

APPENDIX B:

BACKGROUND OF RECOVERED MINERAL COMPONENTS

Background of Recovered Mineral Components

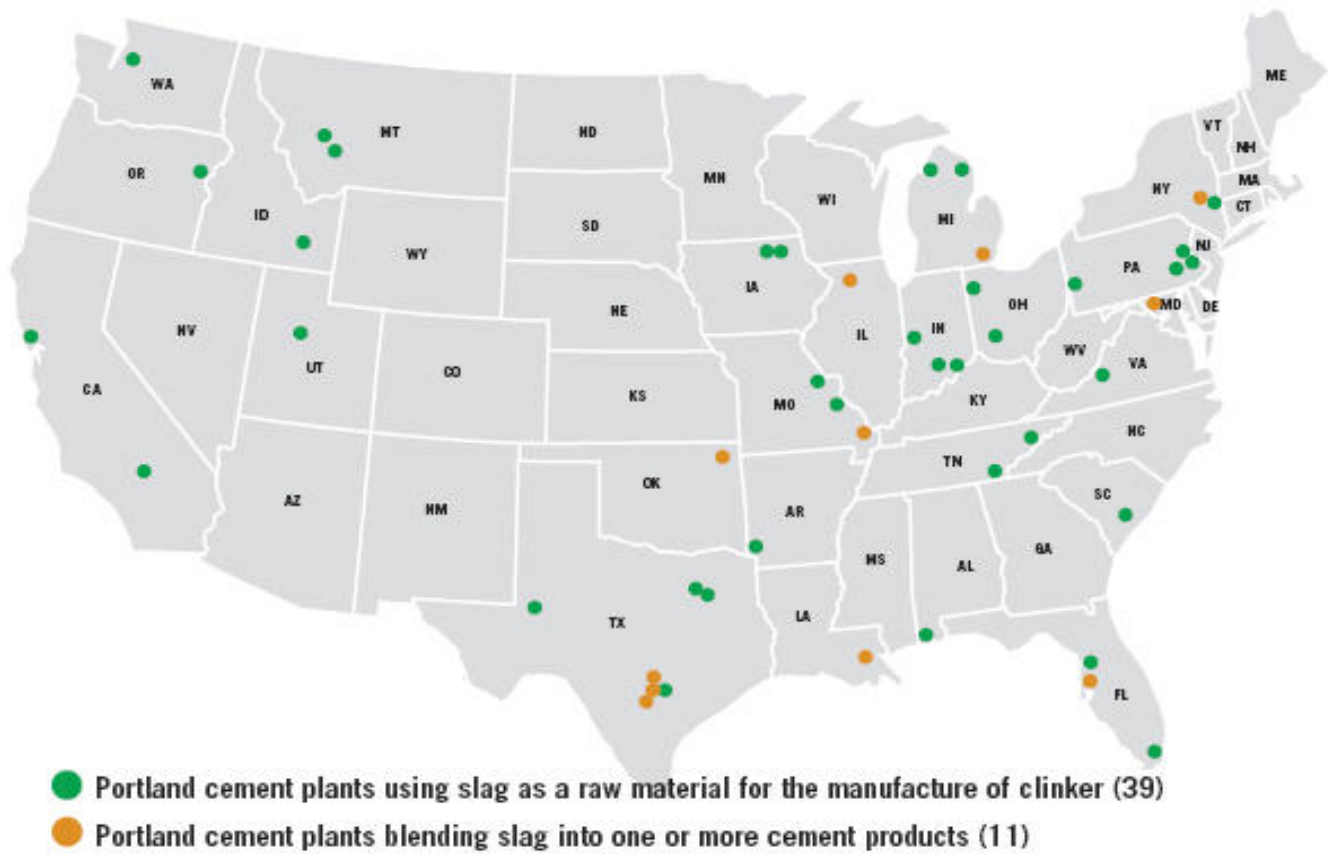
B.1 Iron and Steel Slags

Ferrous slags are by-products from iron and steel manufacturing. There are two main types of ferrous slags produced in the United State—blast furnace slags and steel slags. Blast furnace slags are produced during smelting of iron ore or iron pellets with coke and a flux, such as limestone or dolomite. The calcium in the stone combines with the aluminates and silicates in the ore and ash from the coke to produce this non-metallic material. The slag is removed from the furnace for further processing. Blast furnace slag has many uses, including the production of clinker and blended cements, and as an aggregate in portland cement concrete.

Steel slag is a byproduct from the processing of iron in a basic oxygen furnace (BOF) or scrap steel in an electric arc furnace (EAF). Steel slags also can be used in the manufacture of clinker. More information on steel slag is provided in section B.9. There is still some minor open hearth (OH) furnace material resident in slag piles that is occasionally sold. However, no OH slag is being produced anymore in this country.

In 2005, PCA estimates that 39 cement plants were using slag as a raw material the manufacture of clinker, and 11 plants were blending it into one or more cement products (see Figure B-1) (PCA, 2005).

Figure B-1: Portland Cement Plants Utilizing Slag



B.2 Blast Furnace Slag

Figure B-2: U.S. Blast Furnace Slag Producers



The chemical composition of blast furnace slag varies, but Table B-1 presents a typical range of values (FHWA, 1998).

Table B-1: Typical Chemical Composition of Blast Furnace Slag

Constituent	Mean	Range
-----percent by weight-----		
Calcium Oxide (CaO)	39.0	34 - 43
Silicon Dioxide (SiO ₂)	36.0	27 - 38
Aluminum Oxide (Al ₂ O ₃)	10.0	7 - 12
Magnesium Oxide (MgO)	12.0	7 - 15
Iron (FeO or Fe ₂ O ₃)	0.5	0.2 - 1.6
Manganese Oxide (MnO)	0.4	0.15 - 0.76
Sulfur (S)	1.4	1.0 - 1.9

The National Slag Association provided data on slag usage in concrete as aggregate and as a SCM for the years 1996 through 2005, which is summarized in Table B-2. These data were not broken out by slag type (i.e., granulated vs. air-cooled).

Table B-2: Blast Furnace Slag Production and Usage (National Slag Association Data)

Year	Estimated Slag Production	Slag Used as Concrete Aggregate	Slag Used as Supplementary Cementitious Material
	-----million metric tons-----		
1996	NA*	NA	1.0
1997	NA	1.27	1.2
1998	NA	1.27	1.4
1999	NA	1.36	1.6
2000	10.9	1.27	1.8
2001	9.5	1.36	2.2
2002	9.2	1.36	2.6
2003	9.3	1.36	2.7
2004	9.3	1.45	3.2
2005	10.3	NA	3.3

*NA = data not available

GBFS is a glassy granular material, consisting mainly of silicates and aluminosilicates of calcium. The particle distribution, shape, and grain size of GBFS vary, depending on the chemical composition and method of production, from coarse, popcornlike friable particles to dense, sand-size grains. Whereas portland cement typically is ground to around 3,000-3,500 cm²/g (Blaine) in the United States, granulated slag is typically ground even finer (to about 4,000 – 5,000 cm²/g (Blaine) to achieve satisfactory reactivity.

ASTM C 989 (AASHTO M302) classifies slag by its increasing level of reactivity as follows:

- Grade 80 - slags with low activity index
- Grade 100 - slags with a moderate activity index
- Grade 120 - slags with high activity index

GGBFS is a hydraulic material with inherent cementitious character, that is, it will set up and gain strength on its own when mixed with water. In the presence of alkalis such as may be present in a concrete mix with portland cement, these alkalis will accelerate the hydration of the slag cement to levels similar to that of portland cement. Because of its cementitious nature, it should be noted that 70% slag cement concrete mixtures are usually used to control heat of hydration in mass concrete placement. GGBFS has been used for many years as a SCM in portland cement concrete, either as a mineral admixture or as a component of blended cement. GGBFS slag, when used in general purpose concrete in North America, typically constitutes between 30% and 45% of the cementitious material in the mix. Some slag concretes have a slag component of 70% or more of the cementitious material (Kosmatka, 2002). GGBFS is used in making blended Portland blast furnace slag cement (IS). The use of GGBFS in blended cement is governed by ASTM C-595. The specific gravity of GGBFS is in the range of 2.85 to 2.95, and the bulk density varies from 1,050 to 1,375 kg/m³ (Kosmatka, 2002).

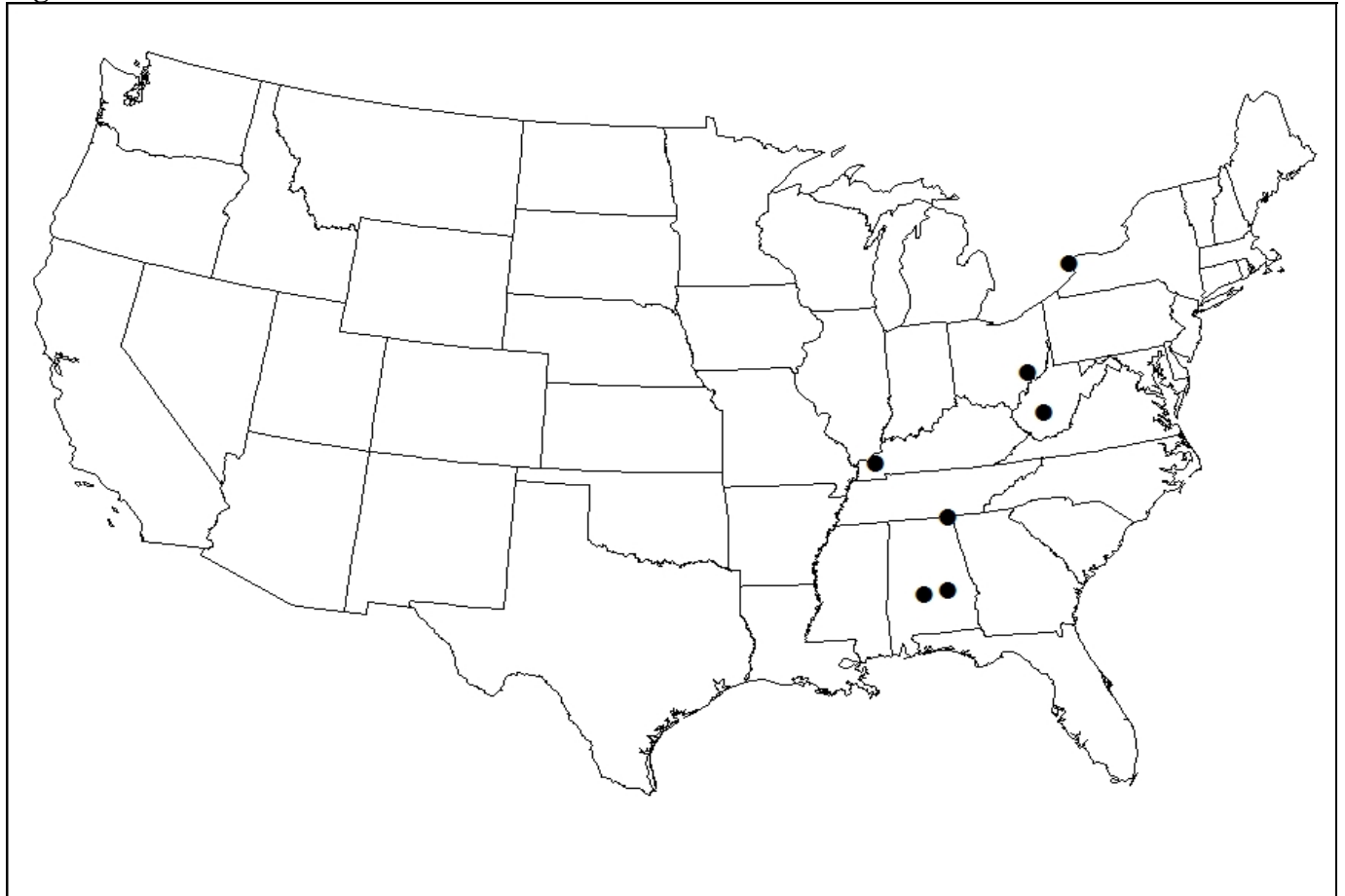
Performance Record

Florida, Maryland, New Hampshire, and Oregon state agencies are reported to be investigating the use of GGBFS as a SCM. At least 11 states (Delaware, Florida, Indiana, Maryland, Massachusetts, Michigan, New Hampshire, North Carolina (limited use on experimental basis), Pennsylvania, South Carolina and Virginia) currently have specifications covering the use of GGBFS as a partial replacement for portland cement. Some state agencies have reported durability problems (decreased salt scaling resistance) with exposed concrete containing blast furnace slag where the amount of GGBFS exceeds about 25% of the total cement.

B.3 Silica Fume

According to the Silica Fume Association, there are five companies producing silica fume in the United States. USGS data indicate that in 2004, silicon alloys and/or silicon metals were produced at six plants, and that a seventh plant was idle in 2004 (Corathers, 2004). Demand for silica fume is high, and the United States is currently importing silica fume from Venezuela, Spain, Argentina, Norway and Iceland. U.S. companies also export silica fume to Canada, Central America, and South America. Figure B-3 illustrates the location of silica fume producers in the United States. Appendix C contains a listing of U.S. silica fume producers.

Figure B-3: U.S Silica Fume Producers



Silica fume has been known to be a beneficial admixture to concrete since the late 1940's. However, silica fume did not become widely used until the development of high-range water-reducing admixtures or superplasticizers. These admixtures are necessary because the high surface area of silica fume increases water demand in concrete, which can have a detrimental effect on concrete properties. The use of water-reducing admixtures or superplasticizers can improve workability and placement of concrete at lower water contents, offsetting the need for additional water in mixes containing silica fume.

The addition of silica fume to concrete mixes improves finished concrete properties through both physical and chemical mechanisms. Physically, the extremely small size of silica fume particles allows them to occupy spaces between cement grains, an arrangement typically referred to as particle packing or micro-filling. Chemically, silica fume particles are highly pozzolanic (i.e., they react with calcium hydroxide (hydrated lime) to produce highly cementitious compounds) due to their high amorphous silicon dioxide content. Therefore, when portland cement releases calcium hydroxide as it hydrates, silica fume reacts with the calcium hydroxide to form additional binder material (DOT, 2005).

The addition of silica fume has two main effects on fresh concrete. First, it makes the concrete more cohesive, which reduces segregation and improves the efficiency of shotcreting. Second,

silica fume reduces the bleeding in concrete by reducing porosity and reacting with lime. Bleeding leads to the formation of capillary channels, which can increase chloride intrusion in finished concrete. In addition, eliminating bleeding allows concrete to be finished earlier, which is advantageous in projects where durability is important, such as in bridge decks or parking structures.

The percentage of silica fume used in high performance concrete (HPC) varies depending on the application and desired performance characteristics of the concrete, but typically ranges from 5% to 20% on a dry weight basis. HPC containing silica fume also often contains coal fly ash. Silica fume also can be used in concrete with other recovered materials such as GGBFS and cenospheres. Because silica fume costs more than portland cement and there are relatively low volumes available, its use is limited primarily to HPC.

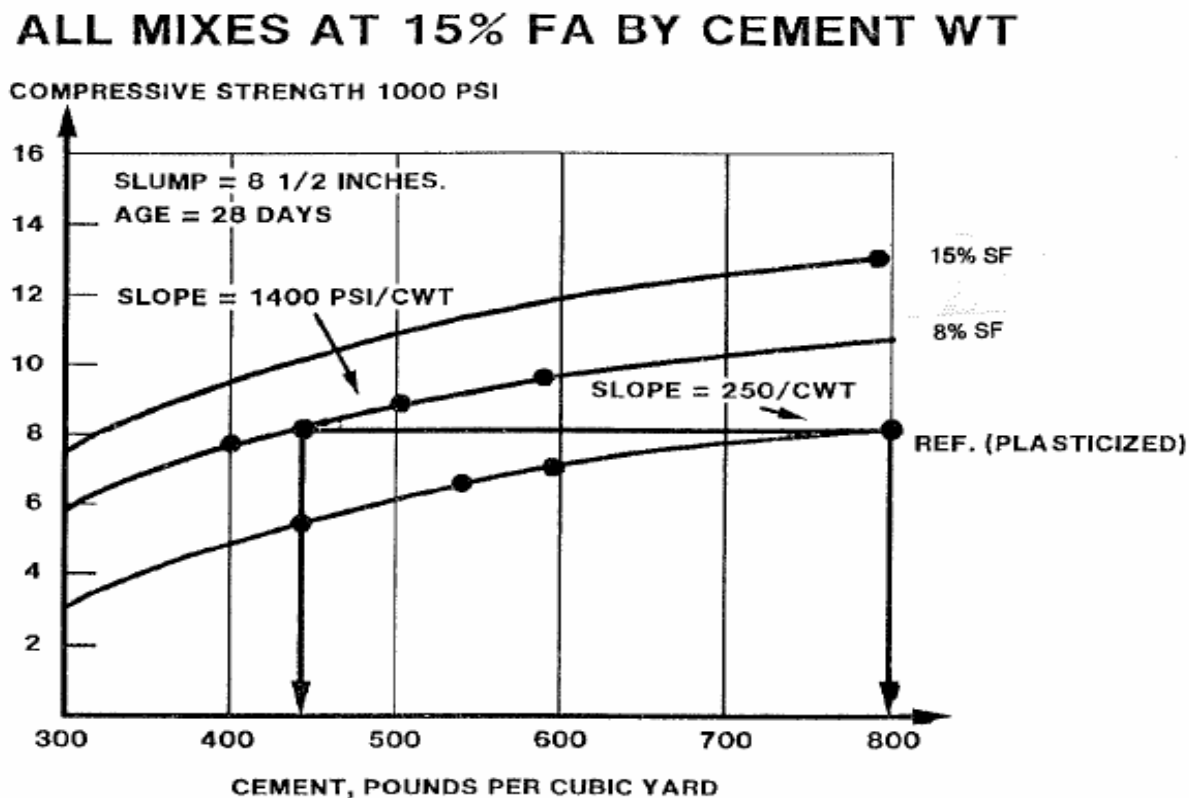
The increased strength of finished concrete with silica fume can mean that less cement is required in concrete mixes, though silica fume is usually used in addition to the standard amounts of portland cement.

Further, silica fume concrete only requires “single-pass” or “one-pass” finishing whereby the finishing is condensed into a single operation. In single-pass finishing, placement, consolidation, surface-closing, and texturing operations follow one another in succession. The concrete is then cured immediately. The total time from placement to final curing is recommended by the Federal Highway Administration (FHWA) to be less than 20 minutes. This rapid finishing technique is cost efficient, but quite different than normal construction practices used over the past 50 years.

Specifications regarding the use of silica fume in concrete can be found in ASTM C1240 (AASHTO M307). ACI 234R-06 describes the physical and chemical properties of silica fume, how silica fume interacts with portland cement, the effects of silica fume on the properties of fresh and hardened concrete, typical applications of silica fume concrete, and recommendations on proportions, specifications, and handling of silica fume in the field.

The Figure B-4 below shows typical concrete made with cement and 15% coal fly ash as substitution for cement. To this reference mix, 8% and 15% silica fume, based on cement weight, was added.

Figure B-4: Cement Mix Continuum



The figure above shows that the efficiency of a pound of cement to concrete strength increases significantly when 8% silica fume, by weight of cement, was added to the mix. The ability to generate increased strength from each pound of cement used means that less cement can be used to achieve a required compressive strength. Also, as the rate or 'slope' is reduced from 1400 to 250psi / cwt, the quality control necessary to achieve that strength becomes more difficult to implement.

B.4 Coal Fly Ash

The U.S. Department of Energy (DOE) conducts several annual surveys to collect data on electric power plants. One such survey (EIA-860: Annual Electric Generator Report) (U.S. DOE, 2004) includes data about generators in electric power plants owned and operated by electric utilities and nonutilities. These data indicate that in 2004 there were 1,526 generating units at facilities that used coal² as a primary fuel source. Of these units, 1,220 were classified as NACIS 22 (electric, gas and sanitary services). It is likely that this represents the universe of U.S. generators that would produce coal combustion products, including coal fly ash.

² This includes facilities that burn anthracite, bituminous and subbituminous coal, lignite, waste coal and synthetic coal.

Another annual DOE survey (U.S. DOE, 2004b) collects data from organic-fueled or combustible renewable steam-electric power plants with a rating of 10 or more megawatts. This survey (EIA-767: Annual Steam-Electric Plant Operation and Design Data) gathers information on, among other things, coal combustion product production. In 2004, 426 facilities reported data on coal fly ash production. These data indicate that approximately 69.8 million metric tons of coal fly ash was produced in 2004 at these facilities.

The American Coal Ash Association (ACAA) also conducts an annual survey of coal combustion product production. ACAA estimates that in 2004 approximately 64.2 million metric tons of coal fly ash were produced in the United States. (ACAA, 2004)

Coal fly ash is produced in abundant quantities and in all areas of the United States. Figure B-5 illustrates the geographic distribution of facilities that produce coal fly ash by state, based on the 2004 EIA-767 data files. Table B-3 shows the number of facilities producing coal fly ash, and coal fly ash production and disposition by state. Additional details on these facilities are included in Appendix .C

Figure B-5: U.S. Coal Fly Ash Producers by State

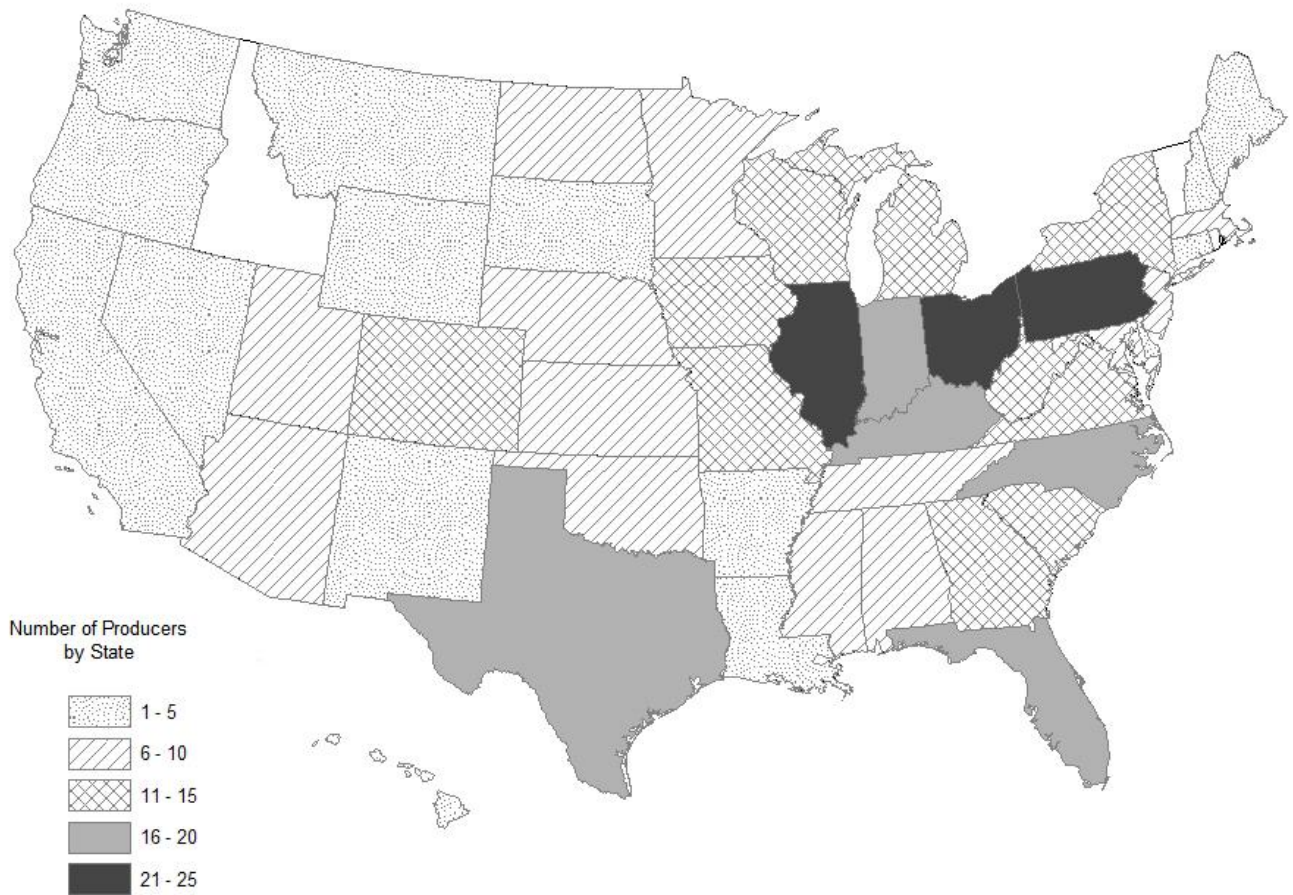


Table B-3: Coal Fly Ash Production and Disposition, by State (2004)*

State	Number of Plants	Total Fly Ash Production	Fly Ash Landfilled	Fly Ash Pondered	Fly Ash Used or Stored On-Site	Fly Ash Sold	Fly Ash Disposed Off-site
		-----thousand metric tons-----					
AL	10	2,150	672	982	--	396	99
AR	3	455	189	--	--	266	--
AZ	6	1,800	550	178	--	1,050	23
CA	1	46	46	--	--	--	--
CO	11	1,090	484	3	41	141	421
CT	4	75	--	--	--	--	75
DE	2	3,269	114	--	3,075	--	81
FL	17	2,658	732	62	42	1,230	593
GA	11	2,369	540	1,054	--	721	54
HI	1	7	--	--	--	--	7
IA	12	838	125	34	59	447	173
IL	23	2,060	18	365	163	683	831
IN	20	4,410	704	2,531	663	382	130
KS	7	642	250	83	--	279	31
KY	19	3,490	1,718	1,172	153	181	266
LA	4	997	383	160	10	445	--
MA	6	248	--	--	4	76	168
MD	9	1,403	381	20	--	379	624
ME	3	578	557	--	--	--	20
MI	15	1,590	656	535	67	289	44
MN	10	860	314	389	--	146	11
MO	15	1,252	206	409	6	560	70
MS	6	1,396	742	79	90	431	54
MT	2	613	--	572	16	24	--
NC	17	2,796	389	900	830	524	153
ND	7	1,299	843	--	48	354	54
NE	6	321	91	--	7	216	8
NH	3	78	13	--	--	3	62
NJ	6	400	--	--	--	--	400
NM	3	2,449	--	397	92	442	1,518
NV	3	553	269	--	--	284	--
NY	12	739	293	--	1	157	287
OH	22	4,124	1,249	1,504	--	555	814
OK	7	926	149	18	19	461	278
OR	1	64	--	--	--	64	--
PA	25	4,262	1,928	578	416	855	484
SC	13	1,177	135	253	--	751	38
SD	1	33	25	--	--	8	--
TN	8	1,758	662	493	35	373	195
TX	20	5,837	2,209	76	9	3,042	501
UT	6	1,355	771	11	333	240	--
VA	15	1,573	730	263	34	17	528
WA	1	463	143	--	--	320	--
WI	14	961	74	--	95	780	14
WV	14	3,201	1,871	721	213	346	51
WY	5	1,125	478	81	--	461	105
Total	426	69,791	21,702	13,921	6,519	18,383	9,266

Source: U.S. Department of Energy (DOE), 2004b. "Annual Steam-Electric Plant Operation and Design Data". EIA-767 data files available at <http://www.eia.doe.gov/cneaf/electricity/page/eia767.html>

* No coal fly ash production was reported in Alaska, Idaho, Rhode Island, or Vermont

Coal fly ash is a finely divided powder resembling portland cement. Most of the coal fly ash particles are solid spheres and some are hollow cenospheres. Plerospheres are also present, which are spheres containing smaller spheres. The particle sizes in coal fly ash vary from less than 1 μm (micrometer) to more than 100 μm with the typical particle measuring under 20 μm . Only 10% to 30% of the particles by mass are larger than 45 μm . The surface area of coal fly ash is typically 3,000 to 5,000 cm^2/gm , although some fly ashes can have surface areas as low as 2,000 cm^2/gm and as high as 7,000 cm^2/gm . For coal fly ash without close compaction, the bulk density can vary from 540 to 860 kg/m^3 , but with close packed storage or vibration, the range can be 1,120 to 1,500 kg/m^3 . The specific gravity of coal fly ash generally ranges between 1.9 and 2.8 (Kosmatka, 2002).

Coal fly ash consists primarily of silicate glass containing silica, alumina, iron and calcium. Minor constituents are magnesium, sulfur, sodium, potassium and carbon. This makeup gives coal fly ash its pozzolanic properties, meaning that it reacts with water and free lime (calcium oxide) to produce a cement-like compound. ASTM C 618 (AASHTO M295) classifies coal fly ash as Class C and Class F based on their pozzolanic and cementitious properties. Some coal fly ash meets both Class C and F classifications.

- **Class C Coal Fly Ash** is high-calcium, containing typically 10% to 30% calcium oxide with carbon contents less than 2%. Many Class C ash exhibits both cementitious and pozzolanic properties.
- **Class F Coal Fly Ash** is generally low-calcium, with less than 10% calcium oxide, with carbon contents usually less than 5%, but may have carbon contents as high as 10%. Many Class F ashes have pozzolanic properties—they require addition of lime to form cementitious compounds.

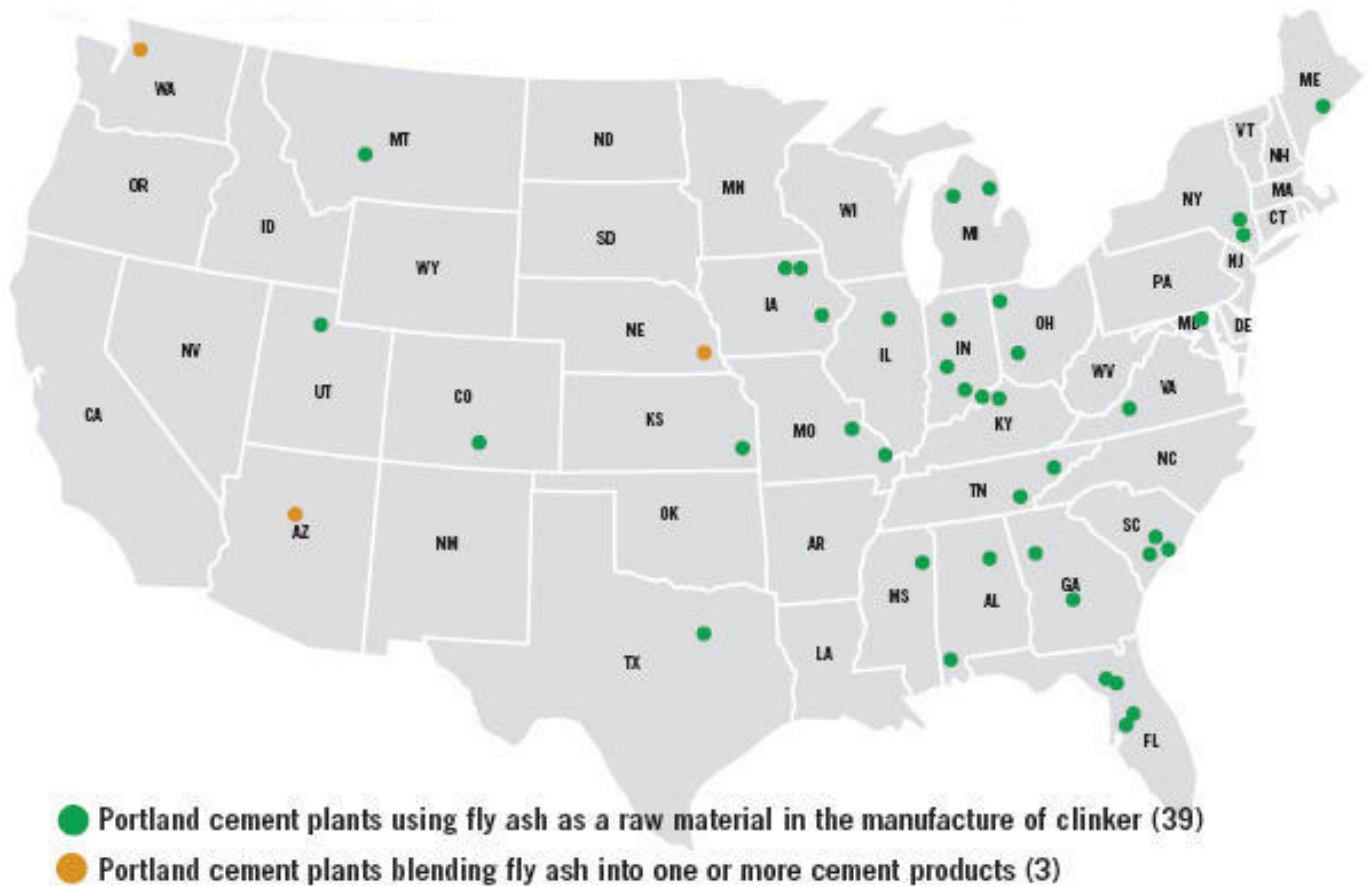
Table B-4 presents typical chemical compositions for coal fly ash produced from different coal types (FHWA, 1998)

Table B-4: Chemical Composition of Various Coal Fly Ash Types

Component	Coal Type		
	Bituminous	Subbituminous	Lignite
	-----percent by weight-----		
SiO ₂	20 - 60	40 - 60	15 - 45
Al ₂ O ₃	5 - 35	20 - 30	10 - 25
Fe ₂ O ₃	10 - 40	4 - 10	4 - 15
CaO	1 - 12	5 - 30	15 - 40
MgO	0 - 5	1 - 6	3 - 10
SO ₃	0 - 4	0 - 2	0 - 10
Na ₂ O	0 - 4	0 - 2	0 - 6
K ₂ O	0 - 3	0 - 4	0 - 4
Loss on Ignition	0 - 15	0 - 3	0 - 5

Figure B-6 shows the locations of the 39 portland cement plants using coal fly ash as a raw feed in the manufacture of clinker and the 3 plants blending coal fly ash into finished cement products.

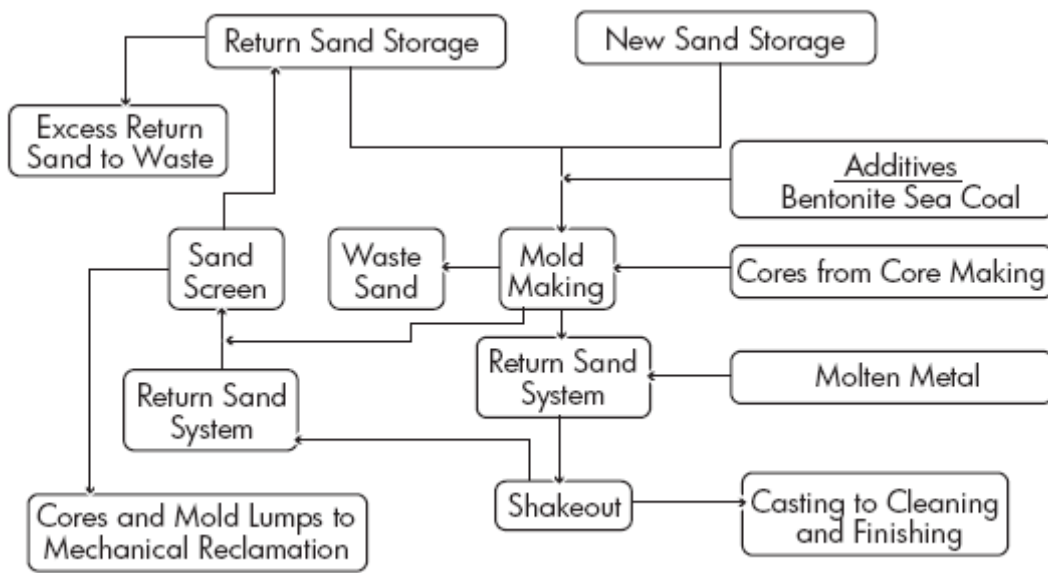
Figure B-6: U.S. Portland Cement Plants Utilizing Coal Fly Ash (PCA, 2005b)



B.5 Foundry Sand

Foundry sand is produced by five different foundry classes. The ferrous foundries (gray iron, ductile iron, and steel) produce the most sand in the United States, while aluminum, copper, brass, and bronze produce the rest. Foundries purchase high-quality, size-specific sand for use in their molding and casting operations. Foundry sand is used to form the outer shape of the mold cavity and relies upon a small amount of bentonite clay to act as the binder material. Depending on the geometry of the casting, sand cores are inserted into the mold cavity to form internal passages for the molten metal. Once the metal has solidified, the casting is separated from the molding and the core sand in the shakeout process. At that point, the old sand is displaced from the cycle as byproduct, new sand is introduced, and the cycle begins again (see Figure B-7) (FHWA, 2004).

Figure B-7: How sand is reused and becomes foundry sand



Two general types of binder systems are used in metalcasting: clay-bonded systems (green sand) and chemically-bonded systems. Both types of sand are suitable for beneficial use but they have different physical and environmental characteristics (FIRST, Undated):

- *Green Sand* molds are used to produce about 90% of casting volume in the United States. Green sand is composed of naturally occurring materials which are blended together: high quality silica sand (85% to 95%); bentonite clay (4% to 10%) as a binder; a carbonaceous additive (2% to 10%) to improve the casting surface finish; and water (2% to 5%). Green sand is the most commonly used RFS for beneficial reuse.
- *Chemically bonded sand* are used both in coremaking, where high strengths are necessary to withstand the heat of the molten metal, and in mold making. Chemically bonded sand is generally light in color and coarser in texture than clay bonded sand.

Availability

Foundries are located throughout the United States in all 50 states. The top ten foundry production states are Alabama, California, Illinois, Indiana, Michigan, Ohio, Pennsylvania, Tennessee, Texas, and Wisconsin. There are approximately 12 cement kilns that are using foundry sand as a raw material, and there is an industry survey under way to obtain more complete data (FIRST, Undated). Cement kilns in New York, Texas, Wisconsin, Ohio, Missouri, Maryland, Illinois, and Iowa have used foundry sand as a source of silica.

B.6 Flue Gas Desulfurization Materials

Figure B-8 shows the locations of portland cement facilities grinding and blending flue gas desulfurization materials with clinker to produce finished cement products.

Figure B-8: U.S. Portland Cement Plants Utilizing FGD Materials (PCA, 2005b)

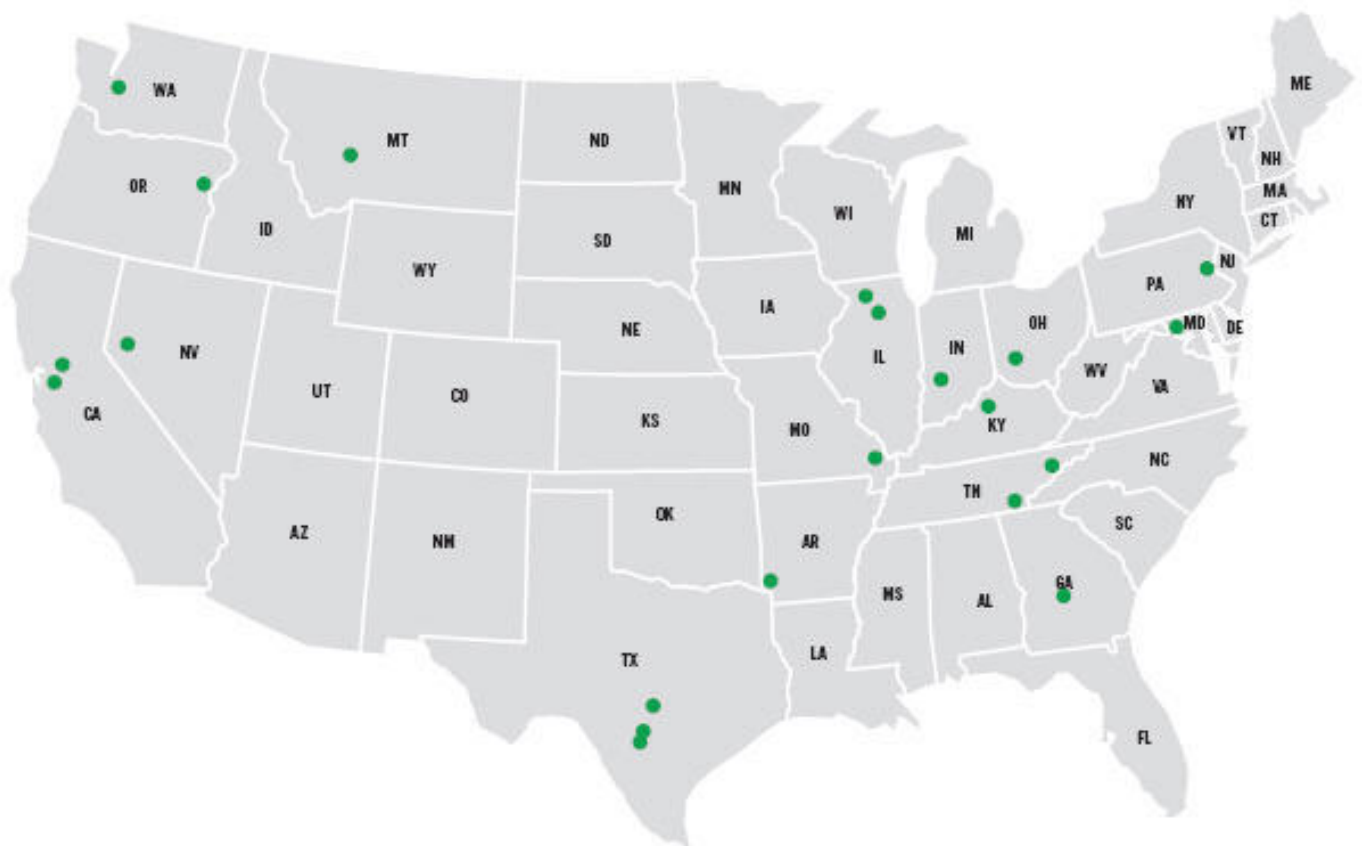


Table B-5 shows the FGD gypsum production and disposition in the United States by state in 2004.

Table B-5: FGD Gypsum Production and Disposition, by State (2004)

State	Number of Plants	Total FGD Gypsum Production	FGD Gypsum Landfilled	FGD Gypsum Pondered	FGD Gypsum Used or Stored On-Site	FGD Gypsum Sold	FGD Gypsum Disposed Off-Site
AL	2	452	--	405	--	47	--
FL	3	1,359	--	--	160	1,199	--
GA	1	29	--	--	--	29	--
IA	1	20	--	--	--	20	--
IL	1	160	6	--	--	154	--
IN	3	879	-	4	--	875	--
KY	5	1,738	--	466	--	1,272	--
NJ	1	39	--	--	--	39	--
NY	1	91	6	--	--	86	--
OH	2	576	--	--	--	576	--
PA	4	1,539	148	--	--	959	432
SC	1	242	--	--	101	141	--
TN	1	1,238	--	--	--	1,238	--
TX	4	329	59	197	--	73	--
WA	1	481	103	--	--	378	--
WV	1	222	--	--	--	222	--
Total	32	9,394	322	1,072	261	7,307	432

B.7 Bottom Ash

Physically, bottom ash is typically grey to black in color. Bottom ashes have angular particles with a very porous surface texture. The ash is usually a well-graded material, although variations in particle size distribution may be encountered in ash samples taken from the same power plant at different times. Bottom ash is predominantly sand-sized, usually with 50% to 90% passing a 4.75 mm (No. 4) sieve, 10% to 60% passing a 0.42 mm (No. 40) sieve, 0% to 10% passing a 0.075 mm (No. 200) sieve. The top size usually ranges from 19 mm (3/4 in) to 38.1 mm (1-1/2 in) (FHWA, 1998).

The specific gravity of dry bottom ash is a function of chemical composition, with higher carbon content resulting in lower specific gravity, typically in the range of 2.1 to 2.7. The dry unit weight of bottom ash is typically in the range of 720 to 1,600 kg/m³ (FHWA, 1998).

Bottom ash is composed primarily of silica, alumina and iron, with smaller percentages of calcium, magnesium, sulfates and other compounds. The composition is controlled primarily by the source of the coal and not by the type of furnace. Bottom ash derived from lignite or sub-bituminous coals has a higher percentage of calcium than the bottom ash from anthracite or bituminous coals. Sulfite content of bottom ash is typically very low (less than 1.0%). Table B-6 presents the chemical composition of several bottom ashes from different coal sources (FHWA, 1998).

Table B-6: Chemical Composition of Select Bottom Ash

Coal Type:	Bituminous			Sub-bituminous	Lignite
	West Virginia	Ohio	Texas		
Location:	-----percent by weight-----				
SiO ₂	53.6	45.9	47.1	45.4	70.0
Al ₂ O ₃	28.3	25.1	28.3	19.3	15.9
Fe ₂ O ₃	5.8	14.3	10.7	9.7	2.0
CaO	0.4	1.4	0.4	15.3	6.0
MgO	4.2	5.2	5.2	3.1	1.9
Na ₂ O	1.0	0.7	0.8	1.0	0.6
K ₂ O	0.3	0.2	0.2	--	0.1

Table B-7 indicates production and disposition of bottom ash by state for 2004.

Table B-7: Bottom Ash Production and Disposition, by State (2004)*

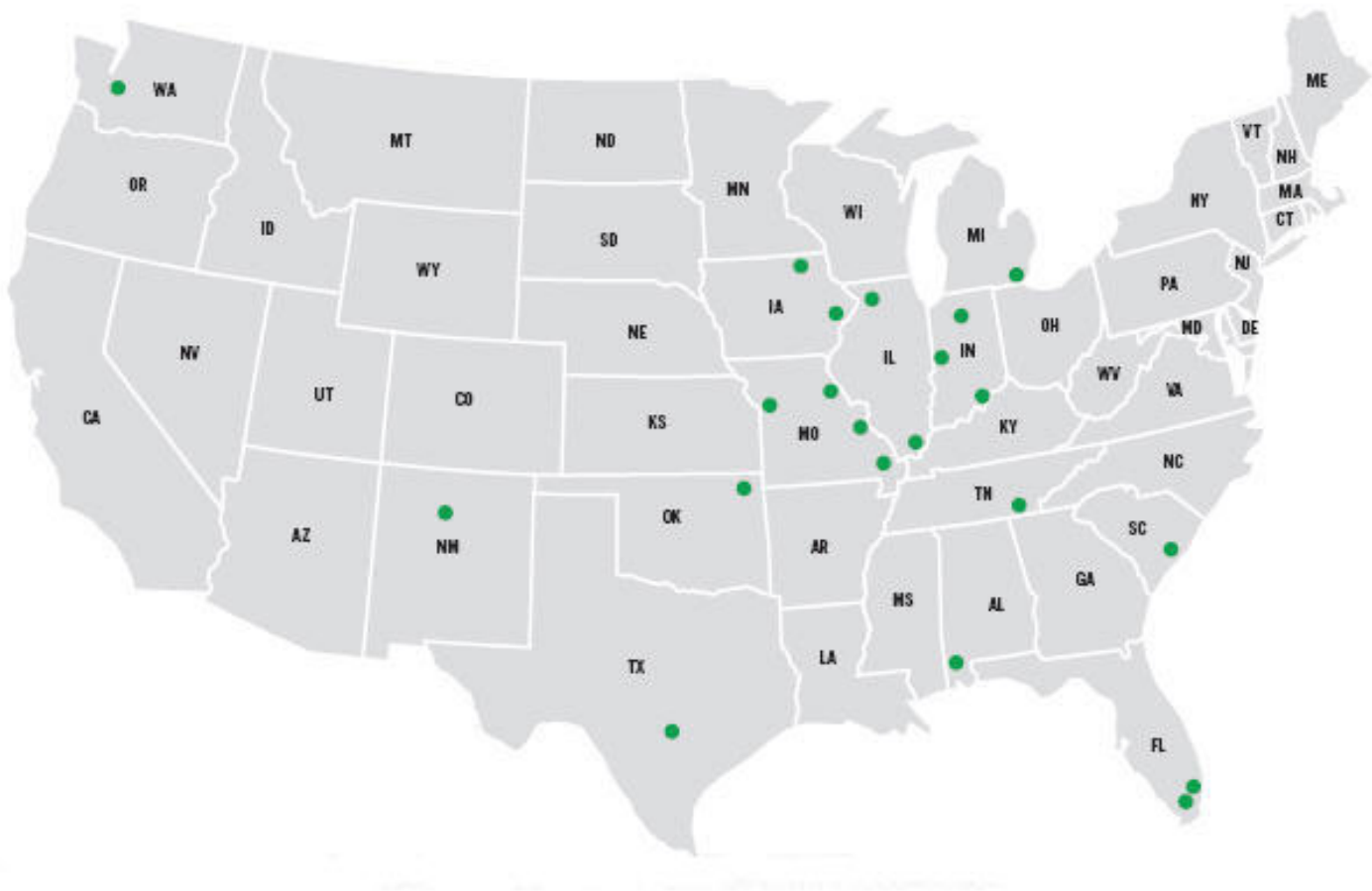
State	Number of Plants	Bottom Ash Total	Bottom Ash Landfilled	Bottom Ash Pondered	Bottom Ash Used or Stored On-site	Bottom Ash Sold	Bottom Ash Disposed Offsite
		-----thousand metric tons-----					
AL	9	548	136	252	106	53	1
AR	3	166	126	13	1	25	2
AZ	6	496	373	115	-	3	6
CO	11	237	85	3	28	18	103
CT	3	26	-	-	-	-	26
DE	2	53	-	-	43	8	2
FL	17	466	201	15	33	149	68
GA	10	451	69	205	11	166	-
HI	1	0	-	-	-	-	0
IA	12	245	16	73	6	110	39
IL	23	1,183	-	158	130	656	239
IN	20	1,379	33	564	302	428	51
KS	7	369	46	72	32	209	10
KY	18	760	124	379	70	42	145
LA	5	164	10	76	-	78	-
MA	4	49	-	-	3	36	10
MD	8	360	32	5	50	157	116
ME	3	149	149	-	-	-	0
MI	15	356	140	2	152	49	13
MN	10	256	17	58	131	48	1
MO	16	766	6	355	12	391	2
MS	5	228	131	0	44	53	-
MT	2	251	-	245	2	4	-
NC	16	395	31	165	37	98	64
ND	7	762	201	247	215	46	53
NE	6	104	51	-	2	47	5
NH	3	51	-	-	(10)	58	2
NJ	6	105	-	-	-	62	43
NM	3	598	-	-	247	-	351
NV	4	184	184	-	-	-	0

State	Number of Plants	Bottom Ash Total	Bottom Ash Landfilled	Bottom Ash Pondered	Bottom Ash Used or Stored On-site	Bottom Ash Sold	Bottom Ash Disposed Offsite
		-----thousand metric tons-----					
NY	11	208	39	-	92	40	37
OH	22	1,213	18	399	266	360	169
OK	6	232	20	13	2	85	113
OR	1	22	13	-	-	9	-
PA	22	906	375	17	103	318	93
SC	14	277	41	138	-	65	33
SD	1	62	44	-	-	18	-
TN	7	350	-	110	198	39	3
TX	19	2,665	1,724	132	83	557	168
UT	6	403	292	111	-	-	-
VA	13	596	204	79	60	73	180
WA	1	1,129	301	-	332	496	-
WI	13	241	52	-	43	147	1
WV	14	566	126	98	128	201	13
WY	5	415	275	140	-	-	-
Total	410	20,442	5,685	4,238	2,952	5,405	2,162

* No bottom ash production was reported for Alaska, California, Idaho, Rhode Island and Vermont.

Figure B-9 presents the locations of portland cement facilities that use bottom ash and/or boiler slag as a raw feed in clinker production.

Figure B-9: U.S. Portland Cement Plants Utilizing Bottom Ash/Boiler Slag (PCA, 2005b)



B.8 Boiler Slag

Boiler slags are predominantly single-sized and within a range of 5.0 to 0.5 mm (No. 4 to No. 40 sieve). Ordinarily, boiler slags have a smooth surface texture, but if gases are trapped in the slag as it is tapped from the furnace, the quenched slag will become somewhat vesicular or porous. Boiler slag from the burning of lignite or subbituminous coal tends to be more porous than that of the eastern bituminous coals. Boiler slag is essentially the size of coarse to medium sand with 90% to 100% passing a 4.75 mm (No. 4) sieve, 40% to 60% passing a 2.0 mm (No. 10) sieve, 10% or less passing a 0.42 mm (No. 40) sieve, and 5% or less passing a 0.075 mm (No. 200) sieve (FHWA, 1998). The specific gravity of boiler slag is typically in the range of 2.3 to 2.9, and the dry unit weight is typically in the range of 960 to 1,440 kg/m³ (FHWA, 1998).

Boiler slag is composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. Like bottom ash, the composition of the boiler slag particles is controlled primarily by the source of the coal and not by the type of furnace. Boiler slag derived from lignite or sub-bituminous coals has a higher percentage of calcium than the boiler slag from anthracite or bituminous coals. Sulfate content is usually very low (less than 1.0%), unless pyrites have not been removed from the boiler slag. Table B-8 presents the chemical composition of select boiler slags (FHWA, 1998).

Table B-8: Chemical Composition of Select Boiler Slags

Coal Type:	Bituminous		Lignite
Location:	West Virginia		North Dakota
	-----percent by weight-----		
SiO ₂	48.9	53.6	40.5
Al ₂ O ₃	21.9	22.7	13.8
Fe ₂ O ₃	14.3	10.3	14.2
CaO	1.4	1.4	22.4
MgO	5.2	5.2	5.6
Na ₂ O	0.7	1.2	1.7
K ₂ O	0.1	0.1	1.1

Figure B-9 above presents portland cement facilities using boiler slag and/or bottom ash as a raw feed in clinker production.

B.9 Steel Slag

Steel slag aggregates are highly angular in shape and have a rough surface texture. The cooling rate of steel slag is sufficiently low so that crystalline compounds are generally formed. The predominant compounds are dicalcium silicate, tricalcium silicate, dicalcium ferrite, merwinite, calcium aluminate, calcium-magnesium iron oxide, and some free lime and free magnesia. The relative proportions of these compounds depend on the steel-making practice and the steel slag cooling rate. Table B-9 presents the typical chemical composition of steel furnace slag. Steel slag typically has a high specific gravity ranging between 3.2 and 3.6, and a unit weight of 1,600 to 1,920 kg/m³ (FHWA, 1998).

Table B-9: Typical Chemical Composition of Steel Furnace Slag

Constituent	Range (percent by weight)
CaO	40 - 52
SiO ₂	10 - 19
Al ₂ O ₃	1 - 3
MgO	5 - 10
FeO and Fe ₂ O ₃	10 - 40
MnO	5 - 8
S	< 0.1
P ₂ O ₅	0.5 - 1
Metallic Fe	0.5 - 10

B.10 Cement Kiln Dust (CKD)

CKD is a fine, dry, alkaline dust that readily absorbs water. It is composed of particles of unburned or partially burned feedstock materials, dehydrated clay, decarbonated (calcined) limestone, ash from combusted fuels, and various minerals formed during the different stages of the clinkering process. While composition varies from plant to plant, the primary constituents of CKD are calcium oxides, silicates, carbonates, potassium oxide, sulfates, chlorides, various metal oxides, and sodium oxide. CaO typically comprises the largest component of CKD, approaching as much as 50% by weight in some cases (U.S. EPA, 1993).

CKD is very fine grained with particle diameters ranging from near zero μm to greater than 50 μm . At least 55% of CKD measures less than 30 μm and nearly 82% is less than 50 μm (U.S. EPA, 1993). Because of its fine grained nature, CKD is readily entrained and transported in the continuous, rapidly flowing, and highly turbulent gas flow of cement kilns. To remove these entrained fine particles from kiln exhaust gas requires the use of complex air-pollution control devices such as electrostatic precipitators or fabric filters (i.e., bag houses). Wet scrubbers, common in other mineral processing industries, can not be used due to the chemically dehydrated nature and cementitious properties of CKD. Cement kiln dust collection systems are especially effective at removing CKD from exhaust gas, typically exhibiting 98% to nearly 100% removal efficiencies (U.S. EPA, 1993).

CKD's alkaline nature derives from its high concentrations of CaO and other alkaline compounds including K₂O, NaOH, Na₂CO₃, and NaSO₄. Even though CKD is a highly alkaline material, because it is a solid, it does not exhibit the RCRA Subtitle C hazardous waste characteristic of corrosivity. (This is because the RCRA hazardous identification regulations do not include a definition for corrosive solids.) When mixed with water, however, the resulting CKD and water mixtures often have pH levels greater than 12.5 and therefore do exhibit the corrosivity characteristic. Studies using the standard EPA leaching procedure (i.e., the Toxicity Characteristic Leaching Procedure or TCLP) show leachate pH levels falling in the 11 to 13 range (U.S. EPA, 1993).

Trace constituents commonly found in CKD include organic chemicals, metals, and radionuclides. Concentrations of heavy metals are of particular concern in the reuse of CKD either directly in the kiln or for other beneficial applications. Studies performed by EPA in preparation for its 1993 Report to Congress consistently found eight Toxicity Characteristic (TC) metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) and nine other metals (antimony, beryllium, copper, manganese, nickel, strontium, thallium, vanadium, and zinc) present in CKD samples. The predominant metals were antimony, barium, lead, manganese, strontium, thallium, and zinc. The others were found in lesser concentrations. While these metals were consistently present in the CKD samples, in general, their concentrations were well below the regulatory TCLP/Toxicity Characteristic levels (U.S. EPA, 1993). A few of the samples, however, did yield results above the regulatory limits for lead (4 of 244 samples), selenium (2 of 129 samples), barium (1 of 88 samples), and cadmium (1 of 88 samples) (U.S. EPA, 1993).

Table B-10 illustrates the typical chemical composition of CKD (FHWA, 1998).

Table B-10: Typical Chemical Composition of CKD

Parameter	Fresh	Stockpiled	
		Sample 1	Sample 2
-----percent by weight-----			
CaO	40.5	31.4	44.2
Free Lime	4.4	0.0	0.0
SiO ₂	14.5	11.7	11.9
Al ₂ O ₃	4.1	3.18	3.24
MgO	1.55	0.97	1.73
Na ₂ O ₃	0.44	0.13	0.27
K ₂ O	4.66	1.65	2.92
Fe ₂ O ₃	2.00	2.16	1.45
SO ₃	6.50	8.24	2.40
Loss on Ignition, 105°C	22.9	40.4	30.2

Figure B-10 below shows the amount of CKD disposed in landfills from 1990 through 2004 and compares the amount of CKD disposed in landfills to clinker production during this same time period. The graph below represents CKD recovered from CKD scrubbers and does not reflect any CKD automatically re-ducted back into the kiln.

Figure B-10 CKD Landfilled; CKD Landfilled versus Clinker Produced

