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Lowering Costs with Dry Coal Cleaning Technology to Meet New Environmental Requirements

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INTRODUCTION

The combination of more stringent environmental requirements and proposed carbon taxes are creating greater pressures on coal-fired generation facilities that could result in a significant reduction in coal utilization if not dealt with in a cost effective manner. Since coal is the most abundant energy source in North America, it is important that we develop more cost effective techniques to deal with these mounting requirements.

In response to these requirements Nalco Mobotec has developed an effective patented dry coal cleaning process called the MagMill that can be applied either at a mine site to treat raw or waste coals or at the power plant where it operates in conjunction with the pulverizer to effectively remove the unwanted materials in a completely dry process. MagMill Co. LLC, a joint venture between Nalco Mobotec and EXPORTech Co., Inc. has constructed demonstration facilities for both the pulverizer and mine-based applications. Validation has been performed on this process with successful results on both Eastern and Western coals.

MINE-BASED PILOT SYSTEM FOR WASTE COAL

It is estimated there are about 3,000 to 5,000 dry waste coal sites in the US, each containing typically two million tons of waste coal. There are also approximately 2,300 fine coal impoundments containing a total of two billion tons of waste fine coal. Blending clean coal recovered from these sites can result in lower cost steam coals, can result in a reduction of Hazardous Air Pollutants (HAP's) such as mercury, arsenic and selenium in the boiler fly ash, and can reduce erosion, abrasion, slagging and fouling in the boiler.

Figure 1. Mine-Based Pilot System

Nalco Mobotec has fabricated and installed a pilot scale test unit, shown in Figure 1, at a mine site in Morgantown, WV, for recovery of clean coal from various coal mining waste materials and for improving raw mined coal. The unit became operational in July, 2010. Initial results of dry processing a coarse coal refuse sample are shown in Table I.

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Table I. Initial Results from Waste Coal Processing with the Mine-Based Pilot System

		Ash		Sulfur		Mercury
	Btu/Lb	**Wt.%**	**Lb/MBtu**	**Wt.%**	**SO_2 Lb/MBtu**	**Lb/TBtu**
Coarse Coal Waste Refuse	3,382	68.63	203	5.02	30	85
Recovered Product	9,203	36.99	40	4.32	9	38

System operating parameters can be adjusted to vary the clean coal product Btu value to optimize the value of recovered products. Initial testing results, shown in Figure 2, achieved total Btu recoveries up to 67%.

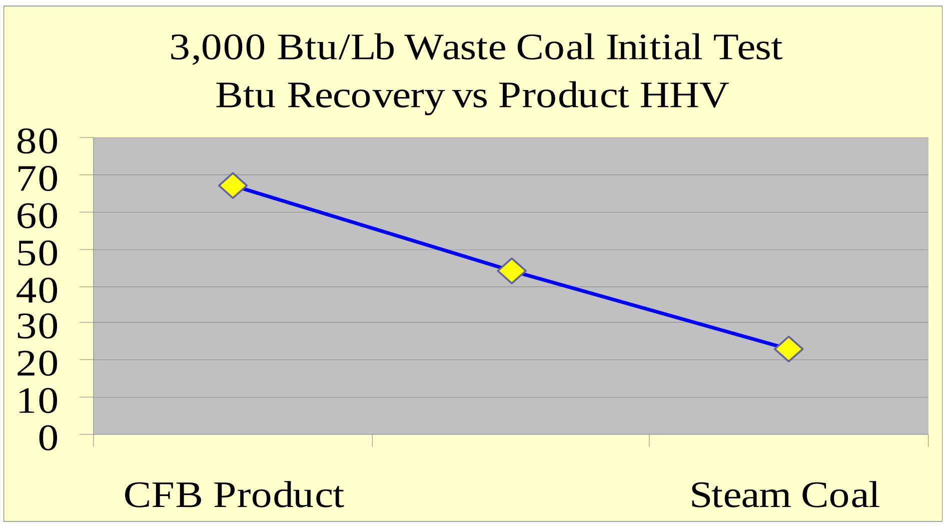

Figure 2. Btu Recovery vs. Product HHV

This Mine-Based Pilot System can process up to three tons per hour of coal waste. It was completely shop assembled in two standard 40 foot shipping containers and shipped to the mine site. It began startup operations in late July, 2010 and to date has processed several runs of a single extremely poor quality coarse coal refuse with encouraging recovery results. A comprehensive test program is currently underway involving coal wastes from both coarse and fine coal impoundments as well as raw run-of-mine coal from several locations which will be tested over the next several months.   The system incorporates specialized magnetic separation equipment in combination with screening, gravity separation, and limited size reduction with commercially available equipment.

BOILER/PULVERIZER TEST FACILITY

A second test unit for the boiler/pulverizer application located at the DTE Energy Services Pet Coke Grinding Facility in Vicksburg, MS is shown in Figure 3. The DTE pulverizer is shown on the left and the MagMill apparatus is contained within the orange structure. Results of processing Eastern and Western coals are given below.

Figure 3. MagMill Test Unit, Vicksburg, MS

<u>Background</u>. Figure 4 illustrates how the MagMill operates in the pulverizer application. The process is designed to improve the quality of coal sent to the burner. Moist raw coal, as-received at the power plant, is fed into the pulverizer where it is dried by hot air blown into the pulverizer. The coal is reduced in particle size to nominally 70-80% smaller than 200 mesh by grinding action inside the mill. With the MagMill configuration, a stream which is concentrated in difficult-to-grind hard and abrasive minerals is withdrawn from the pulverizer and processed by a separator for selective rejection of this undesirable material. The remaining cleaned coal is then returned to the mill for grinding to specification so a clean product which has lowered levels of ash, sulfur, and hazardous heavy metals such as mercury, arsenic, and selenium is fed to the burner. The result is lowered wear and power draw in the pulverizer, reduced erosive wear, slagging and fouling in the boiler, and lower ash, sulfur and HAP's in the plant emissions. The separation technology employed is similar to the mine-based system.

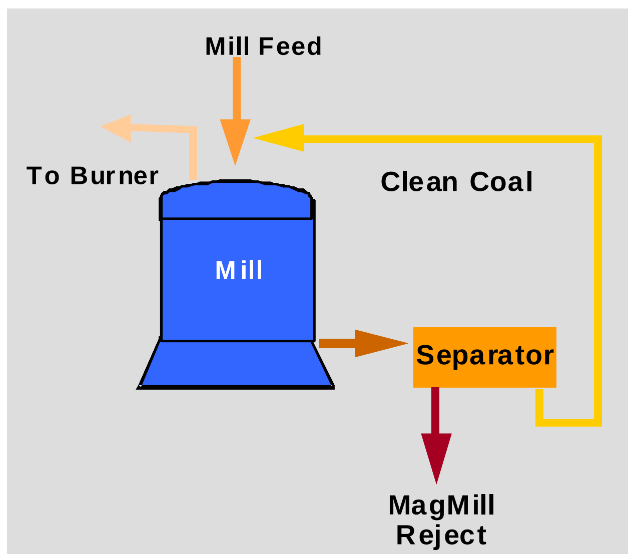

Figure 4. MagMill Pulverizer System

Results of earlier testing are given in Table II which compares measurements of Ash, $LbSO_2$ and Mercury in the feed, reject and product of the mill retrofitted for MagMill operation. Note especially the decrease in Ash, $LbSO_2$ and Mercury and the increase in Btu/Lb in the MagMill product.

Table II. Materials Balance of MagMill Processed Coal
Lower Kittanning Coal

		MagMill
Mill Feed	Lb/hr	3,434
	Btu/Lb	11,989
	Ash, wt%	20.5
	$LbSO_2$/MBtu	9.2
	Mercury, ppm	0.4
	Mercury, Lb/TBtu	33.4
Mill Product	Lb/hr	2,948
	Wt. Recovery, wt%	87
	Btu Recovery, %	94
	Btu/Lb	12,949
	Ash, wt%	15.4
	$LbSO_2$/MBtu	6.1
	Mercury, ppm	0.2
	Mercury, Lb/TBtu	17.0
Mill Reject	Lb/hr	486
	Wt. Recovery, wt%	12.9
	Btu Recovery, %	6.0
	Btu/Lb	5,525
	Ash, wt%	54.9
	$LbSO_2$/MBtu	57.3
	Mercury, ppm	1.6
	Mercury, Lb/TBtu	289.6

The MagMill is very efficient in removing HAP's from coal before it is burned. One reason is the association of the HAP's with pyritic sulfur as shown in Figure 5 where the relationship between sulfur and mercury is shown for Pittsburgh seam coal mined in three different states. Table III shows reductions in selected HAP's from Lower Kittanning and Upper Freeport raw coals processed in the MagMill.

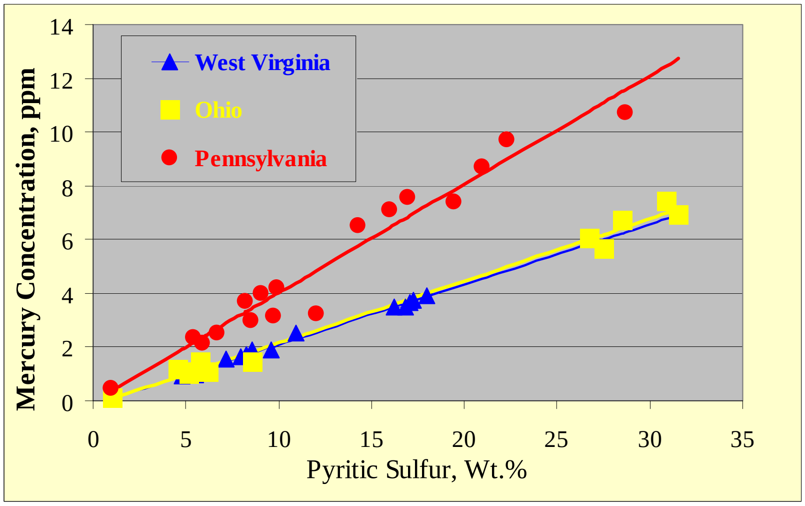

Figure 5. Relationship between Pyritic Sulfur and Mercury, **Pittsburgh Seam Coal**

Table III. Reduction of HAP's Processed in the MagMill

	Lower Kittanning Raw Coal				**Upper Freeport Raw Coal**			
	Concentration, Lb/TBtu*			**Reduction, %**	**Concentration, Lb/TBtu***			**Reduction, %**
	Feed	**Product**	**Reject**		**Feed**	**Product**	**Reject**	
Arsenic	624	356	4,644	43	4,074	1,331	32,160	67
Lead	850	550	5358	35	912	340	6,770	63
Mercury	34	17	286	50	33	13	237	60
Nickel	946	558	6,787	41	1,394	687	8632	51
Thallium	72	32	679	56	117	35	965	70
*TBtu = 10^{12} Btu								

<u>Coals Processed at Vicksburg</u>. Eastern and Western coals have been processed at the Vicksburg facility. Figure 6 shows reductions in ash, sulfur and mercury vs. Btu recovery for a ***Pennsylvania Upper Freeport Coal***. At 95% Btu recovery, the reductions in ash, sulfur and mercury were 34%, 24% and 31%, respectively. The relationship between mercury and pyritic sulfur for Pittsburgh seam coal shown above in Figure 5 holds true for the Upper Freeport seam as well, as is shown in Figure 7.

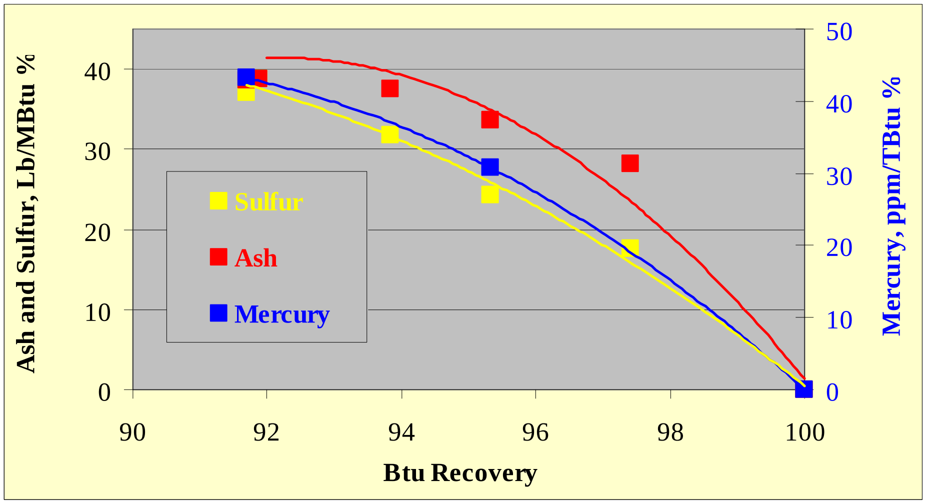

Figure 6. Reductions in Ash, Sulfur and Mercury for **Upper Freeport Coal** Processed at Vicksburg

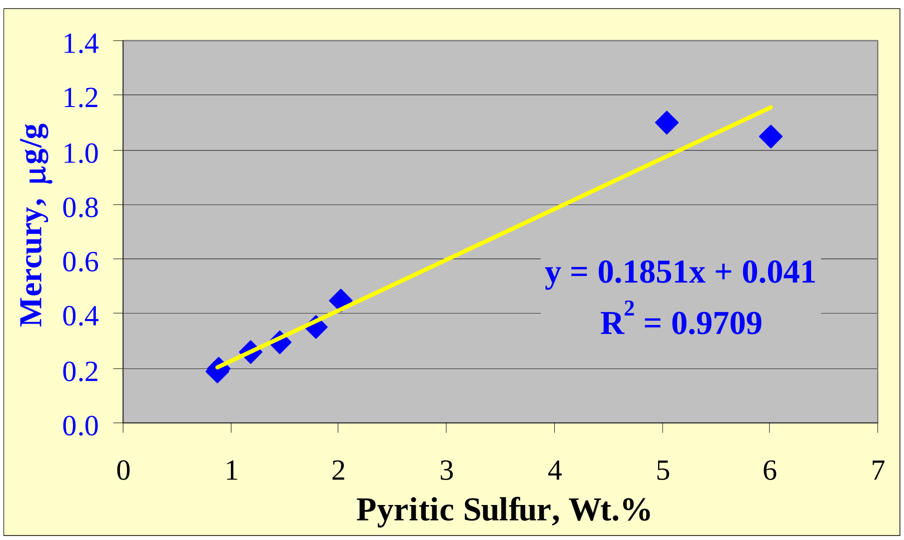

Figure 7. Relationship between Pyritic Sulfur and Mercury for **Upper Freeport Coal** Processed at Vicksburg

A ***Western Sub-Bituminous Coal*** was processed to lower the abrasive qualities of the coal. Table IV shows the direct effect of MagMill treatment on the coal. The data under "Unmodified Mill Ash" shows the weight distribution of the major minerals in the Unmodified Mill product (i.e., after grinding with no MagMill retrofit). The "Feed Total" values represent the mass fractions of the minerals and the values under the heading "Class" represent the mass fractions of the minerals in the size fraction coarser than 25 microns. The values under the heading "Ash" are the contribution of the minerals to the ash shown as "Unmodified Mill Ash" or "MagMill Product Ash" where, for simplicity, it is assumed that the weight of mineral and ash are the same. For example, for the Unmodified Mill with a total ash of 22.4 wt%, the calculated component of quartz in the ash is 3.62 wt% and so on. Only quartz, pyrite and feldspar are reported here. In this analysis, quartz, pyrite, and feldspar collectively make up 7.8 wt% of the total ash but cause the majority of the abrasion and erosion.

The grouping under the label "MagMill Product Ash" represents the concentration of the minerals in the MagMill product. In this case, quartz, pyrite, and feldspar represent a total of 3.0 wt% of the 18.89 wt% MagMill Product Ash. When compared to the 7.8 wt% component of the 22.4 wt% Unmodified Mill Ash, this represents a 61% reduction in the concentrations of components which account for the abrasiveness of the ash. The validity of these calculations was reinforced by combustion testing of the Western lignite coal where it was determined that "…Steam tube erosion index values decreased on average by 48% when firing the magnetically processed coal".

To calculate the erosion rates one employs the correlation equation, Erosion Rate, mg/kg = $1.99 \times \text{vol\%} + 0.42$.

Table IV. Reduction of Abrasive Minerals, **Western Sub-Bituminous Coal**

		Unmodified Mill Ash =		**22.4**	**MagMill Product Ash =**		**18.9**
			> 25 microns			**> 25 microns**	
Mineral	**Density, g/cc**	**Feed Total (Mass %)**	**Class**	**Ash**	**Product Total (Mass %)**	**Class**	**Ash**
Quartz	2.65	23.4	16.2	3.6	21.7	11.0	2.1
Pyrite	5.02	4.5	4.0	0.9	0.6	0.0	0.0
Feldspar	2.76	20.4	14.9	3.3	15.1	5.1	1.0
		Quartz, Pyrite, & Feldspar, wt.%		7.8	Quartz, Pyrite, & Feldspar, wt.%		3.0
		Quartz, Pyrite, & Feldspar, Vol.%		4.2	Quartz, Pyrite, & Feldspar, Vol.%		1.8
		Erosion Rate, mg/kg		8.8	Erosion Rate, mg/kg		4.0
% Reduction Of Combined Quartz, Pyrite & Feldspar Concentration							61%
% Reduction of Erosion Rate							54%

Computer Controlled Scanning Electron Microscopic (CCSEM) images of MagMill separation of nominal 100 micron highly erosive abrasive particles of the Western sub-bituminous coal are shown in Figure 8. The images on the left are of the material extracted from the pulverizer. The images on the right show large particles of pyrite, quartz and combined quartz and feldspar found in the magnetic separator reject stream. Pyrite appears white, quartz and feldspar are grey and coal particles are dark.

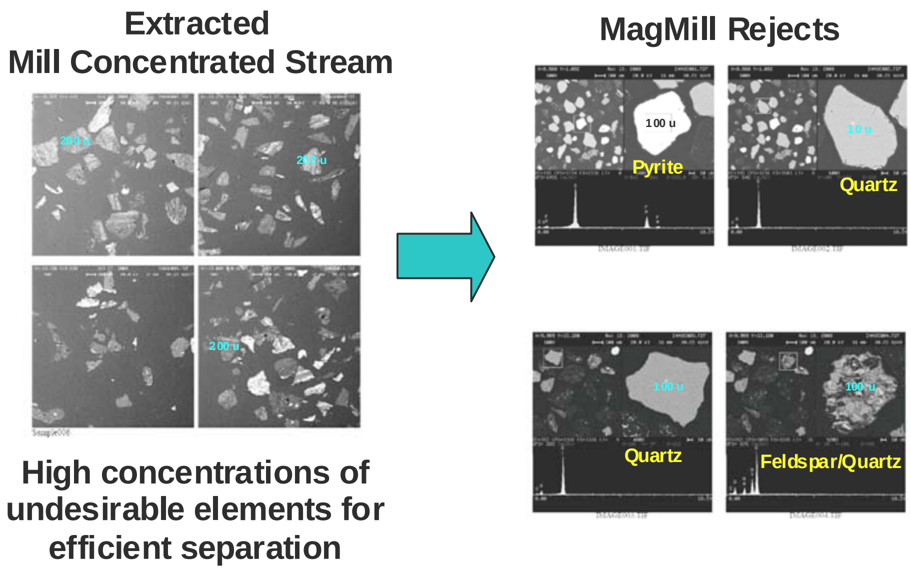

Figure 8. CCSEM Images, **Western Sub-Bituminous Coal**

Reductions in concentrations of mercury, arsenic and pyritic sulfur for a MagMill processed ***Powder River Basin Coal*** are shown in Figure 9. It can be seen that reductions in each of the three quantities ranging between 55 and 65% on a mass/MBtu basis can be achieved at a Btu recovery of 98% for this coal! The relationship between the mercury and arsenic with pyritic sulfur shown in Figure 10 is similar to that of the Eastern US coals shown above for the Pittsburgh and Upper Freeport seams.

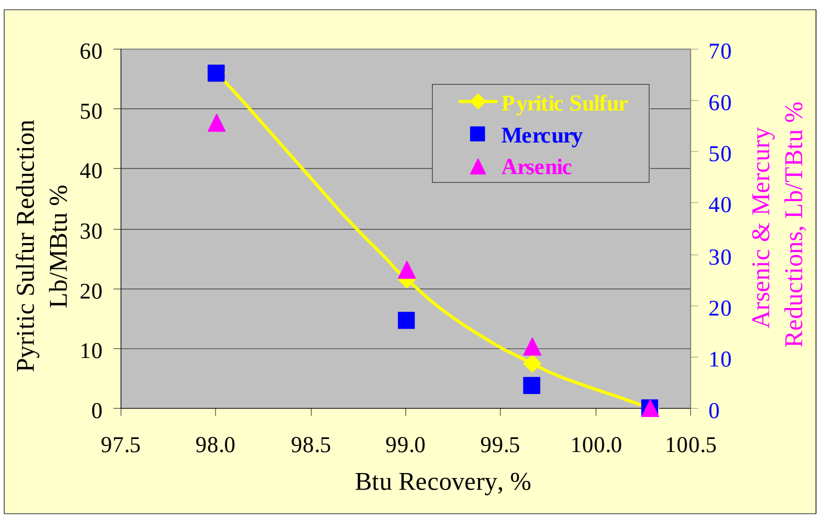

Figure 9. Reductions in Pyritic Sulfur, Mercury and Arsenic for **Powder River Basin Coal** Processed at Vicksburg

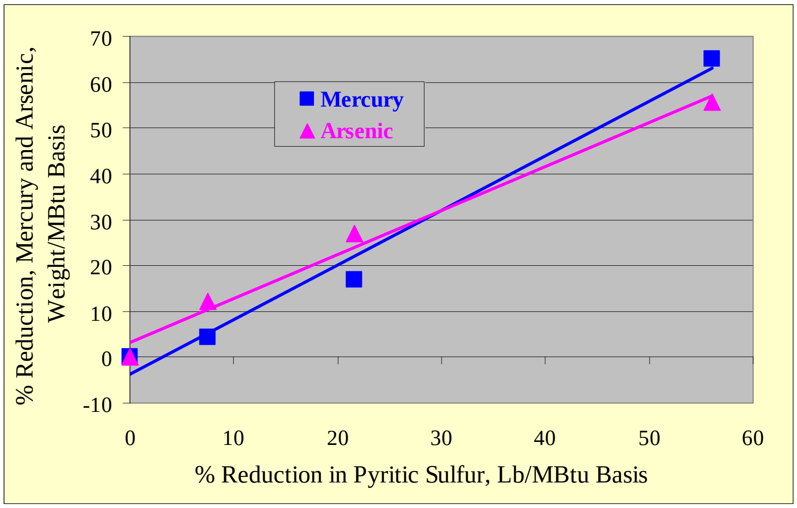

Figure 10. Relationship between Mercury and Arsenic with Pyritic Sulfur for **Powder River Basin Coal** Processed at Vicksburg

A ***Western Lignite Coal*** was processed at the Vicksburg facility. The percentage reductions in ash, sulfur, mercury, and pyritic sulfur given on a mass/MBtu basis in Figure 11 illustrate the extraordinary ability of the MagMill process to separate feebly magnetic iron pyrite, even from coals with low concentrations of ash and sulfur such as the Western coals. Together, almost 66 percent of the mineral sulfur is separated by the process. Figure 12 shows that the relationship between mercury and pyritic sulfur is similar to that observed for all other ranks of coal.

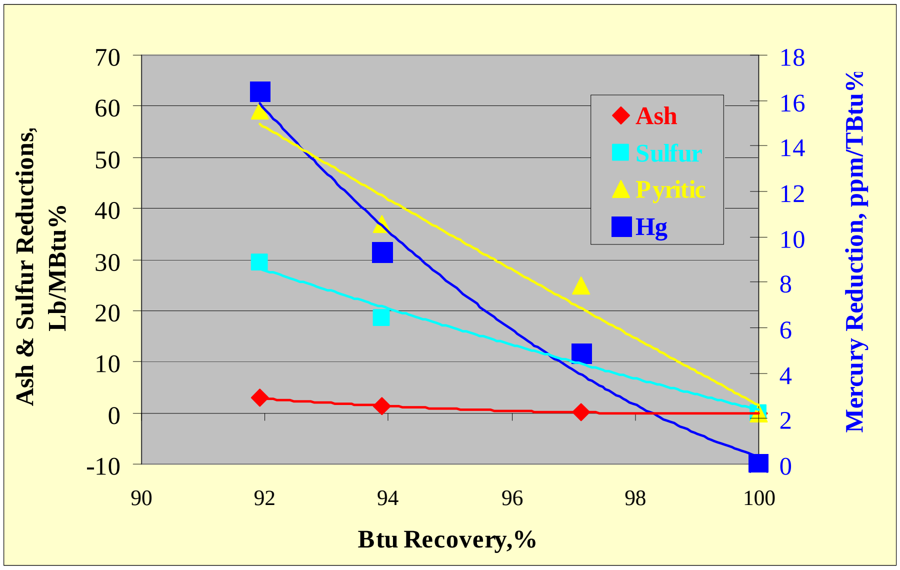

Figure 11. Reductions in Ash, Sulfur and Mercury for **Western Lignite Coal** Processed at Vicksburg

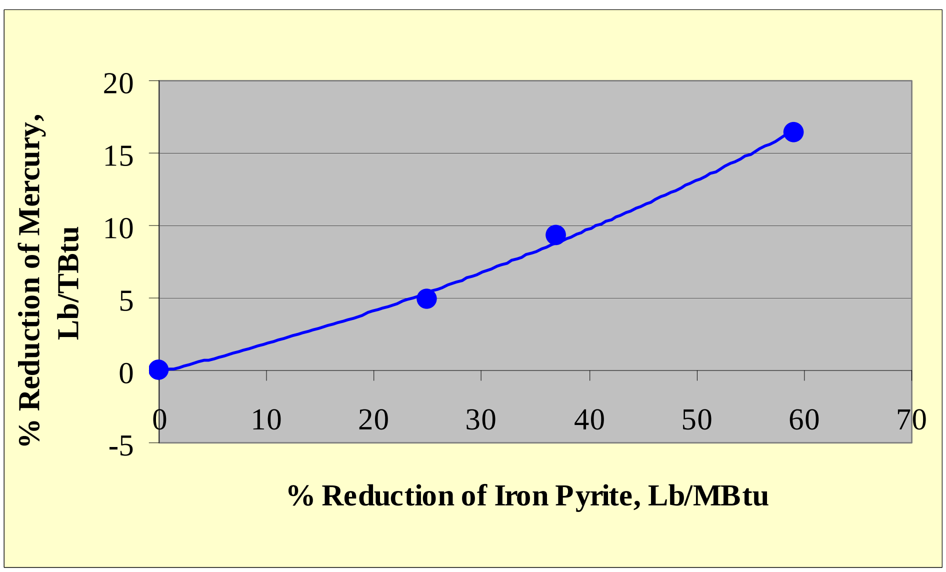

Figure 12. Relationship between Mercury and Pyritic Sulfur for **Western Lignite Coal** Processed at Vicksburg

Combustion testing of the MagMill product of the Western Lignite coal was carried out by an independent test facility. The results are summarized below.

- Magnetic separation significantly reduced iron, titanium, phosphorus, sodium, and potassium concentrations and increased calcium, magnesium, sulfur, barium, and strontium concentrations of the coal ash.
- Increases in calcium and magnesium contents enhanced sulfur absorption capacity of the coal ash.
- As expected, the magnetic separation process significantly reduced the hematite and pyrite contents of the coal.
- The magnetic process was effective in removing 13% of the quartz.
- The deposition rate during firing of the magnetically treated coal was about one-half of what occurred during combustion of the untreated coal.
- Steam tube erosion index values decreased on average by 48% when firing the magnetically processed coal
- Steam tube erosion index for Unit 1 decreased from the medium-erosion-severity range of 34 to 66 to the low (<33)-severity range as a result of the magnetic treatment.
- The magnetic separation process reduced pyrite and quartz concentrations in the lignite resulting in lower tube erosion index values.
- Firing of the magnetically processed coal reduced SO2 emissions by 26% but didn't significantly affect NOx emissions.

Tables V and VI show the elemental oxide compositions and quantitative mineralogy of the Western lignite coal.

Table V. Elemental Oxide Composition of the **Western Lignite Coal**

Fuel Description	**Untreated Lignite**	**MagMill Processed Lignite**	**Relative Percent Difference**
SiO_2	50.9	42.3	-17
Al_2O_3	28.5	24.7	-13
Fe_2O_3	8.66	4.86	-44
TiO_2	1.11	0.77	-31
P_2O_5	0.26	0.14	-46
CaO	3.30	13.5	309
MgO	1.16	4.90	324
Na_2O	0.21	<0.01	-100
K_2O	2.53	1.00	-60
SO_3	3.26	7.49	130
BaO	0.09	0.26	189
SrO	0.06	0.09	50
Total	100.0	100.0	NA

Table VI. Quantitative Mineralogy of the **Western Lignite Coal**

Mineral	Untreated Lignite	MagMill Processed Lignite	Relative Percent Difference
Quartz	16.54	14.3	-13
Hematite	5.9	3.7	-37
Rutile	0.4	1.2	200
Calcite	1.3	1.0	-23
Kaolinite	8.9	17.8	100
Illite	2.8	3.2	14
Iron Aluminosilicate	2.4	2.5	4
Mixed Clays	4.2	9.3	121
Pyrite	20.1	9.1	-55
Gypsum	13.3	9.2	-31
Barite	<0.1	0.3	200
Others	24.1	28.4	18

SUMMARY

A summary of results to date includes the following accomplishments in the pulverizer application:

- Achieved up to 80% Reductions of Hg, As, Se and up to 60% Reductions of Sulfur and Iron Pyrite
- Removed > 50% of Hard to Grind dense and abrasive minerals (Iron Carbonate, Iron Pyrite, Quartz, Feldspar, etc.)
- Achieved total Btu recoveries of 90 to 98%
- Improved performance characteristics of lower cost unwashed coals
- Reduction of groundwater contamination potential of bulk fly ash by reduction of HAP's
- Demonstrated the ability to significantly reduce Mercury emissions on eastern and western coals.

Initial testing of waste coal with the mine-based system has:

- Demonstrated the ability to recover up to 67% of the Btu's
- Reduced mercury over 50% on a Lb/TBtu basis
- Reduced sulfur up to 75% on a Lb/MBtu basis
- Reduced ash up to 80% on a Lb/MBtu basis

- Processed waste coals with heat content down to 2,800 Btu/Lb
- Demonstrated the potential to recover low cost steam or met coal from Coal Wastes

FUTURE PLANS

Our future plans include the following objectives:

- Optimize system to further improve heavy metal reduction
- Optimize mine-based pilot system for coarse and fine coal refuse from additional waste sites
- Build a mine-based commercial system for raw and waste coal recovery
- Build a commercial system for a boiler/pulverizer application
- Demonstrate met coal recovery from waste coals

Mercury reduction requirements now being adopted will greatly increase the Mercury level in fly ash and create potential fly ash disposal problems. As noted by the EPA Information Collection Request[2] excerpted below, arsenic and other heavy metals would create similar issues. *Efficient removal of Mercury and other heavy metals before combustion, dry cleaning of raw coals and the production of steam coals from coal wastes have the potential to lower operating costs while meeting new environmental requirements and lead to more competitive coal-fired generation.*

[2] 12/09 EPA INFORMATION COLLECTION REQUEST FOR NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS (NESHAP) FOR COAL- AND OIL-FIRED ELECTRIC UTILITY STEAM GENERATING UNITS

> Coal-fired units: Mercury and other non-mercury metallic HAP Emissions of certain non-mercury metallic HAP (i.e., antimony (Sb),beryllium (Be),cadmium (Cd), cobalt (Co), lead (Pb), manganese (Mn), and nickel (Ni)) have been assumed to be well controlled by particulate matter (PM) control devices. However, mercury (Hg) and other non-mercury metallic HAP (i.e., arsenic (As), chromium (Cr), and selenium (Se)), because of their presence in both particulate and vapor phases, have been reported, in some instances, to be not well controlled by PM control devices. Also, it has been shown through recent stack testing that certain of these HAP (i.e., As, Cr, and Se) tend to condense on (or as) very fine particulate matter in the emissions from coal-fired units. There are very few recent emissions test data available showing the potential control of these metallic HAP from coal-fired utility boilers.