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DRY COAL CLEANING IN A MAGMILLÔ

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ABSTRACT

Dry coal is ground at the front end of pulverized-coal-fired power plants to pass nominally 200 mesh or 74 microns to assure good combustion characteristics. The degree of liberation of minerals in coal at this particle size is excellent. We present evidence of efficient removal of iron pyrite and associated trace metals in a novel prototype MagMill™ separator consisting of a dry magnetic separator retrofitted to an air-swept pulverizer producing nominal 200 mesh coal. Results of feasibility testing on operating pulverizers in plants in Illinois, West Virginia, Ohio, and Pennsylvania indicate the potential for pre-combustion removal of mercury ranging from 50% to 85% with Btu recoveries of 95% and greater. The MagMill™ reject stream is non-hazardous and can be impounded or sold. Coal dependent, it is estimated that the environmentally friendly technology can be paid out in less than two years while saving the generating station between $1 to $6 per ton of coal burned.

INTRODUCTION

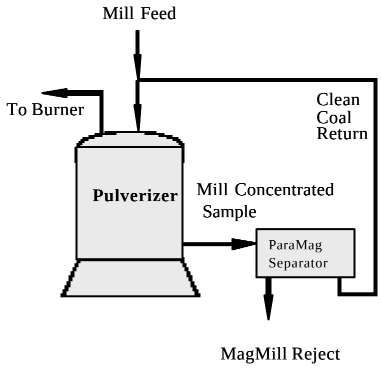
The purpose of this paper is to introduce a novel method for dry removal of minerals and trace metals from coal and to illustrate its potential cost savings to fuel upgrading at the pulverized-coal fired power generating station. The technology is called a MagMill™ (Patent Pending) which retrofits a dry magnetic separator to the pulverizer at the power plant for pre-combustion separation of minerals not removed by conventional wet cleaning at the mine.

MagMillÔ Technology

The MagMill™ is a method for removing inorganic impurities from coal at the power plant. A **high volume** stream rich in inorganic minerals is withdrawn from the pulverizer and processed by the magnetic separator as shown in Figure 1. Clean coal is recovered by the separator and returned to the pulverizer for grinding to specification; concentrated minerals are rejected. In this fashion, inorganic minerals including sulfur and trace elements are removed from the pulverizer before they are overground; similarly, their concentration is reduced in the pulverizer output.

The advantages and benefits are summarized in Figure 1. The process improves plant performance by selectively removing hard and abrasive minerals from the pulverizer before they are overground. The energy draw is reduced and the pulverizer throughput is simultaneously increased. Abrasive wear is reduced in the pulverizer and in all downstream equipment that is touched by the coal. The magnetic separator preferentially rejects iron sulfides. Lowering levels of iron sulfides to low NO_x burners reduces burner-tip fouling and water wall wastage problems. Sulfur emissions are lowered and downstream catalyst poisoning in catalytic reactors is reduced. Entities associated with the iron sulfides, such as trace elements, are also separated. Coal and plant dependent, the net gain for the power plant can be significant. It is estimated that Eastern U.S. pulverized coal fired power plants can save between $1 and $6 per ton of coal burned and pay out the retrofit in less than two years. For a 2000 MW plant burning bituminous coal the net savings can be of the order of $30 million per year.

Feature



Advantages

More effective than conventional coal cleaning

Separation of hard & abrasive minerals

No water

No additives

No storage

No transportation

Benefits

Mill
Reduces wear
Increases pulverizer throughput
Reduces power draw
MagMill™ reject is non-hazardous & can be impounded

Burners and Boilers
Product burns 2 times faster than reject & 1.5 times faster than untreated coal
Product fusion temperatures increased
Reduces water wall wastage

NO_x Reduction
Increases fineness to pipes
Reduces arsenic to SCR's

Fuels Procurement
Enlarges range of fuel sources
Reduces overall costs

Figure 1.
MagMillÔ Technology

MagMillÔ Concept

A variety of mills are employed in power plants; a Babcock & Wilcox MPS 89 shown in cut-away view in Figure 2 is used here as an example. This is an air swept mill producing coal which is 70% to 80% finer than 200 mesh or 74 microns. Coal is fed onto the surface of a rotating table in the grinding zone where it is crushed as the table rotates underneath large and heavy tires. Hot air blown into the grinding zone around the inside circumference of the pulverizer lifts the fine particles produced in the grinding and conveys them to the top of the mill which houses a static classifier. There, oversize particles are returned to the grinding zone and the fines are blown through pipes to the burners. There is a continuous stream of particles circulating inside the pulverizer which carries oversize particles back to the grinding zone. Hard minerals carrying sulfur and trace metals concentrate in this stream on the basis of hardness and density.

Minerals, especially iron sulfides and quartz, are generally the hardest components of coal. A portion of these minerals is withdrawn from the internal circulation of a MagMill™ pulverizer and is sent to a dry beneficiation stage for rejection of the minerals and recovery of the carbon for return to the mill.

This and other air-swept mills employ pyrite traps, such as that shown in Figure 2, to protect the mill from damage. A very small amount of coarse, dense material is withdrawn through the traps, typically at a rate less than 0.1% of that of the feed to the mill. This is not enough material to improve the quality of the mill product but it does protect the mill from damage by large pieces of metal such as rail spikes and other debris coming in with the coal feed. For the MagMill™, however, high ash coal is withdrawn at rates typically 30% of that of the feed for the mill. This is enough material for the magnetic separator to make a marked improvement in the quality of the product.

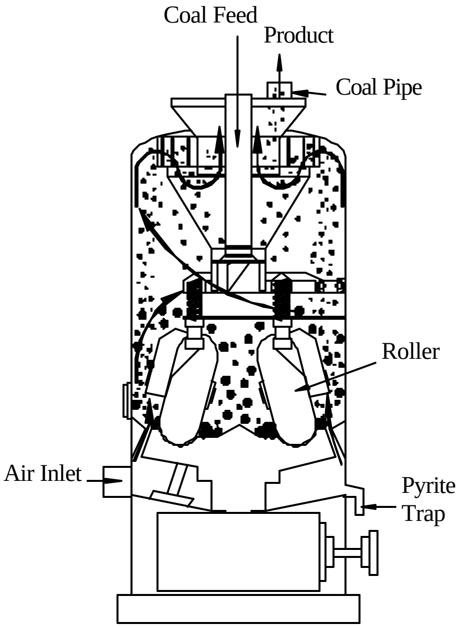


Figure 2
B&W MPS 89 Mill

A MagMill™ reject stream is created at the plant. This material is very high in mineral and trace metal content. The stream is non-hazardous and can be impounded or sold for its mineral value.

Beta Prototype MagMill™

During the summer of 1999 a beta prototype MagMill™ was installed and operated at the Bradley Pulverizer Company pilot test facility in Allentown, PA. The prototype, shown in Figure 3, consisted of a skid-mounted one ton per hour ParaMag™ magnetic separator retrofitted to a 3000 Lb/hr Hercules air swept ring/roller pulverizer with static classifier attached. It was tested to demonstrate sulfur and ash removal from 10 tons each of two North Central Pennsylvania raw coals – Upper Freeport from Clarion County and Lower Kittanning from Clearfield County.

Figure 3
Beta Prototype MagMill™

Measurements of mill power consumption and throughput to produce products of 70 – 80% finer than 200 mesh size were made. Although the prototype MagMill™ was not optimized due to limited time, several runs were made on each coal to verify results and to test mill and coal parameters. The results of one run for each coal are summarized in the following. Details are given elsewhere (Oder, et al., 2001).

The Upper Freeport coal had a 91% Btu recovery while the Lower Kittanning coal had a 94% Btu recovery. These are typical results achieved with the un-optimized prototype testing. They are neither the best nor the worst. When operating at these conditions, the MagMill™ prototype increased the throughput 9% and 12% and decreased the power draw 26% and 12% for the Upper Freeport and Lower Kittanning coals respectively.

Ash and Sulfur Levels, Beta Prototype MagMillÔ

Table I summarizes results of runs for each of the two coals. All measurements are on a dry basis. It is apparent that the Upper Freeport MagMill™ product contains only 44% of the ash, 39% of the total sulfur, and 20% of the iron pyrites of the feed coal while producing the same number of Btu's. The MagMill™ reduces ash and sulfur, especially pyrites, to the burner.

	Upper Freeport				**Lower Kittanning**			
	Concentration			**Recovery**	**Concentration**			**Recovery**
	Lb/MBtu			**%**	**Lb/MBtu**			**%**
	Feed	**Reject**	**Product**	**Product**	**Feed**	**Reject**	**Product**	**Product**
Ash	16.3	17.0	7.2	44.1	17.3	12.9	10.4	60.2
Sulfur	2.2	2.6	0.9	39.1	4.6	3.7	2.7	58.0
Pyritic	1.2	1.9	0.2	20.0	3.2	2.7	1.8	56.3
Sulfate	0.0	0.0	0.0		0.0	0.0	0.0	57.3
Organic	1.0	0.7	0.6	61.1	1.4	1.0	0.9	61.9
HGI	68				78			

Table I
Summary of Results Expressed on Lb/MBtu Basis
Beta Prototype MagMillÔ

Ash Chemistry, Beta Prototype MagMillÔ

The effects of MagMill™ treatment on the ash-fusion temperatures are shown in Table II. Selected ratios determined from ash chemistry are given in the bottom portion of the table. Measured increases in ash fusion temperatures are particularly significant for the Upper Freeport coal.

	Upper Freeport			**Lower Kittanning**		
	Temperature, Deg. F			**Temperature, Deg. F**		
	Feed	**Reject**	**Product**	**Feed**	**Reject**	**Product**
Initial Deformation	2228	2092	2599	2318	2338	2328
Softening	2400	2215	2692	2476	2555	2414
Hemispherical	2510	2376	2700+	2525	2606	2505
Fluid	2579	2489	2700+	2621	2685	2622
	Ratios			**Ratios**		
Base/Acid*	0.29	0.34	0.22	0.50	0.63	0.39
Silica/Alumina *	2.2	2.3	2.0	2.0	2.3	1.8
Iron/Calcium	5.9	14.4	2.9	20.0	68.3	14.5
Iron/Dolomite	4.2	8.3	2.2	13.6	29.4	10.3
Dolomite Percentage	16.1	9.6	26.1	6.4	3.1	8.4
Total Alkalies	4	3	3	2	2	1

Table II
Effects of MagMillÔ Processing on Ash Fusion Temperatures
Beta Prototype MagMillÔ

Trace Metals in MagMillÔ Products

Table III compares measurements of the trace metals in the MagMill™ feed and products for the two coals. The trace metals are sorted by recovery in the table. On an equal Btu basis, the MagMill™ product sends only 32.7% and 43.8% of the mercury in the feed coal to the burner for the Upper Freeport and Lower Kittanning coals, respectively.

	Upper Freeport Run #6					**Lower Kittanning Run #4**			
	Concentration			**Recovery**		**Concentration**			**Recovery**
	Lb/TeraBtu*			**%**		**Lb/TeraBtu***			**%**
	Feed	**Reject**	**Product**	**Product**		**Feed**	**Reject**	**Product**	**Product**
Thallium	117.5	176.3	28.4	24.2	Thallium	72.1	90.1	27.6	38.2
Arsenic	**4073.6**	**5877.5**	**1087.4**	**26.7**	**Mercury**	**33.8**	**38.0**	**14.8**	**43.8**
Lead	912.2	1237.4	277.9	30.5	**Arsenic**	**623.6**	**616.7**	**309.1**	**49.6**
Mercury	**33.2**	**43.3**	**10.9**	**32.7**	Nickel	946.1	901.4	483.9	51.1
Nickel	1394.4	1577.6	561.8	40.3	Lead	849.8	711.6	477.1	56.1
Selenium	**191.5**	**213.4**	**78.5**	**41.0**	Manganese	1428.5	1186.0	806.4	56.5
Manganese	2424.9	2629.4	1027.0	42.4	**Selenium**	**519.6**	**379.5**	**315.9**	**60.8**
Copper	1324.2	1392.0	579.9	43.8	Zinc	1646.5	1186.0	1008.0	61.2
Cobalt	347.5	340.3	163.1	46.9	Molybdenum	203.2	123.3	134.4	66.1
Molybdenum	202.5	167.0	108.7	53.7	Cadmium	11.8	6.6	8.1	68.1
Chromium	1724.2	1051.8	1087.4	63.1	Cobalt	240.7	125.7	168.0	69.8
Zinc	1806.6	1082.7	1147.8	63.5	Chromium	1602.6	782.8	1142.5	71.3
Vanadium	1970.6	866.2	1389.5	70.5	Copper	1128.0	545.6	806.4	71.5
Beryllium	98.9	37.1	72.5	73.3	Vanadium	1535.8	640.5	1142.5	74.4
Cadmium	16.4	4.6	12.7	77.4	Beryllium	69.9	23.5	54.4	77.9
Antimony	17.9	4.9	13.9	77.6	Antimony	16.0	3.1	13.4	84.1
One Tera = 10^{12} = one million million									

Table III
Trace Metal Measurements
Beta Prototype MagMillÔ

POTENTIAL COSTS AND BENEFITS OF THE MAGMILLÔ

The following illustrates the costs and benefits of a MagMill™ retrofit to a 1152 MW plant burning a blend of 80% cleaned and 20% raw Pittsburgh seam coals from Southwestern Pennsylvania and North Central West Virginia. EXPORTech has sampled the mills in this plant to obtain material used for magnetic separation tests. We believe that the results and our computer projections are representative of coals and plants located in the North Central Appalachian Basin in the USA.

The coal quality, price, plant generation, and heat rate have been taken from US Government publications for the year 1999, when the plant was still regulated. Commercial scale MagMill™ results were projected using a computer simulation developed by EXPORTech (Oder, et al., 2001). The cost of the MagMill™ retrofit is based on a conceptual engineering study funded by the EPRI Upgraded Coal Interest Group and ETCi's own cost estimates for the novel separators. The latter are based on vendor quotes and our considerable experience in dry separation technology development. It is to be understood that the economic model is a moving target which changes with advancements to the separations technology and with assessments of the price that the market will bear.

Break Even Example

The numbers in Tables IV through VI are for the specific case where MagMill™ credit is given only for sulfur reduction. The approach is to establish a break-even basis for costs built on the supposition that the MagMill™ operating costs, including refuse disposal, are large enough to offset any savings from lowered sulfur emissions. The potential cost savings for various alternative possibilities which may be more conjectural in nature are then calculated with respect to the break-even case. In the following, calculated numbers are rounded to two significant figures. Published information and results of measurements are given as quoted.

Table IV compares coal requirements for an 1152 MW pulverized coal fired generating plant, **Base Case**, and the same plant retrofitted with a **MagMill**™ installation, also generating 1152 MW. The MagMill™ plant requires approximately 2.5% more feed coal than does the Base Case to generate the same power level because of inefficiencies in the MagMill™ technology. It generates less bottom ash and fly ash and has a significant mineral refuse stream. This example calculates to a 97.5% Btu recovery.

	Base Case	**MagMill™**
Plant MW	1,152	1,152
Plant heat rate	9,564	9,564
Operating hours per year	7,088	7,088
MW-Hr generation	8,165,799	8,165,799
As-Delivered Eastern US Bituminous Coal		
Tons Coal per Year	3,047,925	3,100,000
Delivered Price per Ton Coal – 1999 $	30.86	30.86
Ash (Wt.%)	8.93	8.93
Sulfur (Wt.%)	1.71	1.71
Btu/Lb	12,811	12,811
Coal Delivered to Burner		
Tons Coal per Year	3,047,925	3,000,000
Ash (Wt.%)	8.93	6.8
Sulfur (Wt.%)	1.71	1.3
Btu/Lb	12,811	13,000
MagMill Refuse to Disposal		
Tons Refuse per Year		140,000
Ash (Wt.%)		52
Sulfur (Wt.%)		10
Btu/Lb		7,100

Table IV
Comparison of Base Case and MagMill™ Plants

Table V shows estimates for MagMill™ capital and operating costs for this installation.

Capital Cost, $	$ 9,200,000
Operating Cost, $/T Feed to Pulverizer	
Depreciation, 25 years Straight Line	$ 0.13
Maintenance @ 5% of Capital	$ 0.15
Power @ 0.021$/kW-Hr@ 4kW-Hr/T	$ 0.08
Water @ $0.5/1000 Gallons	$ 0.01
Labor @ 53,500$/Yr	$ 0.02
Total Estimated Operating Cost, $/T Pulverizer Feed	$ 0.39
Other Costs, $/T	
Bottom Ash & Fly Ash Disposal	$ 3
MagMill Refuse Disposal	$ 8

Table V
Estimated MagMillÔ Capital and Operating Costs

Depreciation of the retrofit is straight line over 25 years and is shown as an operating cost. The MagMill™ consumables are electric power costing 21 mills per kW-Hr and cooling water costing $0.5 per 1000 gallons. Labor is figured at $55,300 per year. The cost of disposal of bottom ash and fly ash is estimated at $3 per ton. The bottom line cost of MagMill™ refuse disposal is calculated to be $8 per ton, which value makes the cost difference between the Base Case and the MagMill™ retrofit zero. For this case there is no advantage to the MagMill™.

Using the numbers in Tables IV and V, Table VI compares the cost of the two break-even fuels based on equal net Btu's to the burner.

	Base Case	**MagMill**
Cost of Delivered Fuel	$ 94,000,000	$ 96,000,000
MagMill™ Operating Cost		$ 1,200,000
Cost of Ash Disposal	$ 820,000	$ 610,000
Cost of MagMill™ Refuse Disposal		$ 1,100,000
Cost of Sulfur Emissions	$ 9,600,000	$ 5,100,000
	$ 104,000,000	$ 104,000,000
Net Savings		$ 0

Table VI
Summary of Break Even Costs

Potential Value of the MagMillÔ to the Coal Fired Power Industry

While not all coals and plants are the same, some general observations can be made about the overall benefits possible with use of the MagMill™. Some accrue to the mining industry and some to the power generator. Using Table VI as a basis, four benefits of using the MagMill™ are illustrated in the following examples. It is also possible to consider combinations of these.

Case 1. Mine-Mouth Generation

Several new mine-mouth plants are on the drawing board for the US which present an interesting possibility for dry processing. The cost, limitations, and environmental problems of wet cleaning can be minimized along with the cost of transportation.

For the break-even case presented above, we assume that \$6 of the \$30.86 per ton price of delivered coal is associated with transportation. Removing \$6 per ton from the price drops the cost of delivered coal to the base case plant to \$76,000,000. Further assuming that coal cleaning at the mine is now limited to rock removal, then a higher ash coal can be delivered to the MagMill™ plant, saving an additional \$3.5 per ton from the cost of clean coal. At a price of \$21.36 per ton, the cost of 3,410,000 tons rock-free coal is estimated at \$73,000,000. For the MagMill™ plant, about 10% more coal is delivered, increasing the MagMill™ throughput as well as MagMill™ operating expenses by about 10%. Assuming that the cost of disposal of the MagMill™ refuse associated with transportation is reduced by \$5 per ton drops this cost to \$450,000. The cost of sulfur emissions are approximately the same as the break-even case. **In the mine-mouth arrangement the MagMillÔ saves approximately \$5,950,000 per year which will pay out the MagMillÔ in less than two years.** These costs are summarized in Table VII.

	Base Case	MagMill
Cost of Delivered Fuel	$ 76,000,000	$ 73,000,000
MagMill™ Operating Cost		$ 1,300,000
Cost of Ash Disposal	$ 820,000	$ 620,000
Cost of MagMill™ Refuse Disposal		$ 450,000
Cost of Sulfur Emissions	$ 9,600,000	$ 5,100,000
	$ 86,420,000	$ 80,470,000
Net Savings		$ 5,950,000

Table VII
Cost Comparison for Mine-Mouth Base Case and MagMillÔ Plants

In another sense, dry processing for rock removal at the mine and MagMill™ cleaning at the power plant to replace deep wet cleaning can help the overall system in mine-mouth power generation – not only the power plant. The cost of coal preparation at the mine can be significantly lowered by replacing deep cleaning with less costly rock removal and by disposing coarse dry rock versus fine wet refuse. The overall savings will accrue to both the mine and the plant and can be much greater than that calculated above for the plant alone.

Case 2. 10% Extra Generation Capability

Because the MagMill™ is grinding more of the relatively soft coal and less abrasive and hard mineral gangue, it is possible to increase the throughput of the retrofitted mill by about 10%. This is reflected in an increase in the Hardgrove Grindability Index of the MagMill™ product relative to that of the feed coal. (For plants facing pulverizer problems, spare pulverizer capacity is an attractive possibility even though the plant may be pulverizer limited.) Even when the pulverizer output is increased by 10%, the retrofitted plant emits less sulfur than the base case plant, thus providing a compelling argument for avoiding a New Source Performance Review in the event the base case plant had been grandfathered prior to the retrofit. In this case, all costs are increased by about 10% for the example shown in Table VI. Assuming the plant is not pulverizer limited, for an additional cost of $10 million per year, the plant can generate an extra 115 MW which can be sold at $45 per MW-Hr resulting in **an extra $27 million in sales for the year. The separator will pay out in four months.**

Case 3. 5% Lower Non-Fuel Operating Expenses

The current average operating cost of coal fired power generation in the US is 21 mills per kilowatt-hour (kW-Hr). Roughly 20% of this, or 4 mills per kW-Hr, is non-fuel-related such as parasitic power, maintenance etc. If use of the MagMill™ could reduce this number by 5%, or 0.2 mills per kW-Hr, then the 1152 MW plant can save $1,600,000 per year. **This alone would pay out the MagMill™ in 6 years**.

This is reasonable since, as mentioned above, the MagMill™ provides several advantages to the plant. Separation of the abrasive minerals will reduce maintenance costs for all parts of the plant downstream from the pulverizer which are touched by coal. Using a MagMill™ retrofit, the plant has a choice of producing more coal or of producing finer coal at the original base rate with reduced power draw, thus reducing parasitic power consumption while lowering unburned carbon in its fly ash. Removal of iron pyrite from the flame of low NO_X burners will reduce water wall wastage.

Case 4. Reduced Mercury to the Burner

Proposed Federal regulations call for releasing no more than 10% of the mercury in the coal in the ground to the environment. Approximately 12% of the mercury in Eastern U.S. coals can be removed by conventional coal cleaning while 37% can be removed by advanced coal cleaning at costs ranging between $12,000 and $37,000 per pound of mercury removed (Akers, 1998). The cost for 90% removal at the plant using activated carbon, the only method proven to date, is $39,000 per pound of mercury (Brown, et al., 1999).

The as-delivered Base Case coal has 10.63 pounds of mercury per tera Btu (Tera = 10^{12}). It is optimistically estimated that 29.6% of the mercury in the coal in the ground was removed from the Base Case coal at the mine (advanced coal cleaning is credited with removing 37% of mercury and 80% of the coal has been cleaned, thus 37%*.8 = 29.6%). This calculates to 15.1 pounds of mercury per TBtu in the ground (10.63/(1-.296) = 15.1). Under the proposed regulation, a total of 13.6 pounds of mercury per TBtu must not be released (15.1*.9 = 13.6). Coal cleaning is credited with removal of 4.5 pounds per TBtu (15.1*.296 = 4.5), leaving 9.1 pounds of mercury per TBtu to be removed at the plant.

The plant burns 78.1 TBtu per year. The cost for 90% mercury removal at the plant using activated carbon is $39,000 per pound of mercury. The cost to remove 9.1 pounds of mercury by this method is $30.8 million (pounds to be treated to remove 9.1 pounds per TBtu is 9.1/.9 = 10.1; the cost is 10.1*78.1*$39,000 = $30.8 million).

Measured mercury reductions in the unoptimized tests of the beta-prototype MagMill™ ranged between 46% and 56% based on equal heat to the burner. Computer projections of mercury reductions in operating plants range from 27% for cleaned coals to 85% for blends of washed and raw coals. The results described in Tables IV-VI above are based on an 85% reduction calculated by the simulator.

Assuming the MagMill™ removes 60% of the mercury from the delivered Base Case coal, only 2.7 pounds/TBtu must be removed by other methods (9.1-.6*10.63=2.7). The cost to remove 2.7 pounds by activated carbon treatment is estimated to be $9.1 million (pounds to be treated is 2.7/.9 = 3.0; the cost is 3.0*78.1*$39,000 = $9.1 million**). The annual savings to the plant for mercury removal is $22 million. This savings alone will pay out the MagMillÔ in 5 months.**

CONCLUSIONS

Dry cleaning of coal with a MagMill™ brings unusual opportunities for the coal-fired power industry. The immediate market for the new technology is in retrofitting existing pulverizers. There is an even greater opportunity for designing new pulverizers with separators inbuilt for future markets world-wide. Both approaches emphasize preparation of an upgraded fuel to improve efficiency and performance while also mitigating emissions. The MagMill™ has been successfully subjected to robust testing. It has been demonstrated at the 3000 Lb coal per hour level. It is now time for an in-plant demonstration of this novel new technology.

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