted from fugitive fly ash dust blowing from a nearby ash pond in Derang Village, India (Odisha). **Photo Credit**: Lisa Evans.

2.6. Soil Contamination

Fly ash can contaminate soils surrounding coal plants when fugitive dust is not properly controlled at ash disposal sites or when the power plant stacks lack equipment to capture the ash. Under these conditions, soil may accumulate elevated levels of heavy metals, including arsenic.[143] Heavy metals in soil contaminated by coal ash may pose hazards particularly to young children, who may ingest harmful quantities of the metals.

Plants grown in coal ash-contaminated soils may also experience elevated levels of toxic metals.[144] In addition, the fly ash can render the soil solid and impermeable because of the cementitious qualities of ash. According to one study, fly ash is generally dispersed in surrounding areas between 3 to 4 kilometers from the power plant.[145] Further, it was found that impacted land within 4 kilometers of the power plant experienced decreased productivity.[146] Lastly, soil contamination can lead to elevated levels of contaminants in run-off or in the underlying groundwater.[147]

2.7 Radiation Hazards

Some trace elements found in source coal are inherently radioactive; therefore, coal ash may also be radioactive. The most common radioactive elements found in coal are uranium and thorium and their decay products radium and radon.[148] When the coal is burned, uranium and thorium in coal are retained and concentrated in the coal ash.[149]

A recent study of the radioactivity of U.S. coal ash found levels of radioactivity in coal ash up to five times higher than in normal soil, and up to 10 times higher than in the parent coal itself due to the concentration of the radioactivity during combustion.[150] The U.S. study found that radium isotopes and lead-210, a naturally occurring radioactive element,[151] occur naturally in coal as chemical by-products of its uranium and thorium content.[152] When the coal is burned, the radium isotopes become concentrated in the coal ash residues, and the lead-210 becomes chemically volatile and reattaches itself to tiny particles of fly ash. This causes additional enrichment of radioactivity in the fly ash. While levels of radioactivity in coal differ significantly from mine to mine, commercial uranium recovery projects have been investigated in China to obtain usable volumes of uranium from coal ash disposal sites.[153]

Table 1 The concentrations of radionuclides in coal fly ash[154] (Bq/kg)[155]

COUNTRY	K^{40}	Ra^{226}	Th^{232}
South Africa	148-240	151-248	125-204
Colombia	175-489	94-142	175-489
Australia[156]	210	93	92
Indonesia[157]	400	76	47
United States[158]	N/A	93-341	49-131

People living in very close proximity to large deposits of radioactive coal ash may experience unhealthy doses of radioactivity.[159] In addition, if radioactive coal ashes are used as fill near residences or incorporated into building materials, dangerous levels of radioactivity may result.[160] Lastly, because of the tiny size of fly ash particles, they are much more likely to be suspended in air, and thus people breathing this air may face increased risks from radioactivity.

3. The Fate of Coal Ash: Reuse or Disposal

Coal-fired power plants can dispose of or reuse coal ash in several ways. The least harmful fate of coal ash is "encapsulation," where coal ash is incorporated into a solid substrate. Such reuse is much safer than other reuses because the potential for leaching of toxic chemicals to water or the re-emission of particulates to air is greatly reduced.[161] The primary encapsulated reuses of coal ash are concrete, bricks, tiles, and gypsum board, described below. If ash cannot be reused, the least harmful disposal method is dry disposal in landfills with careful siting, design, monitoring, and water treatment as needed in perpetuity. The most environmentally hazardous disposal methods are wet slurry surface impoundments (also called ash basins, ponds, or yards); disposal in surface coal mines; use as fill in low-lying areas or road embankments; or being mixed into agricultural soils. Coal ash is also sometimes stored in temporary yards or ponds, which also pose environmental hazards, before the ash is transported off site for reuse or disposal.

3.1. Encapsulated Reuse in Concrete, Bricks, and Tiles

Certain types of fly ash can be used as a partial substitute for Portland cement in concrete. Depending on the type of fly ash, about 15-30 percent of Portland cement can be replaced by fly ash in concrete manufacturing.[162] Fly ash can improve the performance of concrete, including increasing its durability and strength.[163] Reduction in the production of Portland cement also conserves resources and avoids adverse impacts from cement production, including mercury and greenhouse gas emissions. The US EPA evaluated the use of fly ash in concrete and determined that it does not pose greater health or environmental hazards than the use of Portland cement.[164]

3.2. Encapsulated Reuse in Gypsum Board (Wallboard)

FGD gypsum is a subset of the wet sludges produced by flue gas desulfurization (FGD) units or scrubbers. FGD gypsum may be used as a full substitute for mined gypsum in wallboard (i.e., drywall), because the primary chemical constituent, calcium sulfate dihydrate, is identical in both materials.[165] However, FGD gypsum may contain some impurities that are not found in mined gypsum.[166] Fly ash is one such impurity, and can result in accelerated wear to the production machinery and physical defects in the final product.[167] As a result, common market specifications established by North American wallboard manufacturers limit the amount of fly ash allowed in the FGD gypsum used in wallboard to one percent by mass.[168] US EPA has evaluated the use of FGD gypsum and determined that it does not pose greater health or environmental hazards than mined gypsum.[169] Use of FGD gypsum avoids the environmental and health costs of mining virgin gypsum.

3.3. Potentially Less Harmful Disposal: Dry, Lined, Engineered Landfills

Dry coal ash landfills may be constructed both below and above the ground surface. Landfills are usually built in sections called "cells," in which dry ash is placed in an "active" cell and compacted until the cell is filled.[170] Completed cells are covered with soil or other material, and then the next cell is opened. Landfills are usually natural depressions or excavations that are gradually filled with waste, and frequently layers of a landfill may reach well above the natural grade.[171] If contaminated leachate and runoff from landfills are not properly controlled, water contamination will occur.[172] Also, because ash is placed dry in a landfill, harmful quantities of fugitive dust are often generated and dispersed by wind.[173]

3.4. Most Harmful Disposal: Surface Impoundments or "Ponds"

According to the US EPA, the "greatest risks to human health and the environment" from coal ash disposal occur when coal ash is disposed in unlined surface impoundments (ponds).[174] Surface impoundments are natural depressions, excavated ponds, or diked basins that contain a mixture of coal ash and water.[175] Coal ash disposed in surface impoundments is sluiced with water from the plant to the pond. The solids gradually settle out of this slurry, accumulating at the bottom of the impoundment.[176] This process leaves a standing layer of water at the surface. Coal ash that accumulates at the bottom of the basin may be left in place, or the basin may be dewatered periodically and the solids removed for disposal elsewhere or reuse.[177]

Routinely, as the ash pond fills, water is decanted from the top of the coal ash pond and discharged to nearby surface water, usually a river or lake. Excess water may also simply be discharged to adjacent land. This water contains varying levels of the toxic chemicals in coal ash, and such discharges can pollute the receiving water and leave long-term contamination in lakes and rivers.[178]

In many countries, wet disposal is the primary means of disposal because it is the cheapest form of dumping.[179] The bottoms of most surface impoundments are unlined or inadequately lined, and contamination of underlying groundwater occurs at most sites.[180] A significant "hydraulic head" created by the pressure of wastewater on top of the ash pushes, or leaches, toxic contaminants into groundwater.[181] Such groundwater contamination endangers nearby communities dependent on underground aquifers for drinking or irrigation. For example, a recent field study documented widespread contamination of drinking water and agricultural land around large, leaking ash ponds in Maharashtra, India.[182] In addition, since groundwater usually flows into nearby surface water, this contamination can also impair the water quality of nearby steams and reservoirs and harm aquatic life.[183]

The disposal of coal ash in large ponds also creates the potential for catastrophic collapse of poorly engineered and inadequately maintained dikes.[184] Coal ash ponds often cover hundreds of acres, and their dams can stand more than 100 meters high. Major disasters have occurred when coal ash dams fail, such as occurred in the U.S. in 2008, where a spill of more than 1 billion gallons of coal ash sludge covered 300 acres, washing away homes downstream.[185] Similarly, in 2017, a coal ash dike in India ruptured, spilling 4.2 million metric tons of coal ash over 100 acres and into the Bheden River.[186]

A relatively new form of disposal is High Concentration Slurry Disposal (HCSD), which are essentially ash ponds where ash is mixed with less water than traditional sluicing. Companies claim HCSD becomes solid within hours.[187] However, there are no studies to confirm this claim, and "HCSD" is an industry invention; it does not represent a set percentage of ash and water, so the mixture differs from site to site. Moreover, rain can quickly change HCSD ponds from thick sludge to a dilute solution. Depending on weather and drainage, HCSD ponds can be full of water or so dry as to become a large uncovered source of fugitive dust. This disposal method carries the same risks of leaching and catastrophic breaches as ash slurry that contains a conventional amount of water. In fact, the 2017 breach in Jharsuguda, Odisha, described below, occurred at an ash pond where the operator used HCSD.[188]

Vedanta Aluminum's fly-ash breach in Katikela, Odisha. **Photo Credit:** Mehboob Mahtab. **From:** Cheryl Colpy, "Regulator and regulated breaching the law in Odisha", Himal South Asian, 1 Feb 2019, https://himalmag.com/cheryl-colopy-odisha-vedanta-pollution-2019/

Catastrophic Coal Ash Spills from Coal Ash Ponds

Kingston, Tennessee, USA: Poorly engineered and maintained coal ash ponds can experience potentially deadly catastrophic breaches. In 2008, 5.4 million tons (more than 1 billion gallons) of coal ash sludge were released over an area of 300 acres when a dike suddenly collapsed at the TVA Power Plant in Harriman, Tennessee.[189] The toxic sludge swept away multiple houses, filled two rivers, and destroyed a residential community.[190] Cleanup of the coal ash took years and cost over $1 billion. More than 50 cleanup workers died of illnesses allegedly caused by exposure to the toxic ash during the cleanup, and more than 200 remain ill, 14 years after the disaster.[191] A recent lawsuit by the sick workers and families of the deceased workers won a verdict for liability against the cleanup contractor who refused to allow the workers to wear protective respirators.[192]

Above: The 2008 TVA Kingston coal ash disaster in Tennessee swept away houses and covered 300 acres in toxic sludge.

Jharsuguda, Odisha, India: In 2017, an 800-metre section of the perimeter dyke on a coal ash pond collapsed in the Indian state of Odisha, sending a 4-million-metric-ton wave of ash flooding across 80 acres of adjacent farmland.[193] The ash stopped only a few meters short of nearby Katikela village. The ash also contaminated the adjacent Bhedan River, causing the level of suspended solids in the river downstream of the breach to be over 42 times the level upstream of the breach.[194] The day after the breach occurred, a spokesman for Vedanta, Ltd., the power company responsible for the spill, stated, "We will clean the farmlands affected by the ash. The damaged ash pond will be repaired and strengthened."[195] However, Vedanta instead moved swiftly to seek regulatory approval to expand the boundaries of the ash pond to include the entire agricultural area that was buried after the breach. Rather than cleaning up its mess, Vedanta sought to exploit the disaster it caused by effectively seizing land that surrounding communities depended on for agriculture.[196] Local villagers and farms filed lawsuits against Vedanta in 2018 seeking cleanup and compensation for damages caused by the spill. [197]

Above: Google Earth images show the Jharsuguda ash pond before and after the 2017 breach.

3.5. Coal Ash Minefills

Minefill (or mine disposal) involves the placement of coal ash in surface or underground mine voids.[198] When coal ash is placed in surface mines, the ash is generally deposited in the mine as backfill and may be combined with the overburden.[199] Often, very large volumes of coal ash are disposed in active or abandoned surface coal mines.[200] Less commonly, coal ash is used to form a grout to fill underground mines.[201] Mine disposal is commonly employed where the power plant and the mine are located near one another, for example, at minemouth plants.[202] Mine disposal has lead to surface water and groundwater contamination because the ash is placed in a highly fractured zone or directly in mine pools that drain to streams or aquifers.[203] In addition to contaminating groundwater and surface water, the disposal of coal ash in surface mines prevents effective rehabilitation of the mine site and is likely to prevent future productive use of the land and underlying aquifer. The U.S. National Academy of Sciences published a report in 2006 that describes the problems inherent in coal ash disposal in surface mines.[204] The report recommends that safer methods of disposal or reuse be employed and that coal ash minefilling be regulated by environmental agencies, in the event that it is permitted.[205] In addition to water pollution, fugitive dust is also a frequent problem at mine dumping sites.

Some proponents of minefilling claim that the addition of alkaline fly ash in mines suffering from acid mine drainage (AMD) can neutralize the drainage through reaction with the fly ash. While some neutralization of AMD may occur at some mines, not all fly ashes have sufficient neutralization capacity, and the practice presents a high risk of causing additional environmental harm. A 2022 study found that addition of fly ash causes the leaching of toxic metals from the ash, including arsenic, selenium, molybdenum, chromium, boron thallium and antimony, resulting in environmental damage that can exceed drinking water and ecological standards.[206] The magnitude of mobilization of toxic elements depends on their concentrations in the fly ash and the pH conditions.

3.6. Coal Ash Used as Fill

Because coal ash is produced in such large quantities and is expensive to dispose of properly, many coal plant owners dispose of the ash as fill in low-lying areas, quarries, road beds, and construction projects.[207] This so-called "reuse" of coal ash can be very dangerous if ash is placed in areas of shallow groundwater, near surface waters, or allowed to sit uncovered where it can be dispersed by wind. Large coal ash fill projects present the same dangers to health and the environment as unlined landfills. These fills can be even more dangerous than ash landfills, as nearby residents may not be aware of the placement of the ash, and no safeguards, such as monitoring or impermeable liners, are used.

3.6.1. "Structural" Fill

Coal ash is often used as an inexpensive material to fill low-lying areas and quarries. Such fills frequently pollute water and air, especially when ash is used to fill wetlands, sand and gravel quarries, and areas of shallow groundwater.[208] Coal ash fill projects frequently serve as disposal areas for large volumes of ash and should be strictly regulated and controlled. Coal ash fills should be lined with an impermealbe liner, monitored and separated from groundwater (constructed at least five feet (1.5 m) above the uppermost aquifer), located distant from residential areas and drinking water wells, and capped with an impermeable cover when completed. Coal ash use in structural fills may also create dangerous fugitive dust. The best practice is to prohibit coal ash fills.

3.6.2. Road Construction

Fly ash and bottom ash are often used for road construction as a fill material, as a sub-base, and in embankments, aggregate, and flowable fill. Coal ash used in road construction must be placed a sufficient distance from groundwater and capped with an impermeable cover (such as concrete or asphalt) to prevent toxic chemicals from leaching into underlying groundwater or surface water. Unpaved roads constructed of ash can also create toxic fugitive dust problems.

3.6.3. Agricultural Use

Coal ash is sometimes proposed as an amendment for soils. Coal ash changes physical properties including soil structure and moisture holding capacity, and chemical properties including pH, nutrient availability, and salinity (electrical conductivity).[209] For example, fly ash, which is generally alkaline and contains both macro and micronutrients (K, Na, Zn, Ca, Mg, and Fe), is used as a soil amendment, purportedly to increase productivity and stabilize agricultural soils.[210] FGD sludge is also used as a soil amendment because of its high calcium and sulfur content. Physically, fly ash can also increase aeration in clay soils or increase the water bearing capacity of sandy soils.[211]

While studies on coal ash as a soil amendment are few, they have identified important risks. The finer the fly ash particle size, the greater the concentration of leachable toxic trace elements.[212] With higher surface to volume ratios, these toxic elements are also more bio-available.[213] Many toxic metals are found in higher concentrations in ash than in soil, thus increasing the amended soil's concentration of those metals.[214] Amended soils also contain a high amount of soluble salts, increasing salinity.[215]

Agricultural impacts include reduced crop growth in amended soils, especially after long-term applications.[216] Mercury, nickel, chromium, lead, molybdynum, selenium, boron, cadmium, zinc, titanium and aluminum all may damage plants or accumulate in them, passing on dangerous levels of toxins to people or animals that eat them.[217] Food crops grown in large amounts of coal ash can also soak up hazardous concentrations of other metals such as arsenic.[218] For example, basil and zucchini grown in soil amended with 5 to 20 percent fly ash absorbed toxic levels of arsenic and titanium. Generally, when fly ash amounts increase, crops absorbed higher concentrations of metals.[219] Given the lack of rigorous reseach into human and environmental impacts of use of coal ash as a fertilizer, this use should be avoided.

Fly ash chemical and physical properties can vary dramatically, so the effects of soil amendment can not be easily predicted. For example, fly ash can be acidic or alkaline, depending primarily on the sulfur content of the source coal, with pH ranging from 4.5 to 12.[220] Studies have also found that impacts of fly ash on soil properties change over time.[221]

FGD sludge is also used as a soil amendment because of its high calcium and sulfur content.[222] As with fly ash, the heavy metals in FGD sludge will leach heavy metals into groundwater or surface water.[223] All of these risks underscore the importance of thorough understanding of properties of any coal combustion residuals as well as the properties of the soil, climate and crops, as well as dosage rates, before any land application.[224]

Given the lack of rigorous research into impacts of use of coal ash as a fertilizer, soil amendments risk significant environmental and public health impacts, and must be carefully assessed.[225]

4. Best Practices for Coal Ash Disposal

Regulations establishing protective standards for management, storage, disposal, and transport of coal ash are inadequate worldwide. In 2015, the U.S. EPA created the first national regulations for coal ash disposal in the United States.[226] These regulations provide a good foundation, but they still leave gaps that must be closed to achieve adequate protection of health and the environment and ensure that industry pays the full cost of safe management and disposal of toxic coal ash. The following list of best practices generally tracks the U.S. EPA's 2015 federal regulation governing the siting, management, monitoring, cleanup, and closure of coal ash dumps. *See Sections 4.2 – 4.6*. Best practices also include eliminating wastewater discharges to surface waters, which is discussed in Sections 4.4.2, below. The critical takeaway is that engineering, monitoring, and cleanup standards that are sufficiently stringent and enforceable by regulators and citizens are necessary to ensure the safe disposal of toxic ash. The following sections provide examples of such standards.

4.1. First Principle Of Proper Ash Management: Keep It Dry

The key to safe disposal of coal ash is to keep ash dry and prevent the release of toxic contaminants to water. Handling of dry coal ash requires the control of fugitive dust, but control mechanisms exist to minimize dispersal. As mentioned in Section 2.1, the most dangerous method of ash disposal is in basins or ponds. There is no reason, other than reducing the cost of disposal, to add water to coal ash after the ash leaves the coal plant boiler. The safest method of ash disposal is dry disposal in a properly sited engineered landfill with the safeguards (liner, leachate collection for precipitation, monitoring wells) described below.

It is critical to keep coal ash dry long after the closure of the disposal site. In the context of ash pond and landfill closures, capping of the waste is often proposed as a method to prevent precipitation from infiltrating into the ash. Infiltration of precipitation is, however, only one way that water can enter the ash. Wherever the bottom of the ponds is located below the normal groundwater elevation, groundwater will continue to flow through the ash and generate leachate.[227] Leachate that is generated in this manner will flow laterally out of the impoundment and have an adverse impact on water quality downgradient of the ash. Even where the bottom of the ash pond is located above the normal groundwater elevation, high water events (associated with high water in the river) can cause the ash to be re-wetted by rising groundwater. Episodic re-wetting of ash placed above the normal water table, but within range of high water events will cause continued generation of ash leachate and impacts to downgradient groundwater quality.[228]

4.2. Siting Prohibitions for Coal Ash Disposal Units

The first rule for safer coal ash disposal is separation of disposal units from water sources, sensitive ecological areas, areas of human habitation, and unstable areas. The following six location prohibitions contained in U.S. EPA regulations are essential guidelines for construction of new dump sites and expansion of existing ones.[229] Poor siting can also provide leverage for forcing closure of dangerous coal ash landfills and ponds. All coal ash disposal units should be required to comply with the following location prohitions:

- **Separation from the Uppermost Aquifer:** All coal ash landfills and surface impoundments (and lateral expansions) should be constructed with a base located at least 2.44 meters (8 feet) above the upper limit of the uppermost aquifer.[230] Placement of coal ash in areas where there is constant or even intermittent contact with the underlying aquifer facilities rapid release of coal ash contaminants to the groundwater. Ash disposed into groundwater will continue to leach toxic pollutants for many decades after placement, including after the disposal unit is capped and closed.
- **Prohibition of Disposal in Wetlands:** Coal ash landfills and surface impoundments should not be located in wetlands due to their high ecological value and the presence of multiple migration pathways for coal ash contaminants.[231] Location of ash dumps in wetlands leads to significant degradation of critical habitat including harm to water quality, fish, wildlife, and other aquatic resources from release of coal ash contaminants.
- **Prohibition of Construction in Fault Areas:** To ensure the long-term structural integrity of coal ash landfills and surface impoundments, coal ash disposal units must not be located within 60 meters (200 feet) of the outermost damage zone of a fault that has had

displacement in Holocene time (roughly the last 12,000 years).[232] Fault means a fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side. Existing disposal units that are located in fault areas should be required to provide a certification from a professional engineer that that an alternative setback distance of less than 60 meters will prevent damage to the structural integrity of the disposal unit.

- **Prohibition of Construction in Seismic Impact Zones:** Coal ash landfills and surface impoundments must not be located in seismic impact zones unless the owner or operator demonstrates that all structural components including liners, leachate collection and removal systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site.[233] A seismic impact zone means an area having a 2% or greater probability that the maximum expected horizontal acceleration, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10 g in 50 years.
- **Prohibition of Construction in Unstable Areas:** Coal ash landfills and surface impoundments must not be located in an unstable area. An unstable area is a location that is susceptible to natural or human induced events or forces capable of impairing the integrity, including structural components of some or all of the coal ash disposal unit that are responsible for preventing releases from such unit.[234] Unstable areas can include poor foundation conditions, areas susceptible to subsidence, mass movements, and karst terrains. If construction must occur in an unstable area, the owner or operator must demonstrate, with a certification by a professional engineer, that recognized and generally accepted good engineering practices have been incorporated into the design of the disposal unit to ensure that the integrity of the structural components of the unit will not be disrupted. The owner or operator must consider all of the following factors, at a minimum, when determining whether an area is unstable: (1) On-site or local soil conditions that may result in significant differential settling; (2) On-site or local geologic or geomorphologic features; and (3) On-site or local human-made features or events (both surface and subsurface).
- **Limitation on Construction in Floodplains:** Coal ash landfills and surface impoundments should not be built in the floodplains due to the likelihood of inundation by flood waters and the release of coal ash to the flooding river. At minimum, coal ash disposal units shall not restrict the flow of the base flood, reduce the temporary water storage capacity of the floodplain, or result in washout of coal ash, so as to pose a hazard to human life, wildlife, or land or water resources.[235] A "base flood" means a flood that has a 1 percent or greater chance of recurring in any year or a flood of a magnitude equaled or exceeded once in 100 years on the average over a significantly long period. "Floodplain" means the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands, which are inundated by the base flood. "Washout" means the carrying away of solid waste by waters of the base flood.

4.3. Engineering and Management Standards for Coal Ash Disposal At Active Coal Ash Disposal Facilities

The following engineering and operating safeguards for coal ash disposal facilities are needed to minimize releases of coal ash and its contaminants to air, water and soil and to detect releases when they occur.

4.3.1. Impermeable Liners

Any newly constructed ash disposal facility should include, at minimum, a composite liner comprising an upper component consisting of, at a minimum, a 30-mil geomembrane liner (GM), and the lower component consisting of at least a two-foot layer (60 centimeters) of compacted soil or clay with a hydraulic conductivity of no more than 1×10^{-7} centimeters per second (cm/sec).[236] GM components consisting of high-density polyethylene (HDPE) must be at least 60-mil thick. The GM or upper liner component must be installed in direct and uniform contact with the compacted soil or lower liner component. Failure to establish complete and intimate contact between the HDPE liner and underlying clay will cause the composite liner to fail and result in leaks.

A more protective liner system than the composite liner described above is a double liner that consists of either two single liners, two composite liners, or a single and a composite liner.[237] The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in all hazardous waste landfills in the United States.

4.3.2. Leachate collection and removal system

All liners (both double and composite) will eventually leak due to deterioration that causes cracks and holes, and rips caused by faulty liner installation and/or waste deposition.[238] For that reason, a leachate collection and removal system is necessary to prevent the leachate from entering groundwater. The leachate collection system consists of gravel or some other porous medium placed under the ash and above the liner, which is designed to allow leachate to flow rapidly to the top of the HDPE liner. Once it reaches the sloped liner, the leachate is supposed to flow across the top of the liner to a collection pipe, where it will be transported to a sump, where the leachate can be pumped from the landfill. According to regulations, the maximum elevation of leachate ("head") in the sump is to be no more than 1 foot (30 centimeters). In actual practice, leachate collection systems often fail due to plugging because of the generation of fine-grained material and chemical precipitates.[239] Leachate collection systems can only be installed in dry landfills. This is another reason why ash disposal in dry landfills is far safer than disposal in coal ash ponds.

4.3.3. Groundwater Monitoring

Disposal facility operators must be required to implement a comprehensive groundwater monitoring network, including sufficient well locations, monitoring frequency, pollutants to be measured, benchmark values, and statistical analyses that will be used to interpret future data.[240] The following considerations should be taken into account when designing groundwater monitoring systems:[241]

- The well network should be able to characterize groundwater all around the disposal unit. There is rarely a single 'downgradient' direction, and groundwater flow can change over time, so it is important to capture as much of the area as possible. The wells should be located at the waste unit boundary (a vertical surface located at the limit of the disposal unit that extends down into the uppermost aquifer). This ensures that contamination leaving the disposal unit is detected at the earliest possible time.
- Wells should be monitored quarterly, or at the very least semi-annually, to be able to capture seasonal changes in groundwater quality. The groundwater monitoring plan should call for increased monitoring when contamination appears.
- The list of measured pollutants must include all of the following coal ash indicators: boron, calcium, chloride, fluoride, pH, sulfate, total dissolved solids, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, manganese, mercury, molybdenum, selenium, thallium, vanadium, and radium 226 and 228 combined. Pollutants known to be elevated in the impoundment or in local groundwater should also be measured routinely.
- The monitoring program should identify benchmark values above which the concentration of a pollutant in a well will be considered too high. Ideally, each contaminant will have two benchmark values – a health-based value and a statistical value. Concentrations above the health-based value will indicate that water is unsafe to drink and will require corrective action to restore the groundwater to safe water quality levels. The use of statistical benchmarks depends on the type of statistical test used (see next bullet).
- Statistical tests compare one well to an unpolluted well (inter-well comparison). Benchmarks in an inter-well test are representative values from unpolluted (background or upgradient) wells. Downgradient concentrations above these benchmarks will indicate that a pollutant is elevated due to the release of coal ash leachate and that increased monitoring, and perhaps corrective measures, are necessary.
- Necessity for site-wide monitoring: At most coal plants, past disposal areas (old landfills, ponds and fill areas) contribute to groundwater and surface water contamination. It is therefore necessary that both active and inactive dump sites at coal plants be monitored and that all are subject to cleanup requirements.

4.3.4. Corrective Action (Mandated Cleanup)

The purpose of requiring groundwater monitoring at the boundary of the coal ash pond or landfill is to prevent the off-site migration of toxic contaminants from the coal ash. Thus it is imperative that cleanup or corrective action be mandated when downgradient wells indicate that groundwater is being polluted by the waste unit.[242] It is critical to require initiation of effective cleanup as soon as feasible, as well as to require notification of government officials and the affected public. In general, an adequate corrective action program has the following mandatory elements that require the polluter to: (1)

notify the authorities and the public of the release to groundwater or surface water; (2) immediately investigate the release to determine its full nature and extent, including the testing of all drinking water wells within 0.5 mile (0.8km) of the disposal unit; (3) determine a remedial action that will restore the groundwater or surface water to pre-release conditions within a reasonable timeframe; (4) control the source of the release and prevent further releases; (5) inform the public of the release and the proposed cleanup plan; (6) obtain public comment and regulatory approval of the cleanup plan; (7) complete the cleanup within a time certain and as soon as feasible; and (8) obtain a determination by regulatory officials and a qualified professional engineer that the cleanup is complete.[243]

4.3.5. Structural Integrity Requirements For Ash Ponds

As stated above, the first rule of safe coal ash disposal is to keep the ash dry. Slurrying of coal ash and disposal in ponds or surface impoundments is the most dangerous disposal practice because it increases the likelihood and severity of groundwater contamination, poses the threat of catastrophic dike failures, and produces voluminous quantities of contaminated wastewater that is routinely discharged to nearby surface waters. The following design standards applicable to coal ash ponds will increase their safety, but there is no substitute for the elimination of wet disposal of coal ash entirely and the conversion to dry methods of disposal in engineered landfills.

4.3.5.1. Engineering Safeguards

A facility operator must be required to demonstrate that coal ash ponds meet detailed structural stability standards and hydrologic and hydraulic capacity requirements. These technical requirements are commonly applied to dams worldwide, but coal ash impoundments are largely exempt from the engineering standards. Since 2015, the U.S. EPA applies standard dam structural requirements to coal ash ponds.[244] Among the requirements are standards pertaining to spillways,[245] safety factors pertaining to the long-term maximum storage pool loading conditions,[246] the maximum surcharge pool loading condition,[247] the susceptibility to seismic events,[248] and the susceptibility of the dikes to liquefaction.[249] Coal ash impoundments that fail any one of these structural standards must undergo immediate remediation or be securely closed.

4.3.5.2. Inspections and Monitoring of Ash Ponds

Facility operators should conduct an annual structural stability assessment by a qualified professional engineer to document whether the design, construction, operation, and maintenance of the pond is consistent with recognized and generally accepted good engineering practices for the maximum volume of fly ash and water that is impounded therein.[250] Such annual inspections should be made publicly available and submitted to government regulators. If any deficiencies are discovered, they should be documented in detail and immediately resolved. Proof of remedial actions should be publicly available and submitted to the regulatory authority.

Facility operators should also conduct weekly inspections of all impoundment dikes by a person trained to recognize specific appearance of structural weakness and other conditions that have the potential to disrupt the safety of the pond. These weekly pond inspections are necessary to uncover any appearances of actual or potential structural weakness and other conditions that are disrupting or have the potential to disrupt the operation or safety of structure, and all instrumentation installed on the dike should be monitored at least monthly for evidence of movement or instability.

4.3.6. Fugitive Dust Control

To reduce risks of exposure to fugitive dust emissions, owners of ash disposal units should adopt measures that effectively minimize fly ash from becoming airborne, including fly ash fugitive dust originating from landfills, ponds, dikes, roads, and other fly ash handling areas.[251] Such measures should include locating coal ash inside an enclosure or partial enclosure; operating a water spray, fogging system or chemical dust suppressants on all areas of exposed ash; reducing fall distances at material drop points; using wind barriers, compaction or vegetative covers; establishing and enforcing reduced vehicle speed limits; paving and sweeping roads; covering trucks transporting coal ash and periodically washing trucks that haul ash; reducing or halting operations during high wind events; and applying soil or other appropriate materials over all freshly placed ash as well as inactive portions of landfills. In addition, owners should be required to install air monitoring devices sufficient to detect and measure the presence of fugitive fly ash dust emanating from the pond, landfill and other fly ash handling areas. If a village is located within 3 kilometers of the disposal area, air monitoring devices should be located in such villages. Such air monitoring systems should be installed, maintained, and operated in compliance with performance specifications that are designed to ensure accurate monitoring results.

Toxic fugitive fly ash dust thoroughly coats surfaces in a village near a coal ash pond where blowing dust is uncontrolled. Derang Village, Odisha, India. April 2017. **Photo credit:** Lisa Evans

4.3.7. Inspection (Landfills)

Regular inspection of landfill operations must be conducted to ensure proper maintenance and the effective operation of all safety controls. Since coal ash is an inherently unstable material, landfills must be visually inspected weekly by a qualified person for any appearances of actual or potential structural weakness and other conditions that potentially disrupt the operation or safety of the unit (e.g., signs of structural weakness or distress).[252] In addition, the owner of the unit should annually have an inspection performed by a qualified professional engineer to ensure that the design, construction, operation, and maintenance of the unit is consistent with recognized and generally accepted good engineering standards. The inspection must, at a minimum, include: a visual inspection of the unit to identify signs of distress or malfunction; identification of any changes in geometry of the structure since the previous annual inspection; identification of any appearances of an actual or potential structural weakness of the unit, including any existing conditions that are disrupting or have the potential to disrupt the operation and safety of the unit. These inspections should also include an estimation of the total amount of coal ash disposed at the site. As with the inspections of coal ash ponds described above, all inspections should be publicly available for examination, preferably by posting on a publicly accessible internet site, be submitted to a government agency and clearly document all deficiencies found. The owner/operators should similarly be required to remediate all deficiencies and post evidence of all corrective action after completion.

4.4. Closure/Post-Closure Of Coal Ash Disposal Units

4.4.1. General Principles For Safe Closure

Coal ash disposal facilities continue to pose threats to human health and the environment long after they stop receiving ash. These risks can be minimized, however, through careful planning. Every disposal facility should have a closure plan and a post-closure care plan. Both plans should at minimum include the following elements:[253]

- **Site and waste characterization.** The closure plan should fully document the current state of the site and the surrounding area, including:
  - Detailed chemical analysis of the contents of the impoundment or landfill.
  - Three-dimensional characterization of geology, hydrology, and chemistry to depths potentially impacted by the unit.
  - Characterizaton of the waste in relation to underlying groundwater: A coal ash disposal facility must never be allowed to close with waste in contact with the underlying groundwater. If ash remains in contact with groundwater, contaminants will be released to the water in perpetuity.
  - Location of the floodplain in relation to the disposal unit: Coal ash disposal facilities should also be prohibited from closing with their waste remaining in floodplains. Coal ash disposal facilities in floodplains experience periodic rewetting of ash and the release

of hazardous constituents during flooding. Rising water levels can also result in the catastrophic collapse of retaining walls and structures.

  – Water quality data sufficient to characterize groundwater upgradient and downgradient of the disposal unit and surface water upgradient and downstream of the site. Data should be collected monthly or quarterly for a year or more before closure to provide a solid baseline for future monitoring.

  – It is critical that the site characterization include data for pollutants that are known to be associated with coal ash, including boron, calcium, chloride, fluoride, pH, sulfate, total dissolved solids, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, manganese, mercury, molybdenum, selenium, thallium, vanadium, and radium 226 and 228 combined.

  – All aquifers susceptible to contamination should be fully characterized. There may be multiple distinct groundwater aquifers beneath the site.

- **Predictions for future conditions.** The post-closure care plan should model the change in water quality over time. If the groundwater is currently contaminated, the plan should estimate how quickly it will improve, and how much of that contamination is expected to leak into surface water. These predictions should account for the anticipated effects of any control measures (groundwater remediation systems, slurry walls, liners, caps, etc.).

- **Corrective action plan.** Post-closure care plans should include clear triggers for remedial action, and this is usually set out in a corrective action plan. A corrective action plan may, for example, require the owner to increase monitoring when contamination exceeds specific benchmarks and perform certain corrective measures when an increase in contamination persists for more than six months.[254] This part of a post-closure care plan frequently has loopholes that give an owner ways to avoid timely remediation. Red flags may include:

  – Provisions that allow an owner to waive requirements by having an engineer sign off on a less protective alternative.

  – Provisions that give owners extended periods of time to demonstrate that contamination is coming from somewhere other than an impoundment.

  – Provisions that allow owners to discontinue the monitoring of coal ash indicators if they are below benchmark values or not increasing over time. Coal ash indicators should be monitored for the entire post-closure period, which under any circumstances should not be less than 30 years after closure and installment of a final cap.[255]

- **Enforceability.** Closure and post-closure plans should be strict – the agencies overseeing the site should be required to enforce the law when closure requirements are not being implemented, when contamination becomes evident, or when post-closure monitoring and maintenance requirements are violated.

- **Public participation.** Each closure and post-closure plan should be subject to public notice and comment. The public must have the opportunity to weigh in on these plans, with sufficient time to review the relevant documents, before approval is finalized.

- **Transparency.** All of the closure-related documents, including supporting documentation, regular monitoring reports, financial assurance, and communications between the disposal unit owner and regulators, should be publicly available and preferably posted on publicly accessible internet sites.

4.4.2. Concerns Specific to Pond Closure: Draining Impoundments

Coal ash ponds must be dewatered before further closure activities can proceed. The dewatering (draining) process presents risks of a sudden pulse of contamination that could impair receiving waters. As the water level is drawn down in the pond, contaminant concentrations tend to increase in the wastewater. Treatment of effluents may become necessary to ensure protection of receiving waters. The following guidelines will help reduce risks associated with the draining of impoundments:

- Drawdown of water must be limited to one foot (30.48cm) per seven days to ensure structural stability.

- During pumping, weekly monitoring must be conducted for the following parameters: total arsenic, total selenium, total mercury (Method 1631 E), total chromium, total lead, total cadmium, total copper, total zinc, and total dissolved solids.

- Enforceable limits must be set for all of the above parameters, and such limits must reflect the capacity of the receiving body to maintain water quality standards following discharges.

- Water should be drained using a floating pump suction with free water skimmed from the basin surface using an adjustable weir.
- The operator must be required to conduct daily monitoring of flow.
- There must be continuous monitoring of Total Suspended Solids (TSS) with auto pump shut-off if limits are exceeded.
- There must be real time pH monitoring with auto shut-off if 15 minute running average pH falls below 6.1 standard units or rises above 8.9 standard units.
- Monitoring reports must be publicly available as they are produced.
- Water quality standards in the receiving stream shall not be contravened.
- The drawdown of the impoundment must be no less than three feet above the ash.

4.4.3. Post-Closure Best Practices

Even the proper closure of a coal ash landfill and impoundment, including the installation of an impermeable cap atop the waste, will not necessarily prevent continued leaching of hazardous contaminants from the coal ash into groundwater and surface water. Often the base of coal ash dumps are in contact with underlying groundwater. Therefore the groundwater will continue to pass through the buried ash after closure and will continue indefinitely to carry away toxic chemicals from the ash. In addition, it often takes decades for coal ash to reach its highest leaching potential.

Therefore it is necessary to require long-term groundwater monitoring, as well as inspections and maintenance of the cap, for many decades following completion of closure. U.S. regulations require such monitoring for at least 30 years, but this period of time is likely inadequate for most dumps.[256] Groundwater contamination discovered after closure of the site should trigger remedial actions to restore the groundwater to original conditions.[257]

4.5. Financial Assurance For Closure, Post-Closure And Remediation

Financial assurance (also known as bonding) for landfills and surface impoundments is a critical safeguard and an important tool for ensuring safe waste disposal operations. Owners and operators of coal ash dumps should be required to demonstrate adequate financial resources sufficient to cover closure, post-closure care, and clean up resulting from facility operations. Strict financial assurance requirements protect public health and the environment by promoting the proper and safe handling of hazardous materials and protecting against a liable party defaulting on closure or cleanup obligations. Bonding achieves this protection by: (1) promoting the proper handling of coal ash in the first instance; (2) ensuring that funds will be available to address contamination; (3) preventing the shifting of cleanup costs from the responsible party to the taxpayer; and (4) ultimately making facilities and land available to the public for reuse.

Further, financial assurance requirements give owners and operators an incentive to locate, design, and operate facilities to minimize closure and post-closure costs and to improve operating procedures and reduce the risk of accidents. Sloppy design and operating procedures are more likely to be avoided because there is a strong incentive to reduce bond costs. In other words, financial assurance regulations serve the primary purpose of deterring environmental misconduct by promoting safer design and operation in the first instance.[258]

4.6. Enforceable Requirements, Public Participation and Transparency

All of the above requirements should be contained in enforceable, site-specific disposal permits that are issued after the opportunity for public comment and hearing.

4.6.1. Site-Specific Permits

Site-specific permits are preferable to general facility standards because permits can be tailored to the vulnerabilities of the individual disposal sites. Greater oversight over groundwater monitoring, structural stability of the unit, and protection of air, groundwater, surface water, and agricultural land can be accomplished through protective permit conditions. In addition, site-specific permitting may eliminate entirely industry schemes that cannot be implemented without degradation of the environment or injury to public health.

4.6.2. Effective Oversight

It is essential that regulatory agencies regularly inspect and monitor coal ash disposal sites for compliance with permit conditions. At least annual inspections must be required, along with regular reporting of water and air monitoring data. Further, monitoring data must be measured against enforceable limits of concentrations of polluants in air and water. Regulatory agencies should be authorized to respond to exceedances of pollutants by issuance of fines sufficient to deter noncompliance and to force a shutdown, if an owner/operator cannot comply. Lastly, permits must have limited durations, no longer than five years, and full compliance audits must be required prior to reissuance.

4.6.2.1. Public Reporting and Public Access to Data

Public access to permit documents and monitoring data is essential. The U.S. federal rule requires each owner/operator of coal ash disposal units to maintain a publicly accessible website where compliance documents, monitoring data and inspection reports are posted. Regulations mandating timely posting, formatting of data, and organization of internet files are necessary to ensure transparency and easy public access to current and historical information.[259]

4.6.2.2. Enforcement Through Citizen Suits

All permit requirements should be enforceable through citizen suits. Again, it is critical that enforceable limits be established in permits for coal ash pollutant levels in water discharges, groundwater and air. Mandatory monitoring and frequent public reporting of pollutant levels is critical to ensure the viability of citizen suits.

Conclusion

Safe disposal of the toxic waste generated from burning coal is essential to protecting the health and environment of communities living near coal-fired power plants. An abundance of data from reckless dumping of coal ash at hundreds of U.S. coal plants demonstrates that disposal without necessary safeguards results in widespread poisoning of water, air and soil. Coal ash, which contains chemicals that can cause cancer and damage every major organ in the human body, must be securely disposed or safely reused in a manner that prevents toxic releases. As documented in this report, coal ash in air and water results in serious harm to human health and ecosystems. Further, across the globe, harm from coal ash falls disproportionately on poor and non-white communities that are often burdened by multiple sources of pollution and threats to their health and environment.

While it is critical to prevent such harm by adhering to safe disposal practices that minimize the release of ash and its hazardous constituents from current generation of ash, it is also essential to address the legacy of dangerous coal ash dumps that have been created through decades of dumping worldwide. Both proper waste management of recently generated ash and the cleanup of water and land contaminaed by legacy ash dumps are essential to solve the coal ash crisis. Ultimately, to protect health and the environment worldwide, we must cease creating coal ash by ending the burning of coal and transitioning to clean and renewable energy generation.

Endnotes

1 In the United States, where it has been studied for decades, the United States Environmental Protection Agency (U.S. EPA) and public interest groups have documented over hundreds of sites where coal ash pollution has poisoned drinking water, air, and surface water. *See*, e.g., Earthjustice, *Coal Ash Contaminated Sites* http://earthjustice.org/features/coal-ash-contaminated-sites; *See also* Environmental Justice Australia, *Toxic and Terminal: How the regulation of coal-fired power stations fails Australian communities* (2017) https://www.envirojustice.org.au/powerstations/; S. Narayan, Healthy Energy Initiative, *Poisoned: Report on the Environmental Sampling around the Coal Mines, Thermal Power Plants and Ash Ponds in Tamnar Block of Raigarh, Chhattisgarh* (2017) http://www.healthyenergyinitiative.org/wp-content/uploads/2017/08/Poisoned-English-Version-Aug-2017.pdf. A bibliography of articles on harm caused by coal can be found at Earthjustice, *Coal Ash: Reports & Publications* https://earthjustice.org/features/campaigns/coal-ash-reports-and-publications. Lastly, a comprehensive assessment of all regulated coal ash disposal units is contained in Environmental Integrity Project and Earthjustice, *Coal's Poisonous Legacy: Groundwater Contaminated by Coal Ash Across the U.S.* (rev. July 11, 2019), https://environmentalintegrity.org/wp-content/uploads/2019/03/National-Coal-Ash-Report-Revised-7.11.19.pdf

2 R. Kikuchi, Department of Environmental Protection, University of Helsinki, *Application of coal ash to environmental improvement Transformation into zeolite, potassium fertilizer, and FGD absorbent*, Resources, Conservation and Recycling Vol. 27 (1999) p. 334 https://core.ac.uk/download/pdf/14900157.pdf.

3 International Energy Agency, *Key coal trends, Coal information: Overview* (Jul. 2018) p. 3 https://webstore.iea.org/coal-information-2018-overview.

4 Id. at p. 11.

5 J. Brighton, CU Citizen Access, *Loose regulations allow coal ash to threaten river* (Sep. 6, 2018) https://www.cu-citizenaccess.org/2018/09/06/loose-regulations-allow-coal-ash-to-threaten-river/; *See also* Earthjustice, *Waste Deep: Filling Mines with Coal Ash is Profit for Industry, But Poison for People* https://earthjustice.org/sites/default/files/library/reports/earthjustice_waste_deep.pdf.

6 75 Fed. Reg. 35,128, 35,138 (Jun. 21, 2010).

7 *See* 75 Fed. Reg. 35,139, 35,153, 35,168 (Jun. 21, 2010).

8 *See* Earthjustice, *Mapping the Coal Ash Contamination* https://earthjustice.org/features/map-coal-ash-contaminated-sites; See also Environmental Justice Australia, *Unearthing Australia's toxic coal ash legacy* (2019) https://www.envirojustice.org.au/our-work/community/air-pollution/coal-ash/.

9 In the United States, where it has been studied for decades, the United States Environmental Protection Agency and public interest groups have documented hundreds of sites where coal ash pollution has poisoned drinking water, air, and surface water. See, for example, Earthjustice, Coal Ash Contaminated Sites, http://earthjustice.org/features/coal-ash-contaminated-sites. *See, also*, documentation of damage in Australia: Environmental Justice Australia, "Toxic and Terminal: How the regulation of coal-fired power stations fails Australian communities" (2017), available at https://www.envirojustice.org.au/powerstations/, and India: Shweta Narayan, "Poisoned: Report on the Environmental Sampling around the Coal Mines, Thermal Power Plants and Ash Ponds in Tamnar Block of Raigarh, Chhattisgarh"(2017), available at http://www.healthyenergyinitiative.org/wp-content/uploads/2017/08/Poisoned-English-Version-Aug-2017.pdf.

10 U.S. Geological Survey, *Trace Elements in Coal Ash, Fact Sheet 2015–3037* (2015) p. 1 https://pubs.usgs.gov/fs/2015/3037/pdf/fs2015-3037.pdf.

11 Id.

12 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) p. 27 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.

13 *See* G. Schwartz, et al, *Ranking Coal Ash Materials for Their Potential to Leach Arsenic and Selenium: Relative Importance of Ash Chemistry and Site Biogeochemistry*, Environmental Engineering Science 35(7), pp. 728-738 (Jul. 1, 2018) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6034393/ ("The ability of fly ash particles to capture trace elements varies with particle surface area and flue gas temperature, with lower flue gas temperatures and high particle surface areas tending to increase trace element sorption or deposition on fly ash (Meij, 1994; Hower et al., 1999). Trace element concentrations in the ash materials vary according to the point of collection in the combustion process. Volatile trace elements, such as cadmium, chromium, lead, nickel, zinc, copper, vanadium, mercury, arsenic, and selenium are one to two orders of magnitude more concentrated in fly ash relative to bottom ash").

14 Y. Gu, et al, *Evaluation of elemental mercury adsorption by fly ash modified with ammonium bromide, J. of Thermal Analysis and Calorimetry* Vol. 119(3) pp. 1663-1672 (Mar. 2015) https://www.researchgate.net/publication/276315479_Evaluation_of_elemental_mercury_adsorption_by_fly_ash_modified_with_ammonium_bromide.

15 *See* Earthjustice and Physicians for Social Responsibility, *Ash in Lungs: How Breathing Coal Ash is Hazardous to Your Health* (Jul. 2014) https://earthjustice.org/blog/2014-july/ash-in-lungs-how-breathing-coal-ash-is-hazardous-to-your-health.

16 The wet sludge generated from the wet scrubbing process using a lime-based reagent is predominantly calcium sulfite, while the wet sludge generated from the wet scrubbing process using a limestone-based reagent is predominantly calcium sulfate. The dry powdered material from dry scrubbers that is captured in a baghouse consists of a mixture of sulfites and sulfates. The three leading FGD technologies used in the U.S. are wet scrubbing (85% of the installations), dry scrubbing (12%), and dry sorbent injection (3%). Wet scrubbers typically remove more than 90% of the SOx, compared to dry scrubbers, which remove 80%. *See* U.S. EPA, *Air Pollution Control Technology Fact Sheet* https://www3.epa.gov/ttncatc1/dir1/ffdg.pdf.

17 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) p. 36 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.

18 *See* J. Lu, U.S. EPA, *Chemical Speciation of Flue Gas Desulfurization (FGD) Sludge Constituents* (July 1981) https://nepis.epa.gov/Exe/ZyNET.exe/2000TB8D.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1981+Thru+1985&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C81thru85%5CTxt%5C00000011%5C2000TB8D.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL.

19 *See* Id. *See also* T. Higgins, PhD, Power, *Flue Gas Desulfurization Wastewater Treatment Primer* (Mar. 1, 2009) https://www.powermag.com/flue-gas-desulfurization-wastewater-treatment-primer/.

20 *See* U.S. EPA, *Coal Ash Basics* https://www.epa.gov/coalash/coal-ash-basics.

21 *See* U.S. EPA, *Coal Ash Basics* https://www.epa.gov/coalash/coal-ash-basics. *See also* American Coal Ash Association, *About Coal Ash – Boiler Slag*, https://www.acaa-usa.org/AboutCoalAsh/WhatareCCPs/BoilerSlag.aspx.

22 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) p. 33-39 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.

23 *See* N. Lauer, J. Hower, H. Hsu-Kim, R. Taggart, A. Vengosh, *Naturally Occurring Radioactive Materials in Uranium-Rich Coals and Associated Coal Combustion Residues in the United States*, Environmental Science & Technology Vol. 49 (18) (Sep. 2015) p. 11231. https://www.researchgate.net/publication/281542084_Naturally_Occurring_Radioactive_Materials_in_Coals_and_Coal_Combustion_Residuals_in_the_United_States; *See also* N. Lauer, A. Vengosh, S. Dai, *Naturally Occurring Radioactive Materials in Uranium-Rich Coals and Associated Coal Combustion Residues from China*, Environmental Science & Technology Vol. 51 (22) (Nov. 2017) p. 13488 https://www.researchgate.net/publication/320955985_Naturally_Occurring_Radioactive_Materials_in_Uranium-Rich_Coals_and_Associated_Coal_Combustion_Residues_from_China.

24 Institute for Energy Economics and Financial Analysis, *Australian Export Coal Quality* (Nov. 2015) p. 2 http://ieefa.org/wp-content/uploads/2015/10/IEEFA-Australian-coal-briefing-note.pdf.

25 Id.

26 China Heavy Machinery Industry Association, *Module II Coal Chemicals*, Table M-II 1.1 http://nptel.ac.in/courses/103107082/module2/lecture1/lecture1.pdf.

27 Institute for Energy Economics and Financial Analysis, *Australian Export Coal Quality* (Nov. 2015) p. 2 http://ieefa.org/wp-content/uploads/2015/10/IEEFA-Australian-coal-briefing-note.pdf.

28 S. Schweinfurth, U.S. Geological Survey Professional Paper, *An Introduction to Coal Quality* in B. Pierce, et al., *The National Coal Resource Assessment Overview* (2009) p. 10 https://pubs.usgs.gov/pp/1625f/downloads/ChapterC.pdf.

29 *See, e.g.*, K. Liu, W. Xie, et al, Combustion Laboratory, Western Kentucky University, *Investigation of Polycyclic Aromatic Hydrocarbons in Fly Ash from Fluidized Bed Combustion Systems*, Environ. Sci. Technol. Vol. 34 (2000) p. 2273 (Polycyclic Aromatic Hydrocarbons were found in higher concentrations in fly ash than in the raw coal).

30 U.S. EPA, Office of Solid Waste & Emergency Response, *Report to Congress: Wastes from the Combustion of Fossil Fuels* (1999) pp. 3-17 https://www.epa.gov/sites/production/files/2015-08/documents/march_1999_report_to_congress_volumes1and2.pdf.

31 *See* U.S. EPA, Office of Research & Dev., *Characterization of Coal Combustion Residues from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control* (July 2008) p. 13 https://nepis.epa.gov/Exe/ZyNET.exe/P100EEGL.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czy-

files%5CIndex%20Data%5C06thru10%5CTxt%5C00000032%5CP100EEGL.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL#; *See also* U.S. EPA, Office of Research & Development, *Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control* (Feb. 2006) p. xiii https://nepis.epa.gov/Exe/ZyNET.exe/P1006ATD.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5CTxt%5C00000014%5CP1006ATD.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL#.

32 *See* Physicians for Social Responsibility and Earthjustice, *Coal Ash: The Toxic Threat to Our Health and Environment* (2010) p. vii https://www.psr.org/wp-content/uploads/2018/05/coal-ash.pdf.

33 *See* Earthjustice, *Harm to Human Health from Breathing and Ingesting Coal Ash Toxicants* https://earthjustice.org/documents/reference/harm-to-human-health-from-breathing-and-ingesting-coal-ash-toxicants.

34 U.S. EPA, Integrated Risk Information System, Arsenic (CASRN 7440-38-2) (Dec. 2002) https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0278_summary.pdf.

35 *See* Earthjustice, *Harm to Human Health from Breathing and Ingesting Coal Ash Toxicants* https://earthjustice.org/documents/reference/harm-to-human-health-from-breathing-and-ingesting-coal-ash-toxicants.

36 RTI International, on behalf of U.S. EPA, *Human and Ecological Risk Assessment of Coal Combustion Wastes* (Aug. 6, 2007) (draft) ("EPA Risk Assessment") https://content.sierraclub.org/coal/sites/content.sierraclub.org.coal/files/elp/docs/us-general_epa-coal-ash-report_2007-8-6.pdf.

37 C. Sears, and K. Zierold, Global Pediatric Health Volume 4, *Health of Children Living Near Coal Ash*, 2017) pp. 1, 4-5 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5533260/.

38 RTI International, on behalf of U.S. EPA, *Human and Ecological Risk Assessment of Coal Combustion Wastes*, supra n. 36, p. 4-7.

39 *See* U.S. EPA, Office of Solid Waste and Emergency Response, *Wastes from the Combustion of Fossil Fuels Volume 1 – Executive Summary* (Mar. 1999) pp. 4-17, 4-18 https://www.epa.gov/sites/production/files/2015-08/documents/march_1999_report_to_congress_volumes1and2.pdf.

40 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Toxicological Profile for Aluminium* (Sep. 2008) p. 16 https://www.atsdr.cdc.gov/toxprofiles/tp22.pdf.

41 U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Aluminium* (Sep. 2008) p. 13 https://www.atsdr.cdc.gov/toxprofiles/tp22.pdf.

42 New Jersey Department of Health, *Hazardous Substance Fact Sheet: Antimony* (Feb. 2012) p. 1 https://nj.gov/health/eoh/rtkweb/documents/fs/0141.pdf.

43 G. Zheng, H. Zhong, Z. Guo, Z. Wu, H. Zhang, C. Wang, et al. *Levels of heavy metals and trace elements in umbilical cord blood and the risk of adverse pregnancy outcomes: a population-based study*, Biol Trace Elem Res. Vol. 160 No. 3 (Sep. 2014) pp. 437–44 https://link.springer.com/article/10.1007/s12011-014-0057-x.

44 New Jersey Department of Health, *Hazardous Substance Fact Sheet: Antimony* (Feb. 2012) p. 1 https://nj.gov/health/eoh/rtkweb/documents/fs/0141.pdf.

45 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Toxicological Profile for Arsenic* (2012) pp. 327-328 https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.

46 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Toxicological Profile for Arsenic* (2012) p. 18 https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.

47 Id.

48 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Toxicological Profile for Arsenic* (2012) pp. 7-8, 17 https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.

49 U.S. EPA, Office of Water, *Environmental Assessment for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (Sep. 2015) pp. 3-3, 3-8 https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric-envir_10-20-15.pdf.

50 Environmental Integrity Project, *Forty-Nine Coal-Fired Plants Acknowledge Groundwater Contamination in Response to EPA Data Collection* (Apr. 2012) pp. 1, 4-7 (Tables A-B) http://www.environmentalintegrity.org/news_reports/documents/20120426_Final_ICRDataReport.pdf; *see also* U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Boron* (2010) pp. 2, 137, 141 https://www.atsdr.cdc.gov/ToxProfiles/tp26.pdf.

51 U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Boron* (2010) p. 103 https://www.atsdr.cdc.gov/ToxProfiles/tp26.pdf.

52 U.S. EPA, Office of Water, *Environmental Assessment for the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (Sep. 2015) pp. 3-8 https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric-envir_10-20-15.pdf.

53 U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Boron* (2010) p. 5 https://www.atsdr.cdc.gov/ToxProfiles/tp26.pdf.

54 Id.

55 U.S. EPA, *Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (Sep. 2015) pp. 3-10 https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric-envir_10-20-15.pdf.

56 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Public Health statement: Cadmium* (CAS # 7440-43-9) (Sep. 2012) p. 5 https://www.atsdr.cdc.gov/ToxProfiles/tp5-c1-b.pdf.

57 Id

58 U.S. Department of Health and Human Services, National Toxicology Program, *Report on Carcinogens, Fourteenth Edition - Cadmium and Cadmium Compounds* https://ntp.niehs.nih.gov/ntp/roc/content/profiles/cadmium.pdf.

59 U.S. EPA, *Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (Sep. 2015) pp. 3-7 https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric-envir_10-20-15.pdf.

60 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Public Health statement: Cadmium* (CAS # 7440-43-9) (Sep. 2012) p. 5 https://www.atsdr.cdc.gov/ToxProfiles/tp5-c1-b.pdf.

61 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Public Health statement: Chromium* (Sep. 2012) p. 4 https://www.atsdr.cdc.gov/ToxProfiles/tp7.pdf.

62 Id.

63 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Public Health statement: Chromium* (Sep. 2012) pp. 4, 13 https://www.atsdr.cdc.gov/ToxProfiles/tp7.pdf.

64 U.S. EPA, *Characterization of Coal Combustion Residues from Electric Utilities – Leaching and Characterization Data* (Dec. 2009) pp. 91-92 https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007JBD.PDF?Dockey=P1007JBD.PDF.

65 U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Public Health statement: Chromium* (Sep. 2012) p. 5 https://www.atsdr.cdc.gov/ToxProfiles/tp7.pdf.

66 U.S. Department of Health and Human Services, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Cobalt* (Apr. 2004) pp. 10, 47 https://www.atsdr.cdc.gov/ToxProfiles/tp33.pdf.

67 *See* K. Chibowska et al, *Effect of Lead (Pb) on Inflammatory Processes in the Brain*, Int. J. Mol. Sci. Vol. 17 No. 12 (Dec. 2016) p. 2140 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5187940/.

68 U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Lead* (Aug. 2007) p. 36 https://www.atsdr.cdc.gov/ToxProfiles/tp13.pdf.

69 *See* World Health Organization, Lead Poisoning and health (Aug. 2018) http://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health.

70 *See, e.g.*, C. Verma et al, *Heavy metal contamination of groundwater due to fly ash disposal of coal-fired thermal power plant, Parichha, Jhansi India, Civil and Environmental Engineering* (Jun. 2016) https://www.cogentoa.com/article/10.1080/23311916.2016.1179243.

71 U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Lead* (Aug. 2007) pp. 3-4 https://www.atsdr.cdc.gov/ToxProfiles/tp13.pdf.

72 U.S. EPA, *Provisional Peer Reviewed Toxicity Values for Lithium* (Jun. 12, 2008) pp. 4, 7 https://cfpub.epa.gov/ncea/pprtv/documents/Lithium.pdf.

73 U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Manganese* (Sep. 2012) p. 12 https://www.atsdr.cdc.gov/ToxProfiles/tp151.pdf.

74 U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Manganese* (Sep. 2012) p. 17 *https://www.atsdr.cdc.gov/ToxProfiles/tp151.pdf*.

75 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Public Health Statement: Manganese* (Sep. 2012) p. 68 https://www.atsdr.cdc.gov/ToxProfiles/tp151.pdf.

76 U.S. EPA, *Steam Electric Power Generating Point Source Category: Final Detailed Study Report* (Oct. 2009) p. 6-5 https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005J8A.PDF?Dockey=P1005J8A.PDF.

77 *See* U.S. Department of Health, Agency for Toxic Substances and

Disease Registry, *Public Health Statement: Mercury* (Mar. 1999) §§ 1.5-1.6 https://www.atsdr.cdc.gov/ToxProfiles/tp46-c1-b.pdf.

78 Union of Concerned Scientists, *Coal and Air Pollution* (Dec. 2017) http://www.ucsusa.org/clean_energy/coalvswind/c02c.html.

79 *See* U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Mercury* (Mar. 1999) § 1.2 https://www.atsdr.cdc.gov/ToxProfiles/tp46-c1-b.pdf.

80 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Public Health Statement: Mercury* (Mar. 1999) §§ 1.5-1.6 https://www.atsdr.cdc.gov/ToxProfiles/tp46-c1-b.pdf.

81 U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Public Health Statement: Mercury* (Mar. 1999) § 1.6 https://www.atsdr.cdc.gov/ToxProfiles/tp46-c1-b.pdf.

82 *See* U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Draft for Public Comment: Molybdenum* (Apr. 2017) p. 9 https://www.atsdr.cdc.gov/ToxProfiles/tp212.pdf.

83 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Draft for Public Comment: Molybdenum* (Apr. 2017) pp. 46-47 https://www.atsdr.cdc.gov/ToxProfiles/tp212.pdf.

84 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Nickel* (Aug. 2005) pp. 5-8 https://www.atsdr.cdc.gov/toxprofiles/tp15.pdf.

85 U.S. EPA, *Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (Sep. 2015) pp. 3-9 – 3-10, https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric-envir_10-20-15.pdf.

86 U.S. EPA, *Steam Electric Power Generating Point Source Category: Final Detailed Study Report* (Oct. 2009) p. 6-6 https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005J8A.PDF?Dockey=P1005J8A.PDF.

87 U.S. EPA, *How Does PM Affect Human Health* https://www3.epa.gov/region1/airquality/pm-human-health.html.

88 *See* U.S. Department of Health, *Agency for Toxic Substances and Disease Registry, Toxicological Profile for Radium* (Dec. 1990) p. 3 https://www.atsdr.cdc.gov/toxprofiles/tp144.pdf.

89 *See* U.S. Department of Health, *Agency for Toxic Substances and Disease Registry*, *Public Health Statement: Selenium* (Sep. 2003) § 1.5 https://www.atsdr.cdc.gov/ToxProfiles/tp92-c1-b.pdf.

90 *See* U.S. EPA, *Steam Electric Power Generating Point Source Category: Final Detailed Study Report* (Oct. 2009) pp. 6-4, https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005J8A.PDF?Dockey=P1005J8A.PDF.

91 A.D. Lemly, *Selenium Impacts on Fish: An Insidious Time Bomb*, Human and Ecological Risk Assessment Vol. 5 No. 6 (1999) p. 1142 https://www.fs.usda.gov/treesearch/pubs/1361.

92 *See*, e.g., A.D. Lemly, *Toxicology of selenium in a freshwater reservoir: Implications for environmental hazard evaluation and safety*, Ecotoxicology and Environmental Safety Vol. 10 (Dec. 1985) pp. 314-338; A.D. Lemly, *Teratogenic effects of selenium in natural populations of freshwater fish*, Ecotoxicology and Environmental Safety Vol. 26 (Oct. 1993) pp. 181-204; A.D. Lemly, *Ecosystem recovery following selenium contamination in a freshwater reservoir*. Ecotoxicology and Environmental Safety Vol. 36 (1997) pp. 275-281 https://www.srs.fs.usda.gov/pubs/ja/ja_lemly022.pdf; A.D. Lemly, *Aquatic selenium pollution is a global environmental safety issue*, Ecotoxicology and Environmental Safety Vol. 59 (Sep. 2004) 44-56, https://www.sciencedirect.com/science/article/pii/S0147651303000952.

93 World Health Organization, *Sulfate in Drinking-water* (2004) p. 4 https://www.who.int/water_sanitation_health/dwq/chemicals/sulfate.pdf.

94 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Medical Management Guidelines for Sulfur Dioxide* (Oct. 2014) pp. 5-6 https://www.atsdr.cdc.gov/MHMI/mmg116.pdf.

95 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Thallium* (Jul. 1992) p. 3 https://www.atsdr.cdc.gov/ToxProfiles/tp54.pdf.

96 *See* Earthjustice, *Harm to Human Health from Breathing and Ingesting Coal Ash Toxicants* https://earthjustice.org/documents/reference/harm-to-human-health-from-breathing-and-ingesting-coal-ash-toxicants.

97 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Vanadium* (Sep. 2012) pp. 5-6, 12 https://www.atsdr.cdc.gov/ToxProfiles/tp58.pdf.

98 U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Zinc* (Aug. 2005) p. 5 https://www.atsdr.cdc.gov/ToxProfiles/tp60.pdf.

99 Id.

100 *See* F. Robles, Miami Herald, *Coal ash from U.S. blamed for Dominican town's birth defects* (Nov. 2009) https://www.mcclatchydc.com/news/nation-world/world/article24563092.html.

101 *See* O. Alfonso, Centro de Periodismo Investigativo, *Arroyo Barril: Coal Ash And Death Remain 15 Years Later* (Dec. 2018) http://periodismoinvestigativo.com/2018/12/arroyo-barril-coal-ash-and-death-remain-15-years-later/.

102 Id.

103 U.S. Geological Survey, *Trace Elements in Coal Ash Fact Sheet 2015–3037* (May 2015) https://pubs.usgs.gov/fs/2015/3037/pdf/fs2015-3037.pdf.

104 A.D. Lemly & J.P. Skorupa, *Wildlife and the coal waste policy debate: Proposed rules for coal waste disposal ignore lessons from 45 years of wildlife poisoning*, Environmental Science and Technology Vol. 46 No. 16 (2012) p. B https://pubs.acs.org/doi/abs/10.1021/es301467q.

105 *See* U.S. Department of Health, Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Selenium* (Sep. 2003) p. 283 https://www.atsdr.cdc.gov/ToxProfiles/tp92.pdf.

106 *See* Environmental Integrity Project, Earthjustice, et al., *Closing the Floodgates: How The Coal Industry Is Poisoning Our Water and How We Can Stop It* (2013) p. 4 https://earthjustice.org/sites/default/files/ClosingTheFloodgates-Final.pdf.

107 *See* B. Gottlieb, Physicians for Social Responsibility, et al, *Selling our health down the river: Why EPA Needs to Finalize the Strongest Rule to Stop Water Pollution from Power Plants* ("Power plants discharge more than 5.5 billion pounds of pollutants into U.S. waterways every year, contributing to the contamination of more than 23,000 miles of rivers and 185 water bodies whose fish are too toxic to eat."); *See* also A. D. Lemly, *A White Paper on Environmental Damage from Coal Combustion Waste: The Cost of Poisoned Fish and Wildlife* (Dec. 15, 2010) (reporting on coal combustion waste contamination at 22 sites in the U.S.).

108 *See* Clean Water Fund, *Coal Ash Threatens our Health and Environment* http://www.cleanwateraction.org/files/publications/factsheets/CoalAshFactSheet03%2015%2012a.pdf. ("At least 137 cases of water contamination from coal ash have been documented by EPA and environmental organizations, though since most disposal sites are not monitored, the actual number of water contamination occurrences could be much higher").

109 *See* Environmental Integrity Project, Earthjustice, et al., *Closing the Floodgates: How The Coal Industry Is Poisoning Our Water and How We Can Stop It* (2013) p. 1 https://earthjustice.org/sites/default/files/ClosingTheFloodgates-Final.pdf.

110 *See* Earthjustice, *Mapping the Coal Ash Contamination* https://earthjustice.org/features/map-coal-ash-contaminated-sites.

111 *See* Environmental Integrity Project, Earthjustice, et al., *Closing the Floodgates: How The Coal Industry Is Poisoning Our Water and How We Can Stop It* (2013) p. 6 https://earthjustice.org/sites/default/files/ClosingTheFloodgates-Final.pdf.

112 L. Ruhl, A. Vengosh *et al., The Impact of Coal Combustion Residue Effluent on Water Resources: A North Carolina Example*, Environmental Science and Technology Vol. 46, No. 21 (2012) pp. A, F http://www.southeastcoalash.org/wp-content/uploads/2012/05/Impacts-of-Coal-Combustion-Waste-Effluent-on-NC-Waters1.pdf.

113 Zhen Wang, Ellen Cowan, Keith Seramur, Gary Dwyer, Jessie Wilson, Randall Karcher, Stefanie Brachfeld, and Avner Vengosh, *Legacy of Coal Combustion: Widespread Contamination of Lake Sediments and Implications for Chronic Risks to Aquatic Ecosystems*, Envtl. Sci. & Tech., Oct. 3, 2022, available at https://pubs.acs.org/doi/10.1021/acs.est.2c04717.

114 *See* Environmental Integrity Project, Earthjustice, et al., *Closing the Floodgates: How The Coal Industry Is Poisoning Our Water and How We Can Stop It* (2013) p. 1 https://earthjustice.org/sites/default/files/ClosingTheFloodgates-Final.pdf.

115 This is a decrease from 100 million. *See* American Coal Ash Association, 2020 Coal Combustion Product (CCP) Production and Use Survey Report, available at https://acaa-usa.org/wp-content/uploads/2021/12/2020-Production-and-Use-Survey-Results-FINAL.pdf; U.S. EPA, *Final Rule: Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities* (Apr. 17, 2015) Fed. Reg. 80, 21303 https://www.federalregister.gov/documents/2015/04/17/2015-00257/hazardous-and-solid-waste-management-system-disposal-of-coal-combustion-residuals-from-electric.

116 U.S. EPA, *Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (Sep. 2015) pp. 3-13, 3-34, 3-38, https://www.epa.gov/sites/production/files/2015-10/documents/steam-electric-envir_10-20-15.pdf.

117 *See* Environmental Integrity Project, Earthjustice, et al., *Closing the Floodgates: How The Coal Industry Is Poisoning Our Water and How We Can Stop It* (2013) p. 1 https://earthjustice.org/sites/default/files/ClosingTheFloodgates-Final.pdf.

118 Physicians for Social Responsibility, *Coal Ash Toxics: Damaging to Human Health* (2018) https://www.psr.org/wp-content/uploads/2018/05/coal-ash-toxics.pdf.

119 C. Rowe et al., *Ecotoxicological Implications of Aquatic Disposal of Coal Combustion Residues in the United States: A Review*, Environmental Monitoring and Assessment Vol. 80: 207-276 (2002) pp. 215, 229-231 https://www.ecophys.fishwild.vt.edu/wp-content/uploads/rowe-et-al.-2002-coal-waste.pdf

120 C. Rowe et al., *Ecotoxicological Implications of Aquatic Disposal of Coal Combustion Residues in the United States: A Review*, Environmental Monitoring

and Assessment Vol. 80: 207-276 (2002) pp. 215, 231-247 https://www.ecophys.fishwild.vt.edu/wp-content/uploads/rowe-et-al.-2002-coal-waste.pdf

121 C. Rowe *et al., Ecotoxicological Implications of Aquatic Disposal of Coal Combustion Residues in the United States: A Review*, Environmental Monitoring and Assessment Vol. 80: 207-276 (2002) pp. 215, 231-236 https://www.ecophys.fishwild.vt.edu/wp-content/uploads/rowe-et-al.-2002-coal-waste.pdf. *See generally*, A.D. Lemly, *Selenium Impacts on Fish: An Insidious Time Bomb*, Human and Ecological Risk Assessment Vol. 5, No. 6 (1999) https://www.fs.usda.gov/treesearch/pubs/1361.

122 See A.D. Lemly, *Symptoms and implications of selenium toxicity in fish: the Belews Lake case example*, Aquatic Toxicology Vol. 57 No. 39 (2002) https://www.srs.fs.usda.gov/pubs/ja/ja_lemly013.pdf.

123 Physicians for Social Responsibility, *Coal Ash Toxics: Damaging to Human Health*, supra n. 79 (noting, for example, that when mercury "has accumulated to high concentrations in fish, this becomes a major pathway for human exposure").

124 *See* Lemly, A.D. and Skorupa J. P. 2012. *Wildlife and the Coal Waste Policy Debate: Proposed Rules for Coal Waste Disposal Ignore Lessons from 45 Years of Wildlife Poisoning. Environmental Science and Technology 46 (16): 8595-8600* and Lemly, A.D. 2010. *A White Paper on Environmental Damage from Coal Combustion Waste: The Cost of Poisoned Fish and Wildlife.* Prepared for U.S. Environmental Protection Agency Office of Resource Conservation and Recovery. EPA Docket ID No. EPA–HQ–RCRA–2009–0640.

125 *See* Environmental Integrity Project, *Coal's Poisonous Legacy Groundwater Contaminated by Coal Ash Across the U.S.* (Jul. 11, 2019) p. 17 http://www.environmentalintegrity.org/wp-content/uploads/2019/03/National-Coal-Ash-Report-Revised-7.11.19.pdf ("Coal ash dumps in contact with groundwater are expected to have more frequent and more severe contamination, as coal ash constituents can be directly leached into groundwater. To avoid this heightened risk, the Coal Ash Rule requires existing ash ponds and new ash landfills to be separated from groundwater by a certain distance. Specifically, they must be built "with a base that is no less than 1.52 meters (five feet) above the upper limit of the uppermost aquifer" unless an owner can demonstrate that there is never any connection between a coal ash unit and the underlying groundwater aquifer") (citing 40 CFR §257.60). See also, T. Praharaj, et al, *Delineation of groundwater contamination around an ash pond: Geochemical and GIS Approach*, Environment International Vol. 27(8) pp. 631-638 (Mar. 2002) https://www.sciencedirect.com/science/article/pii/S0160412001001210. (investigating levels of metal contamination in groundwater due to particulate matter fallout and leaching from ash pond); C. Verma, et al, Heavy metal contamination of groundwater due to fly ash disposal of coal-fired thermal power plant, Parichha, Jhansi, India, Cogent Engineering Vol. 3(1) (Jun. 2, 2017) (finding coal ash leachate produced groundwater pollution levels of heavy metals above limits prescribed by the World Health Organization).

126 RTI, *Human and Ecological Risk Assessment of Coal Combustion Wastes* (2007) http://www.southeastcoalash.org/wp-content/uploads/2012/10/epa-coal-combustion-waste-risk-assessment.pdf (the "infiltration rate," meaning the "average rate at which water percolates through the landfill over time" is "greatly influenced by whether and how a WMU [Waste Management Unit] is lined").

127 RTI, *Human and Ecological Risk Assessment of Coal Combustion Wastes* (2007) Section 3.4 http://www.southeastcoalash.org/wp-content/uploads/2012/10/epa-coal-combustion-waste-risk-assessment.pdf.

128 Environmental Integrity Project and Earthjustice, *Groundwater Poisoned by Coal Ash Across the United States: A Comprehensive Survey of Monitoring Data Generated by the 2015 Coal Ash Rule* (Feb. 28, 2019) https://earthjustice.org/features/map-coal-ash-contaminated-sites. An updated analysis of monitoring data in 2022 by Earthjustice and the Environmental Integrity Project confirmed that 91 percent of U.S. coal plants are continuing to contaminate groundwater above federal standards.

129 *See* Environmental Integrity Project and Earthjustice, *Groundwater Poisoned by Coal Ash Across the United States: A Comprehensive Survey of Monitoring Data Generated by the 2015 Coal Ash Rule* (July 23, 2019) https://earthjustice.org/features/map-coal-ash-contaminated-sites.

130 Earthjustice and Physicians for Social Responsibility, *Ash in Lungs: How Breathing Coal Ash is Hazardous to Your Health*, (Jul. 2014) p.3 https://earthjustice.org/blog/2014-july/ash-in-lungs-how-breathing-coal-ash-is-hazardous-to-your-health.

131 Id.

132 Id.

133 J. Thorac, *Air particulate matter and cardiovascular disease: the epidemiological, biomedical and clinical evidence*, Journal of Thoracic Disease Vol. 8(1): E8-E19 (2016) p. E14 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4740122/; *see also* U.S. EPA, *Linking Air Pollution and Heart Disease* https://www.epa.gov/sciencematters/linking-air-pollution-and-heart-disease.

134 Valencic, Aaron. "Dust Suppression in Coal Ash Applications," 2013 World of Coal Ash (WOCA) Conference, Lexington, KY, available at http://www.flyash.info/2013/098-Valencic-2013.pdf.

135 *See* Earthjustice and Physicians for Social Responsibility, *Ash in Lungs: How Breathing Coal Ash is Hazardous to Your Health*, (Jul. 2014) https://earthjustice.org/blog/2014-july/ash-in-lungs-how-breathing-coal-ash-is-hazardous-to-your-health.

136 Earthjustice and Physicians for Social Responsibility, *Ash in Lungs: How Breathing Coal Ash is Hazardous to Your Health*, (Jul. 2014) p.5 https://earthjustice.org/blog/2014-july/ash-in-lungs-how-breathing-coal-ash-is-hazardous-to-your-health.

137 Id.

138 Id.

139 IARC, 100C IARC Monographs, *Silica dust, crystalline, in the form of quartz or cristobalite* (2012) p. 370 https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100C-14.pdf.

140 R. Raja, et al, *Impairment of soil health due to fly ash-fugitive dust deposition from coal-fired thermal power plants*, Environmental Monitoring and Assessment, Vol. 187(11) p. 679 (Nov. 2015) https://www.ncbi.nlm.nih.gov/pubmed/26450689 (fly ash fugitive dust was "found in the close proximity of power plants, which led to high pH and greater accumulation of heavy metals").

141 B. Gottlieb, S. Gilbert, L. Evans, *Coal Ash: The toxic threat to our health and environment*, Physicians for Social Responsibility and Earthjustice (2010) p. vi https://www.psr.org/wp-content/uploads/2018/05/coal-ash.pdf.

142 *See* J. Satterfield, Knox News, *Sickened Kingston coal ash workers left with faulty, manipulated test results* (Sep. 2, 2018) Knox News https://www.knoxnews.com/story/news/crime/2018/09/02/kingston-coal-ash-spill-faulty-manipulated-testing/1126963002/. Nearly a decade after the TVA Kingston spill in 2008, more than 50 cleanup workers are dead and at least 200 are sick or dying — all with common ailments known to be caused by long-term exposure to arsenic, radium and the host of other toxins and metals found in the ash. https://wpln.org/post/kingston-coal-ash-cleanup-workers-still-seek-damages-more-than-13-years-after-spill/; *See also*, L. Jamali, Marketplace, NPR, *They cleaned the U.S.' largest coal ash spill: many have died waiting for compensation*, (Sep 26,2022) https://www.marketplace.org/2022/09/26/they-cleaned-u-s-largest-coal-ash-spill-many-have-died-waiting-for-compensation/

143 M. Cimitile, Scientific American, *Is Coal Ash in Soil a Good Idea?* (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/; *see also* J.J. Bilski & A.K. Alva, *Transport of Heavy Metals and Cations in a Fly Ash Amended Soil*, Bull. Envtl. Contamination & Toxicology Vol. 55 No. 502 (1995) https://link.springer.com/article/10.1007/BF00196028; R.L. Aitken & L.C. Bell, *Plant Uptake and Phytotoxicity of Boron in Australian Fly Ashes*, Plant and Soil Vol. 84, No. 245 (1985) p. 245 https://www.jstor.org/stable/42935594?seq=1#page_scan_tab_contents; J.T. Sims et al., *Evaluation of Fly Ash as a Soil Amendment for the Atlantic Coast Plain: Soil Chemical Properties and Crop Growth, Water, Air and Soil Pollution* Vol. 81 No. 363 (1995); A. Singh et al., *Effects of Fly Ash Incorporation on Heavy Metal Accumulation, Growth and Yield Responses of Beta vulgaris Plants*, Bioresource Tech. Vol. 99 No. 7200 (2008); S.S. Brake et al., *Effects of Coal Fly Ash Amended Soils on Trace Element Uptake in Plants*, Envtl. Geology Vol. 45 No. 680 (2003); A.K. Gupta & S. Sinha, *Growth and Metal Accumulation Response of Vigna radiata L. var PDM 54 (Mung Bean) Grown on Fly-Ash Amended Soil: Effect on Dietary Intake*, Envtl. Geochem. & Health Vol. 31 No. 463 (2009); D.C. Adriano et al., *Effects of High Rates of Coal Fly Ash on Soil, Turfgrass, and Groundwater Quality, Water, Air, and Soil Pollution* Vol. 139 No. 365 (2002).

144 M. Cimitile, Scientific American, *Is Coal Ash in Soil a Good Idea?* (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/

145 S. Adak, K. Adhikari, K. Brahmachari, *Effect of Fly Ash on Crop Coverage around Coal-Fired Thermal Power Plant in Rural India*, International Journal of Environment, Agriculture and Biotechnology (IJEAB) Vol-1, Issue-3 (Sep. 2016) http://dx.doi.org/10.22161/ijeab/1.3.34.

146 Id.

147 Id.

148 J. Hardcastle, Environmental Leader, *Radioactive Contaminants Found in Coal Ash* (Sep. 8, 2015) https://www.environmentalleader.com/2015/09/radioactive-contaminants-found-in-coal-ash/. (reporting on a Duke University-led study that showed the presence of radioactive contaminants in coal ash from all three major U.S. producing coal basins) (citing N. Lauer, et al, *Naturally Occurring Radioactive Materials in Coals and Coal Combustion in the United States*, Environmental Science and Technology Vol. 49(18) (Sep. 2, 2015) pp. 11227-11233 https://pubs.acs.org/doi/10.1021/acs.est.5b01978).

149 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) p. 39 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.

150 *See* N. Lauer, J. Hower, H. Hsu-Kim, R.Taggart, A. Vengosh, *Naturally Occurring Radioactive Materials in Coals and Coal Combustion Residuals in the United States*, Environmental Science & Technology Vol. 49 No. 18 (Sep. 2, 2015) pp. 11227-11232 https://pubs.acs.org/doi/10.1021/acs.est.5b01978.

151 Id.

152 Id.

153 Y. Sun, G. Qi, X. Lei, H. Xu, Y. Wang, *Extraction of uranium in bottom ash*

derived from high-germanium coals, Procedia Environmental Sciences Vol. 31 (2016) p. 590 https://cyberleninka.org/article/n/1386508.pdf; *See also* O.D. Maslov, S. Tserenpil, N. Norov, M.V. Gustova, et al, *Uranium Recovery from Coal Ash Dumpes of Mongolia*, Solid Fuel Chemistry Vol. 44 No. 6 (2010) pp. 433-438 https://www.researchgate.net/publication/226511436_Uranium_recovery_from_coal_ash_dumps_of_Mongolia.

154 Dez ML. Dinis, et al, *Modeling Radionuclides Dispersion and Deposition Downwind of a Coal-Fired Power Plant*, Procedia Earth and Planetary Science Vol. 8 (2014) pp. 59-63 https://www.sciencedirect.com/science/article/pii/S1878522014000149.

155 A becquerel (Bq) is the SI derived unit of radioactivity. One becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second.

156 Israeli National Coal Ash Board, *Radioactive Elements* http://www.coal-ash.co.il/english/info_radio.html

157 Id.

158 These values represent levels of radioactive materials in CCRs from the Illinois, Appalachian and Power River Basins. See, N. Lauer, J. Hower, H. Hsu-Kim, R. Taggart, A. Vengosh. *Naturally Occurring Materials in Coal Combustion Residuals in the United States*, Environ. Sci. Technology, 2015, 49, 18, 11227–11233, https://pubs.acs.org/doi/10.1021/acs.est.5b01978

159 Z. Papp, Z. Dezső, S. Daróczy, *Significant radioactive contamination of soil around a coal-fired thermal power plant*, Journal of Environmental Radioactivity, Vol. 59 No. 2 (2002) pp. 191-205 https://www.sciencedirect.com/science/article/pii/S0265931X01000716.

160 *See* K. Asaduzzaman, F. Mannan, M. Khandaker, M. Farook, A. Elkezza, Y. Amin, et al., *Assessment of Natural Radioactivity Levels and Potential Radiological Risks of Common Building Materials Used in Bangladeshi Dwellings*, PloS ONE 10(10): e0140667 (Oct. 16, 2015) https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0140667.

161 S. Slesinger, *Coal Ash: Why it is better recycled than as a waste* (Feb. 13, 2014) https://www.nrdc.org/experts/scott-slesinger/coal-ash-why-it-better-recycled-waste.

162 M. Thomas, Ph.D, Professor of Civil Engineerings, University of New Brunswick, Portland Cement Association, *Optimizing the Use of Fly Ash in Concrete* (2007) https://www.cement.org/docs/default-source/fc_concrete_technology/is548-optimizing-the-use-of-fly-ash-concrete.pdf.

163 Id.

164 U.S. EPA, *Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard* (Feb. 2014) p. iii https://www.epa.gov/sites/production/files/2014-12/documents/ccr_bu_eval.pdf.

165 Id.

166 Id.

167 R. Siddique, Thapar University, Patiala, India, *Wear Resistance of High-Volume Fly Ash Concrete*, 17 Leonardo Journal of Sciences 21-36 (Dec. 30, 2010) https://www.researchgate.net/publication/49596783_Wear_Resistance_of_High-Volume_Fly_Ash_Concrete.

168 U.S. EPA, *Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard* (Feb. 2014) p. 4 https://www.epa.gov/sites/production/files/2014-12/documents/ccr_bu_eval.pdf.

169 U.S. EPA, *Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard* (Feb. 2014) p. iii https://www.epa.gov/sites/production/files/2014-12/documents/ccr_bu_eval.pdf.

170 National Research Council, Division on Earth and Life Studies, *Managing Coal Combustion Residues in Mines*, (Aug. 14, 2006) p. 20 https://books.google.co.id/books?id=jqScAgAAQBAJ&pg=PT34&lpg=PT34&dq=Landfills+are+usually+built+in+sections+called+%E2%80%9Ccells,%E2%80%9D+in+which+dry+ash+is+placed+in+an+%E2%80%9Cactive%E2%80%9D+cell+and+-compacted+until+the+cell+is+filled.&source=bl&ots=Xh9i7ttUOV&sig=ACfU3U037kKMn7QzIl4d1DsYiaxSJVzVKA&hl=en&sa=X&ved=2ahUKEwjG8bzFucLmAhUjPn0KHR8ZCpcQ6AEwAHoECAoQAQ#v=onepage&q=Landfills%20are%20usually%20built%20in%20sections%20called%20%E2%80%9Ccells%2C%E2%80%9D%20in%20which%20dry%20ash%20is%20placed%20in%20an%20%E2%80%9Cactive%E2%80%9D%20cell%20and%20compacted%20until%20the%20cell%20is%20filled.&f=false.

171 Id.

172 Tennessee Valley Authority and U.S. EPA, *Effects of Coal-ash Leachate on Ground Water Quality*, (1980) p. xii https://nepis.epa.gov/Exe/ZyNET.exe/9101FPKG.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1976+Thru+1980&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C76thru80%5CTxt%5C00000030%5C9101FPKG.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL (stating "The dry disposal of coal-ash… can generate ash leachate with water from direct precipitation and/or rainfall runoff").

173 U.S. EPA, *Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills – Draft* (May 2010) § 2.1 https://www.efis.psc.mo.gov/mpsc/commoncomponents/viewdocument.asp?DocId=935784779.

174 EPA, Human and Ecological Risk Assessment of Coal Combustion Residuals, Docket ID No. EPA-HQ-RCRA-2009-0640-11993, at 5-5, tbl. 5-3 (Dec. 2014) ("Sensitivity analyses on liner type indicate that disposal of CCR wastes in unlined surface impoundments and landfills presents the greatest risks to human health and the environment").

175 National Research Council, Division on Earth and Life Studies, *Managing Coal Combustion Residues in Mines*, (Aug. 14, 2006) p. 20, supra n. 171.

176 Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities, 80 Fed. Reg. 21,302 ("Particulate solids from the waste stream gravitationally settle while clarified waters ultimately discharge into nearby streams and wetlands").

177 National Research Council, Division on Earth and Life Studies, *Managing Coal Combustion Residues in Mines*, (Aug. 14, 2006) p. 20, supra n. 169.

178 L. Ruhl, A. Vengosh, G. Swyer, H. Hsu-Kim, G. Schwartz, A. Romanski, S. Smith, *The impact of coal combustion residue effluent on water resources: A North Carolina example*, Environmental Science & Technology Vol. 46 No. 21 (Sep. 2012) p. A https://pubs.acs.org/doi/10.1021/es303263x; *see also* J. Harkness, B. Sulkin, A. Vengosh, *Evidence for coal ash ponds leaking in the southeastern United States*, Environmental Science & Technology Vol. 50 No. 12 (Jun. 2016) p. 6591 https://pubs.acs.org/doi/abs/10.1021/acs.est.6b01727.

179 American Coal Ash Association, *Frequently Asked Questions* https://www.acaa-usa.org/aboutcoalash/ccpfaqs.aspx (If the material can be piped, rather than trucked, costs are usually lower. In these types of situations, cost may be as low as $3.00 to $5.00 per ton).

180 *See* Environmental Integrity Project, *Ashtracker* www.ashtracker.org; *see also* Environmental Integrity Project, *Groundwater Contamination from Texas Coal Ash Dumps* (Jan. 17, 2019) https://earthjustice.org/sites/default/files/files/Texas-Coal-Ash-Report.pdf; J. Bruggers, Inside Climate News, *Coal Ash Is Contaminating Groundwater in at least 22 States*, Utility Reports Show (Jan. 18, 2019) https://insideclimatenews.org/news/16012019/coal-ash-groundwater-contamination-map-arsenic-power-plant-utility-reports.

181 80 Fed. Reg. 21,328.

182 *Polluted Power: How Koradi & Khaperkheda Thermal Power Stations are Impacting the Environment*, Manthan Adhyayan Kendra (18 Nov. 2021), available at https://www.manthan-india.org/pollut ed-power-how-koradi-khaperkheda-thermal-power-stations-are-impacting-the-environment/.

183 80 Fed. Reg. 21,325 (summarizing cases where unlined liners led to contamination of ground and surface water).

184 S. Sturgis, Facing South, *EPA releases locations of high-hazard coal ash dumps; most are in the South* (Jun. 30, 2009) https://www.facingsouth.org/2009/06/epa-releases-locations-of-high-hazard-coal-ash-dumps-most-are-in-the-south.html (quoting EPA Administrator Lisa Jackson who stated "The presence of liquid coal ash impoundments near our homes and business could pose a serious risk to life and property in the event of an impoundment rupture"); see also U.S. EPA, EPA Posts List of 44 *"High Hazard Potential" Coal Ash Waste Impoundments* (Jun. 29, 2009) https://archive.epa.gov/epapages/newsroom_archive/newsreleases/078f5ec6b5804809852575e4006f980b.html.

185 U.S. EPA, *EPA Response to Kingston TVA Coal Ash Spill* https://www.epa.gov/tn/epa-response-kingston-tva-coal-ash-spill.

186 *See Coal Ash in India: A Compendium of Disasters, Environmental and Health Risks*, Healthy Energy Initiative (July 2020), *available at* http://www.indiaenvironmentportal.org.in/files/file/Coal-Ash-in-India-A-compendium-of-Disasters-Environmental-and-Health-Risks.pdf.

187 *Abel News*, Abel Pump Technology (2015) https://www.abelpumps.com/Newsletter/ABEL_News_March_2015.html (claiming "Ash slurry with 65% concentration… with such little water content the dry ash solidifies in 3 to 5 hours").

188 Vedanta, *Power Plant*, http://www.vedantaaluminium.com/operations-cpp.htm (the plant at Jharsuguda "has adopted the state-of-art Digital Control System, High Concentration Slurry Disposal (HCSD) of fly & bottom ash").

189 *See* The Center for Media and Democracy, Source Watch, *TVA Kingston Fossil Plant coal ash spill* https://www.sourcewatch.org/index.php/TVA_Kingston_Fossil_Plant_coal_ash_spill.

190 *See* Scientific American, *The Lasting Damage of the Tennessee Coal Ash Spill* https://www.scientificamerican.com/article/tennessee-coal-ash-spill/.

191 *See* J. Satterfield, Knoxville News Sentinel, *Jury: Jacobs Engineering endangered Kingston disaster clean-up workers* (Nov. 7, 2018) https://www.knoxnews.com/story/news/crime/2018/11/07/verdict-reached-favor-sickened-workers-coal-ash-cleanup-lawsuit/1917514002/.

192 *See* J. Bruggers, Inside Climate News, *A Coal Ash Spill Made These Workers Sick. Now, They're Fighting For Compensation* (Dec. 4, 2018) https://

insideclimatenews.org/news/04122018/toxic-coal-ash-spill-illness-verdict-kingston-tennessee-cleanup-workers-compensation.
193 M. Mohanty, Economic Times, *After breach in ash pond, five power units of Vedanta ordered shut*, (Sep. 14, 2017) https://economictimes.indiatimes.com/industry/indl-goods/svs/metals-mining/after-breach-in-ash-pond-five-power-units-of-vedanta-ordered-shut/articleshow/60517305.cms.
194 The New Indian Express, *Show cause to Vedanta for ash pond breach* (Sep. 8, 2017) https://www.newindianexpress.com/states/odisha/2017/sep/08/show-cause-to-vedanta-for-ash-pond-breach-1654015.html ("after the breach of ash pond, concentration of total suspended solids (TSS) content in the downstream of the site in Bheden river stands at a massive 2,812 mg/litre against 66 mg/litre observed in the river's upstream").
195 Odisha Sun Times Bureau, *Vedanta ash pond wall collapses in Odisha's Jharsuguda; paddy fields affected* (Aug. 29, 2017) https://odishasuntimes.com/vedanta-ash-pond-wall-collapses-in-odishas-jharsuguda/.
196 *See* M/s Vedanta Limited, *Pre-feasibility report for the proposed expansion of aluminium smelter production capacity from 16 LTPA smelter & `1`5 MW CPP to 18 LTPA smelter & 1215 MW CPP at Bhurkamunda/Brundamal Village, Jharsuguda District, Odisha* (November 2017) http://environmentclearance.nic.in/writereaddata/Online/TOR/02_Nov_2017_171422177BF9EUACEAnnexure-Pre-feasibilityReport.pdf.
197 C. Colopy, Himal South Asian, *Regulator and regulated breaching the law in Odisha* (Feb. 1, 2019) https://himalmag.com/cheryl-colopy-odisha-vedanta-pollution-2019/.
198 Earthjustice, *Waste Deep: Filling Mines with Coal Ash is Profit for Industry, But Poison for People* https://earthjustice.org/sites/default/files/library/reports/earthjustice_waste_deep.pdf.
199 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) p. 17 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.
200 Earthjustice, *Waste Deep Filling Mines with Coal Ash Is Profit for Industry, But Poison for People* (Jan. 2009) https://earthjustice.org/sites/default/files/library/reports/earthjustice_waste_deep.pdf (Estimating 24 million tons of coal ash are placed in active or abandoned mines each year).
201 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) p. 17 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.
202 Id.
203 *See* Earthjustice et al., Petition for the Issuance of Rules to the Office of Surface Mining Reclamation and Enforcement (2015) https://www.osmre.gov/programs/rcm/petitions/WEGPetition041414.pdf.
204 The National Academies of Sciences, *Managing Coal Combustion Residues in Mines* (2006) https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.
205 Id. at p. 5 https://www.nap.edu/catalog/11592/managing-coal-combustion-residues-in-mines.
206 Rachel Weinberg, Rachel Coyte, Zhen Wang, Debabrata Das, & Avner Vengosh, *Water quality implications of the neutralization of acid mine drainage with coal fly ash from India and the United States*, Fuel, vol. 330 (Dec. 2022), *available at* https://www.sciencedirect.com/science/article/abs/pii/S0016236122025042.
207 S. Sturgis, Facing South, *Dumpsites in Disguise* (May 27, 2010) https://www.facingsouth.org/2010/05/dumpsites-in-disguise.html.
208 See id.
209 N.L. Ukwattage, et al., *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 402 https://www.sciencedirect.com/science/article/pii/S001623611300104X; S. Brake, R. Jensen, J.M. Mattox, *Effects of coal fly ash amended soils on trace element uptake in plants*, Environmental Geology, Vol. 45 No. 5 (Mar. 2004) pp. 680-689 https://www.researchgate.net/publication/225454292_Effects_of_coal_fly_ash_amended_soils_on_trace_element_uptake_in_plants; M. Cimitile, Coal Ash in Soil a Good Idea? Scientific American, Is (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/; A. Singh et al., *Effects of Fly Ash Incorporation on Heavy Metal Accumulation, Growth and Yield Responses of Beta Vulgaris Plants*, 99 Bioresource Tech. 7200 (2008); R. Sahu & R. Padhy, *Growth, Yield and Elemental Status of Rice (Oryza Sativa) Grown in Fly-Ash Amended Soil*, 16 Ecotoxicology 271 (2007); A. Gupta & S. Sinha, *Growth and Metal Accumulation Response of Vigna radiata L. var PDM 54 (Mung Bean) Grown on Fly-Ash Amended Soil: Effect on Dietary Intake*, 31 Envtl. Geochem. & Health 463 (2009).
210 N.L. Ukwattage, P.G. Ranjith, M. Bouazza, *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 402 https://www.sciencedirect.com/science/article/pii/S001623611300104X.
211 C. Carlson, D. Adriano, *Environmental Impacts of Coal Combustion Residues*, Journal of Environmental Quality Vol. 22 No. 2 (Jan. 2009) pp. 227-242 https://www.researchgate.net/publication/255063266_Environmental_Impacts_of_Coal_Combustion_Residues.
212 N.L. Ukwattage, et al., *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 403 https://www.sciencedirect.com/science/article/pii/S001623611300104X.
213 Id.
214 Id.
215 N.L. Ukwattage, et al., *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 402 https://www.sciencedirect.com/science/article/pii/S001623611300104X.
216 M. Cimitile, Scientific American, *Is Coal Ash in Soil a Good Idea?* (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/.
217 N.L. Ukwattage, et al., *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 403 https://www.sciencedirect.com/science/article/pii/S001623611300104X. For mercury, see K. Schroeder and C. Kaires, *Distribution of Mercury in FGD byproducts*, 2005 World of Coal Ash (2005), http://www.flyash.info/2005/100sch.pdf.
218 Id.
219 When the amount of fly ash increased, the crops absorbed higher concentrations of arsenic and titanium. Basil and zucchini contained potentially toxic amounts of arsenic exceeding 6 parts per million. Concentrations of greater than 2 ppm had severe effects on vegetables, damaging the plants and decreasing production. S. Brake, R. Jensen, J.M. Mattox, *Effects of coal fly ash amended soils on trace element uptake in plants*, Environmental Geology, Vol. 45 No. 5 (Mar. 2004) pp. 680-689 https://www.researchgate.net/publication/225454292_Effects_of_coal_fly_ash_amended_soils_on_trace_element_uptake_in_plants; *See also* M. Cimitile, Scientific American, *Is Coal Ash in Soil a Good Idea?* (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/ ("Although the potential human health effects are unknown, fly ash fertilization can lead to possible toxic accumulation in crops if not monitored properly").
220 N.L. Ukwattage et al., *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 402 https://www.sciencedirect.com/science/article/pii/S001623611300104X.
221 N. Ukwattage et al. 2013, citing L .Sale et al. *Temporal influence of fly ash on select soil physical properties*, Can J Soil Sci 1997;77:677–83.
222 K. Schroeder and C. Kaires, *Distribution of Mercury in FGD byproducts*, 2005 World of Coal Ash (2005), http://www.flyash.info/2005/100sch.pdf.; M. Cimitile, Is Coal Ash in Soil a Good Idea? Scientific American (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/.
223 Id.
224 N.L. Ukwattage et al. *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 402 https://www.sciencedirect.com/science/article/pii/S001623611300104X.
225 N.L. Ukwattage et al. *The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon)*, Fuel Vol. 109 (July 2013) p. 402 https://www.sciencedirect.com/science/article/pii/S001623611300104X; M. Cimitile, Scientific American, *Is Coal Ash in Soil a Good Idea?* (Feb.6, 2009) https://www.scientificamerican.com/article/coal-ash-in-soil/;
226 U.S. EPA, *Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments*, 40 C.F.R. Part 257, Subpart D (2015) https://www.govinfo.gov/app/details/CFR-2016-title40-vol27/CFR-2016-title40-vol27-part257-subpartD.
227 *See* B. Kleinmann, 2017 World of Coal Ash Conference, Lexington, KY, *Coal Combustion Residuals and Groundwater: It's Complicated* (May 9-11, 2017), http://www.flyash.info/2017/024-Kleinmann-woca2017p.pdf.
228 See Elec. *Power Research Inst., Evaluation and Modeling of Cap Alternatives at Three Unlined Coal Ash Impoundments* at 5-1 (Sept. 25, 2001), available at https://www.epri.com/research/products/000000000001005165. ("[W]hen ash remains below the water table, dewatering may be less effective because groundwater continues to leach constituents from the saturated ash, particularly if the impoundment is underlain by geologic media with relatively high rates of groundwater flow. In the case of [one power plant included in the study], concentrations increased because groundwater contact time with the saturated ash increased when the hydraulic gradient of the pond was removed.").
229 *See* 40 C.F.R. §§ 257.60-64.
230 *See* 40 C.F.R. § 257.60; *See also* 25 Pa. Code § 290.411.
231 *See* 40 C.F.R § 257.61.
232 *See* 40 C.F.R. § 257.62.
233 *See* 40 C.F.R. § 257.63.
234 *See* 40 C.F.R. § 257.64.
235 *See* 40 C.F.R. § 257.8.
236 *See* 40 C.F.R. § 257.70(b).

237 *See* 40 C.F.R. § 264.301(c)(1)(i).
238 *See* 40 C.F.R. § 257.70(d).
239 *See* J. Bass, *Avoiding failure of leachate collection systems*, 3 Waste Management & Research 233, (1985) https://www.sciencedirect.com/science/article/pii/0734242X85901132.
240 See 40 C.F.R. §§ 257.90-95.
241 See generally, 40 C.F.R. §§ 257.90-95. Some recommendations are more protective than the U.S. EPA regulations.
242 See 40 C.F.R. § 257.96-98.
243 See 40 C.F.R. § 257.96-98.
244 See generally 40 C.F.R. § 257.73.
245 See 40 C.F.R. § 257.73(d)(1)(v).
246 See 40 C.F.R. § 257.73(e)(i).
247 See 40 C.F.R. § 257.73(e)(ii).
248 *See* 40 C.F.R. § 257.73(e)(iii).
249 Liquefaction is the process of seemingly solid materials, like coal ash, acting non-solid (like a liquid) due to vibration or saturation. Liquefaction of coal ash can result in the flow of millions of tons of coal ash from a dike or landfill after a breach. *See* 40 C.F.R. § 257.73(e)(iv).
250 *See* 40 C.F.R. § 257.83.
251 *See*, for example, the US EPA's coal ash disposal rule at 40 C.F.R. § 257.80, which requires the owner or operator of a coal ash landfill to adopt measures that will effectively minimize coal ash from becoming airborne at the facility, including coal ash fugitive dust originating from coal ash units, roads, and other coal ash management and material handling activities.
252 *See* 40 C.F.R. § 257.84 pertaining to inspection requirements for CCR landfills.
253 40 CFR § 257.102(b); see also § 257.104(d).
254 *See* 40 C.F.R. § 257.96.
255 *See* 40 C.F.R. § 257.104 (pertaining to post-closure care requirements).
256 *See* 40 C.F.R. § 257.104.
257 *See* 40 C.F.R. § 257.96.
258 While US EPA failed to require financial assurance requirements for coal ash disposal units, the agency does require such bonding for owners and operators of hazardous waste facilities *See* 40 C.F.R. § 264, Subpart H (Financial Requirements). *See also* Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities; Financial Requirements, 47 Fed. Reg. 15032, 15044-45 (Apr. 7, 1982).
259 *See,* for example, 40 C.F.R. § 257.107. Note, however, that the U.S. federal rule requirements concerning the internet posting of documents fail to cover the full set of compliance documents. In addition, the federal rule lacks specificity regarding the required form of posted documents and data. These deficiencies have created gaps in available information and the dissemination of documents that lack transparency.