One Year of Operating Experience with a Prototype Fluidized Bed Coal Dryer at Coal Creek Generating Station[1]

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ABSTRACT

U.S. lignites have moisture contents ranging from 25 to 40 percent. This results in lower heating value, higher fuel flow rate, higher stack flue gas flow rate and stack loss, higher station service power, lower plant efficiency, and higher mill, coal pipe and burner maintenance requirements compared to that of the Eastern bituminous coals. Despite problems associated with their high-moisture content, lignite and sub-bituminous coals from the Western U.S. are attractive due to their low cost and emissions, and high reactivity.

A low-temperature coal drying process employing a fluidized bed dryer (FBD) and waste heat was developed in the U.S. by a team led by Great River Energy (GRE) and Lehigh University's Energy Research Center (ERC). The demonstration is being conducted with U.S. Department of Energy (DOE) funding under DOE Award Number: DE-CF26-04NT41763. The benefits of reduced-moisture-content lignite are being demonstrated at GRE's Coal Creek Station.

INTRODUCTION

When high-moisture coals are burned in utility boilers, about seven percent of the fuel heat input is used to evaporate fuel moisture. The use of high-moisture coals results in higher fuel flow rate, higher stack flue gas flow rate, higher station service power, lower plant efficiency, and higher mill, coal pipe and burner maintenance requirements compared to that of the Eastern bituminous coals. Despite problems associated with their high-moisture content, lignite and sub-bituminous coals from the Western U.S. are attractive due to their low cost and emissions.

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Countries with large resources of high-moisture low-quality coals are developing coal dewatering and drying processes. However, thermal processes developed thus far are complex and require high-grade heat to remove moisture from the coal. This significantly increases process cost, which represents a main barrier to industry acceptance of the technology.

A low-temperature coal drying process employing a fluidized bed dryer (FBD) and waste heat was developed in the U.S. by a team led by Great River Energy (GRE) and Lehigh University's Energy Research Center (ERC). The demonstration is being conducted with U.S. Department of Energy (DOE) funding under DOE Award Number: DE-CF26-04NT41763.

The objective of GRE's Lignite Fuel Enhancement project is to demonstrate a 5 to 15 percentage point reduction in lignite moisture content (about ¼ of the total moisture content) by incremental drying using waste heat from the power plant. The benefits of reduced-moisture-content lignite are being demonstrated at GRE's Coal Creek Station (CCS), using a phased approach. The project is divided into two phases.

In Phase 1 of the project, a 115 t/hr prototype coal dryer was designed, constructed, and integrated into Unit 2 at CCS. The prototype coal drying system was instrumented to allow experimental determination of FBD performance, and CCS Unit 2 performance over a range of dryer operating conditions. Additional coal dryers will be designed, built, installed, and tested in Phase 2 of the project. With all coal dryers in service it will be possible to reduce the moisture of total coal feed to CCS Unit 2. The efficiency improvement, emissions reduction, and the effects of burning dried coal on unit operation will be determined.

The prototype dryer at Coal Creek has been in almost continuous operation for over a year. To date it has processed more than 300,000 tons of wet North Dakota lignite. Operating experience, dryer performance results, and the effects of burning a lower moisture coal on unit performance, emissions, and operations are described in this paper.

DESCRIPTION OF THE HOST UNIT

CCS is a 1,150 MW lignite-fired power plant located in Underwood, North Dakota. The plant supplies electricity to 38 member cooperatives in Minnesota. Two tangentially fired CE boilers supply steam to two single reheat GE G-2 turbines rated at 576 MW each. The units are designed for 1,005°F main steam and reheat steam temperature at a 2,520 psia throttle pressure. Three mechanical draft cooling towers are used to reject heat to environment. The boiler fires lignite coal from the nearby Falkirk mine that has a HHV of 6,200 Btu/lb and total moisture content of approximately 38 percent. An aerial photograph of CCS is presented in Figure 1.

Figure 1: Aerial Photograph of Coal Creek Station

A schematic representation of heat flows for the CCS Unit 2 is given in Figure 2. For full unit load (gross power output of 576.7 MW) and fuel containing 40 percent moisture, the heat input with the fuel (Q_{fuel}) is approximately 5,670 MBtu/h. The boiler loss (Q_{loss}), including dry stack loss (Q_{stack}) and fuel moisture evaporation loss (Q_{evap}) is approximately 1,090 MBtu/h, or 19.2% of the fuel heat input. This gives a boiler efficiency of 80.78%.

The dry stack loss is 436 MBtu/h, representing 7.7 percent of the fuel heat input. The loss due to evaporation of fuel moisture is 370 MBtu/h (approximately 6.6 percent of fuel heat input). Engineering analyses show that using waste heat in flue gas to remove 5 percent of coal moisture would decrease the stack temperature by approximately 30 ^oF.

Thermal energy (Q_T) transferred to the working fluid in the boiler is about 4,580 MBtu/h. The thermal efficiency of the steam turbine cycle is approximately 43 percent, which gives rejected heat of approximately 2,600 MBtu/h (46 percent of the fuel heat input). The gross unit efficiency is approximately 34.7 percent, with a gross unit heat rate of 9,825 Btu/kWh. Engineering analyses show that, at full unit load, approximately 2 percent of the heat rejected in the condenser/cooling tower would be needed to decrease the coal moisture content by 5 percent.

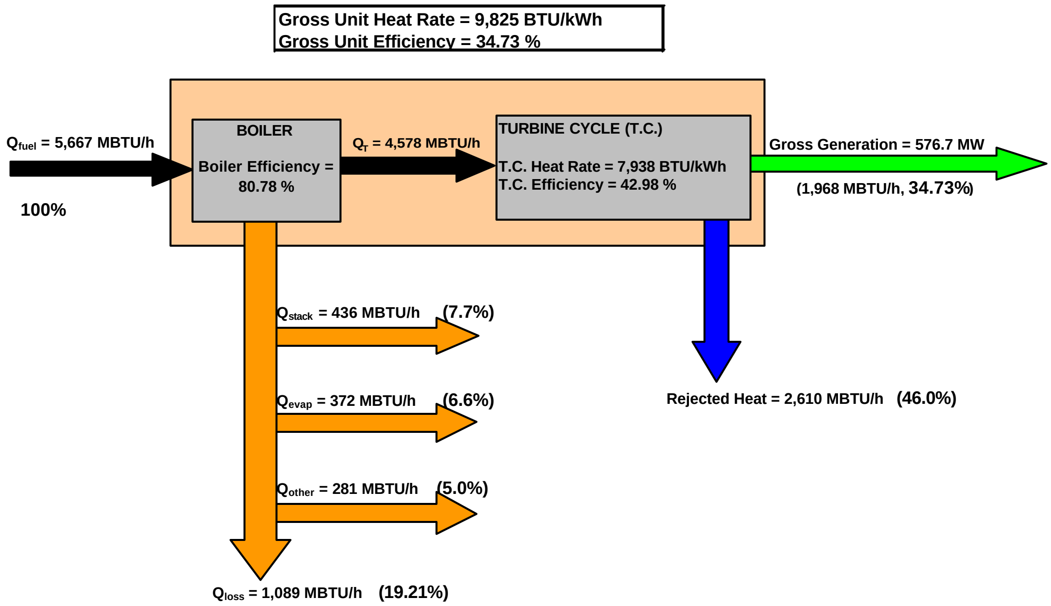

Figure 2: Coal Creek Unit Heat Flow Schematic – One Unit

PREVIOUS WORK

During the 1990's the engineering staff at CCS began investigating alternative approaches to dealing with future emission regulations. Conventional approaches included changing fuels and/or adding environmental control equipment. This approach often results in lowering emissions at the expense of increases in unit heat rate and operating and maintenance costs. Higher heat rate results in higher required fuel heat input, higher CO_2 emissions, higher flow rate of flue gas leaving the boiler and lower plant capacity. Lower capacity is due to higher station service power requirements or limited equipment capacity. Also, increased flue gas flow rate requires a larger size of environmental control equipment, higher equipment cost and station service power.

A theoretical analysis was performed by the ERC in 1997-98 to estimate the magnitude of performance improvement that could be achieved by firing coal having lower moisture content [1]. The results showed that a decrease in fuel moisture would have a large positive effect on unit performance, Figure 3.

Based on these theoretical results, CCS personnel performed test burns with partially dried lignite in 2001 to confirm whether the boiler and coal handling system could handle the partially dried lignite. Except for dust in the transfer hoppers, no other fuel handling problems were encountered. Also, test results confirmed the theoretical performance improvement predictions [2]. Results from other coal drying studies are described in [**3**] to [**8**].

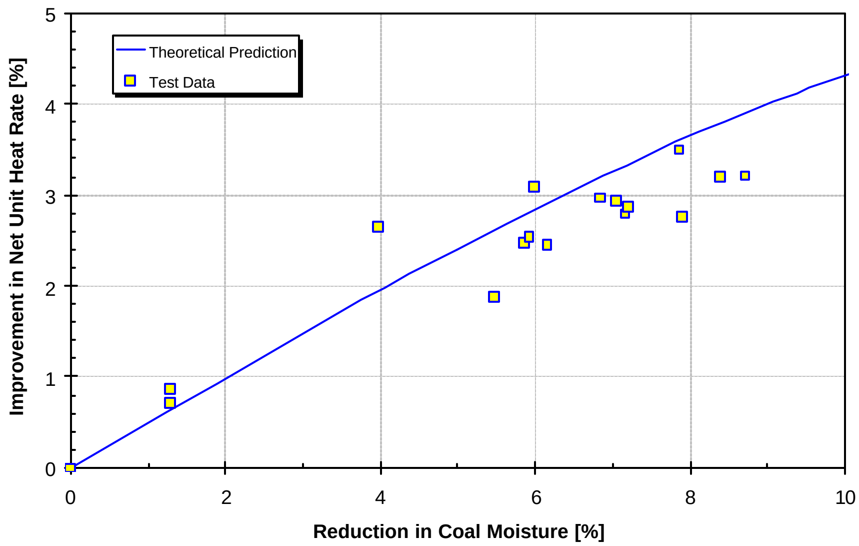

Figure 3: Effect of Fuel Moisture on Unit Performance

After demonstrating the benefits of firing dried fuel, a technology for coal drying needed to be selected. Based on laboratory testing conducted at the ERC in 2002, a fluidized bed dryer (FBD) was selected as the best technology due to its high heat and mass transfer coefficients and compact size. GRE submitted an application to DOE, in 2002 under the Clean Coal Power Initiative (CCPI) to develop a prototype fluidized bed coal dryer and develop and install a full-size coal drying system on one unit at CCS. A Cooperative Agreement was negotiated with DOE for funding under the CCPI in July 2004.

The project is divided into two phases. The first phase involves design, construction, installation and testing of a prototype coal drying system at CCS consisting of one FBD. Performance testing was performed in March and April 2006. The second phase of the project involves installation of a full-scale drying system at CCS capable of drying 500 tons/hr of wet lignite fuel.

PROTOTYPE COAL DRYING SYSTEM

The CCS prototype coal drying system uses low-grade waste heat to evaporate a portion of the fuel moisture from the lignite feedstock. Moisture removal is accomplished in a FBD. No other heat sources are used for coal drying.

Coal feed for the dryer is supplied from an existing coal bunker. The wet coal (feed stream) is fed by a vibrating coal feeder to a coal crusher and crushed to -1/4”. The crushed coal is screened and conveyed to the dryer inlet hopper. The dried coal (product stream) leaving the dryer is stored in a coal bunker before feeding it to a coal mill.

Fluidization and heating of coal and removal of coal moisture is accomplished within the fluidized bed by hot fluidization air. The air stream is cooled and humidified as it flows upwards through the coal bed. The quantity of moisture, which can be removed from the bed of fluidized coal, is limited by the drying capacity of the fluidization air stream. However, the drying capacity of the fluidization air stream can be increased by supplying additional heat to the bed by the in-bed heat exchanger. The in-bed heat exchanger not only increases drying capacity of the fluidizing air stream but it also reduces the quantity of drying air required to accomplish a desired degree of coal drying. With sufficient in-bed heat transfer surface, the fluidizing/drying air stream could be reduced to the value corresponding to the superficial fluidization velocity.

A dust collector (baghouse) is used to remove elutriated fines from the moist air leaving the dryer. The clean moist air is discharged through a stack to the atmosphere, as shown in Figure 4.

Figure 4: Moist air leaving dust collector is discharged into the atmosphere

Operation of the prototype coal drying system at CCS is completely automated, including the startup, shutdown, and emergency shut down procedures. Heat input to the FBD is controlled automatically to match the heat required to remove a desired amount of moisture from the dryer feed stream.

RESULTS

A number of performance tests were conducted in spring 2006 under controlled conditions to determine dryer performance and effect of partially dried coal on boiler and unit efficiency, and stack emissions. Also, the FBD performance during regular dryer operation was determined for the March to April 2006 time period.

Plant operating parameters such as: main and reheat steam temperature and desuperheating spray flow rates, coal flow rate, mill and fan power, flow rates of primary air to the mills, temperature of air and flue gas at a number of state points, and plant emissions were measured and recorded by the plant Ph.D. historian. Coal composition and HHV were determined from coal samples that were collected manually and by automatic coal samplers.

Dryer Performance

Performance of a FBD is affected by many operating and design parameters. The most important include: flow rate and inlet moisture content of coal, flow rate, temperature and humidity of drying/fluidizing air, bed depth, coal residence time, and heat input by the in-bed heat exchanger. The total coal moisture (TM) and higher heating value (HHV) measured in the feed and product streams during regular FBD operation are summarized in Table 1.

Table 1: Regular FBD Operation, March-April 2006: Coal Moisture and HHV

Parameter	Feed TM %	Product TM %	Change TM % Abs	Change TM % Rel
Average Total Moisture, TM	36.78	28.55	8.23	22.4
Std. Deviation	1.26	1.00	1.07	
Std. Deviation of the Mean	0.34	0.27	0.30	

Parameter	Feed HHV [BTU/lb]	Product HHV [BTU/lb]	Change HHV [BTU/lb]	Change HHV [%]
Average HHV	6,290	7,043	752	12.0
Std. Deviation	159	121	131	
Std.Deviation of the Mean	43	33	37	

The average moisture reduction, achieved during regular FBD operation, was 8.23 ± 0.3 percent, or 22.4 percent of the feed moisture. The improvement in HHV was 752 ± 74 Btu/lb, or 12 percent of the feed HHV. The test results from controlled performance tests are presented in Figures 5 and 6.

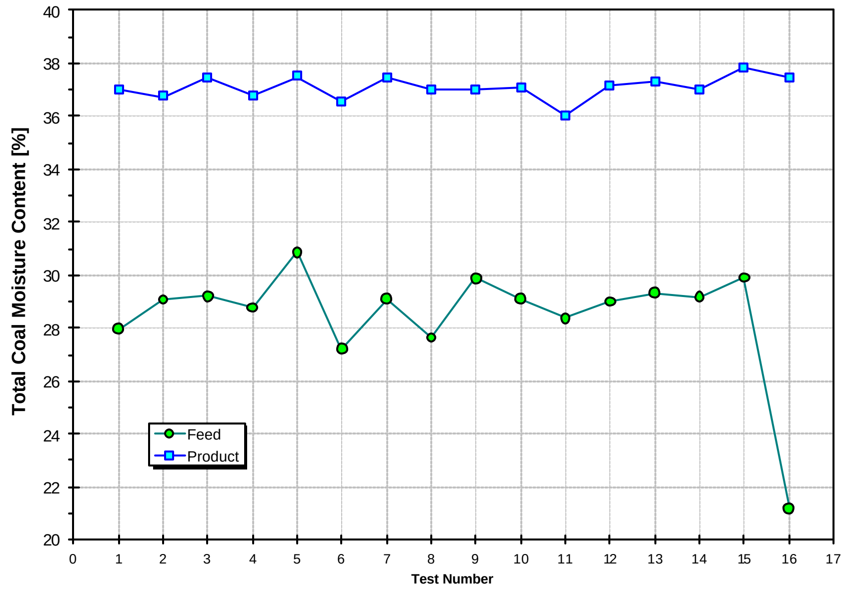

Figure 5: Total coal moisture content in feed and product streams: Performance tests

The Test 16 results show a much lower TM content and higher HHV value compared to the other tests and were, therefore, considered outliers and excluded from the statistical analysis of test data. The average moisture reduction for the FBD performance tests was 8.08 ± 0.42 percent. The HHV was on average improved by 727 ± 62 Btu/lb.

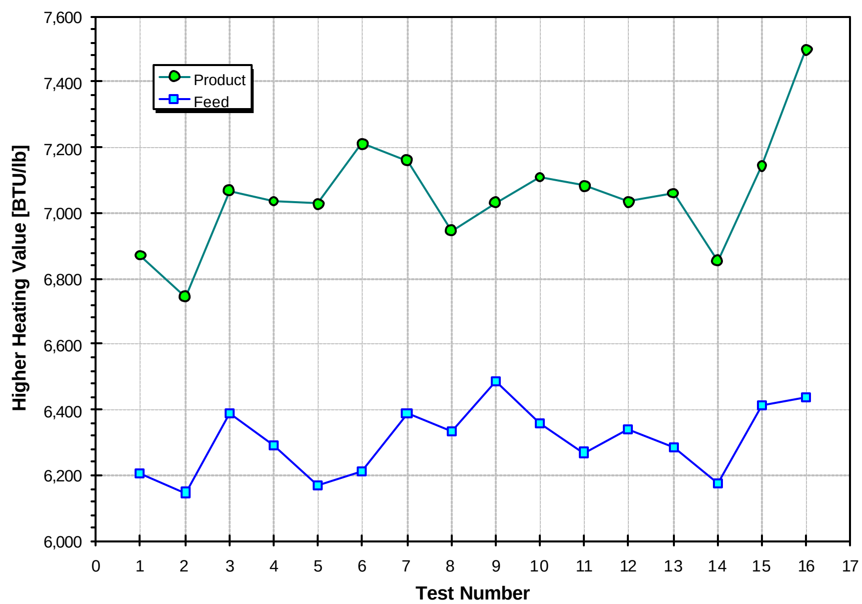

Figure 6: HHV in feed and product streams: Performance tests

It has to be noted that, during the performance tests, the FBD was operated conservatively, i.e., the fluidizing air temperature and in-bed heat input were lower than design. As more operating experience was gained, the FBD operating conditions were gradually increased. With higher fluidizing air temperature and higher in-bed heat input, coal moisture was reduced by more than 10 percentage points, and HHV was improved by 1,300 Btu/lb.

Unit Performance

As predicted by theoretical calculations and confirmed in test burns, firing of a partially dried coal in the boiler has a positive effect on boiler and unit efficiency, and stack emissions. The actual improvement in performance and reduction in emissions were determined from the performance test data.

In the current arrangement of a prototype coal drying system at CCS, the prototype coal dryer supplies partially dried coal to coal mill No. 26. Wet coal was supplied to other mills. With the prototype coal dryer operating at a nominal coal feed rate of 75 tons per hour, dried coal represents approximately 14 percent of the total coal input to the boiler.

The properties of the dried and wet coal streams were mass-averaged to determine properties of the coal blend supplied to the boiler. The results are summarized in Table 2. The composition and HHV of the coal blend were determined from the following expression:

$$X_{Mass\text{-}Average} = X_{Blend} = X_{Dry}\ M_{Dry}/M_{Total} + X_{Wet}\ M_{Wet}/M_{Total} \qquad \text{Eqn. 1}$$

Where:

X_{Blend} Composition or HHV of blended coal
X_{Dry} Composition or HHV of dried coal out of the prototype FBD
X_{Wet} Composition or HHV of wet coal
M_{Dry} Flow rate of dried coal out of the prototype FBD
M_{Wet} Flow rate of wet coal to the boiler
M_{Total} Total coal flow rate, where:

$$M_{Total} = M_{Dry} + M_{Wet} \qquad \text{Eqn. 2}$$

Table 2: Properties of the Coal Blend (Mass-Average Dry) and Wet Coal

Description	Units	Mass-Average Dry	Average Wet	% Change WRT Wet	Absolute Change WRT Wet
C	% by weight	39.55	39.00	1.4	0.6
S	% by weight	0.68	0.66	1.6	0.0
H	% by weight	3.34	3.35	-0.1	0.0
N	% by weight	0.54	0.53	1.4	0.0
O	% by weight	8.55	8.26	3.5	0.3
Moisture	**% by weight**	**35.92**	**37.06**	**-3.1**	**-1.14**
Ash	% by weight	11.42	11.14	2.5	0.3
Total	**% by weight**	100.00	100.00		
HHV	**BTU/lb**	**6,402**	**6,299**	**1.63**	**103**
TOTAL FEEDER COAL FLOW RATE	**klbs/hr**	**953**	**971**	**-1.83**	
Total heat input	**MBTU/hr**	**6,102**	**6,117**	**-0.24**	
MAF-Basis HHV	**BTU/lb**	**12,157**	**12,160**	**-0.03**	**-4**

The results from Table 2 show that, with one full-size prototype coal dryer in service, the total moisture of the coal blend was reduced by 1.14 percentage points, or 3.1 percent on a relative basis. The improvement in HHV was 103 Btu/lb, or 1.63 percent. The total coal flow rate, measured by the coal feeders, was reduced by 1.83 percent. As expected, the coal HHV, expressed on a moisture-and-ash-free (MAF) basis, remained constant.

The measured and theoretically predicted reductions in total coal flow rate are compared in Figure 7. The results show an excellent agreement between the calculated and measured values.

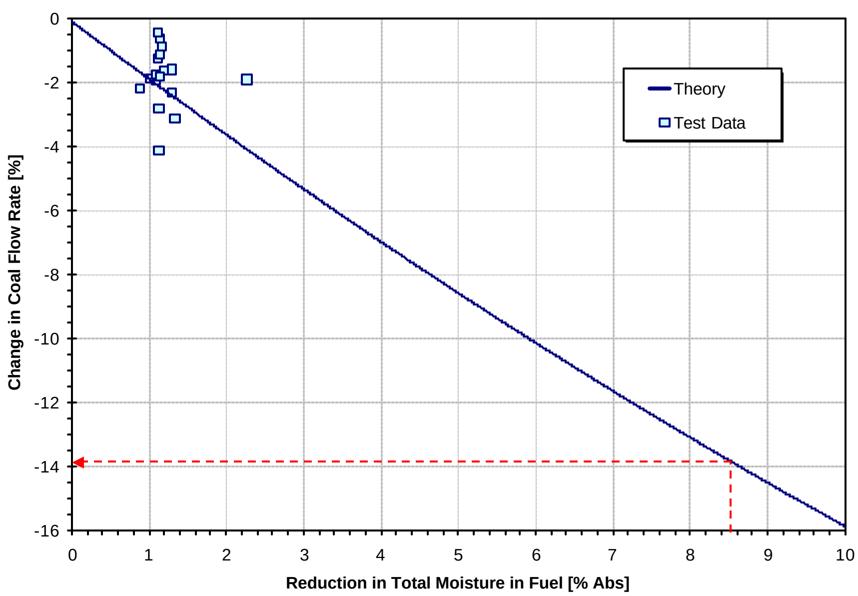

Figure 7: Measured and predicted reduction in coal flow rate vs. reduction in coal TM content

For a target value of coal moisture reduction of 8.5 percent, the predicted decrease in coal flow rate is approximately 14 percent. This decrease is due to the higher HHV of the partially dried coal and improved boiler and unit efficiency.

With drier coal, mill power was on average 3.3 percent lower compared to the wet coal. This decrease in mill power is partially due to a decrease in coal flow rate, and partially due to the reduced mill power required to grind drier coal. The comparison of the measured and theoretically predicted mill power reductions, presented in Figure 8, shows an excellent agreement between the calculated and measured values.

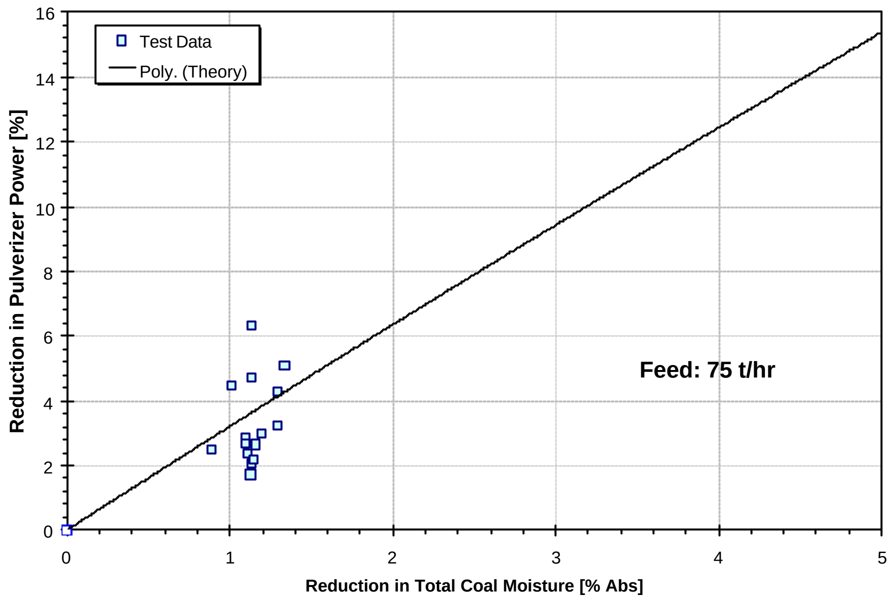

Figure 8: Comparison of predicted and measured reduction in mill power

For a target value of coal moisture reduction of 8.5 percent, the predicted decrease in mill power is 25 percent. Also, temperature of the air-coal mixture leaving the mill grinding partially dried coal was 10 ^{o}F higher compared to the other mills grinding wet coal. This increase is due to the lower moisture content and higher temperature of partially dried coal entering the mill.

Also, with the prototype coal dryer in service, feeder trips for the mill receiving dried coal were eliminated. This is because the oversize material, typically responsible for the trips, was either screened out or discharged from the dryer with the rest of the non-fluidizable material.

The flow rates of combustion air and flue gas decrease as coal moisture content is reduced. A decrease in combustion air flow rate is due to the improvement in boiler and unit efficiency, which result in a reduction in coal flow rate and heat input. The decrease in flue gas flow rate is due to the improvement in boiler and unit efficiency, and decreased coal moisture content, which results in lower water vapor content of flue gas. Therefore, the decrease in flue gas flow rate is larger compared to the decrease in combustion air flow rate.

A comparison between measured and predicted decrease in flue gas flow rate is presented in Figure 9. The flue gas rate was measured by the plant CEM. The results show a very good agreement between the measured and predicted values. For a target value of total moisture reduction of 8.5 percent, the predicted decrease in flue gas flow rate is approximately 3.9 percent.

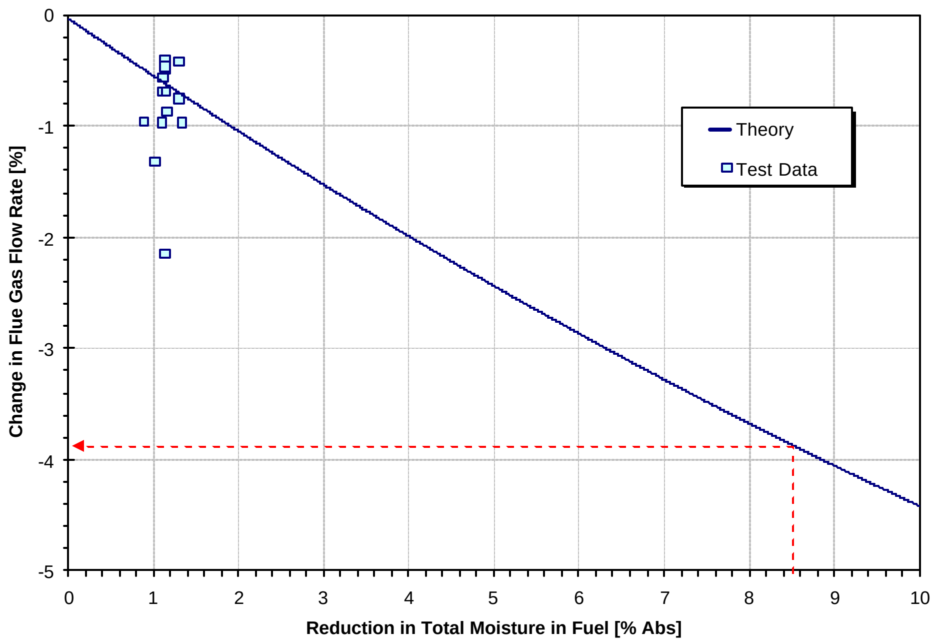

Figure 9: Comparison of measured and predicted reduction in flue gas flow rate

With the presently used fan flow control methods at CCS, the forced draft (FD) fan power remained virtually constant for the partially dried and wet coals. For the partially dried coal, the induced draft (ID) fan power was reduced 1.43 percent, while the primary air (PA) fan power was 5.6 percent higher compared to the wet coal operation.

The mass and energy conservation method was combined with theoretical air preheater (APH) and FBD models to calculate theoretical boiler efficiency, η_B, values. The mass and energy balance approach and performance test data were used to calculate actual (test) values of boiler efficiency. The boiler efficiency improvement, $\Delta\eta_B$, is defined as:

$$\Delta\eta_B = \eta_{B,\ Dry\ Coal} - \eta_{B,\ Wet\ Coal} \qquad \text{Eqn. 3}$$

Theoretical and actual values of $\Delta\eta_B$ are presented in Figure 10 as functions of the total coal moisture reduction (ΔTM). The results show that η_B values for partially dried coal are consistently higher compared to the η_B values for wet coal. The average boiler efficiency improvement is:

$$\Delta\eta_{B,\ \text{Prototype System, Test}} = 0.37 \pm 0.11 \text{ percentage points}$$

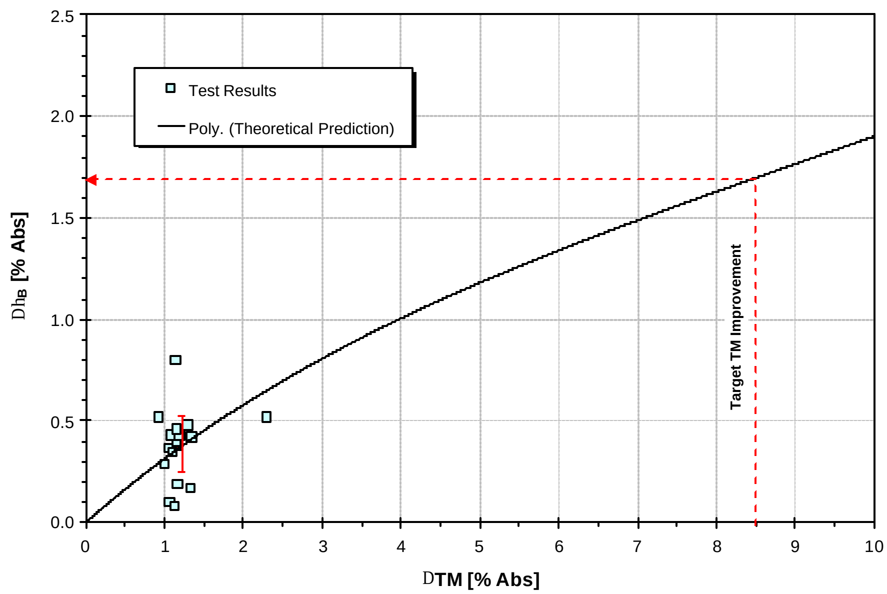

Figure 10: Predicted and test values of boiler efficiency improvement

With the exception of one outlier test point, the results in Figure 10 show excellent agreement between theoretical predictions and test results. With four prototype coal dryers in service and target coal moisture reduction of 8.5 percent, the predicted improvement in boiler efficiency is:

$$\Delta\eta_{B,\ \text{Prototype System, Target Moisture Reduction}} = 1.70 \text{ percentage points}$$

It has to be noted that the prototype coal drying system at CCS does not include all components that will be incorporated into the full-scale coal drying system. Theoretical calculations show that the boiler efficiency improvement that would be achieved by the full-scale coal drying system at CCS would be 0.43 percentage points higher compared to the prototype coal drying system. Thus, the boiler efficiency improvement at the target coal moisture reduction level of 8.5 percent and four coal dryers in service would be:

$$\Delta\eta_{B,\ \text{Full-Scale System, Target Moisture Reduction}} = 2.13 \text{ percentage points}$$

The net unit heat rate, HR_{net}, was calculated from the following expression:

$$HR_{net} = \frac{\dot{Q}_{fuel}}{P_g - P_{ss}} = \frac{HR_{cyclegross} \times P_g}{?_B (P_g - P_{ss})} \qquad \text{Eqn. 4}$$

Where:

$HR_{cycle,gross}$	Gross turbine cycle heat rate
η_B	Boiler efficiency
P_{ss}	Total measured station service power (mills, fans, coal crusher, etc.)
P_g	Gross unit power output

The relative improvement, ΔHR_{net} in net unit heat rate is defined as:

$$\Delta HR_{net} = (HR_{net,\ Wet\ Coal} - HR_{net,\ Dry\ Coal}) / HR_{net,\ Wet\ Coal} \times 100\% \qquad \text{Eqn. 5}$$

Theoretical and actual values of the net unit heat rate improvement are presented in Figure 11 as functions of ΔTM. The results show that HR_{net} values for the partially dried coal are consistently lower compared to the values obtained with the wet coal. The average net unit heat rate improvement is:

$$\Delta HR_{net,\ Prototype\ System,\ Test} = 0.37 \pm 0.14\%$$

With the exception of one outlier test point, the results in Figure 11 show excellent agreement between theoretical predictions and test results. With four prototype coal dryers in service and target total coal moisture reduction of 8.5 percent, the predicted improvement in net unit heat rate is:

$$\Delta HR_{net,\ Prototype\ System,\ Target\ Moisture\ Reduction} = 2.05\%$$

Similar to the boiler efficiency, theoretical calculations were performed to determine improvement in net unit heat rate that would be achieved by the full-scale coal drying system at CCS. With four coal dryers in service and target coal moisture reduction level of 8.5 percent the net heat rate improvement would be:

$$\Delta HR_{net,\ Full\text{-}Scale\ System,\ Target\ Moisture\ Reduction} = 2.39\%$$

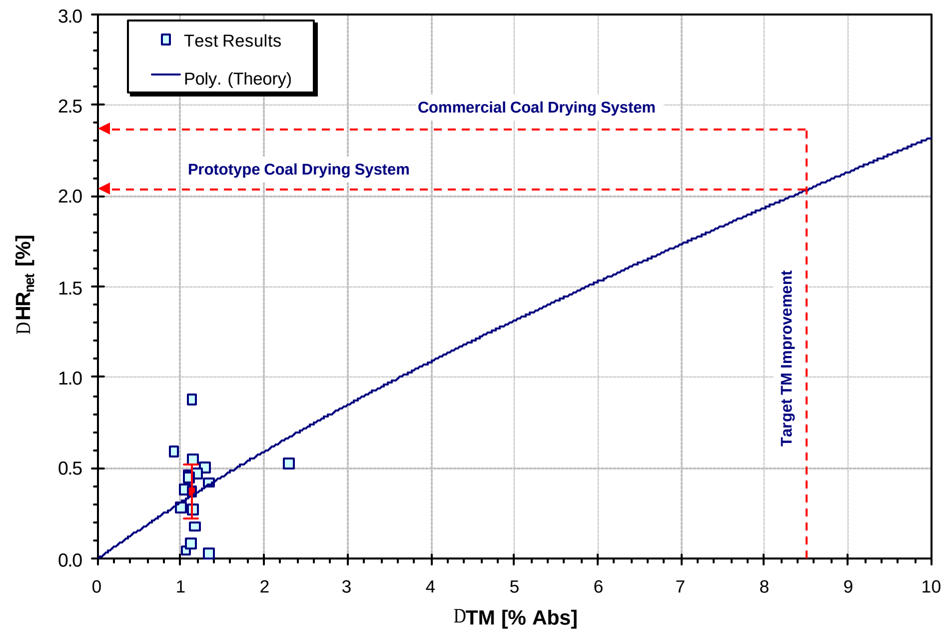

Figure 11: Predicted and test values of relative net unit heat rate improvement

If VSDs were used for the fan flow control, fan power requirement would be lower compared to the currently used flow control methods, Figure 12. For the prototype coal drying system and partially dried coal, the FD fan power would be reduced by 0.94 percent compared to the IGV flow control, while the ID fan power would be 1.55 percent lower compared to the IGV/ID flow control. The PA fan power would be 1 percent lower compared to the IGV flow control.

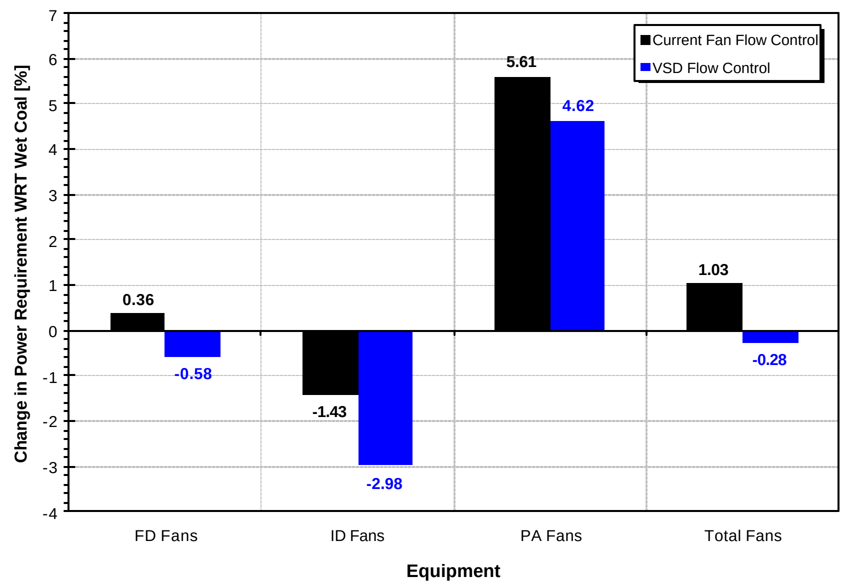

Figure 12: Effect of VSDs on fan power: partially dried vs. wet coal

The final result would be a 1.31 percent reduction in total fan power, and a 0.48 percent improvement in net unit heat rate.

$$\Delta HR_{\text{net, Prototype System, VSD}} = 0.48\%$$

To determine the overall performance improvement, the net heat rate improvement due to VSDs needs to be added to the ΔHR_{net} due to the partially dried coal. For the full-scale coal drying system at CCS operating at target moisture reduction level, and VSD fan drives, the overall improvement in unit performance would be close to 3 percent.

Emissions

The reduction in NO_x and SO_x emissions, flue gas flow rate, and flue gas CO_2 concentration, measured by the plant CEM, achieved by firing partially dried coal are summarized in Table 3. The reduction in flue gas mass flow rate (0.55 percent) is lower compared to the reduction in volumetric flow rate (0.73 percent) due to the change in flue gas density. With the partially dried coal, the flue gas density is higher compared to the wet coal.

Table 3: Reduction in stack emissions, flow rate, and CO_2 concentration due to drier coal

Description	% Change WRT Wet
NOx Emissions	-7.52
SOx Emissions	-1.90
Flue Gas Flow Rate -Volumetric	-0.73
Mass Flue Gas Flow Rate - Mass	-0.55
Flue Gas CO_2 Concentration	0.27

The 7.5 percent reduction in NO_x mass emissions obtained with drier coal is significantly higher compared to the reduction in flue gas flow rate, and cannot be explained by a flow reduction. This NO_x reduction it is attributed to a lower primary air flow rate to mill No. 26 handling partially dried coal. From the NO_x minimization tests, performed by the ERC and GRE engineers at CCS in 1997 [9], it is known that NO_x emissions at this plant are quite sensitive to the primary air flow; NO_x decreases as primary air flow is reduced.

With partially dried coal, the primary air flow rate to the No. 26 mill was, on average, reduced by 12 percent. The recently performed modifications to the coal mills will allow the primary air flow to be decreased by almost 30 percent. This will result in a further decrease in NO_x emissions. With the full-size coal drying system in service and the reduced primary air flows to the mills, the reduction in NO_x emissions is expected to exceed 10 percent.

The reduction in CO_2 mass emissions is proportional to the improvement in unit efficiency. For the prototype coal drying system operating at target moisture reduction of 8.5 percent, the reduction in CO_2 emissions is approximately 2 percent. For the full-size coal drying system, target moisture reduction, and VSD fan drives, CO_2 emissions will be reduced by approximately 3 percent.

With the partially dried coal, SO_x emissions were reduced by approximately 1.9 percent, Table 3. The decrease in SO_x emissions is higher compared to the flue gas flow rate reduction because with a lower flue gas flow rate, the flue gas bypass around the scrubber decreases (CCS is a partially scrubbed unit), resulting in higher SO_x removal. With the full-scale coal drying system operating at the target moisture reduction level, the flue gas flow rate to the scrubber will be reduced by approximately 4 percent, resulting in an additional reduction in SO_x emissions.

The expected reduction in SO_x emissions for a full-scale coal drying system at CCS is expected to be significantly higher compared to the prototype system. The difference is in the treatment of the segregation stream – a flow of non-fluidizable material discharged from the FBD. The sulfur content of the segregation stream is significantly higher compared to the product stream because the pyrites, having higher density than coal, are segregated out from the bed of fluidized coal.

The full-scale coal drying system is designed to process the segregation stream. After processing this stream will not be returned to the boiler, and sulfur input to the boiler would be reduced by 7 to 12 percent. By combining reductions due to lower scrubber bypass and lower sulfur input to the boiler, the potential reduction in SO_x emissions that could be achieved with the full-scale coal drying system at CCS operating at 100 percent capacity and target coal moisture removal level of 8.5 percent is estimated to be in the 10 to 15 percent range.

The reduction in Hg emissions, achieved during FBD performance tests at CCS, is proportional to the improvement in unit efficiency, and is estimated to be in the 0.4 percent range. Similar to the SO_x emissions, the expected reduction in Hg emissions for the full-scale coal drying system at CCS will be significantly higher compared to the prototype. The Hg content of the segregation stream is significantly higher compared to the product stream because, for the Falkirk lignite, a significant portion of Hg is bound to the pyrites that are segregated out from the FBD. It is estimated that 15 to 20 percent of Hg could be removed from coal in the FBD by segregation, resulting in a proportional decrease in Hg emissions.

The reduction in flue gas moisture content by coal drying also has a positive effect on Hg oxidation in flue gas stream. The oxidized mercury, Hg^{2+}, is water-soluble and can be removed in the wet scrubber, resulting in a further reduction in Hg emissions.

ON-SITE vs. OFF-SITE COAL DRYING

Although the main objective of the lignite fuel enhancement project at CCS is development of the on-site coal drying system and demonstration of its benefits on unit efficiency and emissions, a part of the project activity focused on exploring opportunities for producing dried coal for the off-site users.

Theoretical calculations performed to determine effect of dried coal on boiler and unit efficiency have shown that efficiency improvement that would be achieved by firing the off-site dried coal is larger, compared to the efficiency improvement achieved by using the on-site coal drying process, Figure 13.

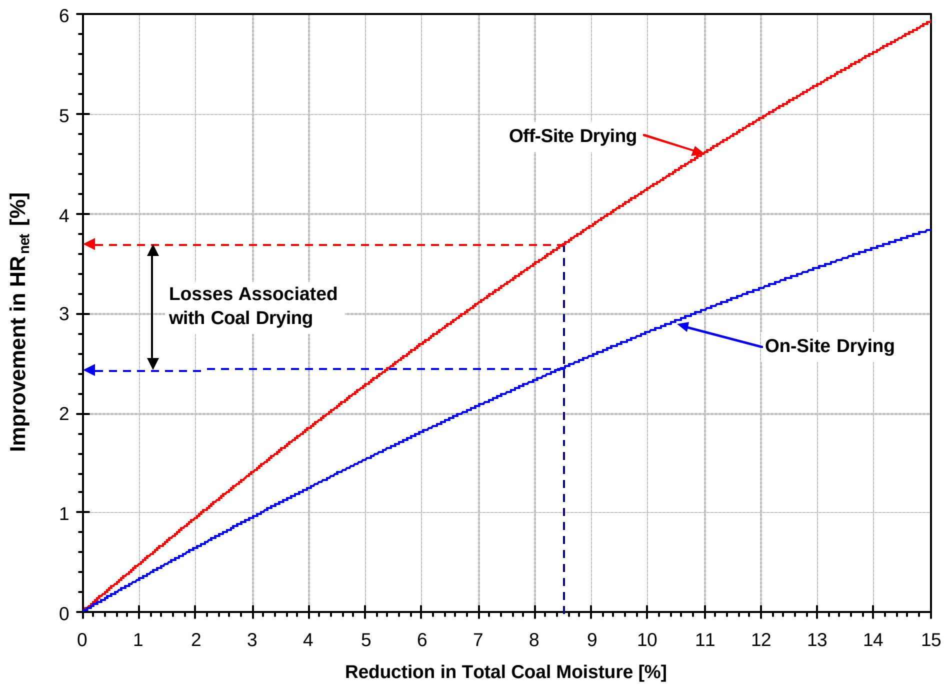

Figure 13: Performance improvement: On-site vs. off-site coal drying

The difference is due to the losses associated with the coal drying process (FBD thermal losses, and fluidizing air fan power requirements). The losses increase as more moisture is removed from the wet coal feed. For a target coal moisture removal of 8.5 percent and the off-site dried coal, the improvement in net unit heat rate, compared to the wet coal, would be 3.7

percent (1.3 percent higher compared to the on-site coal drying). For the 15 percent moisture removal, the efficiency of the unit firing the off-site dried coal would be 6 percent higher, compared to the wet coal.

CONCLUSIONS

A low-temperature coal drying process employing a fluidized bed coal dryer and waste heat was developed in the U.S. by a team led by GRE and ERC. The benefits of the partially dried lignite are being demonstrated at GRE's Coal Creek Station using a phased approach. In Phase 1 of the project, a prototype coal drying system employing one FBD was designed, constructed, and integrated into Unit 2 at Coal Creek. The prototype coal drying system at CCS has been in almost continuous fully automatic operation since February 2006. Dryer inspections revealed no wear or damage to its internals.

With the prototype coal dryer in service, feeder trips for the mill receiving dried coal were eliminated. This is because the oversize material, typically responsible for the trips, was either screened out or discharged from the dryer with the rest of the non-fluidizable material.

Performance tests were conducted in spring 2006 under controlled and regular operating conditions to determine dryer performance and effect of a partially dried coal on boiler and unit efficiency, and stack emissions. With one FBD in service, the boiler efficiency improvement of 0.37 percentage points was achieved.

For a target reduction in total coal moisture of 8.5 percent and four FBDs in service, the improvement in boiler efficiency would be 1.70 percentage points. The corresponding improvement in net unit heat rate would be 2.05 percent. The improvement in unit heat rate is higher compared to the boiler efficiency improvement because the mill and fan power requirements for the dried coal are lower compared to the wet coal. The full-size coal drying system, having a similar configuration to the prototype, would be more efficient, achieving 2.13 percentage point improvement in boiler efficiency, and approximately 3 percent improvement in net unit heat rate.

With one FBD in service, NO_x emissions were reduced by 7.5 percent and SO_x emissions by 1.9 percent. For the prototype coal drying system, the reduction in CO_2 and Hg emissions is proportional to the efficiency improvement. Emissions reduction for the full-size coal drying system will be higher: NO_x will be reduced by more than 10 percent, SO_x reduction is expected to be in the 10 to 15 percent range, the reduction in Hg emissions is expected to exceed 15 to 20 percent.

The coal drying technology can be retrofitted to the existing power plants and should be integrated into a new plant design to improve efficiency, reduce emissions, and improve plant economics. The effect of the on-site coal drying on efficiency of subcritical, supercritical, and ultra-supercritical lignite-fired units is summarized in Figure 14. The results show that the efficiency improvement that would be achieved by reducing coal moisture by 15 percentage points is comparable to the efficiency improvement due to raising steam parameters from the supercritical to ultra-supercritical conditions.

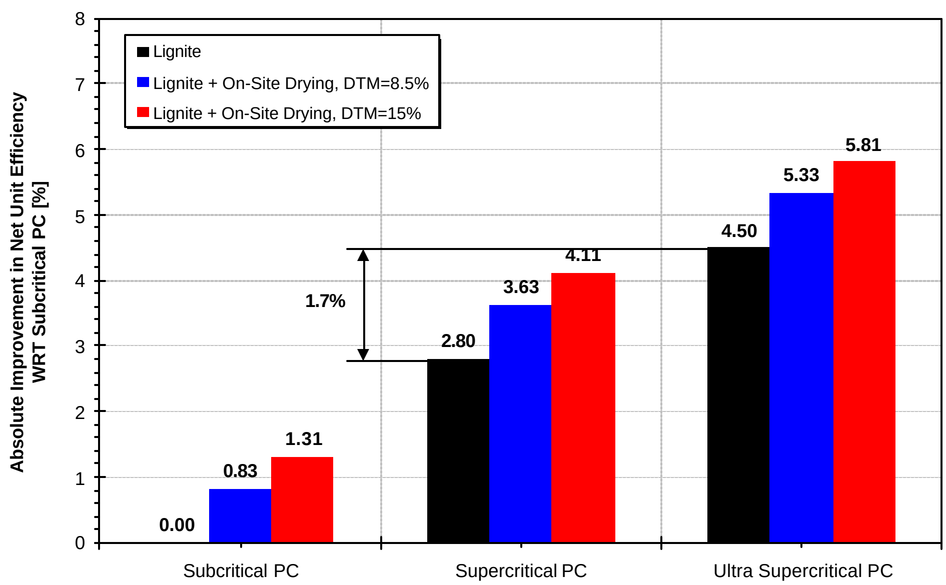

Figure 14: Effect of on-site coal drying on efficiency of subcritical, supercritical, and ultra-supercritical units

For the off-site dried coal, the benefit of removing 8.5 percentage points of coal moisture is comparable to the efficiency improvement due to raising steam parameters from the supercritical to ultra-supercritical conditions, Figure 15. For a 15 percentage point moisture reduction, the benefit of coal drying outweighs the benefit of ultra supercritical steam conditions.

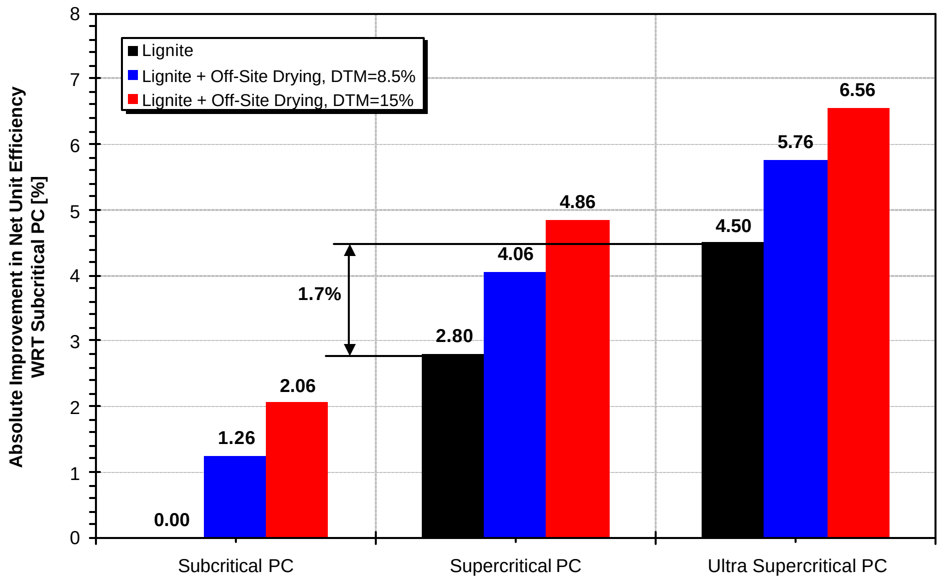

Figure 15: Effect of off-site coal drying on the efficiency of subcritical, supercritical, and ultra-supercritical units

In conclusion, significant improvements in efficiency and reduction in emissions could be achieved by retrofitting the existing sub-bituminous coal-fired units with a coal drying system, and producing dried coal for the off-site use. For maximum efficiency, the new sub-bituminous coal-fired supercritical and ultra-supercritical plants should be designed and built with an integrated coal drying system.

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