Market Assessment and Technical Feasibility Study of Pressurized Fluidized Bed Combustion Ash Use

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CONTRACT INFORMATION

Contract Number:	DE-FC21-93MC30127
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Industrial Co-Sponsors:	Electric Power Research Institute Foster Wheeler Energy International, Inc.
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INTRODUCTION

The commercial introduction of pressurized fluidized bed combustion (PFBC) has spurred evaluation of ash management options for this technology. The unique operating characteristics of PFBC compared to atmospheric fluidized bed combustion (AFBC) units indicate that PFBC ash will exhibit unique chemical and physical characteristics, and hence, unique ash use opportunities.

The utilization of ash from fluidized bed combustion (FBC) units is a promising ash management option. The chemical characteristics of pressurized fluidized bed combustion (PFBC) ash compared to other FBC ashes have generated interest in the use of PFBC ash for various construction and agricultural applications. However, before commercial entities and financial institutions are ready to commit to the concept of PFBC, ash management options must be documented and the costs determined.

Western Research Institute (WRI), in conjunction with the Electric Power Research Institute, Foster Wheeler Energy International, Inc. and the U.S. Department of Energy (DOE) Morgantown Energy Technology Center (METC), has undertaken a research and demonstration program designed to examine the market potential and the technical feasibility of ash use options for PFBC ashes. The assessment is designed to address six applications, including: (1) structural fill, (2) road base construction, (3) supplementary cementing materials in portland cement, (4) synthetic aggregate, and (5) agricultural/soil amendment applications. Ash from low-sulfur subbituminous coal-fired Foster Wheeler Energia Oy pilot circulating PFBC tests in Karhula, Finland, and ash from the high-sulfur bituminous coal-fired American Electric Power (AEP) bubbling PFBC in Brilliant, Ohio, were evaluated in laboratory and pilot-scale ash use testing.

This paper addresses the technical feasibility of ash use options for PFBC units using low-sulfur coal and limestone sorbent (Karhula ash) and high-sulfur coal and dolomite sorbents (AEP Tidd ash).

OBJECTIVES

Western Research Institute (WRI), has initiated a project under sponsorship of the Electric Power Research Institute (EPRI), Foster Wheeler Energy International, Inc., and the U.S. Department of Energy (DOE), Morgantown Energy Technology Center (METC) that addresses ash use markets and options for PFBC technologies. The overall objectives of this study are to determine the market potential and the technical feasibility of using PFBC ash in high-volume use applications. The study is of direct use to the utility industry in assessing the economics of PFBC power generation, particularly in light of ash disposal avoidance achieved through ash use. Additional benefits can be realized to a utility through CO_2 offset credits resulting from ash penetration into certain markets that generate high levels of greenhouse gases during manufacturing (e.g., cement production).

The specific objectives of the program are:

- to define present and future market potential of PFBC ash for a range of applications;
- to assess the technical feasibility of PFBC ash use in construction and soil/spoil amendment applications; and
- to demonstrate the most promising of the ash use options in full-scale field demonstrations.

RESULTS

A laboratory and pilot-scale testing program was conducted to address the use of PFBC ash in both construction-related applications as well as agricultural and soil remediation applications. The study has focused to date on two ash sources: (1) ash from the Foster Wheeler Energia Oy Karhula circulating PFBC pilot plant and (2) ash from the AEP Tidd bubbling PFBC demonstration plant. Ashes from the Foster Wheeler Energia Oy R and D Laboratory CPFBC pilot unit in Karhula, Finland, represent the combustion of low-sulfur Powder River Basin subbituminous coal (Black Thunder) with limestone sorbent. Fly ash and bed ash from the AEP Tidd bubbling PFBC facility in Brilliant, Ohio represented ash from the combustion of high-sulfur Ohio No. 8 (Illinois Basin) coal and Plum Run dolomite.

Ash Characteristics

With the exception of relatively high mineral carbon, the chemistry of the PFBC ashes is typical of ashes from FBC of low-sulfur and high-sulfur coals using limestone and dolomite sorbents. The chemical compositions of the Karhula and AEP Tidd ashes have been presented in Bland et al., (1995a). The Karhula ashes are composed principally of anhydrite ($CaSO_4$), calcite ($CaCO_3$), coal ash oxides, and dehydroxylated clays. In addition to these phases, the Tidd ashes contain dolomite ($(Ca,Mg)_2CO_3$) and periclase (MgO), reflecting the use of a dolomite sorbent. These results are similar to those reported by Bigham et al.(1993). It should be noted that the dolomite is principally in the fly ash, while periclase is principally in the bed ash. The dolomite in the fly ash is probably the result of fine dolomite sorbent blow-through. The lack of lime (CaO) in the PFBC ashes is distinctly different from AFBC ashes, which contain large amounts of lime. In PFBC systems, the partial pressure of CO_2 favors the equilibrium conditions of both calcination and recarbonization. This results in low lime and high carbonates (calcite or dolomite) in pressurized FBC ash as compared to high lime and low carbonates in the atmospheric FBC ash.

The general physical properties of the ashes were also determined, including particle size distribution, specific gravity, and bulk densities. The size distribution is similar to that of other FBC ashes reported in the literature (Georgiou, et al., 1993; Bland, et al., 1993b; Bigham, et al., 1993). The bulk densities of the Karhula and the AEP Tidd fly ashes and bed ashes were determined according to ASTM procedures. The bulk densities for the Karhula ashes were 59.2 pcf (poured) and 72.5 pcf (packed) for the fly ash and 85.4 pcf (poured) and 95.4 pcf (packed) for the bed ash, while those for the Tidd ash were 53.3 pcf (poured) and 74.3 pcf (packed) for the fly ash and 80.2 pcf (poured) and 90.1 pcf (packed) for the bed ash. Specific gravities for the Karhula fly ash and bed ash materials were determined to be 2.8 and 2.7 g/cc, respectively, while the specific gravities of the Tidd fly ash and bed ash were 2.8 g/cc and 3.0 g/cc, respectively.

Ash Use Applications

Laboratory and pilot-scale tests were conducted to address the use of Karhula and Tidd PFBC ash in a number of construction-related applications, including (1) cement replacement and cement manufacturing, (2) fills and embankment construction, (3) soil stabilization applications, and (4) synthetic aggregate production. In addition, greenhouse and soils amelioration studies were conducted to addresss ash use in agricultural and soils remediation aplications.

PFBC Ash Use in Concrete and Cement Production The use of PFBC ash appears to be technically feasible in the cement industry. PFBC ash use in concrete and in cement production, including (1) the replacement of cement in portland cement concrete; or (2) the use as pozzolanic material in the production of pozzolanic cements (e.g., Type IP); and (3) the use as set retardant interground with cement as a replacement for gypsum.

The concrete and cement markets for PFBC ash are very large. Over 6 million tons of fly ash are used annually as a replacement for portland cement in ready-mix concrete and concrete products. Approximately 42% of all ready-mix concrete contains fly ash at an average of 20% replacement of the cement. In addition, over 80 million tons of portland cement were produced in the United States, consuming approximately 1 million tons of fly ash in the production of pozzolanic cement.

Cement Replacement - The use of PFBC ash in concrete and concrete products relies on the pozzolanic property of the ash. Fly ash, including FBC ash, is known to be a pozzolan and therefore is used as a cement replacement in portland cement concrete. The use of PFBC ash as a pozzolan for portland cement and concrete products is dependent on a number of characteristics that are tested according to methods of ASTM C-311 and must comply with the specifications of ASTM C-618. The fly ashes from Karhula and AEP Tidd were analyzed for chemical and physical properties as related to their use as pozzolans for cement replacement in portland cement and concrete products. The results are presented in Table 2. The data indicate that the ashes do not qualify as pozzolans according to ASTM C-311 because the sulfate levels exceed the ASTM C-618 specification of 5% maximum SO_3 content. This will restrict the use of certain PFBC ashes as pozzolans for portland cement applications.

Portland Cement Production - PFBC ash can be incorporated into the cement manufacturing process as an ingredient in the clinker production and secondly as an interground material in the production of Type IP pozzolanic cements. The characteristics of the ash for these applications are defined under ASTM C-595 and C-593.

Table 2. Results of ASTM C-311 Testing of Karhula and AEP Tidd Fly Ashes as Pozzolans for Cement Replacement

	Karhula Fly Ash	**AEP Tidd Fly Ash**	**ASTM C-618 Specifications**	
			Class F	**Class C**
Chemical Properties				
SiO_2+Al_2O_3+Fe_2O_3 (wt.%)	57.57	49.39	70 min	50 min
Sulfur Trioxide (wt.%)	12.17	10.55	5 max	5 max
Moisture Content (wt. %)	0.09	0.11	3 max	3 max
Loss on Ignition (wt. %)	0.81	11.08	6 max	6 max
Available Alkalis (wt.%)	0.70	0.68	1.5 max	1.5 max
Physical Properties				
Fineness (% retained 325 mesh)	25.58	21.97	34 max	34 max
Pozzolanic Activity Index				
With PC* (% of control @ 28 days)	83.4	89.8	75 min	75 min
Water Requirement (% of control)	97.7	98.3	105 max	105 max
Soundness - Autoclave Expansion (%)	-0.040	0.000	0.8 max	0.8 max
Drying Shrinkage Increase @ 28 days (%)	0.016	0.011	0.03 max	0.03 max

*PC - portland cement

Table 3. Summary of PFBC Ash Use in Type IP Blended Hydraulic Cement – Chemical Specifications

Chemical Requirements	Karhula Fly Ash[1]	AEP Tidd Fly Ash[2]	ASTM C-595 Specifications
MgO (%)	2.9	4.0	5.0 Max.
SO3	2.9	2.9	4.0 Max.
LOI	1.0	1.8	5.0 Max.
Fly Ash Addition (%)	23.8	18.0	-
Gypsum Required (%)	-	2.15	-

1. Calculations are based on fly ash interground with Type I portland cement to achieve (1) equivalent of 5% gypsum addition or (2) a maximum of 4% MgO content in cement.

The use of ash as a pozzolan in blended cement according to ASTM C-595 does not rely on the chemical properties of the pozzolan and instead is based on performance specifications for the resultant blended cement. Calculations were made related to the potential use of the PFBC ashes in the manufacturing of blended Type IP cement and are presented in Table 3. It is clear that PFBC ash could be used in substantial amounts in Type IP portland cement.

PFBC Ash Use as Structural Fill and Embankment Materials The application of PFBC residue as an engineered material for structural fills and embankments represents a large-scale use option. Structural fills and embankments are numerous in the road construction, mining and industrial construction industries.

In addition to these compacted fill applications, PFBC ash is potentially applicable for use in controlled density low-strength flowable fill (CDLSFF) applications. This material is not really concrete and is highly flowable (slump 9-10 inches). CDLSFF is usually mixed in a ready-mix concrete truck, with mixing continuing during transport to prevent segregation. The CDLSFF is discharged and placed using chutes or can be pumped using standard concrete or grout equipment. A number of applications have been documented for CDLSFF, including excavatable backfills and trench/pipe bedding, structural fills, road bases, caisson and pile fills, and mine void filling. PFBC ash is expected to be marketable in both of the compacted fill and flowable fill applications.

Geotechnical tests using the ashes from Karhula and AEP Tidd were conducted to determine the possible use of the ashes as compacted structural fill or embankment material, as well as flowable fill material for excavatable trench grade and structural fill applications. A description of the results of testing for each of these engineered fill materials is provided below.

Compacted Fills and Embankments - The geotechnical tests related to compacted structural fills and embankments focused on the moisture-density relationship (Proctors), unconfined compressive strength, expansion and swell, and permeability.

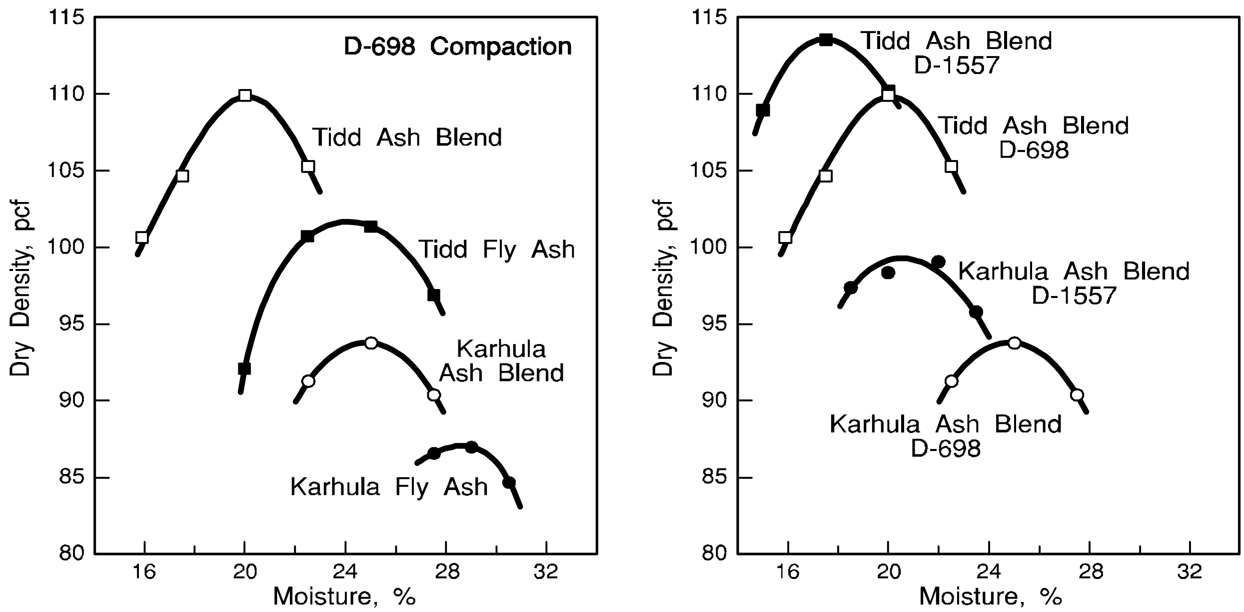

Figure 1 . Moisture-Density Relationships of Karhula and AEP Tidd PFBC Ashes

Moisture-density relationships were determined using ASTM D-698 and ASTM D-1557 compactive efforts. The compactive effort employed in the ASTM D-1557 tests is twice that for ASTM D-698. These compactive efforts typically cover the range of compaction achievable with standard construction equipment. The results are presented in Figure 1. The lower optimum moisture and higher maximum dry density observed for the ash blend is consistent with the larger particle size and specific gravity of the bed ash relative to the fly ash. The ASTM D-698 and D-1557 modified Proctor data are consistent with the expected behavior of different compactive efforts (i.e., lower optimum moisture and higher maximum dry density for increased compactive effort).

Testing also addressed the strength development of the Karhula and AEP Tidd ash blends as related to their use in compacted structural fills and embankments. The ash blends are a composite of the fly ash and the bed ash in approximate proportions to that produced in the combustor. Specimens were prepared at the optimum moisture and densities represented by ASTM D-698 and D-1557 and cured under sealed and saturated (100% relative humidity) conditions at 23°C.

Strength development for the Karhula and AEP Tidd ash blends under sealed conditions for different compactive efforts is presented in Figure 2. Both of the PFBC ashes showed strengths in excess of the needs of fills and embankments. The strength development of the Karhula PFBC ash is a factor of 4 to 10 times higher than that for other soils and fill materials, while the strength of the AEP Tidd ash was even higher. The ASTM D-1557 compacted specimens were stronger than the ASTM D-698 compacted specimens, as expected. The differences in strength between the Karhula and AEP

Tidd ashes are related to differences in the hydration reaction chemistry of the two ashes (Bland, 1995a). These differences appear to be more related to fuel sulfur content and hence sorbent requirement and the type of sorbent used than to whether the ash was produced in a circulating or bubbling PFBC unit.

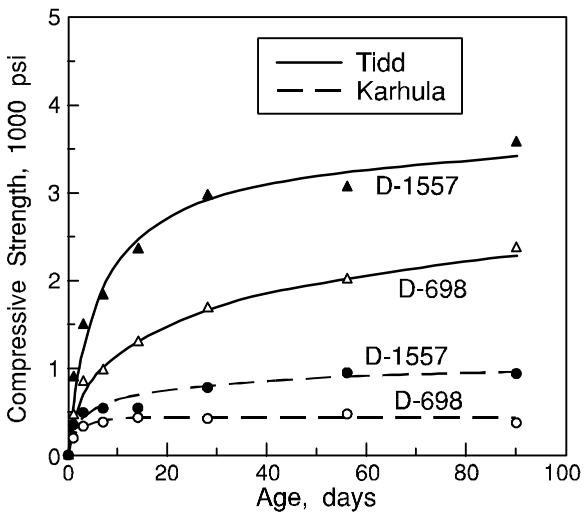

Figure 2. Strength Development of Karhula and AEP Tidd Ash Blends, Sealed Curing Condition at 23°C

The expansion properties of the conditioned and compacted Karhula and AEP Tidd ashes were determined according to modified ASTM C-157 procedures in which the expansion is essentially unrestricted. The results for the Karhula and AEP Tidd ash blend for ASTM D-698 and D-1557 compactive efforts are essentially identical, with expansion of near zero percent. In addition, the ASTM D-698 and D-1557 compacted ash blend specimens cured under both sealed and saturated conditions showed essentially no expansion. The Karhula and AEP Tidd ash blends appear to be dimensionally stable and thereby suited for compacted fill and embankment applications.

The permeability of the Karhula and AEP Tidd ash blends were determined according to ASTM procedures. The ashes were compacted at ASTM D-698 optimum moisture. As expected, the permeability of the ash blends continued to decrease with curing. Hydraulic conductivities in the range of 9 x 10^{-6} cm/sec were determined at early ages and continued to decrease to values of 2 x E-6 cm/sec, after which the values appeared to stabilize. These values are typical of those reported for CFBC ashes (Georgiou, et al., 1993).

Controlled Density Low-Strength Flowable Fills - The second application involves controlled density low-strength flowable fill, which has been used in construction applications for a number of years. Controlled density low-strength flowable fill material is a mixture of cement, fly ash, sand and water that has a specific strength dependent upon the end use. CDLSFF offers favorable economics compared to other fill materials because it requires less excavation and compaction during construction.

The results of tests using Karhula and AEP Tidd PFBC ashes in CDLSFF are represented in Table 4. Structural fill grade CDLSFF requiring in excess of 1200 psi strength and excavatable trench fill grade, requiring strengths in the range of 100 to 200 psi, were tested. The data clearly show that both the Karhula and the AEP Tidd fly ashes can be used as CDLSFF.

PFBC Ash Use for Soil Stabilization The use of PFBC ash and other FBC residues for stabilization of soils is a potentially

Table 4. Summary of Properties of Flowable Fill Materials Made with Karhula and AEP Tidd PFBC Ash

	Structural Fill Grade		Excavatable Trench Fill Grade	
	Karhula	AEP Tidd	Karhula	AEP Tidd
Mix Components (lbs/yd ^{3})				
Portland Cement	190	190	80	80
PFBC Fly Ash	450	450	450	450
Penetration Resistance (psi)				
4 hours	58	5	4	0
8 hours	314	109	28	16
24 hours	384	786	128	192
Compressive Strength (psi)				
2 days	131	88	46	6
7 days	298	398	84	143
28 days	1031	1199	203	234

large ash use market. This ash use application is similar to the cement stabilization of soils commonly applied in the construction industry. Soil stabilization is based on the treatment of clay soils with a material to provide strength and stability. Cement, fly ash and lime-ash materials are commonly employed at levels of 10 to 20% of the soil. FBC ashes exhibit self-cementing characteristics and, as such, have been proposed as a viable stabilizing agent.

For a material to be considered as a cementing agent for soil stabilization applications, the material must show strength development, freeze/thaw durability, and wet/dry durability in compliance with ASTM D-1632, D-560, and D-559, respectively. A viable cementing material needs to exhibit sufficient strength in the range of 4000 psi and durability of 12 cycles of freeze/thaw and wet/dry for the cementing material only. These requirements result from stabilized soil specifications of 400 psi and durability to 12 cycles of wet/dry and freeze/thaw when soils are treated at 10 to 0% cementing levels.

Unconfined Compressive Strength Relationship - Testing was conducted using the Karhula and AEP Tidd ash blends with and without hydrated lime addition, in order to determine their potential as a cementing agent for soil stabilization applications. The test specimens were cured under sealed and saturated conditions (23°C). Typical results of the testing are displayed in Figure 3. The strength development of both of the PFBC ashes was more than sufficient for soil stabilization applications. The results showed 5% hydrated lime increased the strength development dramatically (over 6,000 psi at 90 days for Karhula ash and over 9,000 psi at 90 days for AEP Tidd ash). The ash blend without hydrated lime enhancement showed strengths of less than 1000 psi for the Karhula ash and less than 3,500 psi for the AEP Tidd ash. As mentioned earlier, these differences in strength are due to differences in the hydration chemistry of the two ashes (Bland, 1995a). Once again, these differences appear to be more related to fuel sulfur content and hence sorbent requirement and the type of sorbent used than to whether the ash was produced in a circulating or bubbling PFBC unit. The low strengths of the ash blends without lime are sufficient for many applications, such as fills and embankments. However, for other applications, such as soil stabilization, lime enhancement will be required at some level (e.g., 5% or less).

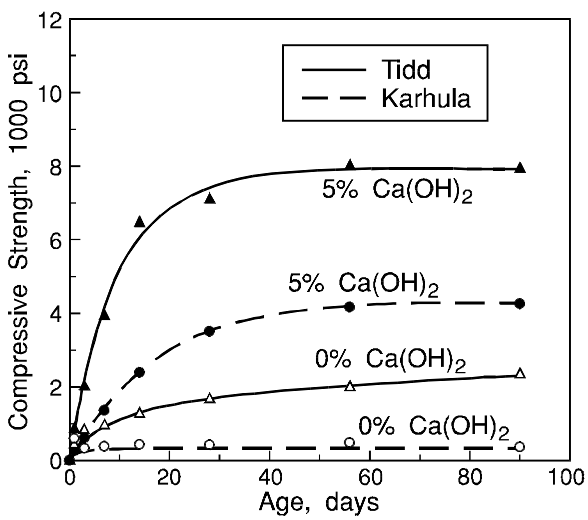

Figure 3. Strength Development of Karhula and AEP Tidd Ash Blends with and without Lime Enhancement

Expansion Properties - The expansion properties of the conditioned and compacted Karhula and AEP Tidd ashes with and without hydrated lime addition were tested for soil stabilization applications, according to a modified ASTM C-157 procedure. The Karhula and AEP Tidd ashes with and without hydrated lime addition were conditioned and compacted at the ASTM D-698 optimum moisture and proctor density. The results for the Karhula ash are shown in Figure 4.

The lime-enhanced Karhula ash blend showed expansion in the range of 1.5%, while the ash blend without lime enhancement showed essentially no expansion. The expansion noted for the lime-enhanced ash appears to occur early, within the first 20 to 30 days. Although the expansion is significant, it appears controllable and manageable, and it should be possible to balance the strength and swelling properties in certain applications. For example, in certain grouting applications, such as subsidence control in underground construction operations, controlled expansion of the magnitude reported is desirable.

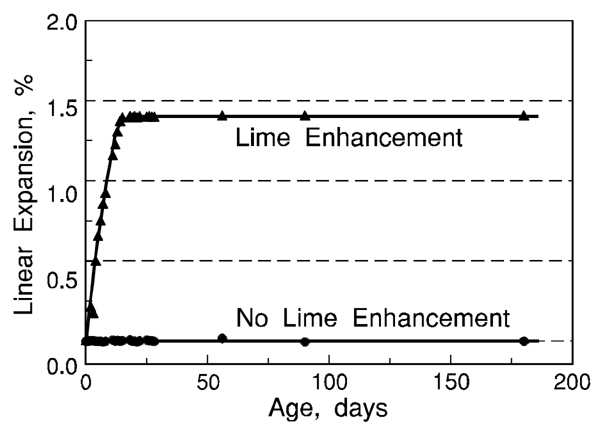

Figure 4. Expansion of Karhula Ash Blend with and without Lime Enhancement

Freeze/Thaw and Wet/Dry Cycles - Conditioned and compacted Karhula and AEP Tidd ash blend specimens were subjected to 12 cycles of freeze/thaw (ASTM D-560) and wet/dry (ASTM D-559) conditions. The results indicated that the PFBC ashes with 5% lime addition survived the entire 12 cycles with losses less than the 15% maximum limit. In fact, losses in the range of 1% were determined for these PFBC ashes.

PFBC Ash Use in Synthetic Aggregate Production The aggregate market in the United States is enormous. In 1992, approximately 1.2 billion tons of crushed stone and approximately 0.8 billion tons of sand and gravel were produced for a market valued in excess of $8 billion. The aggregate market encompasses conventional aggregate products, such as masonry units and ready-mix concrete. Also, with crushing, aggregates can be produced for use in asphalt paving, road base construction and even roller compacted concrete. Lightweight aggregate can also be used in many structural building products.

Synthetic aggregate has been manufactured from power plant ash that can meet the requirements for conventional aggregate products, such as masonry units and ready-mix concrete, and with crushing can be produced for use in asphalt paving, road base construction and even roller-compacted concrete. As such, synthetic aggregate for construction applications appears to be a major market for PFBC ashes, as well as a method for storage of ash in the construction off-season.

Pelletizing Trials - Pelletizing trials were conducted simulating the AET process for the pelletization of FBC ashes, as described in the literature (Bland et al., 1992, 1993). A schematic of the AET pelletizing process for PFBC ash is presented in Figure 5.

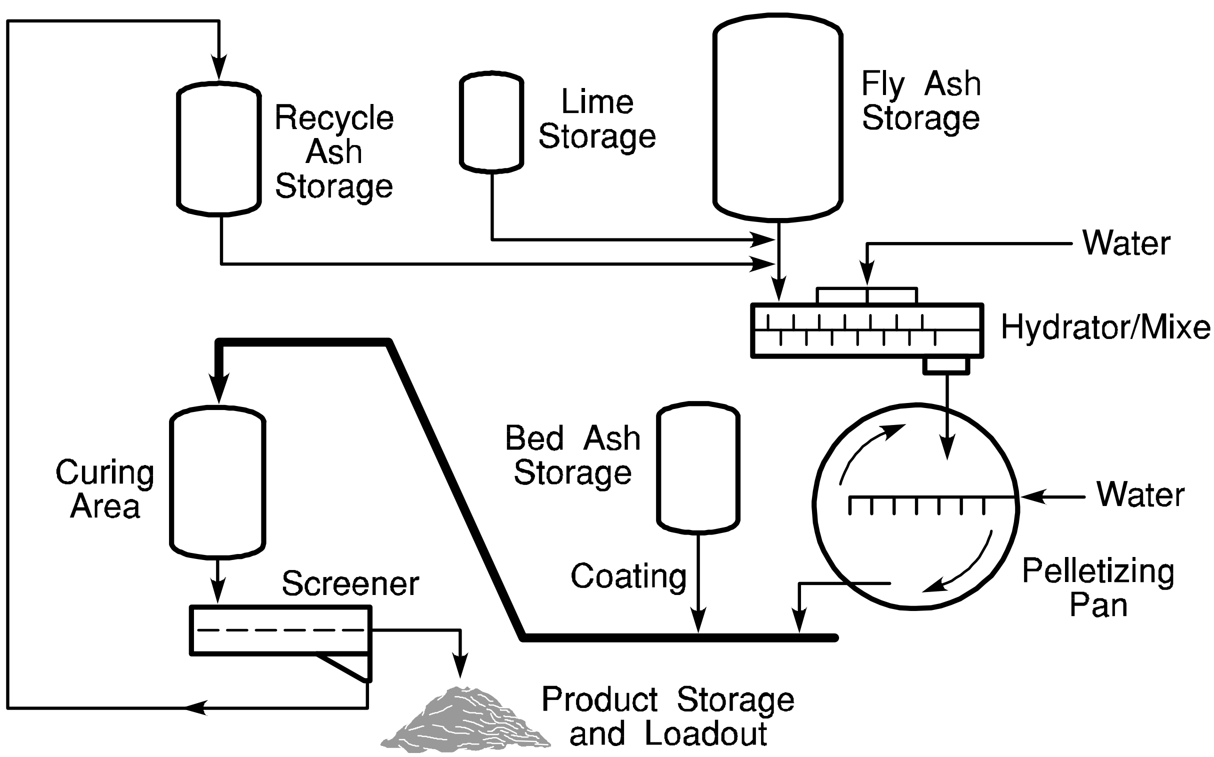

Figure 5. Schematic of the AET Synthetic Aggregate Process for PFBC Ashes

Table 5. Summary of the Properties of PFBC Ash-Based Synthetic Aggregate

Aggregate Properties*	No Lime Enhancement Karhula Ash	No Lime Enhancement AEP Tidd Ash	Lime Enhancement Karhula Ash	Lime Enhancement AEP Tidd Ash
Crush Strength (lbs)				
24 hours	23	75	323	240
48 hours	24	81	306	226
7 days	31	104	340	276
28 days	52	164	289	282
LA Abrasion Resistance				
Grade	B	C	B	C
Loss @ 28 days (%)	75.29	42.1	26.07	11.1
Resistance				
Loss after 5 cycles**	27.97	15.08	-4.23	2.35

* Curing Conditions - 180 °F Sealed for 24 hours.
** Magnesium Sulfate Solution.

Pelletizing trials were conducted at the WRI Waste Management Laboratory, employing a high-speed pin mixer for conditioning of the ash and a 3-foot diameter pelletizing pan for the agglomeration of the conditioned ash into a pelletized form.

Pelletizing trials have been conducted employing Karhula and AEP Tidd ash blends with and without lime enhancement. The pelletizing trials were conducted to address the water requirement and other processing parameters pertinent to defining the technical feasibility and relative economics of aggregate production from PFBC ashes.

Pelletized Ash Testing - The pelletized aggregate produced from Karhula and AEP Tidd PFBC ash was tested according to ASTM procedures as they relate to its use in various construction applications. Pelletized ash from each of the pelletizing trials was tested for crush strength, Los Angeles abrasion resistance (ASTM C-131) and soundness (ASTM C-88). The results of testing are presented in Table 5.

The results indicate that without hydrated lime addition, the pelletized PFBC ash does not meet the ASTM or AASHTO construction aggregate requirements of a maximum of 40% weight loss. However, the addition of 5% hydrated lime results in compliance with ASTM and AASHTO requirement for construction aggregate. The soundness of the aggregate using magnesium sulfate solutions were well below the AASHTO specifications of less than 18% loss after 5 cycles. In fact, the Karhula aggregate actually gained weight due to continued hydration during the five cycles.

Ash Use in Soil/Mine Spoil Amendment Applications

PFBC ash use as a soil amendment for agricultural and reclamation activities represents a potentially large market. A number of benefits can result from the application of PFBC residue to agricultural soils or mine spoils, including the modification of soil pH, supply of essential plant micro-nutrients for crop production, increasing water infiltration, and modification of soil structure promoting root growth. The availability of nutrients, such as sulfur, potassium, and phosphorous, along with micronutrients is also expected to benefit plant growth. In addition, the neutralization potential of the ash materials can alleviate acid conditions found in many soils. Also, PFBC ash contains anhydrite or gypsum, often used to reclaim sodic materials (i.e., materials influenced by high levels of sodium).

PFBC ashes generated at the Karhula and AEP Tidd plants were evaluated as soil amendments to ameliorate acid and sodic conditions on problem soils. As mentioned earlier, this material was thought to be useful because of its high neutralization potential, high $CaSO_4$ content, and nutritional potential. A very important consideration for the use of this material for ameliorating problem soils was the potential for negative impact of other constituents on the environment. Saturated paste extracts have shown that the ash materials do not contain any elements at concentrations deemed harmful to the environment.

<u>Acidic Soils and Mine Spoils Amelioration Study</u> - Laboratory equilibration studies were conducted to address the use of PFBC ashes as amendments to ameliorate acidic spoil and soil conditions. The laboratory equilibration study was designed to determine the potential of the ash materials to neutralize the available acid and the potential acidity associated with oxidation of reduced materials present in the spoil. An acid spoil material from Texas was used for the study. Humidity cells were used to simulate the oxidation of acid-forming soils under amended and non-treated conditions. Ag-lime ($CaCO_3$) and Karhula fly ash were used as the soil neutralization amendment materials in the equilibrium humidity cell studies. The acid spoil material was treated with three levels of ag-lime and three levels of Karhula fly ash:

- Level 1 = 30.4 g ag-lime or 89.1 g Karhula fly ash/1000 g of spoil
- Level 2 = 26.2 g ag-lime or 77.4 g Karhula fly ash/1000 g of spoil
- Level 3 = 17.6 g ag-lime or 51.6 g Karhula fly ash/1000 g of spoil

The amount of ag-lime used was based on the calcium carbonate equivalent (CCE) of the material and the acid/base accounting values of the acid spoil. The PFBC fly ash application rates were equivalent to the acid neutralization potential used for the ag-lime tests. Treatment of acid soils usually employs an application rate of 1.2 times that calculated from the neutralization potential. The humidity cell equilibration study showed the Karhula fly ash to be an effective acid neutralization amendment (Figure 6).

The acid present in the treated materials was neutralized and the formation of acid from acid-forming minerals present in the spoil material was significantly reduced due to treatment with PFBC ashes. It is apparent that the neutralization reaction rate of the Karhula fly ash in raising pH of the acid spoil is slower than that of the ag-lime. While the Karhula fly ash shows a delayed response, the ag-lime reacted immediately with the spoil material, increasing the pH and maintaining it with time. Although the Karhula fly ash is an effective long-term amendment for acid soils and spoils, the lower early pH levels of approximately 4 for the Karhula fly ash-treated spoils may cause some problems with germination and early plant growth with sensitive plant species.

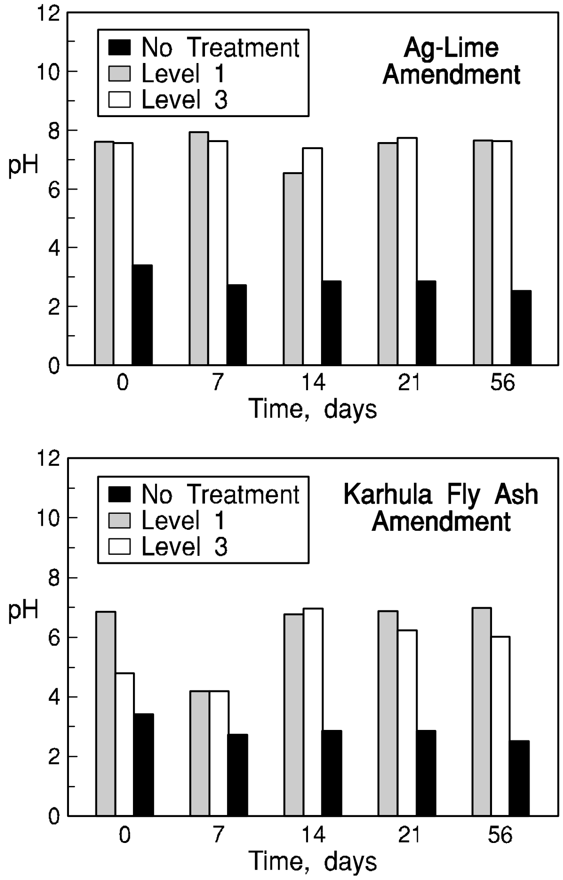

Figure 6. Influence of Ag-Lime and Karhula Fly Ash on Acidic Mine Spoil pH

Greenhouse Productivity Study - A greenhouse study was conducted to show the influence of PFBC ashes on the productivity of acidic mine spoil containing very high potential acidity. The study compared the production of Garrison Meadow foxtail grass (*Alopecuras protensis cult. Garrison*) on acid spoil materials amended with ash from the Karhula and AEP Tidd operations and with ag-lime ($CaCO_3$). The greenhouse study was conducted under controlled conditions of light, temperature, fertilizer levels, and soil moisture requirements to maximize plant growth conditions. Fertilizer additions were based on nitrogen, phosphorous, and potassium levels and did not include concerns for nutrient ratios and micronutrient deficiencies.

The results of the study are shown in Figure 7. The results clearly indicate that extremely poor quality soils can be successfully treated with PFBC ashes, resulting in good plant productivity. The results show PFBC ashes to be as effective as ag-lime in seed germination and more effective than ag-lime in plant production and root penetration. Total plant production was about 25% higher for the Tidd and Karhula ash treatments compared to the ag-lime treatment at the high level (Level 1) of application (Figure 7).

At the low amendment application rate the Karhula treatment resulted in plant production about 30 % higher compared to the Tidd and ag-lime treatments, which were comparable. An obvious factor responsible for the differences in the plant production between the PFBC ash-amended spoils and the ag-lime amended spoil was the root penetration. The PFBC ash treated soils contained root matter throughout the potted soil, while much of the root mass in the ag-lime treated soil was associated with the sides of the pots. No problems with the early low pH were found.

Sodic Soils Amelioration Study - Permeability testing of sodic spoil materials collected from a mine site located in North Dakota indicated that PFBC ash was an effective treatment resulting in the potential for enhanced root

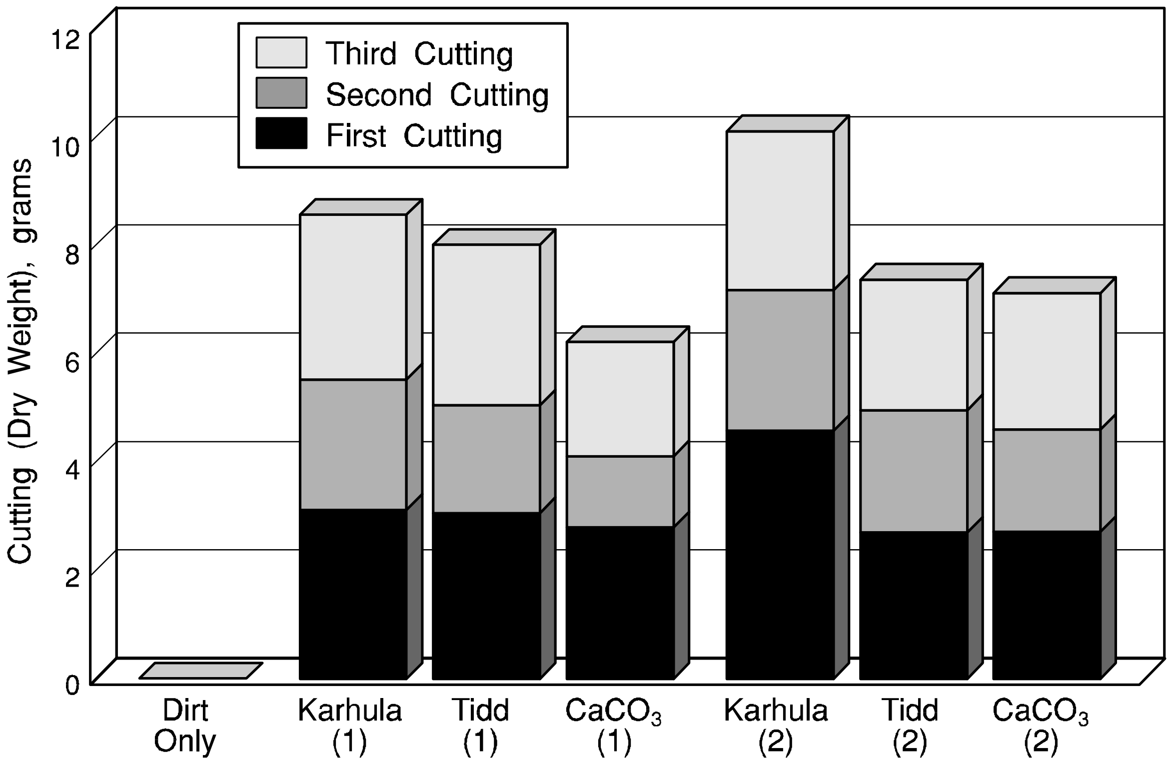

Figure 7. Dry Weight Production of Meadow Foxtail Grass Grown on Karhula Fly Ash, AEP Tidd Fly Ash and Ag-Lime Amended Acidic Mine Spoil (Level 1 –High Application Rate; Level 2–Low Application Rate)

penetration and gas and liquid movement within the spoil material. The untreated spoil material allowed no water penetration into the material or movement through the material during the permeability tests. Treated material allowed water penetration and movement through the material at a relatively high rate.

FUTURE ACTIVITIES

Activities for FY '96 includes the acquisition and testing of an additional ash from the Foster Wheeler Energia Oy R and D center in Karhula Finland. This ash was produced in the 10 MW_e PCFBC pilot plant employing high sulfur bituminous coal and limestone sorbent from Illinois. As such, this ash expands the range of composition of ashes evaluated in this project. The testing will evaluate construction related applications including cement and concrete use, fills and embankment construction, soil stabilization; and synthetic aggregate production. In addition, a greenhouse study will be conducted related to its use in agricultural and soils remediation applications.

ACCOMPLISHMENTS

In summary, Western Research Institute, in conjunction with the Electric Power Research Institute, Foster Wheeler International, Inc., and the U.S. Department of Energy (METC), has undertaken a research and demonstration program designed to examine the market potential and the technical feasibility of ash use options for PFBC ashes. Ash from low-sulfur subbituminous coal-fired Ahlstrom pilot circulating PFBC tests in Karhula, Finland, and ash from the AEP's high-sulfur bituminous coal-fired bubbling PFBC in Brilliant, Ohio, were evaluated in laboratory and pilot-scale ash use testing at WRI.

The technical feasibility study examined the use of PFBC ash in construction-related applications, including its use as a cementing material in concrete and use in cement manufacturing, fill and embankment materials, soil stabilization agent, and use in synthetic aggregate production. Testing was also conducted to determine the technical feasibility of PFBC ash as a soil amendment for acidic and sodic problem soils and spoils encountered in agricultural and reclamation applications.

The results of the technical feasibility testing indicated the following:

- PFBC ash does not meet the chemical requirements as a pozzolan for cement replacement. However, it does appear that potential may exist for its use in cement production as a pozzolan and/or as a set retardant.

- PFBC ash shows relatively high strength development, low expansion and low permeability properties that make its use in fills and embankments promising.

- Testing has also indicated that PFBC ash, when mixed with low amounts of lime, develops high strengths, suitable for soil stabilization applications and synthetic aggregate production. Synthetic aggregate produced from PFBC ash is capable of meeting ASTM/AASHTO specifications for many construction applications.

- The residual calcium carbonate and calcium sulfate in the PFBC ash has been shown to be of value in making PFBC ash a suitable soil amendment for acidic and sodic problem soils and mine spoils.

In conclusion, PFBC ash represents a viable material for use in currently established applications for conventional coal combustion ashes. As such, PFBC ash should be viewed as a valuable resource, and commercial opportunities for these materials should be explored for planned PFBC installations.

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ACKNOWLEDGMENTS

The authors acknowledge the support of the Electric Power Research Institute, Foster Wheeler Energy International, Inc., and the U.S. Department of Energy (DOE), Morgantown Energy Technology Center (METC), under Cooperative Agreement Number DE-FC21-93MC30127. The support of Dr. Madhav Ghate, METC COR is appreciated.

The authors also wish to acknowledge the technical assistance of Kumar M. Sellakumar of Foster Wheeler Energy International, Inc.; John M. Wheeldon and Richard Brown of EPRI; American Electric Power Services for contributing the ashes from AEP Tidd and Kamalendu Das of METC for his project support and assistance.