Chapter 6

Commercial Applications of We Energies Bottom Ash

Introduction

We Energies bottom ash can be beneficially utilized in a variety of manufacturing and construction applications. These applications include both confined and unconfined geotechnical uses, as an ingredient for the production of soil products and as an aggregate for concrete products. When using bottom ash, it is important to compare the applications and material properties to local and state regulations and specifications. In order to evaluate potential applications, We Energies has studied the properties and performance of the material with the assistance of several consulting firms and research institutions. We Energies bottom ash is predominantly used for the following applications:

1. Road base and sub-base
2. Structural fill
3. Backfill
4. Drainage media
5. Aggregate for concrete, asphalt and masonry
6. Abrasives/traction
7. Manufactured soil products

Road Base and Sub-Base

STS Consultants, Ltd. conducted a study for We Energies to evaluate the potential use of Pleasant Prairie Power Plant bottom ash as a base course in road construction (42). The study evaluated potential applications, and initiated durability and structural testing of bottom ash from We Energies Pleasant Prairie Power Plant.

The following tests were performed:

- Particle size analysis (ASTM D-422)
- Moisture-density relationship test - to establish maximum dry density (ASTM D-698-78, Method A).
- California Bearing Ratio (CBR) test - to develop a basis for comparison of bottom ash material with conventional base course aggregates (ASTM D-1883).
- Laboratory permeability test (ASTM D-2434)
- Direct shear test - to determine the angle of internal friction (ASTM D-3080)

The scope of this study included establishing an equivalent thickness of bottom ash compared to conventional aggregates in road construction. To address frost susceptibility in a meaningful manner, a sample of bottom ash was compacted into a 6" mold at its optimum moisture content. The mold with its perforated base was placed in a container of water for three (3) days to allow the sample to absorb water. The sample was then frozen and subsequently thawed. Volume change measurements were made after both freezing and thawing.

The gradation of bottom ash tested was comparable to a silty fine to coarse sand with little gravel. However, bottom ash was considerably finer grained than the conventional gradation for fine aggregate.

The PPPP bottom ash exhibited a maximum dry density of 88.5 pounds per cubic foot and optimum water content of 28%. Conventional aggregates have maximum densities in the range of 105 to 120 lb/cu ft. at optimum moisture contents typically in the range of 8% to 16%.

The CBR test results showed PPPP bottom ash had a CBR value on the order of 30% of that of conventional aggregate. In general, more coarsely graded and more angular materials tend to exhibit greater stiffness and tend to distribute load more evenly. The results showed that when used in a comparable thickness, bottom ash exhibits less favorable load distribution characteristics and would be more flexible, i.e., greater surface deformation under a load, than for conventional aggregates.

However, based on accepted pavement design principles, it was estimated that bottom ash used at approximately 1.5 times the thickness of conventional aggregates achieves a comparable stress level in the underlying clay subgrade. For equivalent deformation, it was estimated that the thickness of bottom ash should be two times the thickness of conventional aggregates to maintain similar deflection at the surface of the base course layer (42). Figure 6-1 shows the stress penetration CBR curve for PPPP bottom ash.

The report also evaluated frost susceptibility, since bottom ash contains more fine-grained particles than conventional aggregates. The permeability study of compacted bottom ash was in the same range as conventional base course aggregates, i.e., 8×10^{-4} to 5×10^{-5} cm/sec. However, due to the presence of slightly higher fines when compared to conventional materials, it is recommended that bottom ash be used at locations with reasonably good drainage.

The direct shear test indicated an angle of internal friction of 40 degrees and cohesion of 750 psf, for the ash tested. The friction angle is consistent with this type of material. Figure 6-2 is a graph showing the normal stress vs. shearing stress relationship. However zero cohesion was expected due to its similarity to silty sand. Freeze-thaw test results showed a volumetric expansion of the compacted ash of 0.4% upon freezing. But after thawing, the net volumetric expansion was 0.1%.

Table 6-1 shows the gradation for PPPP bottom ash and crushed aggregate base course (crushed gravel) per the 1996 Wisconsin DOT Standard Specification for Highway and Structure Construction at the time of testing. A comparison of We Energies' bottom ash to crushed aggregate base course in 2003 Wisconsin DOT Standard Specifications can be found in Chapter 3.

Table 6-1: Grain Size Distribution (ASTM D422) PPPP Bottom Ash and Comparison with WDOT Crushed Gravel Specification for Crushed Aggregate Base Course

Sieve Size	PPPP Bottom Ash % Passing	Gradation No. 1 Crushed Gravel % Passing	Gradation No. 2 Crushed Gravel % Passing	Gradation No. 3 Crushed Gravel % Passing
1.5”	100.00	100	-	-
1”	98.15	75 - 100	100	100
.75”	94.09	-	-	95 - 100
.50”	85.29	-	-	-
.375”	78.28	40 - 75	50 - 85	50 - 90
#4	57.78	30 - 60	35 - 65	35 - 70
#8	41.51	-	-	-
#10	36.99	20 - 45	25 - 50	20 - 55
#16	27.92	-	-	-
#30	17.72	-	-	-
#40	13.10	10 - 30	10 - 30	10 - 35
#50	10.56	-	-	-
#100	6.05	-	-	-
#200	3.05	3 - 10*	3 - 10*	8-15

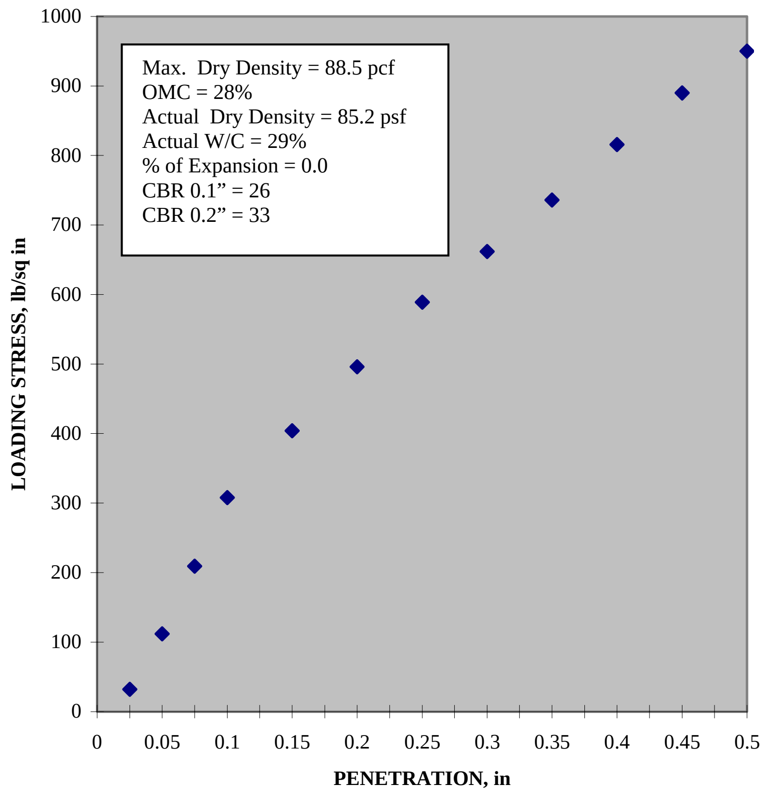

Figure 6–1: Loading Stress vs. Penetration (California Bearing Ratio) Curve for PPPP Bottom Ash

* Limited to a maximum of 8% in the base course placed between old and new pavement

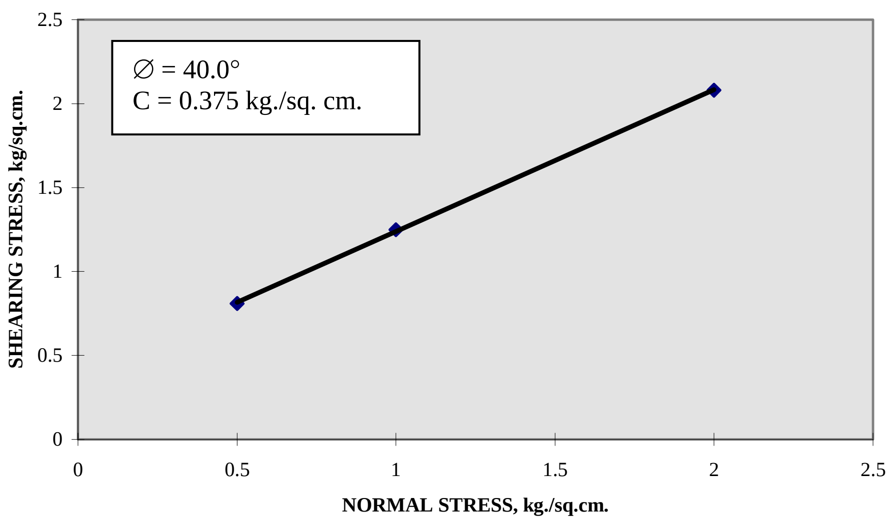

Figure 6–2: Normal Stress vs. Shearing Stress PPPP Bottom Ash

Field Study

Following the initial study conducted on the suitability of bottom ash from PPPP as a base course, another study was commenced with field observation and testing on the performance of bottom ash during construction of another roadway in the Lakeview Corporate Park (43). The purpose of the testing was:

1. To further evaluate the equivalency ratio using field plate load bearing tests.
2. To evaluate frost susceptibility during a winter season by level survey techniques.
3. To observe the general performance of the road subgrade for various thickness of base course.

Plate Load Test

As part of the road subgrade preparation, crushed limestone was placed in thicknesses varying from 0” to 6”. Bottom ash was placed above the proof rolled subgrade and leveled with a Caterpillar 14G grader. Bottom ash was then compacted close to its Modified Proctor maximum dry density, in the range of 83 to 95 lb/cu ft. Crushed stone and gravel were placed in a parallel stretch of roadway and compacted to approximately 100% of its Modified Proctor maximum dry density. Plate load tests were performed in accordance with Military Standard 621A (Method 104).

Based on the test performed, a subgrade reaction modulus of 380 pounds per cubic inch (pci) was calculated. A similar test performed at the surface of the native subgrade gave a reaction modulus of approximately 212 pci. This gives a modular ratio of bottom ash to subgrade of approximately 1.9. Originally, a modular ratio of approximately 3 had been calculated. Conservatively, a modular ratio of 2 is appropriate.

Level Survey

The road surface was initially surveyed to establish a baseline for the determination of freeze-thaw effects. The level survey conducted on February 9, 1989, recorded a maximum surface heave of 0.6”, but after the spring thaw, the surface elevations were within ± 0.24”. These heaves were observed on both surfaces with and without bottom ash base course. The survey did not find any distinct pattern of response with the bottom ash experiencing neither greater nor lesser net heave during freeze-thaw cycles.

General Road Performance

The surface of the concrete road was inspected initially and found to be in competent condition, free of substantial ruts, cracking and other signs of pavement distress. The pavement was observed again after spring thaw and found to be in good condition. This indicated that the subgrade performed satisfactorily through the first winter.

It was concluded that the PPPP bottom ash materials are well suited for use as general structural fill in road subgrade preparations or below structural elements. Based on field observations, it was recommended to use bottom ash in a 2 to 1 thickness ratio compared to conventional base course material, to enhance the performance of the pavements. The reason for this recommendation is the lesser degree of stiffness of the bottom ash. It was concluded that in well-drained pavement sections, bottom ash base course (in the recommended thickness) should perform well.

Bottom Ash as Base Course Aggregate for Flexible Pavement Sections

The earlier study evaluated the performance of bottom ash as a base course material for a rigid pavement section. Though the pavement section performed well, a rigid pavement was used in that study and the performance of that section cannot be assumed to represent the behavior of less rigid pavement sections. Hence, a second pilot study was undertaken to evaluate the use of bottom ash for conventional base course aggregate in a flexible pavement section, such as parking lots and bituminous-paved roads (44).

A.W. Oakes & Son had observed that the actual performance of bottom ash in constructed haul roads was excellent. From this experience, they suggested that the ash might be effective at lesser thicknesses than recommended in the original study performed by STS Consultants, Ltd. A.W. Oakes & Son suggested that a pavement section consisting of 4” – 6” of bottom ash over 4” – 6” of open-graded crushed stone would serve as an excellent base for a heavy duty asphalt pavement.

Pavement Construction

A failed section of pavement 24 ft. wide by 55 ft. long located at the entrance drive of A.W. Oakes & Son Land Reclamation Landfill Facility in Racine, Wisconsin, was replaced with 4¾” of bituminous concrete pavement placed over 4½” – 6½” of bottom ash which was over 8” of an open-graded crushed stone base layer. The test section was constructed in November and December of 1993. Field density tests were performed by STS Consultants on the in-place bottom ash and on the in-place bituminous pavement using a nuclear density meter (44).

Figure 6-3: Bottom ash base course for concrete building slab in Racine, Wisconsin

Pavement Performance

The test pavement was evaluated by STS Consultants, Ltd. on March 21, 1994; November 22, 1994; April 20, 1995 and April 22, 1997. The field observations revealed that the pavement section performed well with only minor rutting in wheel traffic areas. The depth of rutting increased slightly over the years, but was not considered abnormal. The asphalt surface showed no signs of alligator cracking.

No direct correlation can be made with the adjoining pavement, since the age and construction of this pavement is unknown. However, from field observations, it was concluded that the pavement section appeared to be comparable to or better than the adjacent pavement. Recent evaluation of the pavement by We Energies staff confirmed that the pavement is in good condition.

We Energies Bottom Ash Backfill

We Energies bottom ash has been successfully used as a backfill material on numerous projects. PPPP bottom ash is a clean, durable, torpedo sand-like material. Other We Energies bottom ashes are finer or include gravel size gradation particles as well.

The suitability of bottom ash as a backfill material can be understood from its close resemblance to commonly used natural granular backfill materials. In most cases, the most critical factor is the gradation of backfill material.

Sieve analyses indicated that bottom ash from PPPP and PIPP (Units 7–9) meets the gradation requirements for a granular backfill material by both the WDOT and the MDOT. The bottom ash from PIPP Units 1-6 does not meet the specifications because over 23% of fines passed the No. 200 sieve. However this ash from PIPP can be blended, washed or screened to meet the requirements. Other analyses have shown that bottom ash from OCPP also meets the WDOT gradation requirement for granular backfill.

Figure 6-4: Bottom ash structural backfill being used for building construction in Racine, Wisconsin

Permeability of the backfill is a common concern, especially in applications where the backfill material is subjected to a moist environment. Permeability is also one of the major reasons that sand is a preferred backfill material when compared to clay.

Since the gradation of bottom ash and sand are similar, they tend to exhibit similar permeability. Clean fine sand has a coefficient of permeability (K) in the range of 0.004 to 0.02 cm/sec (45). The drainage characteristics associated with the above K values are considered good. Most We Energies bottom ashes have a coefficient of permeability in this range and can be considered to provide good drainage when used as a backfill material.

Table 6-2 gives the coefficient of permeability for We Energies bottom ash and conventional backfill materials.

Table 6-2: Permeability and Drainage Characteristics of Backfill Material

Type	Approximate Coefficient of Permeability K, cm/sec	Drainage Characteristics
Clean Gravel	5 - 10	Good
Clean Coarse Sand	0.4 - 3	Good
Clean Medium Sand	0.05 - 0.15	Good
VAPP Bottom Ash	0.0054	Good
OCPP Bottom Ash	0.001	Good
PIPP 1-6 Bottom Ash	0.0048	Good
PPPP Bottom Ash	0.0049	Good
PWPP Bottom Ash	0.0046	Good
Clean Fine Sand	0.004 - 0.02	Good
Silty Sand and Gravel	10^{-5} - 0.01	Poor to Good
Silty Sand	10^{-5} - 10^{-4}	Poor
Sandy Clay	10^{-6} - 10^{-5}	Poor
Silty Clay	l0^{-6}	Poor
Clay	10^{-7}	Poor
Colloidal Clay	10^{-9}	Poor

Bottom ash has a lower density when compared to conventional backfill materials. Conventional backfill materials (like sand) typically have a maximum dry density of 105 to 120 lb/cu ft. We Energies bottom ash has a maximum dry density in the range of 49 to 89 1b/cu ft. VAPP bottom ash showed the lowest dry density of 49 lbs./cu ft., and PPPP bottom ash had the highest density of 89 lbs/cu ft.

Bottom ashes from VAPP and MCPP have a higher percentage of fines and are more sensitive to moisture changes. However, bottom ash from other power plants performed well when compacted at the optimum moisture content. Soil generally exhibits lateral earth pressure. Structures like retaining walls have to be designed, considering the lateral pressure exerted by soil retained by the structure. The angle of internal friction for various backfill materials is shown in Table 6-3.

Table 6-3: Approximate Friction Angle

Soil Type	Ø Degrees	Tan Ø
Silt or Uniform Fine to Medium Sand	26 to 30	0.5 to 0.6
Well-Graded Sand	30 to 34	0.6 to 0.7
Sand and Gravel	32 to 36	0.6 to 0.7

The friction angle of bottom ash is very similar to that of well-graded sand and gravel. The lateral earth pressure on the structure can be reduced because of the lower material density. Assume that the dry unit weight of a specific bottom ash in such a situation is only ⅔ of the dry unit weight of conventional backfill material. Because the friction angle value remains more or less the same, the lateral earth pressure will also be reduced to ⅔ of regular fill. Due to the reduced lateral pressure on the wall, it can be designed as a thinner section, with less reinforcement, or with a higher safety factor.

Bottom Ash as an Anti-Skid Material

Bottom ash performs as an excellent anti-skid material when spread on ice or snow covered roads. Bottom ash does not have the corrosivity of salt, as only a very small fraction of it is soluble. The performance of bottom ash as an anti-skid material is not temperature dependent. For this reason, bottom ash can be considered a better anti-skid material than road salt. The WisDOT recommends the following rate of application (46):

1. A rate of 500 pounds per mile on average snowy and icy roads.
2. A rate of 800 pounds per mile at intersections, hills, curves and extremely icy areas.

Used tires are sometimes burned with coal in some power plants in the United States. Bottom ash produced from plants that burn tires may contain steel wires that are left from the steel belted radial tires. Bottom ash containing steel wires is not suitable for use on roads as steel can puncture tires of vehicles traveling on these roads.

We Energies power plants do not burn used tires with coal. Hence, the bottom ash will not contain such steel wires and is acceptable for use as an anti-skid material on roads. Bottom ash will usually require screening to meet anti-skid material gradation requirements.

Bottom Ash as an Aggregate in Asphaltic Concrete

A.W. Oakes & Son replaced fine aggregates with bottom ash in asphaltic concrete mixtures for paving projects. Since bottom ash particles are porous, the consumption or absorption of asphalt binder is higher than when the conventional fine aggregate is used. Hence, from a purely economical point of view, We Energies bottom ash is not best suited as an aggregate for asphaltic concrete. However, other bottom ash sources have been extensively used by West Virginia Department of Transportation for asphalt roads, particularly for secondary roads (47).

Bottom Ash as a Bike Trail Base and Surface Material

Bottom ash has been successfully used as a base and surface material for bike trails and as a surface course material in parks and for running tracks.

In several states in the United States, bottom ash has been used as a finish grade surfacing material. The New River Trail in Virginia surfaced a portion of its 57-mile route with bottom ash. This project demonstrated significant savings in cost compared to a similar crushed stone surface (47).

We Energies Bottom Ash as a Manufactured Soil Ingredient

During the past several years, We Energies studied the properties of bottom ash and its use as a soil-amending agent to heavy clayey soils to increase its workability and porosity. Studies conducted at the University of Wisconsin-Madison (48) revealed that land application of bottom ash had no negative effect on the crops or soil during the five-year period of study.

Bottom ash from the OCPP and PPPP were used on farms in Kenosha County, Wisconsin, at a rate ranging from 100 to 200 tons per acre. Bottom ash was tilled into the soil to a depth of approximately 10".

Corn was grown on this field for two years and soybeans were grown for one year. Chemical analysis conducted on the soil throughout the three-year study revealed that there was no appreciable movement of nutrients or heavy metals below the 10" plow layer. Chemical analysis of corn and soybean seed and edible tissue for heavy metals and nutrient uptake indicated no adverse effect. Crop yield at the bottom ash treated soils was generally higher than from the non-treated soils.

The Scott's Company of Maryville, Ohio, studied the properties of We Energies bottom ash and determined that it is suitable as an ingredient in manufactured soil products. The bottom ash from Milwaukee County Power Plant, Port Washington Power Plant and Valley Power Plant were used in their studies.

Figure 6–5: "Before" grass growing on We Energies' landscaping with Scott's 10% bottom ash topsoil blend at We Energies' Milwaukee County Power Plant.

Their investigation has determined that the addition of 10–15% (weight basis) of bottom ash provides desired soil porosities. In addition, the ash blended soils exhibit excellent micronutrient composition.

The mixture also meets all of the state and federal limits for trace elements in composted soils. Bottom ash has been blended with peat, compost and manure to manufacture about 300 cubic yards of manufactured topsoil for We Energies landscaping projects with excellent results.

Figure 6–6: "After" grass is growing on landscaping with Scott's Hyponex 10% bottom ash topsoil blend at We Energies' Milwaukee County Power Plant.

Table 6-4 shows the summary of total elemental analysis results for fly ash and bottom ash and comparison to Wisconsin DNR, NR 538 standards, together with various naturally occurring materials. Table 6-5 shows ASTM water leach test data, in a similar fashion.

Additional information on environmental considerations is provided in Chapter 9.

Table 6-4: Total Elemental Analysis
Comparison of Sample We Energies Fly Ash, Bottom Ash and Natural Materials

Parameter	Units	NR 538 Category 1 Criteria	NR 538 Category 2 Criteria	Fly Ash	Bottom Ash	Road Gravel	Sand	Pea Gravel	Crushed Limestone	Garden Top Soil	Recycled Concrete
Antimony	mg/kg	6.3									
Arsenic	mg/kg	0.042	21	31	4.2	2.8	1.1	2.1	1.0	4.0	2.3
Barium	mg/kg	1100		2000	410						
Beryllium	mg/kg	0.014	7	11	1.4	0.2	0.2	0.3		0.8	0.8
Boron	mg/kg	1400		690	60						
Cadmium	mg/kg	7.8		2.3	0.059						
Chromium	mg/kg	14.5 as Cr+6			65.5	22.4	34.1			59.1	33.2
Lead	mg/kg	50			23.6	14.1				43.3	
Mercury	mg/kg	4.7			0.11						
Molybdenum	mg/kg	78		12	1.6						
Nickel	mg/kg	310		40.4	28.1	6.4					6.2
Selenium	mg/kg	78									
Silver	mg/kg	9400									
Strontium	mg/kg	9400				71.7	65.5	74.3	25.6	129.4	113.4
Thallium	mg/kg	1.3									
Vanadium	mg/kg	110		201							
Zinc	mg/kg	4700		111	49.7	16.0	11.2	9.8	5.3	162	23.3

Note: Concentrations not shown are below the analytical detection levels

Table 6-5: ASTM D3987 Water Leach Test Data
Comparison of Sample We Energies Fly Ash, Bottom Ash and Natural Materials

Parameter	Units	NR 538 Category 1 Criteria	NR 538 Category 2 Criteria	Fly Ash	Bottom Ash	Road Gravel	Sand	Pea Gravel	Crushed Limestone	Mequon Clay	Garden Top Soil	Recycled Concrete
Aluminum	mg/l	1.5	15	9.7	3.6	0.128	0.18	0.091	0.032	0.086	0.138	2.9
Antimony	mg/l	0.0012	0.012			0.0055		0.0032	0.0052	0.0026	0.0047	0.002
Arsenic	mg/l	0.005	0.05	0.003	0.004					0.0017	0.0016	
Barium	mg/l	0.4	4	0.76	0.25	0.0021	0.0017	0.0024	0.0018	0.0071	0.0135	0.146
Beryllium	mg/l	0.0004	0.004	0.0031		0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
Cadmium	mg/l	0.0005	0.005									
Chloride	mg/l	125		0.57								
Chromium	mg/l	0.01	0.1	0.11	0.0013							0.019
Copper	mg/l	1.3			0.0096							
Iron	mg/l	0.15			0.1					0.033	0.092	0.008
Lead	mg/l	0.0015	0.015		0.0016			0.0012				0.0012
Manganese	mg/l	0.025	0.25		0.0033					0.003		0.003
Mercury	mg/l	0.0002	0.002									
Molybdenum	mg/l	0.05		0.23	0.014							
Nickel	mg/l	0.02										
Selenium	mg/l	0.01	0.1	0.034	0.0013							
Sulfate	mg/l	125	1250	35	68						28.1	11
Thallium	mg/l	0.0004	0.004									

Note: Concentrations not shown are below the analytical detection levels

We Energies Bottom Ash as a Soil Ingredient for Green Roofs

We Energies bottom ash was also used experimentally as a portion of a soil ingredient in green roofs. Green roofs involve growing plants on rooftops, thus replacing the vegetated footprint that was destroyed when the building was constructed. Establishing plant material on rooftops provides numerous ecological and economic benefits including stormwater management, energy conservation, mitigation of the urban heat island effect, increased longevity of roofing membranes, as well as providing a more aesthetically pleasing environment to work and live. Examples of green roofs are shown in Figures 6-7 and 6-8.

Additional loading is one of the main factors in determining both the viability and the cost of a green roof installation, especially when a green roof is not part of the initial design of the building. Bottom ash is a lightweight material.

Figure 6–7: Green Roof at ABC Supply Company, Inc.

Blending bottom ash with the soil provides a lightweight growing media for the plants of the green roofs. We Energies' bottom ash was used for a small portion of the green roof (as a blended soil ingredient) by ABC Supply Company, Inc. in Beloit, Wisconsin. Additional information can be found on website at: http://www.greengridroofs.com/Pages/system.htm

Figure 6–8: Green Roof at ABC Supply Company, Inc.

We Energies Recovered Ash and Reburning

Coal Ash Recovery (U.S. Patent # 6,637,354) (49)

As part of We Energies' continued effort to find innovative applications for its coal combustion products, and to preserve valuable licensed landfill capacity, We Energies has patented a process for recovery of coal combustion products from the PPPP ash landfill. The PPPP ash landfill occupies an area of approximately 163 acres and is located north of Bain Station road and south of Highway 50.

The landfill was placed in operation in 1980 and consists of 25 cells with a total licensed capacity of 3,012,155 cubic yards of coal combustion products. Cell 1 was constructed with a natural 5 ft. thick clay liner and cells 2–4 were constructed with a 5 ft. thick recompacted clay groundwater separation liner. Currently only cells 1–3 are filled and cell 4 is partially filled. Since demand for bottom ash and fly ash has continued to increase since the 1980's, the quantity of material that goes into these landfills is limited. Since 1998, more material has been recovered from the landfill than placed in it.

The coal combustion materials landfilled in cells 1–4 consist primarily of bottom ash, solidified fly ash and wastewater treatment system solids. We Energies ash reclamation plan is to excavate the landfilled material, crush and

Figure 6-9: Coal ash recovery from the Pleasant Prairie Power Plant ash landfill for use as granular base course material

screen if necessary, test and store for reuse in compliance with the criteria defined in NR 538, plus boron as an additional leachable parameter in

Figure 6-10: Recovered coal ash from the Pleasant Prairie Power Plant ash landfill

accordance with a Cooperative agreement signed with the Wisconsin DNR (50). Any material that is found to be unsuitable for beneficial application such as miscellaneous debris or soil is separated and properly placed in designated areas within the current active cell.

The first pilot project to reprocess landfilled combustion products were carried out in July 1998 and the second in October 1998. An earthwork contractor who was very experienced in landfill and ash management performed the work. A state certified material testing laboratory was also hired to monitor and sample the processed material, during the first operation. The contractor's engineer collected samples during the second operation. Samples were collected every 30 minutes from the transfer point where the ash fell onto the stacker conveyor during the entire operation per ASTM sampling procedure D2234. A composite sample was prepared for every 5000 tons processed and tested.

Both ash recovery operations worked very smoothly, and were dust free due to the residual moisture and low fines content of the material processed.

Figure 6-11 shows the grain size distribution range of the recovered ash. It is important to mention that the samples tested had excellent grain size distribution and a small amount of material passing the #200 sieve. Tests run

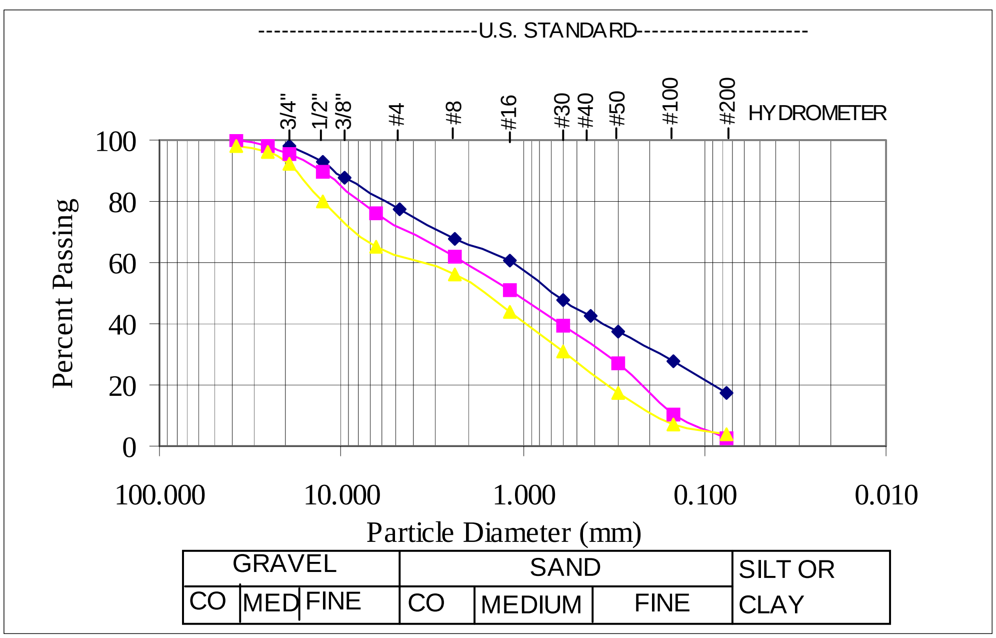

Figure 6–11: Gradation Distribution Range of Recovered Ash

to evaluate the environmental effects of this material also gave encouraging results. The ash met all of the NR538 category 2 criteria with the exception of dissolved aluminum. However the concentration of aluminum was only slightly above the limits (18 to 22 mg/l vs. 15 mg/l criteria).

The only other compounds detected that were within one order of magnitude of the category 2 criteria were antimony, barium, chromium and sulfate. The remaining elements were either non-detectable or were several orders of magnitude below the category 2 criteria.

The first 10,000 tons of recovered ash was used as a sub-base material under pavements. This practice has continued due to the excellent sub-base and base performance of the interlocking angular shaped recovered ash particles for this application. This is an application meeting NR538.10 (5) category 4 standards. However the recovered ash test results meet most of the NR 538 category 2 requirements.

In February 2001, Wisconsin DNR and We Energies entered into an agreement in which an ash sampling and testing procedure was specified. In order to determine the chemical consistency of the coal combustion materials recovered from the landfill, the ash will be excavated, processed, and stored in a designated area in the landfill in no larger than 50,000 cubic yard piles. A representative sample will be obtained per each 10,000 tons of reclaimed material for testing using guidelines presented in ASTM D2234. A minimum of five discrete samples of at least 25 pounds each will be collected from different locations on the storage pile. These discrete samples will be composited, mixed, and volume reduced by manual riffling to develop the analysis sample. Testing will be performed to measure category 2 parameters (described in ch. NR 538, Wis. Adm. Code), as well as boron as an additional leachable parameter, for use as sand/gravel/and crushed stone replacement materials. These recovered materials will be used in category 4 or 5 applications (described in ch. NR 538, Wis. Adm. Code).

Reburning of Coal Ash (U.S. Patent # 5,992,336) (51)

If coal ash has a significant amount of unburned carbon, it cannot be utilized directly in applications such as concrete, and concrete products. According to ASTM C618, an ash must have a LOI value no higher than 6% for use in concrete. An upper limit of 3% is more realistic. Higher LOI ash cannot be used because of color problems and concerns for durability under freezing and thawing conditions.

We Energies is utilizing an innovative technique, reburning of coal ash, to treat high carbon coal ash using existing capital installations, and particularly the existing pulverized coal boilers. Coal ash, either fly ash or bottom ash or a mixture of both, is added in a fine particle condition to the furnace of a pulverized coal boiler in a small proportion to the pulverized coal fed to the furnace. The ash is burned with the pulverized coal. The proportion of coal ash is preferably in the range of 1% – 3.5%, by weight of the pulverized coal.

The high carbon coal ash generally results from burning bituminous coal while sub-bituminous coal will typically result in a low carbon ash with an LOI of less than 1%. The high LOI fly ash and bottom ash formed from a pulverized coal furnace burning bituminous coal can be rendered into a usable fly ash and bottom ash having very low LOI such as produced in a pulverized coal furnace using subbituminous coals. This can be achieved by adding the high LOI coal ashes to the coal stream which normally produces low LOI coal ashes.

The bottom ash and fly ash may be handled separately. The bottom ash typically has a larger particle size and may require grinding to reduce it to the size of the pulverized coal stream. The preferred approach for handling of the bottom ash is to add it to the store of coal prior to the coal being ground.

For instance in original tests conducted in 1996, bottom ash having an LOI of 37.9% and a moisture content of 60.0% was added to loaded coal cars using a front end loader. The bottom ash was added at a ratio of 5% of the coal prior to unloading in a rotary car unloader. The coal cars were then unloaded in a normal manner and the coal was transported by a conveyor system to one of five coal silos. The bottom ash and coal mixture was then milled and injected into the boiler with the fuel stream during normal operation in the furnace along with coal from the other four silos and mills that did not contain bottom ash. Thus, the actual ratio of bottom ash to coal transported for combustion was 1% of the overall fuel being burned. The addition of the 1% of bottom ash was not significant from an operational viewpoint. There was no discernable difference in emissions, and the bottom ash coal fuel blend had adequate fineness for combustion. The fly ash from the reburning of the bottom ash exhibited a LOI of between 0.2% and 0.4% and has a slightly reduced calcium oxide content. Bottom ash typically represents less than 20% of the coal ash.

High LOI fly ash can be introduced using four approaches: (1) introduced with the pulverized coal stream entering the pulverizer classifiers. This has the advantage of thorough mixing upstream of the burners and would require only a slight additional volume of air to transport the fly ash; (2) introduced with the pulverized coal stream at each burner location; (3) introduced with the secondary air flow stream as it enter the furnace. The secondary air flow with the fly ash provides sufficient mixing; (4) introduced through heat-resistant or stainless pipes; and (5) introduced into the furnace either above or adjacent to the existing burner level through separate pipes. Injection points through a waterwall could be used, although this may require modifications of the waterwalls in the boilers.

For instance in original tests conducted in 1996, a fly ash having an LOI of 26.5% and a moisture content of 0.3% was introduced into a coal pulverized furnace through injection pipes. The fly ash was stored in a horizontal silo from which it was pumped through stainless steel pipes extending through the furnace wall immediately above two coal burners. The hose was connected to a reducer splitter where the 5” diameter hose was reduced to two 2” diameter hoses. The fly ash was pumped at a rate of approximately 1% –2% of the coal flow into the furnace. The addition of the fly ash to the combustion did not affect combustion. The resulting fly ash from the reburning had an LOI of between 0.2% and 0.5% based upon samples taken at intervals over four days. Reburning of high carbon bituminous coal ash in sub-bituminous pulverized fuel furnaces is now a regular procedure at We Energies Pleasant Prairie Power Plant in Wisconsin and Presque Isle Power Plant in upper Michigan with excellent results.

We Energies Bottom Ash as Fine Aggregate in Concrete Masonry Products

Natural volcanic combustion products have been used in the manufacture of masonry products since ancient times. Several decades ago cinders, a combustion product of lump coal combustion, were used as a lightweight aggregate in the manufacture of masonry blocks. However, not much technical data was available on these products. Today, fly ash and bottom ash have been extensively investigated to determine performance.

We Energies has investigated the suitability of its bottom ash and fly ash in the manufacture of concrete bricks, blocks and paving stones. The following data is from research conducted at the Center for By-Products Utilization (CBU) of the University of Wisconsin-Milwaukee for We Energies at two local manufacturing plants (52).

Concrete masonry products can be manufactured either by the wet-cast process or the dry-cast process. Several mixes were designed at the CBU for the manufacture of concrete bricks, blocks and paving stones using the dry-cast method. Actual manufacture of the dry-cast test products was performed at Best Block Company in Racine, Wisconsin, using standard manufacturing equipment.

Tables 6-6 – 6-8 show the mixture design data for bricks, blocks and paving stones using the dry-cast method. Tables 6-9 – 6-11 show the compressive strength data for the above-mentioned products. The three mixtures for each product have varying amounts of fly ash and bottom ash. Each of the three products also has a control mixture with no fly ash and no bottom ash.

Table 6-6: Dry-Cast Concrete Brick Mixtures Using OCPP Bottom Ash and Fly Ash

Mix No.	BR-1	BR-2	BR-3	BR-4
Field Mix Designation	1	3	8	10
Fly Ash, [A/(C+A)](%)	0	29	29	41
Bottom Ash, [BA/S+BA)](%)	0	0	23	33
Cement, C (lb/yd^3)	345	260	245	215
Fly Ash, A (lb/yd^3)	0	110	100	150
Net Water, W (lb/yd^3)	145	160	190	260
[W/(C+A)]	0.43	0.43	0.55	0.72
SSD Fine Aggregate, S (lb/yd^3)	2335	2365	1655	1455
SSD Bottom Ash, BA (lb/yd^3)	0	0	490	705
SSD ⅜" Crushed Limestone Aggregate (lb/yd^3)	795	805	750	750
Moisture Content of Mixture, %	5.6	5.9	7.8	10.1
Unit Weight (lb/ft^3)	134.0	137.0	127.0	131.0
Test Batch Yield (yd^3)	0.60	0.60	0.60	0.60

The dry-cast concrete brick mixture BR-1 (control mix) had a 56-day strength that was lower than that of BR-2, a similar mix containing fly ash. Twenty-five percent cement was replaced with fly ash at a 1 – 1.3 replacement ratio. The exact proportions can be seen in Table 6-6.

Brick mixtures BR-3 and BR-4 containing bottom ash and fly ash showed lower compressive strengths at the 56-day age. The compressive strengths obtained were all above 3,000 psi. This level of strength is good for most applications. Similar strength patterns are also seen for blocks and paving stones.

Long-term behaviors of these masonry products are currently being studied at CBU. When this information is available, a better conclusion can be made about these products. However, based on available data, it can be seen that concrete bricks, blocks and paving stones with reasonable strength can be made using fly ash and bottom ash.

Table 6-7: Dry-Cast Concrete Block Mixtures

Mix No.	BL-1	BL-2	BL-3	BL-4
Field Mix Designation	13	14	16	18
Fly Ash, [A/(C+A) (%)	0	30	29	40
Bottom Ash, [BA/(S+BA)] (%)	0	0	23	33
Cement, C (lb/yd^3)	345	265	245	215
Fly Ash, A (lb/yd^3)	0	110	100	150
Net Water, W (lb/yd^3)	161	160	190	260
[W/(C+A)]	0.36	0.43	0.54	0.71
SSD Fine Aggregate, S (lb/yd^3)	2300	2355	1775	1430
SSD Bottom Ash, BA (lb/yd^3)	0	0	495	715
SSD 3/8" Crushed Limestone Aggregate (lb/yd^3)	795	815	755	765
Moisture Content of Mixture, %	5.9	5.9	6.5	10.1
Unit Weight (lb/ft^3)	137	137	127	131
Test Batch Yield (yd^3)	0.60	0.60	0.60	0.60

Table 6-8: Dry-Cast Concrete Paving Stone Mixtures

Mix No.	PS-1	PS-2	PS-3	PS-4
Field Mix Designation	2	4	6	11
Fly Ash, [A/(C+A)] (%)	0	18	18	30
Bottom Ash, [BA/(S+BA)] (%)	0	0	24	33
Cement, C (lb/yd^3)	650	560	510	425
Fly Ash, A (lb/yd^3)	0	125	115	180
Net Water, W (lb/yd^3)	16	180	195	190
[W/(C+A)]	0.25	0.26	0.31	0.31
SSD Fine Aggregate, S (lb/yd^3)	2205	2235	1540	1255
SSD Bottom Ash, BA (lb/yd^3)	0	0	475	605
SSD 3/8" Crushed Limestone Aggregate, (lb/yd^3)	750	760	695	650
Moisture Content of Mixture, %	5.7	6.1	7.6	8.0
Unit Weight (lb/ft^3)	139	143	131	122
Test Batch Yield (yd^3)	0.62	0.61	0.66	0.70

Table 6-9: Compressive Strength of Dry-Cast Concrete Bricks

Mixture No.	Field Mix No.	Fly Ash %	Bottom Ash %	Compressive Strength (psi)					
				5 Day		28 Day		56 Day	
				Act.	Avg.	Act.	Avg.	Act.	Avg.
BR-1	1	0	0	3255	3660	4005	4530	4480	4750
				3830		4345		4730	
				3895		4485		4735	
				--		4525		5055	
				--		4850		--	
				--		4935		--	
BR-2	3	29	0	2740	3360	3855	4650	490	5300
				3365		4645		5025	
				3970		4659		5220	
				--		4780		5550	
				-		4880		5785	
				--		5065		--	
BR-3	8	29	23	2260	2360	2530	2740	2600	3210
				2360		2610		3285	
				2460		2705		3305	
				--		2810		3375	
				--		2880		3480	
				--		2930		--	
BR-4	10	41	33	1690	1870	2835	3130	2650	3490
				1770		3130		3570	
				2140		3175		3635	
				--		3190		3700	
				--		3225		3910	
				--		3230		--	

ASTM C90 requirement for compressive strength is 1900 psi minimum average of 3 units and 1700 psi minimum individual brick.

Table 6-10
Compressive Strength of Dry-Cast Concrete Blocks

Mixture No.	Field Mix No.	Fly Ash %	Bottom Ash %	Compressive Strength (psi) based on average net area							
				7 Day		14 Day		28 Day		91 Day	
				Act.	Avg.	Act.	Avg.	Act.	Avg.	Act.	Avg.
BL-1	13	0	0	2605	2780	2825	3150	2850	3290	3240	3350
				2775		3290		3415		3360	
				2955		3345		3610		3460	
BL-2	14	30	0	2830	2990	2805	2880	3405	3690	4200	4240
				3055		2880		3545		4215	
				3080		2950		4115		4300	
BL-3	16	29	23	2075	2150	2875	2960	3030	3100	3130	3260
				2190		2875		3110		3225	
				2195		3125		3150		3435	
BL-4	18	40	33	1315	1410	1790	1810	2040	2220	2075	2340
				1405		1805		2220		2260	
				1520		1825		2390		2695	

ASTM C90 requirement for compressive strength is 1900 psi minimum average of 3 units and 1700 psi minimum individual brick.

Table 6-11: Compressive Strength of Dry-Cast Concrete Paving Stones

Mixture No.	Field Mix No.	Fly Ash %	Bottom Ash %	Compressive Strength (psi)									
				5 Day		8 Day		28 Day		56 Day		91 Day	
				Act.	Avg.	Act.	Avg.	Act.	Avg.	Act.	Avg.	Act.	Avg.
				3820		7100		4460		5515		7050	
				5805		7630		4855		5745		7495	
PS-1	2	0	0	7025	5550	8095	7610	4950	4900	7515	7040	8235	7595
				--		--		5020		8075		--	
				--		--		5040		8365		--	
				--		--		5085		--		--	
				7745		7020		5640		7120		7700	
				7770		7265		5645		7895		7735	
PS-2	4	18	0	7880	7800	7950	7410	6645	6880	8075	8020	7790	7790
				--		--		6655		8985		7920	
				--		--		8195		--		8385	
				--		--		8520		--		--	
				3250		3575		5005		5390		5420	
				3935		3750		5015		5660		5775	
PS-3	6	18	24	4065	3840	4295	3870	5080	5310	5725	5740	6030	6050
				--		--		5565		5935		6035	
				--		--		5865		5975		6975	
				2080		2945		2865		2820		3435	
				2440		2815		3080		3245		3545	
PS-4	11	30	33	2295	2270	2520	2760	3155	3190	3285	3290	3675	3690
				--		--		3215		3350		3875	
				--		--		3385		3765		3925	
				--		--		3445		--		--	