UWM Center for By-Products Utilization
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Reduce, reuse, and recycle for sustainable developments.
Minimize use of manufactured materials.
Maximize environmental benefits: clean air, clean water, and resource conservation.
Basic Approach

WASTE is wasted if you waste it, otherwise it is a resource. Resource is wasted if you ignore it and do not conserve it with holistic best practices and reduce societal costs. Resource is for the transformation of people and society.

Focus on turning brown fields into green fields of the 21st Century.
Basic Approach

Recycle. Recycle as is.

Recycle without additional processing, (i.e., without adding any cost to it).
CCPs/CCBs
Coal Combustion Residuals
Fly Ash
Bottom Ash
Slag (Boiler Slag)
Fluidized Gas Desulfurization (FGD)
FBC/AFBC/PFBC Ash/Residual
Spray Dryer Absorber/Clean-Coal Ash
Coal Combustion Products (CCPs)

- Develop recycling technology for high-volume applications of coal combustion products (CCPs) generated by using both conventional and clean-coal technologies.

- Fly ash (Class F, since 1930s, and Class C, since early 1980s), bottom ash, cyclone-boiler slag, and clean-coal ash (CCA - since late 1980s, ash derived from SOx control technologies, including FBC/AFBC/PFBC boilers, as well as dry- or wet-FGD materials from SOx/NOx control technologies).
Figure 2. Examples of Class C and Class F fly ash.
Under a microscope, fly ash particles look like tiny ball bearings. Hard and round, these particles are so small that in laboratory tests for fineness, the ash can be sifted through screens with more than 100,000 openings per square inch. Silica is the primary compound in fly ash.
Fly ash particles (Magnification, 1000 X)
Coal Combustion Products

- Fly ash
- Bottom ash
The precise properties of power plant ash are dependent upon the kind of coal each utility burns. Coal mined in the western United States, for example, produces fly ash that has more lime and less silica than ash from eastern coal.
## Chemical Composition

<table>
<thead>
<tr>
<th>Oxides %</th>
<th>Cement, Type I</th>
<th>St. Helen’s Ash</th>
<th>VPP Class F Ash</th>
<th>Columbia Unit #1 Fly Ash</th>
<th>P-4 Class C Ash</th>
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</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>20.1</td>
<td>62.2</td>
<td>48.2</td>
<td>44.8</td>
<td>32.9</td>
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<tr>
<td>Al₂O₃</td>
<td>4.4</td>
<td>17.6</td>
<td>26.3</td>
<td>22.8</td>
<td>19.4</td>
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<td>CaO</td>
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<td>5.7</td>
<td>2.7</td>
<td>17.0</td>
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<tr>
<td>MgO</td>
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<td>2.2</td>
<td>1.1</td>
<td>5.1</td>
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<td>Fe₂O₃</td>
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<td>TiO₂</td>
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<td>Na₂O</td>
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<td>1.1</td>
<td>0.29</td>
<td>1.9</td>
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<td>Moisture</td>
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<td>0.39</td>
<td>0.13</td>
<td>0.80</td>
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<tr>
<td>LOI</td>
<td>1.1</td>
<td>0.60</td>
<td>7.9</td>
<td>0.27</td>
<td>0.65</td>
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</table>
## PLEASANT PRAIRIE FLY ASH

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th># of Samples</th>
<th>Range</th>
<th>Average</th>
<th>ASTM C-618</th>
</tr>
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<tbody>
<tr>
<td>Silicon Oxide (SiO₂)</td>
<td>7</td>
<td>38.5 – 42.8</td>
<td>40.9</td>
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<td>Aluminum Oxide (Al₂O₃)</td>
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<td>14.2 – 17.9</td>
<td>16.1</td>
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<tr>
<td>Iron Oxide (Fe₂O₃)</td>
<td>7</td>
<td>5.6 – 6.6</td>
<td>6.0</td>
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<tr>
<td>Total (SiO₂+Al₂O₃+Fe₂O₃)</td>
<td>7</td>
<td>61.1 – 66.3</td>
<td>63.0</td>
<td>50.0 Min.</td>
</tr>
<tr>
<td>Sulfur Trioxide (SO₃)</td>
<td>7</td>
<td>2.3 – 3.5</td>
<td>3.0</td>
<td>5.0 Max.</td>
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<tr>
<td>Calcium Oxide (CaO)</td>
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<td>23.4 – 26.9</td>
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<tr>
<td>Magnesium Oxide (MgO)</td>
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<td>4.1 – 4.8</td>
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<td>5.0 Max.</td>
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<td>Loss on Ignition</td>
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<td>0.20 – .64</td>
<td>0.45</td>
<td>6.0 Max.</td>
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<td>Available Alkalies as Na₂O</td>
<td>7</td>
<td>0.87 – 1.6</td>
<td>1.2</td>
<td>1.5 Max.</td>
</tr>
</tbody>
</table>

Center for By-Products Utilization
### PLEASANT PRAIRIE FLY ASH

<table>
<thead>
<tr>
<th>Physical Tests</th>
<th># of Samples</th>
<th>Range</th>
<th>Average</th>
<th>ASTM C-618</th>
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<tbody>
<tr>
<td>Fineness, % Retained on #325 Wet Sieve</td>
<td>7</td>
<td>15.3 – 23.7</td>
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<td>Pozzolanic Activity Index</td>
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<td>With Cement 28 Days</td>
<td>7</td>
<td>86 – 100</td>
<td>92.4</td>
<td>75.0 Min.</td>
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<tr>
<td>With Lime 7 Days</td>
<td>7</td>
<td>1505 – 2520</td>
<td>1805</td>
<td>800 Min.</td>
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<tr>
<td>Water Requirement, % of the Control</td>
<td>7</td>
<td>89 – 95</td>
<td>91</td>
<td>105 Max.</td>
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<tr>
<td>Soundness</td>
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<td></td>
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<td></td>
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<tr>
<td>Autoclave Expansion (%)</td>
<td>7</td>
<td>0.12 - 0.18</td>
<td>0.15</td>
<td>0.8 Max.</td>
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<tr>
<td>Specific Gravity</td>
<td>7</td>
<td>2.42 – 2.64</td>
<td>2.58</td>
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</table>

Center for By-Products Utilization
Of all the uses for fly ash, the best known are as an additive in portland cement concrete and as a supplementary cementitious material. In both of these applications, fly ash increases strength and durability, adding years to the life of the product.
Fly ash is a pozzolan. A pozzolan is an inert siliceous material that in the presence of moisture will combine with calcium hydroxide to produce a cementitious material with excellent structural properties.
COMUNE POZZUOL

MANUTENZIONE STRAORDINARIA MANUFEATTO (CHALET) APRIRE
Portland Cement + Water

Free Lime, Ca(OH)₂

Fly Ash

Cementitious Material
SEM Images of BCN60, 7 days
Increased Strength

Fly ash increases the strength of concrete without increasing the costs. The attainment of high compressive strengths, above 6000 psi (41 MPa), enables the concrete producer to command high-strength prices with virtually no increase in cost. He can also offer standard strengths with a reduction in material cost.
Tighter Surface

Fly ash creates a surface that is more dense, more tightly packed, and more resistant to penetration. This helps concrete resist water, mild acids, and alkalis, without special treatment.
Sharper Detail

Fly ash can be combined with coarse sands to produce sharp detailing. Its fineness fills forms more completely, creating sharper and more chip resistant edges.
Smoother Surface

Heat is one result of the chemical reaction that creates concrete. The expansion of concrete by this heat, as well as contraction upon cooling, can cause cracks to develop in the surface. Fly ash reduces the heat of hydration, producing a smoother, more attractive surface.
Better Flowability

When added to concrete, fly ash works like millions of ball bearings to reduce friction and simplify construction. The ability to pump concrete thirty stories or more, without double pumping and without building a network of cranes and conveyors, makes the job of set up and removal faster.
Resists Effects of Sulfuric Acid

Concrete structures are known to suffer when their wet surfaces are exposed to hydrogen sulfide. This effect can be almost entirely avoided, by using a concrete mixture containing fly ash.
Reduces Bleeding

The improved workability leads to lower water requirements. This results in less bleeding and consequently more durable surfaces.
Why Be Interested in Fly Ash?

The answer to this question is short, simple, and clear: a good fly ash, properly used as an ingredient, produces a better concrete at lower cost. Concrete employing fly ash is better in many important ways than concrete without fly ash. It provides the contractor and building owner with a more durable product, easier to handle, place, and finish. It helps to increase business and profit for the ready-mix plant operator.
Reduces Heat of Hydration

Fly ash reaction generates heat more slowly than the faster reacting portland cement. Some researchers have also shown that substitution can also slow the hydration of portland cement itself. This combination minimizes heat generation in concrete, especially in mass concrete.
Resists Sulfate Attack

Fly ash combines with lime (CaOH$_2$), making it less available to react with sulfates. The resulting cementitious material also blocks concrete bleed channels which can hinder further entry of the aggressive soluble sulfates. This combination will often times improve a concrete’s resistance to sulfate attack.
Resists Alkali Aggregate

Many fly ashes react with available alkalies in the concrete making them less available to react with the aggregates.
Improves Workability

The spherical shape and small size of fly ash particles combine to lubricate the concrete mixture, reducing water demand for a given slump.
Fly ash concrete requires less water than plain concrete at any given slump; and, high workability enables placement at lower slumps. Reduction in water content means more strength and less shrinkage & improved durability.
BENEFITS of FLY ASH in CONCRETE

- Less Water Demand
- Improved Workability
- Improved Pumpability
- Lower Concrete Cost
BENEFITS of FLY ASH in CONCRETE

- Increased Ultimate Strength
- Reduced Permeability
- Improved Durability
- Reduced Shrinkage
- Increased Abrasion Resistance
BENEFITS OF CCPs UTILIZATION

- Avoids Disposal Costs
- Conserves Landfill Capacity
- Reduces Construction Costs
- Enhances Environment from Minimizing Disposal
- Virgin and Manufactured Construction Materials Conserved for Higher Priority Use
High Tech Use of Fly Ash

- Metal Extraction
- Mineral Extraction
- SO₂ Control
- Thermal Insulation
- Heat Resistant Materials
- Rubber Filler
- Plastic Filler
- Metal Filler
- Coagulant
Medium Tech Use of Fly Ash

- Concrete and Cement
- Bricks, Blocks, and Paving Stones
- Ceramic Tiles
- Filler in Asphalitic Mixes
Low Tech Use of Fly Ash

- Structural Fills
- Road Base
- Sludge Stabilization
- Land Reclamation
- Grouting
- Soil Amendment
- Mine Backfills
- Coal Mining Operations
Current Uses

– Concrete
– Bricks, blocks, and paving stones
– Slurry
– Blended Cements
– Aggregates from slag
Manufacturing of bricks with fly ash with or without used foundry sand
Air Content Problems

The fineness of fly ash makes it more difficult to develop and hold entrained air.
Low Early Strength

The lb. per lb. substitution mixture proportioning method may result in lower strengths at early ages. Mixture proportioning should take into consideration form removal sequence and anticipated early loading. Lower early strengths can be readily overcome through the use of appropriate admixtures and/or other adjustments to the mixture.
BOTTOM ASH
## Bottom Ash

<table>
<thead>
<tr>
<th>Compound</th>
<th>PPPP</th>
<th>OCPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO</td>
<td>42.9</td>
<td>50.5</td>
</tr>
<tr>
<td>AlO</td>
<td>18.2</td>
<td>19.3</td>
</tr>
<tr>
<td>FeO</td>
<td>7.4</td>
<td>7.5</td>
</tr>
<tr>
<td>CaO</td>
<td>21.8</td>
<td>7.4</td>
</tr>
<tr>
<td>MgO</td>
<td>3.7</td>
<td>1.9</td>
</tr>
<tr>
<td>SO</td>
<td>0.62</td>
<td>0.75</td>
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<tr>
<td>NaO</td>
<td>1.6</td>
<td>0.75</td>
</tr>
<tr>
<td>KO</td>
<td>0.30</td>
<td>0.74</td>
</tr>
<tr>
<td>LOI</td>
<td>2.0</td>
<td>4.2</td>
</tr>
</tbody>
</table>
BTM ASH Used as Base & Sub-base Aggregates

- Roadways, Highways, and Airfields
- Parking lots
- Concrete Slab-on-grade
- Footings and Foundations
BTM ASH is also used as lightweight aggregates in masonry products & architectural concrete products.
CONCRETE PRODUCTION

To identify and recommend mixture proportions for a high-fly ash structural-grade concrete.
Mixture Evaluation

Proposed mixtures should be evaluated for performance prior to construction. Good quality constituents do not always produce a mixture that will perform as desired.
Class C fly ash has higher calcium content than Class F ash and can be used in much greater quantity than the 15 to 20 percent range for Class F fly ash for structural-grade concrete.
Mixture proportions containing fly ash as a replacement for cement on weight basis in amounts of 0, 20, 30, 40, 50 and 60% were developed for the three strength levels of 3000, 4000, & 5000 psi (21, 28, & 34 MPa).
Concrete with and without air entrainment was produced in which fly ash was substituted for cement in quantities of up to 70% of total cement replacement.
1. Two brands Type I cement
2. Two sources of aggregate
3. Slump – 4” ± 1”
4. Air entrained and non-air entrained
5. Air entrainment 5.5% ± 1%
Sample size – 2 cu. yds. (1.5 cu. m.), produced at two ready-mixed concrete plants.
FRESH CONCRETE
TESTS PERFORMED

1. Temperature
2. Slump
3. Air Content
4. Density
5. Workability noted
## CONCRETE MIXTURE AND TEST DATA

5000 psi (34 MPa) SPECIFIED STRENGTH

P4 ASH – STRUCTURAL CONCRETE

CONCRETE SUPPLIER: Central Ready Mixed Concrete

<table>
<thead>
<tr>
<th>Mixture No.</th>
<th>P4-13</th>
<th>P4-14</th>
<th>P4-15</th>
<th>P4-16</th>
<th>P4-17</th>
<th>P4-18</th>
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</thead>
<tbody>
<tr>
<td>Specified Design Strength, psi</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Cement, lbs</td>
<td>611</td>
<td>490</td>
<td>428</td>
<td>367</td>
<td>305</td>
<td>245</td>
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<tr>
<td>Fly Ash, lbs</td>
<td>0</td>
<td>145</td>
<td>220</td>
<td>295</td>
<td>382</td>
<td>441</td>
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<tr>
<td>Water, lbs</td>
<td>290</td>
<td>291</td>
<td>289</td>
<td>270</td>
<td>278</td>
<td>268</td>
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<tr>
<td>Sand, SSD, lbs</td>
<td>1450</td>
<td>1450</td>
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<td>1450</td>
<td>1450</td>
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<tr>
<td>¾” Aggregates SSD, lbs</td>
<td>1810</td>
<td>1810</td>
<td>1810</td>
<td>1820</td>
<td>1810</td>
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</table>
As the amount of fly ash increased, the water demand decreased while maintaining the same slump (4” ± 1”).
## CONCRETE STRENGTH TEST DATA

5000 psi (34 MPa) SPECIFIED STRENGTH

AVERAGE COMPRESSIVE STRESS, PSI

<table>
<thead>
<tr>
<th>Test Age, Days</th>
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<tr>
<td></td>
<td>P4-13</td>
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<tr>
<td>1*</td>
<td>2519</td>
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<tr>
<td>3</td>
<td>2904</td>
</tr>
<tr>
<td>7</td>
<td>3902</td>
</tr>
<tr>
<td>28</td>
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</tr>
<tr>
<td>56</td>
<td>5848</td>
</tr>
<tr>
<td>91</td>
<td>6134</td>
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</table>

*AFTER ACCELERATED CURING, USING BOILING WATER METHOD.

**CYLINDERS WERE SOFT WHEN TESTED.
## CONCRETE STRENGTH TEST DATA –
### 5000 psi (34 MPa) STRENGTH, PLANT NO.2

<table>
<thead>
<tr>
<th>Mixture No.</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tr>
<td>Fly Ash, %</td>
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<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
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<table>
<thead>
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<td>19 hrs</td>
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<td>2950</td>
<td>3330</td>
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<td>22 hrs</td>
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<td>7710</td>
<td>8100</td>
<td>8210</td>
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</tbody>
</table>
Project experience with high-fly ash content concrete
PROJECT 1: MAY 1984

5” thick slab x 15’ x 20’ = 5 yd³,
70% fly ash replaced for cement.
Frontier Ready Mix Loading Area
Slinger, Wisconsin.
PROJECT 2: SEPTEMBER 1984

24’ wide truck access road.
10” thick x 1400 ft long, = 1000 yd³, 70% fly ash replaced for cement.

Pleasant Prairie Power Plant
Wisconsin, USA.
COMPRESSIVE STRENGTHS

7-day = 1150 PSI
28-day = 2200 PSI
56-day = 3500 PSI
Fly ash is used in large quantities as a fine aggregate in RCCP, and up to 50% of total cementitious materials.
MANUFACTURE OF BLENDED CEMENTS

Raw Material in Production of Cement Clinker
Interground with Clinker
Blended with Cement
HIGH-STRENGTH CERAMIC PRODUCTS

Products with high-flexural strength such as railroad ties, electric line insulators, fence posts, etc.
WATER POLLUTION CONTROL

a) Neutralization of Acidic water
b) Phosphorus Removal from Wastewater
c) Sludge Dewatering
d) Sorbent for Organics
e) Sealing of Contaminated Sediments
Cenospheres are used in metals as a filler. They improve damping and abrasion resistance of the material.
OTHER FILLER APPLICATIONS

- Asphalt Roofing Shingles
- Joint Compound
- Carpet Backing
- Vinyl Flooring
- Industrial Coatings, etc.
RECOVERY OF MATERIALS

a) Carbon
b) Magnetite (Fe$_2$O$_3$)
c) Cenospheres
d) Metals: Alumina, Iron Oxide, etc.
Fly Ash Use for Lightweight Aggregates

a) Unfired (Cold Bonded Process)
b) Sintered (Fired) Aggregates
LIGHTWEIGHT CONCRETE

Concrete with Lightweight Aggregates – fly ash used as a pumping aid.
CCP USES MUST BE:

TECHNICALLY PROVEN.
COMMERCIALY EFFECTIVE.
ENVIRONMENTALLY SOUND.
# FLY ASH CHEMICAL COMPOSITION COMPARISON TO LUNAR SOIL

<table>
<thead>
<tr>
<th></th>
<th>Lunar High Land Soil</th>
<th>Lunar Low More Soil</th>
<th>Oak Creek Class F Fly Ash</th>
<th>Pleasant Prairie Class C Fly Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>44.8%</td>
<td>42.2%</td>
<td>46.8%</td>
<td>35.4%</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>28.5</td>
<td>13.6</td>
<td>23.7</td>
<td>17.5</td>
</tr>
<tr>
<td>CaO</td>
<td>16.9</td>
<td>11.9</td>
<td>3.1</td>
<td>26.1</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>4.2</td>
<td>15.3</td>
<td>13.2</td>
<td>5.3</td>
</tr>
<tr>
<td>MgO</td>
<td>4.9</td>
<td>7.8</td>
<td>1.0</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Energy Conservation

About six million BTUs are needed to produce one ton of cement. Use of fly ash saves that energy and conserves dwindling resources.
La Bella Terra

Every Day is Happy Earth Day
La Bella Terra
Center for By-Products Utilization
Thank you very much for your interest.
Aabhar Tamaro, Afcharisto Poly, Arigatou Gozaimasu, Maraming Salamat, Merci Beaucoup, Muchas Gracias, Grazie Molte, Muito Obrigado, Salamat, Shukriya, Spasibo, Thank you, Toda Raba.
Over 100 million tonnes of CCPs produced in USA each year (from about 55% of total electricity & steam production). Cyclone-boiler slag is 100% recycled. Overall recycling rate of all CCPs is about 35% (2003).

High-sulfur coal ashes, such as Class F fly ash and especially clean-coal ashes, are underutilized.

For 2002, in USA, Fluidized Gas Desulphurization (FGD) Gypsum: 11.4 MT (million tonnes) produced, 7.8 MT used (70%); FGD wet-Scrubbers: 16.9 MT, 0.5 MT (3%); FGD Dry-Scrubbers: 0.9 MT, 0.4 MT (45%); and, A/FBC Ash: 1.2 MT, 0.9 MT (75%). Overall, 30.4 MT produced, 9.6 MT used (32%).