National Energy Technology Laboratory

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Lignite Fuel Enhancement

A DOE Assessment

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DISCLAIMER

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EXECUTIVE SUMMARY

Starting in the mid-1980s, Congress created and funded a series of programs intended to demonstrate the market readiness of new coal-based technologies. These are the Clean Coal Technology (CCT) programs managed by the Department of Energy (DOE) at the National Energy Technology Laboratory (NETL). The first program, the Clean Coal Technology Demonstration Program (CCTDP), comprised five solicitations spanning the period from February 1986, when the first Program Opportunity Notice was issued, to February 2007, when the last Final Report was accepted. A second program, the Power Plant Improvement Initiative (PPII), was introduced in 2001 and consisted of a single solicitation. The current program is the Clean Coal Power Initiative (CCPI). To date, three rounds of CCPI program solicitations have been completed. These demonstrations are conducted at full scale to assess the commercial readiness of the technologies and to provide technical and financial information for future applications.

The primary objective of Round 1 of the CCPI (CCPI-1) was to demonstrate technologies that reduce emissions and improve efficiency and maintainability while extending the asset life of coal-based generation, thus bolstering the long-term viability of the United States' abundant coal resources. One of the projects selected in CCPI-1 was "Lignite Fuel Enhancement" submitted by Great River Energy (GRE). The demonstration technology, DryFining™, uses low-grade waste heat to reduce the moisture content of lignite, which results in improvements in several facets of plant operation. The project was selected for negotiation in January 2003; the Cooperative Agreement was signed in July 2004; and the operation phase concluded on March 31, 2010. The demonstration project was conducted on Unit 2 at GRE's Coal Creek Station (CCS). Unit 2 is rated at 546 megawatt (MWe) and is served by a tangentially-fired boiler that burns lignite.

The Participant (GRE) is also the technology owner and developer. Other team members include Falkirk Mining Company (lignite supplier), Barr Engineering (lignite handling), Lehigh University (collaborator), and the Electric Power Research Institute (EPRI) (collaborator). Heyl

& Patterson, Inc. manufactured the full scale dryers for both units. Overall project management was provided by GRE with oversight by the DOE NETL.
A prototype dryer was operated from February 2006 to the summer of 2009. The prototype dryer, sized for 115 tons per hour (tph) maximum feed rate, was typically operated at 75 tph. The prototype dryer reduced moisture from 36.78 percent to 28.55 percent while reducing sulfur (S) by about 30 percent. Higher Heating Value (HHV) was increased from 6290 Btu/lb to 7043 Btu/lb. Heat rate was projected to improve by over three percent with a full scale system. Based on the results obtained with the prototype, a decision was made to install a full scale DryFining™ system on Unit 2 as the final phase of this project. GRE's Board of Directors also decided to install a full scale system on Unit 1 outside the scope of this project. A significant factor in this decision was that the reduction in emissions resulting from the installation of DryFining™ precluded the need for new flue gas desulfurization (FGD) and mercury (Hg) removal systems.

Baseline tests with wet coal were carried out in September 2009. Installation and commissioning of the full scale systems were completed in December 2009. During January 2010, a series of tests were carried out on a single Unit 1 full scale dryer to confirm the performance of the prototype. It should be noted that Units 1 and 2 are identical as are their DryFining™ systems; therefore, results obtained from one unit are applicable to the other unit. The full scale system testing confirmed the results obtained by the prototype. The demonstration of full scale integrated operation for an entire Unit was scheduled for March and April 2010. Unit 2 was down during this period for a scheduled outage (reasons not related to the dryers). Therefore, Unit 1 had to carry the full station load as well as supply steam to the ethanol plant. While dryer performance and emissions reductions were verified, heat rate was not reported since this abnormal operation would not give representative results. Mercury emissions were reduced by 41 percent, nitrogen oxides (NO_X) by 32 percent, and sulfur dioxide (SO_2) by 54 percent.

Power Engineering magazine recognized DryFining™ CCPI project as the 2010 Best Coal-Fired Project of the Year. This prestigious award, which honors excellence in design, construction, and engineering of power generation facilities worldwide, was presented at the Power-Gen International Conference and Exhibition on December 14, 2010, in Orlando, Florida. In their announcement, *Power Engineering* cited a number of cost and operating advantages, including an overall improvement of plant performance.

I. INTRODUCTION

Coals are generally ranked as anthracite, bituminous, sub-bituminous, and lignite, with anthracite being the oldest and lignite the youngest. As coal ages, its moisture content decreases and heating value increases. Thus lignite, referred to as brown coal in some countries, is considered to have the lowest rank. U.S. sub-bituminous coals generally have moisture contents in the 15 to 30 percent range while lignites have moisture contents ranging from 25 to 40 percent—occasionally higher. Lignites found in Europe and Australia can contain moisture contents of 60 percent or more.

According to the U.S. Energy Information Agency (EIA), recoverable reserves of lignite and sub-bituminous coals are large, with the U.S. having in excess of 140 billion tons (over 53 percent of domestic coal reserves). The EIA expects the use of these coals to continue to increase through 2030 and beyond. The World Coal Institute reports that major reserves of lignite have been found in other countries with Russia having 110 billion tons, China 50 billion tons, and Germany and Australia about 40 billion tons each of recoverable reserves.

These countries are developing coal drying processes, most of which depend on high-grade heat to reduce coal moisture content, or are employing complex equipment arrangements using expensive materials to recover latent heat of vaporization. While the benefits of drying high-moisture coals are widely recognized, these approaches significantly increase the cost of thermal drying.

The CCTDP and the two subsequent programs—the PPII and the CCPI—are government and industry co-funded programs that are administered by the DOE. The goal of these programs is to demonstrate new generations of innovative coal-utilization technologies in a series of projects carried out across the country. These demonstrations are conducted at full scale to prove the technical feasibility of the technologies and to provide performance and financial information for future applications.

The technologies demonstrated in these programs are intended to furnish the marketplace with a portfolio of advanced, more efficient coal-based technologies that meet increasingly strict environmental standards. These technologies will help mitigate the economic and environmental barriers that limit the full utilization of coal. The primary objective of Round 1 of the CCPI (CCPI-1) was to reduce emissions and improve efficiency and maintainability while extending the asset life of coal-based generation, thus bolstering the long-term viability of the United States' abundant coal resources.

The solicitation and project selections for CCPI-1 were completed in January 2003 with the naming of eight projects selected for negotiation. CCPI-1 concluded on March 31, 2010, with the completion of this project. Three of the six projects that entered the negotiation phase have been completed. The others were either withdrawn or negotiations ceased without the award of a Cooperative Agreement. The DOE funding commitments for the three completed projects represented approximately 45 percent ($47 million) of the total estimated costs ($104 million), while Participant commitments totaled approximately $57 million.

One of the projects successfully completed was "Increasing Power Plant Efficiency: Lignite Fuel Enhancement." The project was proposed by GRE and was carried out at their Coal Creek Station (CCS) located in Underwood, North Dakota. Other team members included EPRI, Lehigh University, Barr Engineering, Heyl & Patterson, and Falkirk Mining Company. Barr Engineering was responsible for lignite handling and Falkirk Mining Company was the lignite supplier. EPRI and Lehigh University were collaborators. GRE (the technology developer/owner) provided overall project management with oversight by DOE NETL.

This project was intended to demonstrate GRE's DryFining™ technology that uses low-grade waste heat from the power plant at their Coal Creek Station to achieve a significant reduction in the moisture content of the lignite. The primary goal of the project was to design, install, evaluate, and demonstrate a technology that would remove approximately 25 percent of the moisture from the feed coal, thereby reducing the fuel requirement and providing other benefits to plant operation.

The Cooperative Agreement was awarded on July 9, 2004, and the design phase was completed in June 2007. Construction was completed in June 2009. Startup and operation commenced immediately and continued to the completion of the project. The demonstration phase of the project was completed on March 31, 2010. The final report was accepted by DOE in September 2010.

This report is an assessment of the project conducted by GRE through March 31, 2010.

II. PROJECT PROCESS DESCRIPTION

A. Project Site

The demonstration project was conducted at GRE's CCS, located in Underwood, McLean County, North Dakota. The station consists of two identical tangentially-fired units—Units 1 and 2. They are rated at 546 MWe and both burn lignite that is supplied by the nearby Falkirk Mining Company. Both are equipped with a tangential low-NO_X firing system for NO_X control. Particulate control is provided by two (600 SCA) cold-side electrostatic precipitators (ESP) per unit. Sulfur dioxide (SO_2) is controlled with wet desulfurization systems that use lime as the reagent. Unit 1 came online in 1979 and Unit 2 in 1981. Steam is extracted to supply a nearby ethanol plant.

B. Project Goals

It has been estimated that as much as seven percent of the available plant heat is used to evaporate the moisture when lignites and other low-rank, high-moisture coals are fired in pulverized coal power plants. These plants generally operate at reduced efficiencies, resulting in greater fuel consumption which, in turn, results in higher emissions and increased power consumption by the pulverizers and fans.

Prior to this project, GRE developed a process that evaporates a portion of the moisture from the lignite feedstock using the low-grade plant waste heat sources normally rejected from the power plant. GRE had developed the concept through bench scale and pilot plant work. The overall goals were to demonstrate GRE's Lignite Fuel Enhancement process at the full scale on Unit 2 and to commercialize the technology.

Specific performance goals included demonstrating the ability of the technology to reduce the moisture content of the lignite by 8.5 percentage points (approximately one-fourth of the as-received moisture) thus increasing the heating value of the coal along with commensurate reductions in heat rate, emissions of criteria pollutants, and parasitic power. An additional benefit of the lower heat rate will be lower CO_2 emissions.

C. Project Description

The project was carried out in two phases: Phase 1 of the project consisted of the design, installation, and integration of a prototype dryer with the Coal Creek Unit 2 heat sources and coal handling system. The prototype fluidized bed dryer (FBD) operated almost continuously from February 2006 to summer 2009 at 75 tons per hour (tph). The operation of the FBD prototype confirmed the capability of the scaled-up dryer to reduce fuel moisture to the target level over a range of operating conditions. The success of the prototype dryer led to the decision to proceed with Phase II of the project.

Phase 2 of project included the design, construction, and integration of a full scale coal drying system on Unit 2. GRE also decided to install a full scale drying system on Coal Creek Unit 1 based on the results obtained with the prototype dryer. The installation of the Unit 1 DryFining™ system was not part of the demonstration project. Both systems were fully integrated into their respective heat sources, coal handling, and control systems. In the spring of 2010, while Unit 2 was in outage, Unit 1 was used to determine the effect of dried lignite on unit performance, emissions, and operation. Each full scale coal drying system at Coal Creek includes four moving bed FBDs. Each FBD is sized to operate at a maximum feed rate of 138 tph while normally operating at 125 tph. Each system also includes coal crushers, a coal conveying system, a particulate control system, and instrumentation and controls. Although much of the work on Unit 1 was carried out in parallel with that on Unit 2 (in some cases earlier than on Unit 2) and the systems are identical, it should be noted that all costs for the Unit 1 dryer system were borne entirely by GRE. Since the units are identical, some of the data contained in GRE's final report was obtained from Unit 1 in order to expedite the tests.

The DryFining™ system was commissioned on both 546 MWe units in December 2009, and tests with one coal dryer were conducted in January 2010. The purpose of these tests was to gain preliminary operation and performance information on the dryer and baghouse.

Wet lignite was fired during a series of tests conducted in September 2009 to determine a baseline with wet coal. In March and April 2010, a second test series was performed after the full scale coal drying system was commissioned. Both series of tests were conducted at Coal Creek Unit 1 while it operated at full load, steady-state conditions. These tests were conducted to determine the effect of reduced coal moisture content on unit performance, emissions, and operation.

During the September 2009 tests, the Unit 1 turbine cycle was isolated by switching auxiliary steam extractions to Unit 2. Both boiler efficiency and net unit heat rate were determined by several methods.

During the March/April 2010 tests, Unit 2 was in outage and Unit 1 was carrying all station electrical demand (in addition to providing the extraction steam for the ethanol plant) during the tests with dried coal, resulting in a higher station service and turbine cycle heat rate. Calculations could have been performed to correct for some of these effects; however, this would have introduced uncertainty in the calculated unit performance and effect of dried lignite on performance with respect to heat rate and unit efficiency. Therefore, GRE opted to report only on those aspects of the effect of dried lignite that were not impacted by this limitation. This includes dryer performance, parasitic power requirements, environmental performance, and flue gas flow and characteristics. These items are all based on coal throughput and are not impacted by station load.

D. Technology Description

Figure 1 is a schematic that shows the overall integration of the dryer at Coal Creek Station

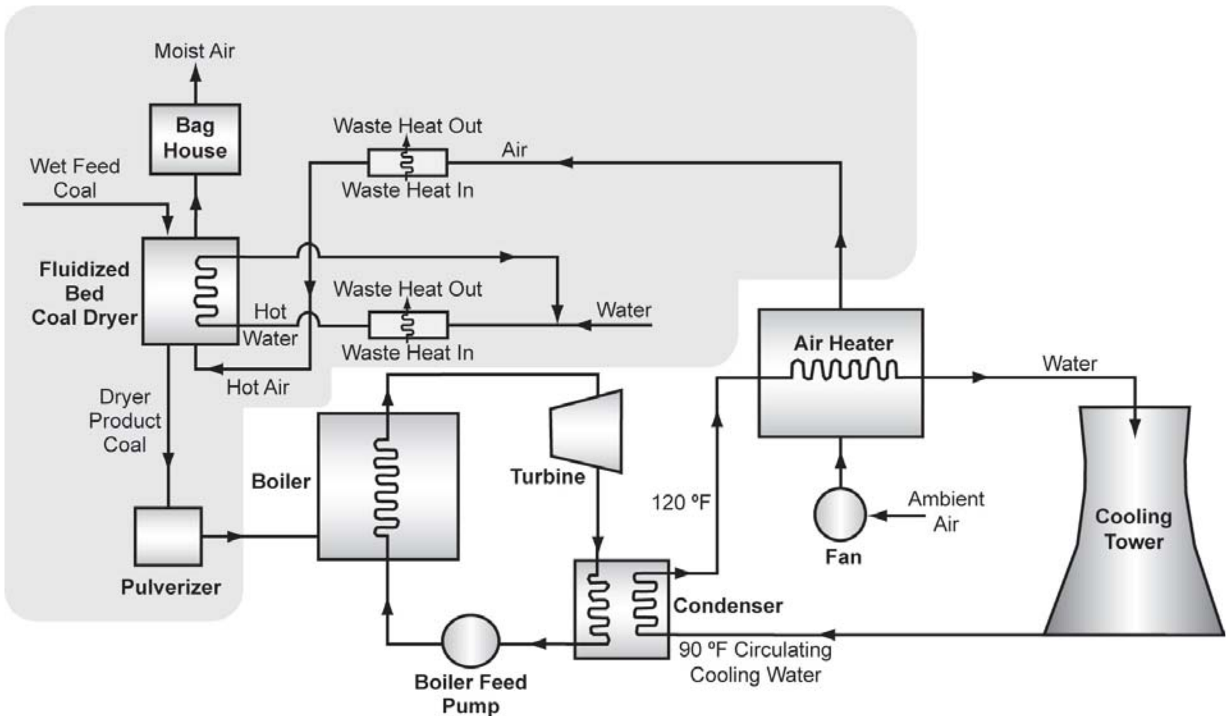

Figure 1. DryFining™ Schematic

For the prototype design, raw wet lignite is fed to the two-stage FBD from crushers, which crush the coal to a ¼ inch size, suitable for fluidized bed operation. Heavier material, primarily mineral matter, tends to gravitate to the bottom of the first stage of the dryer and is removed by a GRE patented segregation device. This mineral rich material tends to have higher S and Hg contents, thus reducing the emission of these pollutants. Low-quality heat to dry the lignite comes from several sources within the plant. The bed of lignite is fluidized by air which has been heated in two steps. This hot fluidizing air supplies a portion of the heat to dry the lignite and serves as the carrier for the evaporated moisture. This moisture-laden air is then passed through a baghouse to remove elutriated fines from the coal.

Additional heat for drying is provided by coils immersed in the fluid bed. These coils carry a circulating water stream, which is heated by interchange with another source of low-quality heat.

Figure 2 shows additional details of the prototype dryer.

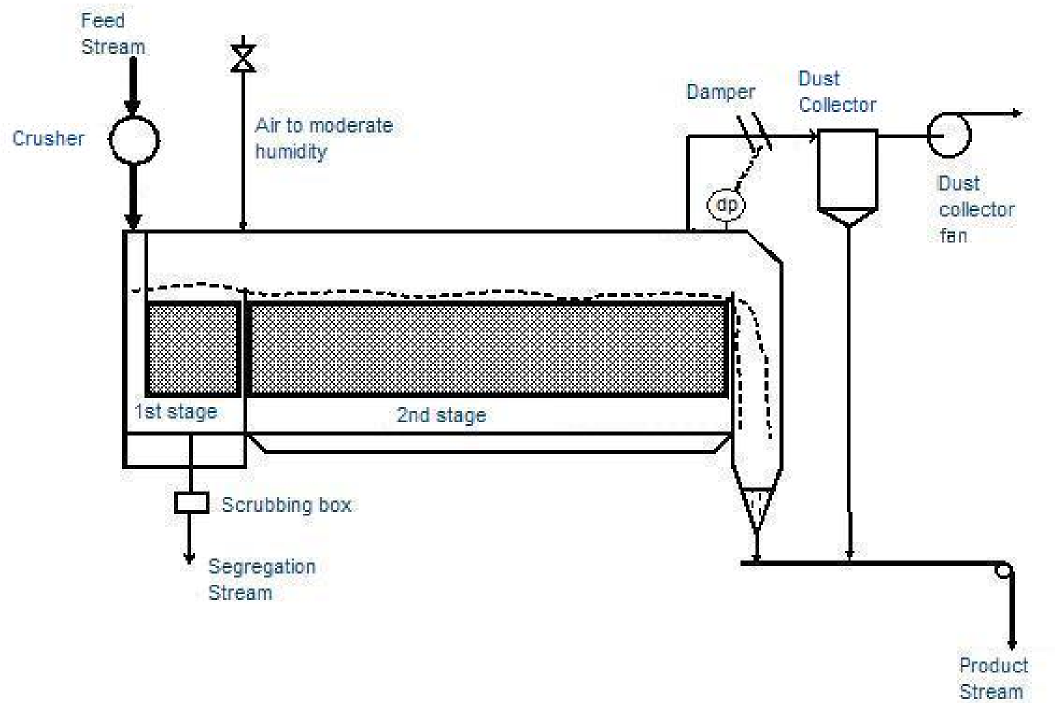

Figure 2. Prototype Dryer Schematic

Coal is crushed to ¼ inch top size by a coal crusher located upstream of the dryer and fed to the first stage of the FBD. The first stage segregates the denser material from the lignite, heats the lignite, and provides some drying. The segregated fraction (high in mineral matter, S, and Hg) is discharged. The first dryer stage also provides a uniform flow of coal to the second stage. Entrained coal fines are removed from the air in a baghouse prior to the air being discharged to the atmosphere.

In the second stage, the coal is heated and dried to a desired outlet moisture level by heat supplied by the fluidizing air and an in-bed heat exchanger. The partially dried coal is discharged from the FBD into a bunker, from which it is fed to the mills.

The full scale FBD uses a three stage design. The first stage of the full scale FBD occupies approximately 20 percent of the total volume, which is similar to the prototype dryer. As with the prototype, the first stage is designed to remove the segregated material.

III. REVIEW OF TECHNICAL AND ENVIRONMENTAL PERFORMANCE

There are two aspects of the FBD system that were demonstrated in this project. One was the ability of the system to achieve the desired level of moisture reduction utilizing only low grade waste heat while removing a significant amount of S and Hg with the mineral matter, thus reducing the emissions of Hg and SO_2. The second aspect was to demonstrate the anticipated benefits of the reduced-moisture coal on power plant operation.

A. Technical Performance

Prototype tests

A series of paired tests were conducted from March to April 2006, in which two consecutive performance tests—one with the prototype dryer in operation and the other with it off—were run per day. The order was randomly selected to minimize bias errors, such as day-to-day variations in plant operating conditions, and other variables. Sixteen paired performance tests were conducted based on statistical analysis. Prototype performance was also monitored during regular dryer operation, and coal quality data were collected during the time period. The results are summarized in Table 1.

Table 1. Prototype Dryer Performance: Coal Moisture and HHV

Parameter	Feed	Product	Change, Absolute	Change, Relative
Total Moisture	36.78 %	28.55 %	8.23 %	22.4 %
HHV	6290 Btu/lb	7043 Btu/lb	752 Btu/lb	12 %

When the 75 tons/hr prototype coal dryer is in service, dried coal represents approximately 14 percent of the total coal flow rate supplied to the boiler. Therefore, a blend of partially dried and wet coal (14% partially dried, 86% wet) would have approximately 1.14 percent lower moisture with an improvement in HHV of 103 Btu/lb or 1.63 percent. Extending these results to a full scale drying technology that processes 100 percent of coal feed indicates that coal moisture would be reduced 8.5 percentage points and the HHV of the coal would increase by approximately 800 Btu/lb. The anticipated changes in operating and performance parameters relative to wet coal are summarized in Table 2. The prototype scale values are measured, while the full scale drying system values are calculated.

Table 2. Change in Operating and Performance Parameters Relative to Wet Coal

Change in Parameter Relative to Wet Coal	Units	Prototype Scale System	Full Scale System
Change in coal flow rate	%	-1.83	-14
Change flue gas flow rate	%	-0.55	-3.9
Change in boiler efficiency **excluding** fan room coils	%-point	0.37	1.70
Change in boiler efficiency including fan room coils	%-point	0.80	2.13
Change in net unit heat rate **excluding fan** room coils	%	0.37	2.05
Change in net unit heat rate including fan room coils	%	0.71	2.39

The non-fluidizable material that sinks to the bottom of the first dryer stage is removed as the segregation stream. Samples were collected during the May-June 2006 time period to determine total moisture, S, and Hg content, and HHV of the feed, product, and segregation streams. Results are summarized in Table 3. Balances of S and Hg based on the paired tests are presented in Figures 3 and 4. Sulfur and Hg in the feed stream are reduced by approximately 30 percent and discharged as the segregated stream. Since these are based on measurements, there are some small errors in the S and Hg balances.

Table 3. Sulfur and Mercury Removed by the First Stage Prototype and HHV Content of the Segregation (Undercut) Stream

Test Number	Sulfur, % of Feed	Mercury, % of Feed	HHV, % of Feed
1	22.5	21.9	10.4
2	29.3	26.5	9.9
3	34.5	45.8	9.7
4	21.2	23.3	10.3
5	19.4	25.2	10.5
6	36.0	36.3	10.2
7	28.2	24.6	10.3
8	25.7	31.5	10.2
8	32.5	42.0	10.0
10	27.4	35.9	10.4
Average	**27.7**	**31.3**	**10.2**

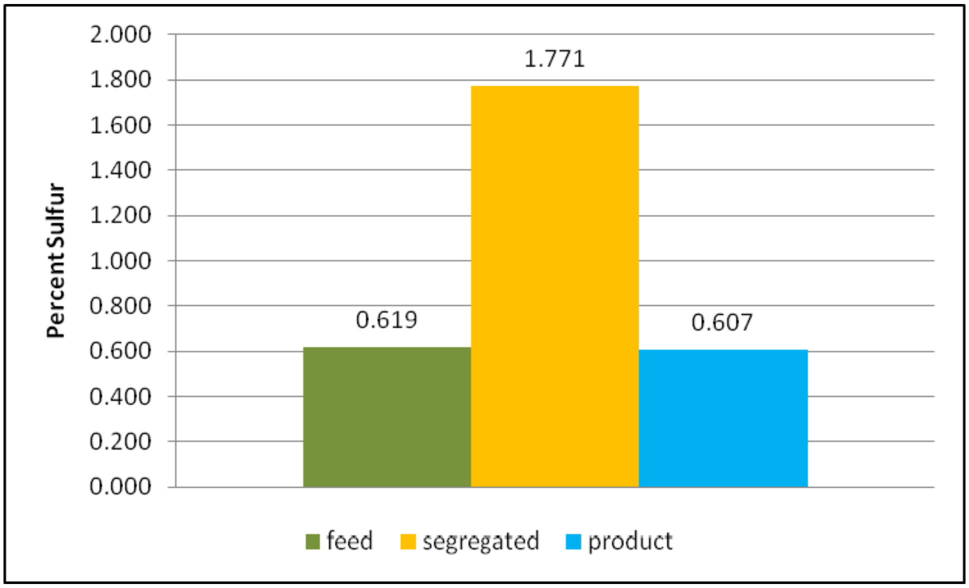

Figure 3. Sulfur Balance around the Prototype FBD

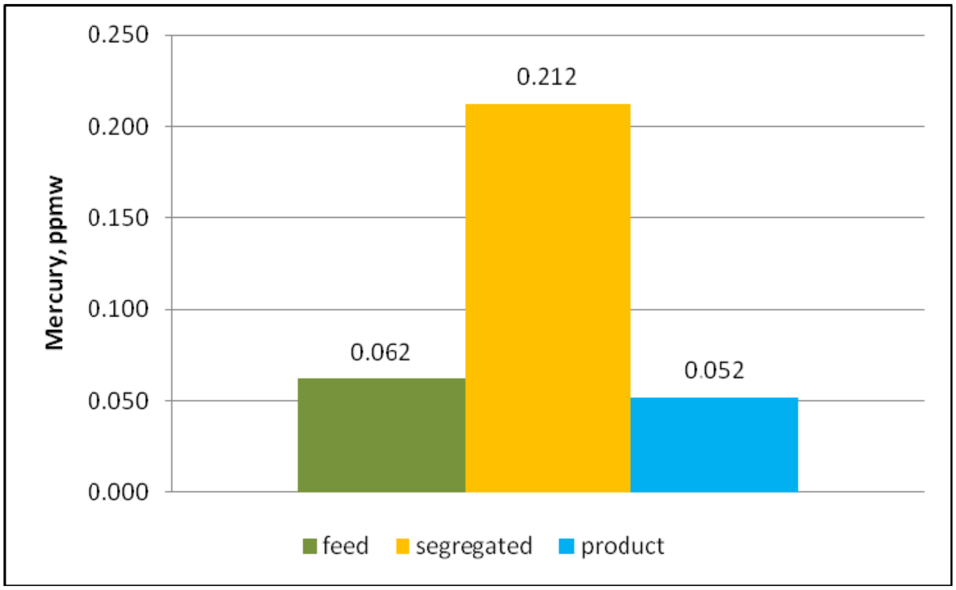

Figure 4. Mercury Balance around the Prototype FBD

The segregation stream contains approximately 10 percent of the inlet HHV. Additional processing of the segregation stream using air jigs is incorporated in the full scale coal drying system. The cleaned segregation stream is returned to the product stream. Less than 0.5% of the HHV is lost by segregation when used in conjunction with air jigs. The direct removal of S and Hg by the FBD is not the only reason for lower emissions. Although the concentrations of these pollutants in the product are only slightly lower than in the feed, the increased HHV of the product means that the amount of these pollutants is reduced substantially when expressed as pounds per million Btu. Less coal is required for a given heat input to the boiler; the unit operates more efficiently, requiring even less coal, and the flue gas volume is lowered resulting in less bypass around the FGD system which, in turn, results in higher S and Hg removal. Mercury removal is also enhanced since burning the dried coal tends to oxidize more of the mercury, which enhances its removal by the FGD system.

Full Scale Tests

The full scale system was designed to process 3.75 million tons of coal per year to meet 100 percent of Unit 2's needs. This required four full scale dryers to reliably provide the necessary capacity. GRE's Board of Directors approved the installation of four additional coal dryers on Unit 1 on the basis of the prototype's performance. Unit 1 dryers were installed concurrently with those for Unit 2. The decision to install the DryFining™ technology on both units was based, in part, on the ability of the technology to remove substantial amounts of sulfur and mercury from the feed to the boilers, which precluded the need to install mercury controls and an upgraded sulfur control system. Both units were commissioned in December 2009 with emissions and performance tests planned for the spring of 2010.

The first series of tests was performed in January 2010 and consisted of running four tests on one of four full scale dryers on Unit 1. The primary purpose of these tests was to confirm the functional performance of the full scale dryer. Coal throughput was 132 to 134 tph. Target heat input heat values were 70 and 85 percent of design, consistent with the power demand on the unit. Test data showed that actual vales of 69 and 80 percent were achieved. Manual samples were taken from the feed segregation and product streams and analyzed for HHV and composition. Flow rates were measured for the raw coal, fluidizing air, and segregation stream. During the tests, the segregated stream was cleaned in air jigs and returned to the product stream. In the future, the segregated stream will be treated in the prototype dryer and sent to GRE's Spiritwood—a Combined Heat and Power plant—for use as a beneficiated fuel.

The results of the functional tests confirmed that the full scale dryers performed as well as the prototype with respect to moisture removal and removal of pollutant precursors (i.e., sulfur). The dryer performance can be seen in Figure 5.

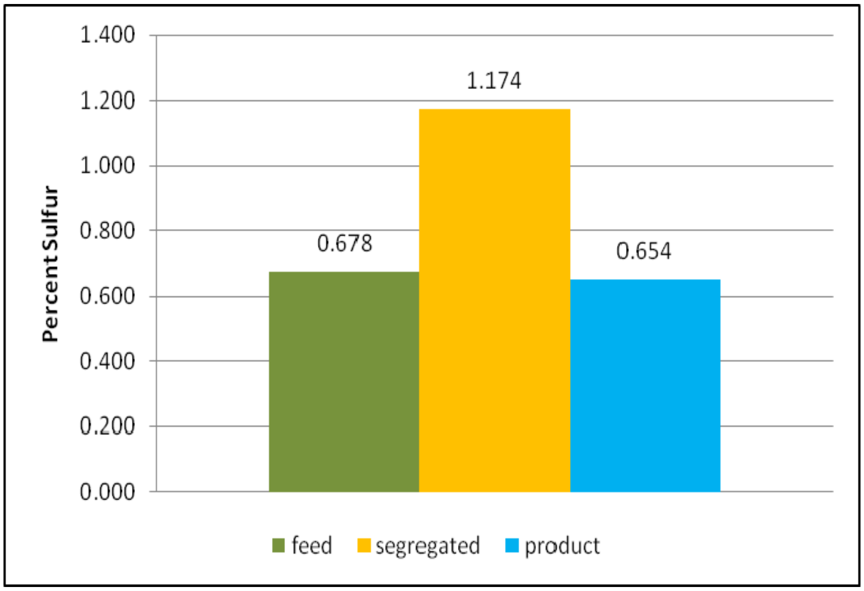

Figure 5. Sulfur Balance around a Full Scale FBD – Test 2

As expected, the average bed temperature in both dryer stages increased as heat input to the dryer increased. At 85 percent heat input, the average second stage bed temperature was approximately 30°F higher than the average first stage bed temperature. Total moisture decreased as heat input to the dryer was increased. At 85 percent heat input, the moisture content in the product stream was 30.2 percent, which compares favorably to the target value of 29.5 percent at full heat input.

According to GRE's final report, "Preliminary tests with dried coal were performed in March/April 2010. During the test, Unit 2 was in outage; therefore, Unit 1 was meeting the entire station electrical demand while providing steam for auxiliary steam extractions from turbine cycle. This resulted in higher station service and approximately two percent higher turbine cycle heat rate. Although, some of these effects could be corrected out, correction of this magnitude would introduce uncertainty in calculated turbine cycle and unit performance and effect of dried coal on unit performance. Baseline tests with dried coal are planned for second half of 2010 when both units will be in service."

GRE's decision not to present adjusted data is reasonable since such data would contain a degree of uncertainty. While the heat rate data are not available, some information is available in GRE's final report. Auxiliary power was virtually unchanged from the wet baseline results since reductions in fan and mill power offset the DryFining™ requirements, and the environmental results (discussed in the next section) indicate that the DryFining™ process performed as expected when compared to the prototype and single-dryer tests.

B. Environmental Performance

Boiler tests with wet coal were performed in September 2009, and preliminary tests with dried coal were performed in March/April 2010. The purpose of these tests was to determine the effectiveness of dried coal in reducing emissions. Results show that NO_X and SO_2 concentration and emissions rates are significantly lower for tests with dried coal, compared to the wet coal baseline.

The results of emission tests performed with wet and dried lignite are summarized in Table 4. For preliminary tests performed with dried coal, the NO_X emission rate decreased by 31.8 percent relative to the wet coal while the SO_2 emission rate was approximately 54 percent lower relative to the wet coal.

Table 4. Effect of Dried Lignite on Emissions Parameters

Parameter at Stack	Units	Wet Coal	Dry Coal	% Change Compared To Wet Coal
NO_X emission rate	lb/MMBtu	0.284	0.194	-31.8
SO_2 Emission Rate	lb/MMBtu	0.577	0.265	-54.1
CO_2 Emissions (Measured)	klb/hr	1229	1232	0.2
CO_2 Emissions (Calculated)	klb/hr	1352	1301	-3.8

Due to the lower flue gas flow, the 0.2 percent increase in CO_2 mass emissions resulted in the CO_2 concentration (measured by the plant monitor for preliminary tests with dried coal) increasing by four percent relative to the wet coal baseline. This increase is attributed to instrument drift, a two percent lower moisture content in the flue gas, and a 0.8 percent higher carbon content in as-received lignite during preliminary tests with dried coal compared to the wet coal baseline tests. The calculated values of CO_2 emissions were approximately 3.8 percent lower compared to the wet coal.

The lower NO_X emissions are largely attributable to lower primary air requirements (since the amount of coal fed to the boilers is less with the dried coal requiring less primary air) as well as to adjustments to the burner tilt angles.

The lower SO_2 emissions are primarily due to three factors: The first is that the first stage dryer removed a considerable amount of pyrites, thus reducing the amount of sulfur fed to the boiler. The second is that with dried coal, the mass and volumetric flow rates of flue gas were 3.4 and 7.8 percent lower. The lower amount of flue gas allows the operators to reduce the bypass around the FGD system. A third factor for lower sulfur and mercury emissions is the reduction in fuel flow due to the improved heating value of the coal.

Mercury emissions are reduced by the DryFining™ process in three ways: (1) as previously discussed, some of the Hg is removed with the segregation stream and fuel flow, resulting in less

Hg in the boiler feed; (2) operating the boiler with dried coal also results in a higher proportion of oxidized Hg fed to the FGD system, which enhances removal in the FGD system; and (3) with dried coal, the average total Hg concentration at the boiler outlet decreased by approximately 20 percent compared to the wet coal baseline. Most of the Hg at that location is elemental, typical for low chlorine coals.

GRE states that (assuming a consistent level of reduction in the concentration of mercury measured by the plant monitor) the overall reduction in Hg was approximately 40 percent. Accounting for the reduction in flue gas flow rate, the actual mass emissions rate of mercury is reduced by 41 percent relative to the wet coal.

IV. DISCUSSION OF RESULTS

As stated earlier, specific performance goals included demonstrating the ability of the technology to reduce the moisture content of the lignite by an 8.5 percentage points (approximately one fourth of the as-received moisture) thus increasing the heating value of the coal, along with commensurate reductions in heat rate, emissions of criteria pollutants, and parasitic power. An additional benefit of the lower heat rate will be lower CO_2 emissions.

GRE effectively demonstrated full scale, fully integrated operation of the DryFining™ system during the operation that took place in March and April 2010. During this time, Unit 1 operated with the plant operating at near or maximum capacity because Unit 2 was out of service for reasons unrelated to the DryFining™ system. The DryFining™ system operated as expected. Since Unit 1 had to provide the full station electrical demand plus extraction steam for the ethanol plant, the drying system's impact on plant efficiency could not be accurately extrapolated to periods of normal operation. However, valid data were obtained for other important variables such as moisture reduction and emissions.

The ability of the DryFining™ system to reduce the moisture of the coal by the target amount of 8.5 percent was clearly demonstrated at several levels. This goal was achieved with the prototype dryer, during operation with the single dryer, and with full scale operation on Unit 1. This resulted in an HHV improvement from 6290 Btu/lb to 7043 Btu/lb.

The full scale operation on Unit 1 also demonstrated that emissions were significantly reduced. Mercury emissions were reduced by 41 percent due to some removal in the first dryer stage and by the increased oxidation of mercury, which allowed for greater removal in the FGD system. NO_X and SO_2 emissions were reduced by 32 and 54 percent, respectively. NO_X emissions were reduced primarily by improved boiler performance enabled by the improved fuel quality. Reduced SO_2 emissions were due to a substantial amount of sulfur being removed in the first dryer stage and the reduced flue gas volume resulted in less gas bypassing the FGD.

In summary, all performance goals, with the exception of the impact of DryFining™ on unit efficiency, were adequately demonstrated. GRE planned to conduct additional tests in 2011 to confirm the impact during normal operation, but these tests are beyond the scope of this report.

V. MARKET ANALYSIS

A. Potential Market

According to the U.S. Energy Information Agency (EIA), recoverable reserves of lignite and sub-bituminous coals are large, with the U.S. having in excess 140 billion tons (over 53 percent of domestic coal reserves). The EIA expects the use of these coals to continue to increase through 2030 and beyond. The World Coal Institute reports that major reserves have been found in other countries with Russia having 110 billion tons, China 50 billion tons, and Germany and Australia about 40 billion tons each of recoverable reserves.

While the benefits of drying high-moisture coals are widely recognized, most approaches significantly increase the cost of thermal drying since additional fuel is required. DryFining™ offers a significant advantage over other processes since it uses low grade waste heat that is normally not recovered. Any power plant utilizing these high-moisture coals may benefit from the demonstration technology, thus providing a huge potential market.

It is likely that some portion of this very large market can realize benefits sufficient to warrant installation of the technology. By the conclusion of the demonstration project, Great River Energy had signed 63 confidentiality agreements, including 15 with utilities. These include parties in Canada, Australia, China, India, Indonesia, and Europe. Three preliminary evaluations have been completed that show comparative improvements can be realized at those stations. This level of interest indicates that there is a significant market for DryFining™. DryFining™ is a process integration, rather than a piece of equipment, and significant engineering and customization is required for a successful implementation. To this end, Great River Energy has entered into a commercialization agreement with WorleyParsons, as the exclusive licensor and process integrator of DryFining™ technology.

B. Capital, Operating, and Maintenance Costs

The DOE cost share in this project is $13.5 million and the corresponding CCPI project value is $31.5 million for Unit 2. In order to provide uniform coal quality to all dryers, GRE decided to upgrade the front-end coal handling systems for both units with its own funds. The costs related to upgrading both coal handling systems, the Unit 1 dryers, and processing of segregated coal from dryers of both units are funded by GRE and are not part of the CCPI project. All other cost information is considered proprietary by GRE.

VI. CONCLUSIONS

This CCPI project has successfully demonstrated full scale integrated operation of the DryFining™ technology and met the selected performance goals. These include coal quality improvements and emission reductions.

Power Engineering selected this project for their 2010 Best Coal-Fired Project of the Year Award. This prestigious award honors excellence in design, construction, and engineering of power generation facilities worldwide.

The DryFining™ technology proved to be an economical and effective means to improve Coal Creek Station performance while reducing emissions to the point where additional environmental controls were not required. This is demonstrated by GRE's decision to install DryFining™ on Unit 1.

The applicability of the technology to other power plants must be determined on a plant-specific basis. Factors that determine the applicability to other plants include specific operating conditions, the need for additional environmental controls, and plant layout. Another important factor is the specific form of the pollutants in the plant's feed coal. If significant amounts of the pollutants are found in the mineral matter, it is likely that DryFining™ can offer significant reductions.

VII. ABBREVIATIONS AND ACRONYMS

CCPI	Clean Coal Power Initiative
CCT	Clean Coal Technology
CCTDP	Clean Coal Technology Demonstration Program
DOE	United States Department of Energy
ESP	electrostatic precipitator
GRE	Great River Energy
HHV	higher heating value
MMBtu/lb	million British thermal units per pound
NETL	National Energy Technology Laboratory
NO_X	nitrogen oxides
PPII	Power Plant Improvement Initiative
SCA	specific collection area
SO_2	sulfur dioxide
tph	tons per hour

VIII. REFERENCES

1. Bullinger, Charles W. and Nenad Sarunac, "Lignite Fuel Enhancement - Final Technical Report", Award No. DE-FC26-04NT41763, June 29, 2010.

2. U.S. Department of Energy, Clean Coal Technology Programs: Program Update, October 2009.