BEFORE THE ENVIRONMENTAL QUALITY COUNCIL
STATE OF WYOMING

In the Matter of the Appeal	)	
And Petition for Review of:	)	
BART Permit No. MD-6040	)	
(Jim Bridger Power Plant); and	)	Docket No. 10-2801
BART Permit No. MD-6042	)	
(Naughton Power Plant).	)	

RESPONSE TO PACIFICORP'S MOTION FOR PARTIAL SUMMARY JUDGMENT

PacifiCorp's letter, received 2/2/09

EXHIBIT 9

PACIFICORP ENERGY
A DIVISION OF PACIFICORP

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RECEIVED FEB 2009 AIR QUALITY DIVISION

January 29, 2009

Mr. David Finley
Wyoming Division of Air Quality
Herschler Building
122 W. 25th Street
Cheyenne, Wyoming 82002

Re: PacifiCorp -- Wyoming BART Determinations and Regional Haze SIP

Dear Mr. Finley,

You have requested that PacifiCorp provide additional support regarding its proposed BART determinations for NO_X emissions at Jim Bridger units 1 – 4 and Naughton unit 3.[1] The information contained in this letter is intended to elaborate on PacifiCorp's BART analyses, which already have been filed with WDAQ for these units.

I. Executive Summary

This letter focuses solely on the proper BART emission limit for NO_X at Naughton unit 3 and the Jim Bridger units. PacifiCorp's individual BART applications for each of these units contain a proposed BART emission limit which can be achieved through the installation of combustion controls such as low-NO_X burners (LNB) and overfire air (OFA). This is appropriate and consistent with the guidance and requirements set forth in "Appendix Y" of EPA's Regional Haze Regulations and Guidelines for Best Available Retrofit Technology; Final Rule ("Regional Haze Rules"), as those are incorporated into Wyoming's state regulations. This is also consistent with the preamble which accompanies Appendix Y and the Regional Haze Rules (the "Preamble"). *See* 70 FR 39104.

Appendix Y references "presumptive BART" emission rates which vary based on boiler design and coal type. To the extent the presumptive BART NO_X emission rates are relevant to Naughton unit 3 and the Jim Bridger units, it is important to note that the coal burned at these units is more comparable to bituminous than subbituminous (as the coal classification relates to NO_X emissions). Correctly assuming that these units burn coal

[1] This letter does not address any of the other PacifiCorp BART-eligible units in Wyoming nor is it intended as a comprehensive list of comments PacifiCorp may choose to make in regard to WDAQ's upcoming BART determinations for the PacifiCorp units.

with bituminous-like NO_x emissions leads to a presumptive BART emission limit for NO_x of 0.28 lb/MMBtu. This presumptive BART emission limit, however, is not the end of the analysis for any of the units, but only serves as a guide against which the calculated BART emission limit can be compared.

Based on a variety of other factors as described herein and in the underlying BART applications, PacifiCorp continues to recommend that assigning a calculated 30-day rolling average BART emission limit for NO_x of 0.26 lb/MMBtu for the Jim Bridger units is appropriate, including the installation of LNB and OFA as the proper BART control technology. Also, assigning a calculated 30-day rolling average BART emission limit for NO_x of 0.35 lb/MMBtu for Naughton unit 3 likewise is appropriate, including the installation of LNB and OFA as the proper BART control technology.

II. Background

In its BART applications for each unit covered by this letter, PacifiCorp and its consultant worked closely with WDAQ staff before submitting detailed BART engineering analyses for Naughton unit 3 and the Jim Bridger units. These analyses resulted in the proposed BART NO_x emission limits and control technologies listed below in Table 1:

Table 1

Unit	Proposed Rate	Proposed Control Technology
Naughton 3	0.35 lb/MMBtu	tune existing LNB and over-fire air system
Jim Bridger 1	0.26 lb/MMBtu	add LNB with separated over-fire air
Jim Bridger 2	0.26 lb/MMBtu	already added LNB with separated over-fire air
Jim Bridger 3	0.26 lb/MMBtu	add LNB with separated over-fire air
Jim Bridger 4	0.26 lb/MMBtu	add LNB with separated over-fire air

In lieu of the above proposed rates, some may argue that WDAQ should instead impose the presumptive BART rate (found in Appendix Y) for tangentially-fired boilers burning subbituminous coal. This rate is 0.15 lb/MMBtu. To the extent this presumptive BART rate is applied, some may argue further that WDAQ should require the installation of SCR as the appropriate BART control technology in order to achieve this NO_x emissions rate. As explained below, however, neither the facts nor the applicable BART requirements support these arguments.

To the contrary, as noted in PacifiCorp's BART applications, and as further explained herein: (i) applying the presumptive BART rate of 0.15 lb/MMBtu for subbituminous coal at these units is not appropriate; and (ii) requiring the installation of SCR at these units likewise is not an appropriate BART control technology.

III. Based on Proper Coal Classification, the "Presumptive" BART NO_x Limit for Naughton Unit 3 and the Jim Bridger Units is 0.28 lb/MMBtu

As explained herein and in the BART applications, to the extent a presumptive BART emission limit (as found in Appendix Y) is relevant, then the appropriate presumptive BART limit for NO_x at Naughton unit 3 and the Jim Bridger units is 0.28 lb/MMBtu.

<u>Presumptive BART</u>

The Preamble to the BART rules observes that "States, as a general matter, must require owners and operators of greater than 750 MW power plants to meet [presumptive] BART limits."[2] 70 FR 39104, 39131. The Preamble goes on to say, however that "a State may establish different requirements if the State can demonstrate that an alternative determination is justified based on consideration of the five statutory factors." *Id.* Specific to NO_x emission limits, the Preamble notes that, "the NO_x limits set forth here today are presumptions only; in making a BART determination, States have the ability to consider the specific characteristics of the source at issue and to find that the presumptive limits would not be appropriate for that source." Id at 39134.

By rule, Wyoming follows Appendix Y in determining the proper BART NO_x emission limits for electric generating units (EGUs). Wyo. Reg., Chap. 6, Sec. 9(c). The presumptive BART NO_x emission limits listed in Appendix Y are "differentiated by boiler design and type of coal burned." *See* 40 CFR Part 51, Appendix Y, IV.E.5. As noted above, the presumptive BART NO_x emission limit (for EGUs with tangentially fired boilers) is 0.15 lb/MMBtu for coal ranked as subbituminous. For coal ranked as bituminous, the presumptive BART NOx emission limit (for EGUs with tangentially fired boilers) is 0.28 lb/MMBtu.[3] *Id.* EPA readily acknowledges that these presumptive NO_x emission limits are based on many assumptions and also that, if one of these assumptions does not apply to a particular unit, it may affect the cost-effectiveness of the presumptive limit.[4]

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[2] The Jim Bridger power plant exceeds 750 MW in total capacity; the Naughton power plant does not.

[3] Even though the Wyoming rules distinguish – based on the amount of generating capacity – between whether Appendix Y "shall" apply or be used merely as "guidance," Appendix Y itself applies the same presumptive NO_x emission limit regardless of facility generating size. "For coal-fired EGUs greater than 200 MW located at greater than 750 MW power plants and operating without post combustion controls [i.e., Jim Bridger units]. . . , we have provided presumptive NO_x limits differentiated by boiler design and type of coal burned . . . . For coal-fired EGUs greater than 200 MW located at power plants 750 MW or less in size and operating without post-combustion controls [i.e., Naughton unit 3], you should likewise assume that these same levels are cost effective. You should require such utility boilers to meet the following NO_x limits, unless you determine that an alternative control limit is justified . . . ." 70 FR 39171.

[4] "The following NO_x emission rates were determined based on a number of assumptions, including that the EGU boiler has enough volume to allow for installation and effective operation of separated overfire air ports. For boilers where these assumptions are incorrect, these emission limits may not be cost-effective." 70 FR 39171.

Coal Classification

Given the large disparity between the presumptive NO_x emission limits for subbituminous and bituminous coals, it is very important to assign the proper coal classification when considering an individual unit. This is particularly true where, as is the case with Naughton unit 3 and the Jim Bridger units, the use of one coal quality classification results in a significantly different presumptive BART rate as compared to another coal classification.

In the Preamble, EPA recognized "that, unlike the methods for controlling SO_2 (which fall within a fairly narrow range of cost effectiveness and control efficiencies), the removal efficiencies and costs associated with the control techniques for NO_x vary considerably, depending on the design of the boiler and the type of coal used." 70 FR 39104, 39134. Also, in that same section of the preamble, EPA recognized that "both cost effectiveness and post-control rates for NO_x do depend largely on boiler design and type of coal burned." *Id.* Therefore, to the extent presumptive BART rates are relevant; the BART analysis for Naughton unit 3 and the Jim Bridger units should carefully consider "the type of coal burned."

Unfortunately, neither Appendix Y, the Preamble, nor the Regional Haze Rules provide a standard or guidance to determine the appropriate coal classification. Instead, Appendix Y simply presumes that coal types are easily classified with a clear distinction between the various coals. This presumption, however, is not correct and certainly should not be the sole basis for assuming that the presumptive NO_x emission rate of 0.15 lb/MMBtu is applicable to Naughton unit 3 and the Jim Bridger units. Indeed, a review of the literature shows that coal types are only loosely defined along a sliding scale, meaning that no bright line distinction between types of coal exists.

Because coal classification is of such fundamental importance in selecting the proper presumptive BART rate, PacifiCorp included in its BART applications an explanation of why the coal burned at Naughton unit 3 and the Jim Bridger units should be considered to be bituminous for the purpose of considering presumptive BART limits for NO_x. In addition, PacifiCorp has attached to this letter a technical memorandum prepared by CH2M Hill entitled "Coal Quality and Nitrogen Oxide Formation" (the "Coal Quality Technical Memo"), which discusses this coal classification issue in more detail. The attached memorandum is intended to amplify similar information provided in the BART applications for these units.

Jim Bridger Units/Naughton Unit 3 Coal Classification

As the Coal Quality Technical Memo explains, a detailed analysis of the key coal characteristics that relate to the formation of NO_x emissions supports the conclusion that the Jim Bridger units and Naughton unit 3 coals should be considered as bituminous for the purpose of applying a presumptive BART NO_x emission limit. This conclusion alone supports presumptive BART limits based on bituminous coal.

As an additional reason, and as explained in the Coal Quality Technical Memo, most coals from the Powder River Basin ("PRB") are classified as subbituminous C and demonstrate high-reactivity and low-NO_x production characteristics. It is against this backdrop of already low NO_x emissions typically associated with PRB subbituminous coal that EPA selected the very low presumptive NOx emission rate of 0.15 lb/MMBtu for tangentially fired boilers (like those at Naughton unit 3 and the Jim Bridger units) and assumed that this rate could be achieved by combustion controls like LNB and OFA. In reaching this conclusion, however, EPA assumed that PRB subbituminous C coals to represent the entire class of subbituminous coals in use across the country since the PRB coals make up the largest share of such coals. However, there are other types of subbituminous coals that occur outside of the PRB that are not as reactive and low NOx forming as the PRB coals. EPA's general assumptions regarding NO_x emissions and subbituminous coals, therefore, fail to recognize that non-PRB subbituminous coals could have higher NO_x emissions than PRB subbituminous C coals. This, in turn, affects the feasibility and cost effectiveness of the presumptive BART NO_x emission limits (as stated in Appendix Y) for boilers using non-PRB subbituminous coal like Naughton unit 3 and the Jim Bridger units.

In other words, with NO_x emissions from PRB subbituminous coal already low compared to other types of coal, EPA apparently believes it is a technologically easy and cost-effective step to impose an even lower presumptive BART emission rate of 0.15 lb/MMBtu (for tangentially fired boilers), which can be achieved by adding combustion controls like LNB and OFA. However, for non-PRB subbituminous coals, it is not such an easy and cost-effective step because combustion controls typically will not be enough to control NO_x emissions to this rate. In this light, EPA's presumed feasibility and cost-effectiveness falls apart because very expensive and impractical post-combustion controls become part of the BART equation for certain subbituminous (non-PRB) coals.

The Coal Quality Technical Memo concludes as follows:

> "For all these reasons, the [Naughton unit 3 and Jim Bridger units] coals . . . are more similar in their NO_x formation potential to bituminous coals than to subbituminous coals such as PRB. Therefore, the presumptive BART limit that should be considered for the Jim Bridger [units] and Naughton [unit 3] . . . should be closer to 0.28 lb/MMBtu presumptive BART limit rather than the subbituminous 0.15 lb/MMBtu limit."

Considering the presumptive BART NO_x emission limit for bituminous coal for Naughton unit 3 and the Jim Bridger units not only complies with the requirements of

Wyoming law (including Appendix Y), but is more stringent than BART limits imposed on other Wyoming sources.[5]

Coal Classification In Other States

The coal classification issue discussed above in regard to presumptive BART limits is not unique to PacifiCorp's units or the state of Wyoming. The State of New Mexico is addressing a similar issue concerning the San Juan Generating Station (SJGS).

In New Mexico, the SJGS argues that it cannot meet the presumptive BART NO_x emissions limit of 0.23 lb/MMBtu (for a dry bottom, wall-fired boiler) for subbituminous coal. Using this presumptive BART limit was problematic because the local New Mexico coal used by SJGS fit into a "gray area" between bituminous and sub-bituminous coal. *See* "Discussion of SJGS Coal Ranking for BART NO_x Presumptive Limit Determination." The SJGS coal was less volatile, and has less oxygen and moisture, than the characteristics of PRB subbituminous coals used in developing the presumptive BART NO_x emission limits under Appendix Y. *Id.* As the SJGS explains, "with respect to NO_x combustion control performance, SJGS coal behaves more like a bituminous coal."[6] *Id.*

The same can be said of the Jim Bridger units and Naughton unit 3 coals. Therefore, if a presumptive NO_x emissions limit is considered for any of these units, PacifiCorp urges WDAQ to take account of the applicable coal characteristics and properly assume that the Jim Bridger units and Naughton unit 3 coals are closer to bituminous in composition than subbituminous. This proper assumption, in turn, leads to the conclusion that if a presumptive BART NO_x emission limit is considered for any of these units, it should be at the 0.28 lb/MMBtu rate presumed for bituminous coal. As explained in the following section, however, the calculated BART emission rates noted in Table I above should control over the presumptive BART rates in any event.

IV. The Five Factor Analysis Also Indicates SCR Is Not Appropriate

[5] For example, Wyoming has proposed higher NO_x emissions rates for other coal fired boilers in Wyoming. When making the BART determination for FMC's Westvaco facility, Wyoming determined that a NO_x emissions rate of 0.35 lb/MBTU was BART. *See* August 4, 2008 BART Application Analysis, AP 6045, pg. 30. Additionally, Wyoming approved a BART NO_x emissions rate of 0.49 lb/MBTU for General Chemical's two coal fired boilers at its Green River Works facility. *See* August 4, 2008 BART Application Analysis, AP 6046, pg. 26. PacifiCorp's proposed "presumptive" BART limit of 0.28 lb/MBTU for the Naughton and Jim Bridger power plants is much lower than these sources.

[6] The BART NO_x emission limit proposed by the New Mexico Environment Department for the SJGS is 0.293 lb/MMBtu. This is consistent with the limit established in a consent decree concerning the plant which is unrelated to the BART determination. For information concerning SJGS BART issues, see http://www.nmenv.state.nm.us/aqb/reghaz/documents/COMPLETEFinalDiscussionofSJGSCoalClassificationRevisi.pdf

Establishing the appropriate presumptive BART NO_x emission limit as described above is only one consideration in making a proper BART determination. Indeed, if an analysis of the five statutory factors supports a different emissions limit, then the presumptive BART rates take on a role only as a non-binding guide or marker for units like Naughton unit 3 and the Jim Bridger units.

Five Factor Analysis and Proposed BART Limits

As noted, the presumptive BART limits are exactly what they purport to be – presumptions that can be rebutted and modified based on additional case by case information. In the Preamble, EPA states that its "presumption accordingly may not be appropriate for all sources. As noted, the NO_x limits set forth here today are presumptions only; in making a BART determination, States have the ability to consider the specific characteristics of the source at issue and to find that the presumptive limits would not be appropriate for that source." 70 FR 39134. Appendix Y further explains that a state "may determine that an alternative control level is appropriate based on a careful consideration of the [five] statutory factors," particularly for boilers where EPA's assumptions related to NO_x emissions rates are incorrect. *See* Appendix Y, IV.E.5.

PacifiCorp already has submitted a detailed five factor analysis for Naughton unit 3 and the Jim Bridger units in their individual BART applications. The final result of this analysis is a proposed BART emission limit for NOx at Naughton unit 3 of 0.35 lb/MMBtu – higher than the presumptive BART limit of 0.28 lb/MMBtu. As for the Jim Bridger units, the result of the analysis is a NOx limit of 0.26 lb/MMBtu – lower than the presumptive BART limit. In each case, however, the proposed BART limits can be met by the installation of combustion controls. Imposing lower NO_x limits than PacifiCorp has proposed would require the installation of post-combustion controls such as SCR, which is contrary to applicable BART requirements because the "cost of compliance" would be too high.

Cost of Compliance

Focusing on the cost of compliance factor, EPA assumes in the Preamble that approximately 75% of the EGUs would have BART NO_x removal costs between \$100 and \$1,000 per ton, and that almost all of the remaining EGUs could install sufficient combustion control technology for less than \$1,500 per ton:

> "The limits provided were chosen at levels that approximately 75 percent of the units could achieve with current combustion control technology. The costs of such controls in most cases range from just over \$100 to \$1000 per ton. Based on our analysis, however, we concluded that approximately 25 percent of the units could not meet these limits with current combustion control technology. However, our analysis indicates that all but a very few of these units could meet the presumptive limits using advanced combustion controls such as rotating opposed fire air

("ROFA"), which has already been demonstrated on a variety of coal-fired units.[7] Based on the data before us, the costs of such controls in most cases are less than $1500 per ton." 70 FR 39135.

EPA's assumptions regarding the cost of controls place Naughton unit 3 or the Jim Bridger units outside the scope of expected removal costs when considering the lower presumptive limit of 0.15 lb/MMBtu. As indicated in the BART applications, these units can only meet this rate by installing SCR. Under this scenario, the incremental control costs per ton would approach $4,000 per ton, well above the presumed control cost range included in the Preamble.

It is for this reason that EPA stated further in the Preamble that SCR generally is not cost effective for EGUs (except for cyclone boilers):

> "We also analyzed the installation of SCRs at BART-eligible EGUs, applying SCR to each unit and fuel type. The cost-effectiveness was generally higher than for current combustion control technology except for one unit type, cyclone units. Because of the relatively high NO_x emission rates of cyclone units, SCR is more cost-effective. Our analysis indicated that the cost-effectiveness of applying SCR on coal-fired cyclone units is typically less than $1500 a ton, and that the average cost-effectiveness is $900 per ton. As a result, we are establishing a presumptive NO_x limit for cyclone units based on the use of SCR. For other units, we are not establishing presumptive limits based on the installation of SCR. Although States may in specific cases find that the use of SCR is appropriate, *we have not determined that SCR is generally cost-effective for BART across unit types*." 70 FR 39135-36. (Emphasis supplied)

V. LNB /OFA Are the Proper BART Control Technology; SCR is Not

Unlike SCR, LNB/OFA is the proper BART control technology for Naughton unit 3 and the Jim Bridger units.

A "BART" determination involves not only the setting of an emissions limit, but also the selection of a particular emissions control technology, or group of technologies, to achieve that limit. Wyoming's BART rules refer to this as "control equipment", "control technology", and "BART technology." Wyo. Reg., Chp. 6, Sec. 9(e)(i)(E), Sec. 9(e)(iii) and (e)(viii). Regardless of the term used, and as explained above, the Preamble and other guidance are clear that LNBs and OFA are intended to be the "BART technology" for the tangentially fired boilers such as Naughton unit 3, the Jim Bridger units, and other similarly situated units.

[7] The BART applications for Naughton unit 3 and the Jim Bridger units explain why ROFA is not a workable alternative for those units.

In the Preamble, EPA stated that, except for cyclone boilers, the "types of current combustion control technology options assumed include low NOx burners, over-fire air, and coal reburning." 70 FR 39134; *see also* 39144 ("For all other coal-fired units, our analysis assumed these units will install current combustion control technology."). In fact, in the Technical Support Document used to develop the presumptive BART NO_x emissions limits, EPA explained that the "methodology EPA used in applying current combustion control technology to BART-eligible EGUs" included applying "a complete set of combustion controls. A complete set of combustion controls for most units includes a low NO_x burner and over-fire air." See, "Technical Support Document, Methodology for Developing NO_x Presumptive Limits," EPA Clean Air Markets Division, pg. 1 (dated June 15, 2005).

The Preamble identifies post-combustion controls for NO_x, such as SCR and SNCR, as "BART technology" for only "cyclone" units. EPA made it clear that for "other units, we are not establishing presumptive limits based on the installation of SCR." 70 FR 39136. Therefore, EPA's presumptive "BART technology" is LNBs and some type of OFA. EPA further elaborated in the preamble on the SCR costs, stating that although "States may in specific cases find that the use of SCR is appropriate, we have not determined that SCR is generally cost-effective for BART across unit types." *Id.*

Other BART eligible sources in Wyoming have determined that LNBs and/or OFA are "BART technology," and that SCR would not be appropriate. For example, after additional analysis and study, Basin Electric recently submitted its analysis that OFA was the appropriate BART technology for the Laramie River Station and that SCRs were not "BART" due to several factors, including the high cost and relatively low visibility improvement. *See* Basin Electric/Laramie River Station Refined BART Visibility Modeling, pages 13 and 14 (submitted July 24, 2008).

Similarly, the State of Wyoming also determined that LNBs and OFA were BART for the coal-fueled boilers at FMC's Westvaco facility and at General Chemical's Green River Works facility. *See* August 4, 2008 BART Application Analysis, AP 6045, pg. 30, and August 4, 2008 BART Application Analysis, AP 6046, pg. 26. All of these BART analyses reviewed SCR and SNCR, but none of them found that SNCR or SCR are BART for any of these facilities. Likewise, LNBs and OFA should be determined to be BART technology for PacifiCorp's Jim Bridger and Naughton EGUs.

A recent survey of the western states indicates that no states have mandated SCR or SNCR as "BART technology" for any EGUs. For example, in Colorado's recent BART determinations, Colorado recognized LNBs and OFA (or some modification of the same) as BART for 14 different EGUs. *See* Colorado's Air Quality Regulations, Part F, IV.D. In fact, consistent with PacifiCorp's position explained above, Colorado believes that Appendix Y and the preamble do not allow post-combustion control, such as SCRs, to be considered at all as "BART technology." In a letter addressing BART issues, Colorado's Air Quality Division explained that "Colorado's BART rule does not allow for post combustion NOx controls. This provision is based upon the preamble to the final EPA

BART rule and Appendix Y." *See* January 11, 2008 letter to Vickie Patton from Colorado Division of Air Quality, pg. 3.

Additionally, the Oregon Department of Environmental Quality, in the August 20, 2008, BART determination for the Boardman power plant, found that SCR was not BART technology and stated that the "capital cost of [SCR] is 7 times that of new low NOx burners with modified overfire air system." PacifiCorp's BART applications confirm that SCR is not cost-effective or otherwise appropriate for Naughton unit 3 or the Jim Bridger units. Therefore, Wyoming, like other western states that have considered the issue, should determine that BART technology for PacifiCorp's Jim Bridger and Naughton power plants is LNBs and OFA, and not SCR or SNCR.

VI. Conclusion

Based on a close examination of the characteristics of coal burned Naughton unit 3 and the Bridger units, it is clear that the appropriate presumptive BART NO_x emission rate for consideration at these units is 0.28 lb/MMBtu. The appropriate calculated NO_x emission rate, however, is 0.35 lb/MMBtu for Naughton unit 3 (30 day rolling average) and 0.26 lb/MMBtu for the Bridger units (30 day rolling average). The appropriate control technology to achieve these rates is LNB and OFA.

Please feel free to contact us with any questions.

Sincerely,

William K. Lawson
Director, Environmental Services

cc: Idaho Power

TECHNICAL MEMORANDUM CH2MHILL

Coal Quality and Nitrogen Oxide Formation

PREPARED FOR: Mike Jenkins

PREPARED BY: Craig Vogel

COPIES: Blain Rawson

DATE: January 15, 2009

Nitrogen oxide (NO_x) formation in coal-fired boilers is a complex process that is dependant on a number of variables, including operating conditions, equipment design, and coal characteristics.

Coal Combustion

During coal combustion, NO_x is formed in three different ways: fuel NO_x, thermal NO_x, and prompt NO_x. The dominant source of NO_x formation (approximately 60 to 80 percent) is the oxidation of fuel-bound nitrogen (fuel NO_x). The amount of nitrogen contained in the coal directly impacts the amount of fuel NO_x formed. During combustion, part of the fuel-bound nitrogen is released from the coal with the volatile matter, and part is retained in the solid portion (char). The nitrogen chemically bound in the coal is partially oxidized to nitrogen oxides NOx (nitric oxide [NO] and nitrogen dioxide [NO_2]) and partially reduced to molecular nitrogen (N_2). The release rate of nitrogen from the volatile fractions of the coal in the early stages of combustion and the release of nitrogen in the char portion later in the combustion process also impact NO_x formation

A smaller part of NO_x formation (20 to 40 percent) is due to high temperature fixation of atmospheric nitrogen in the combustion air (thermal NO_x). Thermal NO_x can be affected exponentially by local temperatures in the combustion zone and can be proportional to the square root of oxygen availability.

A very small amount of NO_x (<5 percent) is called "prompt" NO_x. Prompt NO_x results from an interaction of hydrocarbon radicals, nitrogen, and oxygen.

In a conventional pulverized coal burner, air is introduced to the boiler with turbulence to promote good mixing of fuel and air, which provides stable combustion. However, not all of the oxygen in the air is used for combustion. Some of the oxygen combines with the fuel nitrogen to form NO_x. Low-NO_x burners (LNBs) in combination with overfire air (OFA) are designed to reduce the amount of air introduced during initial combustion when the volatiles are driven off and to introduce air later downstream to combust the remaining unburned char. Hence, LNBs result in less conversion of fuel-bound nitrogen to NO_x and lower combustion temperatures limiting thermal NO_x. In addition, lower temperatures and oxygen availability can reduce hydrocarbon reaction rates, resulting in less prompt NO_x formation. For retrofit of existing boilers, boiler size and configuration can limit the effectiveness of LNBs and OFA.

AQD Jim Bridger BART
002644

Coal Ranking

Coal ranking is a means of classifying coals according to their degree of metamorphism in the natural series, from lignite to subbituminous to bituminous and on to anthracite.

The American Society for Testing Materials (ASTM) has developed a system for generally classifying coals based on their heating value, volatile content, moisture, reactivity, and other properties. Eastern U.S. coals (high volatile bituminous) tend to be high-rank fuels with high heating values and low moisture. At the other end of the spectrum, U.S. lignite coals tend to be low rank, as their heating values are low and moisture content high. Western U.S. coals, like Powder River Basin (PRB), tend to be categorized in the lower rank Subbituminous "C" range, while other western fuels tend to be categorized as higher rank bituminous or subbitbuminous coals. Figure 1 shows the criteria for ASTM's coal rankings.

Most coals from the PRB are classified as Subbituminous C and demonstrate high-reactivity and low-NO_x production characteristics. Based on data from the federal Energy Information Administration, PRB coals currently represent 88 percent of total U.S. subbituminous production and 73 percent of western coal production. Most references to "western" coal and subbituminous coal infer PRB origin and characteristics. Emissions standards differentiating between bituminous and subbituminous coals are presumed to use PRB coal as the basis for the subbituminous standards, due to their dominant market presence and unique characteristics.

Coal Characteristics

Coal characteristics directly and significantly affect NO_x emissions from coal combustion and play an important role in the ability to design and operate LNBs and OFA systems. As previously discussed, the ability to control the introduction of air into the burner zone is of paramount significance. Burner zone stoichiometry is the ratio of combustion air admitted to the furnace versus the theoretical amount of air required for complete combustion. Most units are designed to operate between 1.14 and 1.25 stoichiometry, where 1.0 is the theoretical amount of air just required for combustion. When operating for low NO_x the burner zone stoichiometry is reduced by the air staged through the OFA system. Aggressive low-NO_x-firing systems typically are designed to operate with burner zone stoichiometries less than theoretical (1.0).

Tests run by the boiler manufacturer ALSTOM showed the influence of both fuel type and stoichiometry on NO_x emissions as illustrated in Figure 2. As expected, as the stoichiometry decreases, the percentage of the fuel-bound nitrogen converted to NO_x decreases. This testing also shows the trend that as the fuel rank decreases, the rate at which the fuel nitrogen converts to NO_x also decreases.

Subsequent testing in ALSTOM's laboratory identified some of the key characteristics of the coals and mechanisms for this nitrogen conversion efficiency. In general, the lower the fuel rank, the faster the coal is devolatilized and the faster the fuel-bound nitrogen is released. Based on the chemical kinetics under staged conditions, nitrogen preferentially bonds together to form inert molecular nitrogen N_2 instead of NO or NO_2. Therefore, the more nitrogen that can be released earlier in the combustion process, the lower the NO_x emissions can be. Low-rank coals show favorable behavior with regard to greater fuel nitrogen release during the devolatilization phases of the combustion process; this is conducive to greater NO_x reduction. This is one of the reasons coals like PRB tend to react favorably to staged combustion, producing some of the lowest levels of NO_x observed in U.S. coals.

The coals used at Bridger and Naughton tend to be higher rank than typical PRB coals. As such, they will have less fuel nitrogen released during the devolatilization phase of combustion, and thus will produce somewhat higher NO_x than will true PRB coals when fired under low-NO_x staged conditions.

A second major factor in fuel NO_x is related to how the fuel-bound nitrogen evolves from the solid coal char that is produced once the volatile component of the coal is released and combusted. Generally speaking, approximately 20 to 40 percent of the fuel NO_x can source from fuel-bound nitrogen associated with the solid char. Control of NO from this char nitrogen component cannot be directly controlled by air staging since under staged low-NO_x combustion (reducing or pyrolysis conditions), char nitrogen conversion to NO remains relatively constant. Typically, lower rank (more reactive) fuels have more fuel-bound nitrogen associated with the volatiles than the char, so low-rank coals overall have the lowest NO_x potential.

The performance of the Bridger and Naughton coals tends to fall between the PRB coals and eastern bituminous coals shown. This would support the conclusion that the Bridger and Naughton coals have a NO_x reduction potential below eastern bituminous coals but not as low as true PRB coals.

This conclusion is supported by additional ALSTOM laboratory data shown in Figure 3. Testing in ALSTOM's bench-scale drop tube furnace can determine the relative percentage of fuel-bound nitrogen converted to NO_x in both the devolatilization and char phases of combustion. It is clear that PRB coals can have greater than 78 percent of fuel-bound nitrogen converted to NO_x during devolatilization, which is far greater than that measured for bituminous coals. As a result of these observations, the performance of the Bridger and Naughton coals, in terms of total fuel NO_x emissions, would tend to fall between the PRB coals and eastern bituminous coals shown in Figure 3.

As mentioned earlier, NO_x formed by fixation of atmospheric nitrogen to oxygen (thermal NO_x) is the other main component of total NO_x emissions for a boiler. The other two primary factors are unit design and operating procedures, and are therefore very unit-specific. Unit design affects both the residence time of the combustion process and the thermal aspects of combustion. Unit design determines how "hot" a furnace is, which influences the thermal NO_x contribution for both the baseline and postretrofit NO_x emissions. From its extensive retrofit experience, ALSTOM developed a series of thermal NO_x prediction methodologies based on the physical unit dimensions and the thermal conditions firing eastern and midwestern fuels. These site-specific predictive methodologies are used in combination with the fuel NO_x prediction methodologies described above to make overall stack NO_x emission predictions and commercial guarantees.

Figure 4 shows ALSTOM's experience on coals from the west that rank either as high volatile Bituminous B or C or as Subbituminous B coals. The coals from Bridger and Naughton generally fall in these categories. Considering the data presented in Figure 4, ALSTOM expects that the NO_x emission levels of the Bridger and Naughton coals will be higher than those of PRB coals.

As discussed, there are a number of western coals that are classified as subbituminous; however, they border on being ranked as bituminous and do not display many of the qualities of PRB coals, including most of the low-NO_x-forming characteristics. The coals from the Bridger, Black Butte, Leucite Hills, and Naughton mines fall into this category.

As defined by ASTM, the only distinguishing characteristic that classifies the coals used at Jim Bridger and Naughton as subbituminous rather than bituminous is that they are "agglomerating" and not "nonagglomerating." Agglomerating as applied to coal is "the property of softening when it is heated to above about 400° C [degrees Celsius] in a non-oxidizing atmosphere, and then appearing as a coherent mass after cooling to room temperature. Since the agglomerating property of coals is the result of particles transforming into a plastic or semiliquid state when heated, it reflects a change in surface area of the particle. Thus, with the application of heat, agglomerating coals would tend to develop a nonporous surface while the surface of nonagglomerating coals would become even more porous with combustion. As shown by Figure 5, the increased porosity provides more particle surface area resulting in more favorable combustion conditions. This nonagglomerating property assists in making subbituminous coals more amenable to controlling NO_x by allowing less air to be introduced during the initial ignition portion of the combustion process.

Table 1 compares key NO_x-forming characteristics of the Bridger Mine, Black Butte, Leucite Hills, Naughton, a typical PRB coal, and Twentymile, a representative western bituminous coal.

As shown in Table 1, although Bridger, Black Butte, Leucite Hills, and Naughton are classified as subbituminous, they all exhibit higher nitrogen content, lower moisture content, and lower oxygen content than the PRB coal. The higher nitrogen content is an indication that more nitrogen is available to the combustion process and higher NO_x emissions are likely. Oxygen content can be correlated to the reactivity of the coal with more reactive coals, generally containing higher levels of oxygen. As previously stated, more reactive coals tend to produce lower NO_x emissions and are also more conducive to reduction of NO_x emissions, through use of combustion control measures such as LNBs and OFA. These characteristics indicate that higher NO_x formation is likely with Bridger, Black Butte, Leucite Hills, and Naughton rather than with PRB coal. The Bridger, Black Butte, Leucite Hills, and Naughton coals all contain quality characteristics that fall between a typical PRB coal and Twentymile, a clearly bituminous coal that produces higher NO_x, as has been demonstrated at power plants burning Twentymile coal.

Using Jim Bridger 2 for illustrative purposes, Figures 6 and 7 graphically illustrate the relationship of nitrogen and oxygen content to related BART presumptive NO_x limits for the coals listed in Table 1. Twentymile is used to graphically illustrate achievement of the BART presumptive NO_x limit for a bituminous coal, and the PRB coal corresponds to the subbituminous BART presumptive NO_x limit. This is appropriate since EPA used PRB coal to represent all subbituminous coals for the purpose of establishing the presumptive BART limit for NOx. The Bridger blend consists of a representative combination of coals from the Bridger Mine, Black Butte, and Leucite Hills that has been used at Jim Bridger 2 and

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indicates the average NO_x emission rate achieved during 2003–2005. Jim Bridger 2 represents the NO_x emission rate achieved after installation of ALSTOM's current state-of-the-art TFS2000 LNB and OFA system. This NO_x emission level of 0.28 pounds per million British thermal unit (lb/MMBtu) corresponds to the BART presumptive limit for bituminous coal and underscores the difference in ability to reduce NO_x while burning non-PRB subbituminous coals such as those from the Bridger Mine.

Figures 6 and 7 both demonstrate that with the TFS2000 low-NO_x emission system installed and burning a combination of the Bridger, Black Butte, and Leucite Hill coals, the likely NO_x emission rate will be closer to the bituminous end (0.28) of the BART presumptive NO_x limit range than to the BART subbituminous presumptive NO_x limit of 0.15 lb/MMBtu.

Coal quality characteristics also impact the design and operation of the boiler and associated auxiliary equipment. Minor changes in quality can sometimes be accommodated through operational adjustments or changes to equipment. It is important to note, however, that consistent variations in quality or assumptions of "average" quality for performance projections can be problematic. This is particularly troublesome when dealing with performance issues that are very sensitive to both coal quality and combustion conditions, such as NO_x formation. There is significant variability in the quality of coals burned at Jim Bridger and Naughton. For example, in addition to burning coal from Black Butte and Leucite Hills, Jim Bridger burns coal supplied from the Bridger Mine consisting of three sources: underground, surface, and highwall operations. Each of these coal sources has different quality characteristics as well as inherent variability.

Several of the coal quality characteristics and their effects on NO_x formation have been previously discussed. There are some additional considerations that illustrate the complexity of achieving and maintaining low NO_x emissions with pulverized coal on a consistent, shorter-term (such as a 30-day rolling average) basis.

Good combustion is based on the "three Ts": time, temperature, and turbulence. These parameters along with a "design" coal are taken into consideration when designing a boiler and associated firing equipment, such as fans, burners, and pulverizers. If a performance requirement such as NO_x emission limits is subsequently changed, conflicts with other performance issues can result.

Jim Bridger is located at an altitude of 6,669 feet above sea level, and Naughton is at an elevation of 6,396 feet above sea level. At these elevations, atmospheric pressure is lower (11.5 pounds per square inch) as compared with sea level pressure of 14.7 pounds per square inch. This lower pressure means that less oxygen is available for combustion for each volume of air. In order to provide adequate oxygen to meet the requirements for efficient combustion, larger volumes of air are required. When adjusting air flows and distribution to lower NO_x using LNBs and OFA, original boiler design restrictions again limit the modifications that can be made and still achieve satisfactory combustion performance.

Another significant factor in controlling NO_x emissions is the fineness of the coal entering the burners. Fineness is influenced by the grindability index (Hardgrove) of the coal. Finer coal particles promote release of volatiles and assist char burnout due to more surface area exposed to air. NO_x reduction with high volatile coals is improved with greater fineness and with proper air staging. The lower rank subbituminous coals such as PRB coals are quite friable and easy to grind. Coals with lower Hardgrove Grindability Index values, such as those used at Jim Bridger and Naughton, are more difficult to grind and can contribute to higher NO_x levels. In addition, coal fineness can deteriorate over time periods between pulverizer maintenance and service as pulverizer grinding surfaces wear.

For all of these reasons, the coals from the Bridger Mine, Black Butte, Leucite Hills and Naughton mines that are used at the Jim Bridger and Naughton plants are more similar in their NOx formation potential to bituminous coals than to the subbituminous coals such as PRB. Therefore the presumptive BART limit that should be applied to the Bridger and Naughton plants should be closer to the 0.28 lb/MMBtu presumptive BART limit rather than the subbituminous 0.15 lb/MMBtu limit. This is also demonstrated by the actual performance of the LNB OFA TFS2000 low-NO_x emission system installed on Jim Bridger Unit 2.

TABLE 1
NO_x Characteristics Comparison

Parameter	PRB	Bridger Mine	Black Butte	Leucite Hills	Naughton	Twentymile
Nitrogen (% dry)	1.10	1.26	1.47	1.48	1.24	1.85
Oxygen (% dry)	16.2	13.2	13.4	13.2	15.4	7.19
Moisture (%)	27.3	19.1	20.7	19.0	20.9	9.85
Coal rank	Sub C	Sub A	Sub A	Sub A	Sub A	Bit high vol B

NOTE:
% = Percent

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FIGURE 1
Coal Classification

Table 3
Classification of Coals by Rank[a] (ASTM D 388)

Class	Group	Fixed Carbon Limits, % (Dry, Mineral-Matter-Free Basis) Equal or Greater Than	Fixed Carbon Limits, % Less Than	Volatile Matter Limits, % (Dry, Mineral-Matter-Free Basis) Greater Than	Volatile Matter Limits, % Equal or Less Than	Calorific Value Limits, Btu/lb (Moist,[b] Mineral-Matter-Free Basis) Equal or Greater Than	Calorific Value Limits, Btu/lb Less Than	Agglomerating Character
I. Anthracitic	1. Meta-anthracite	98	—	—	2	—	—	Nonagglomerating
	2. Anthracite	92	98	2	8	—	—	
	3. Semianthracite[c]	86	92	8	14	—	—	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	—	—	Commonly agglomerating[e]
	2. Medium volatile bituminous coal	69	78	22	31	—	—	
	3. High volatile A bituminous coal	—	69	31	—	14,000[d]	—	
	4. High volatile B bituminous coal	—	—	—	—	13,000[d]	14,000	
	5. High volatile C bituminous coal	—	—	—	—	11,500	13,000	
						10,500[e]	11,500	Agglomerating
III. Subbituminous	1. Subbituminous A coal	—	—	—	—	10,500	11,500	Nonagglomerating
	2. Subbituminous B coal	—	—	—	—	9,500	10,500	
	3. Subbituminous C coal	—	—	—	—	8,300	9,500	
IV. Lignitic	1. Lignite A	—	—	—	—	6,300	8,300	
	2. Lignite B	—	—	—	—	—	6,300	

[a]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high volatile bituminous and subbituminous ranks. All of these coals either contain less than 48% dry, mineral-matter-free Btu/lb.

[b]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c]If agglomerating, classify in low volatile group of the bituminous class.

[d]Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile C bituminous group.

FIGURE 2
Nitrogen Conversion to NO_x

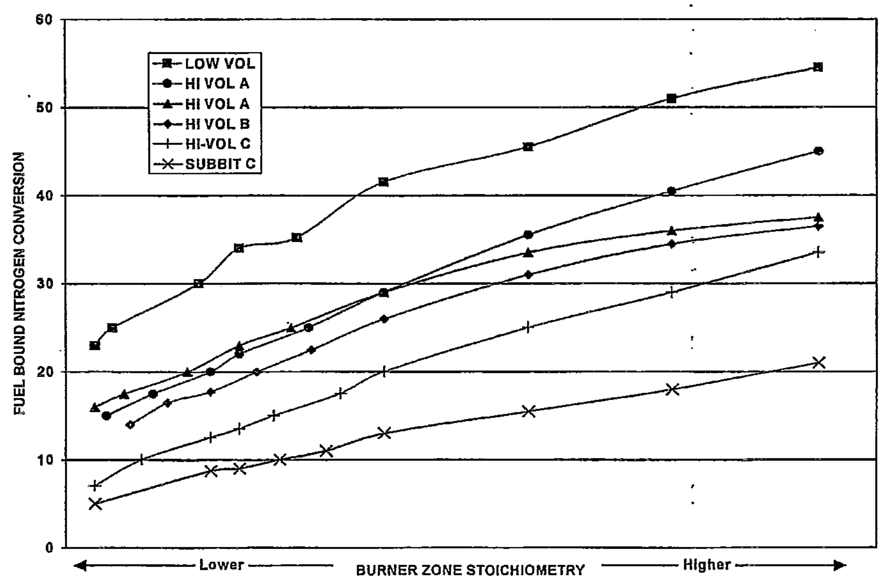

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FIGURE 3
Fuel Nitrogen Conversion during Coal Devolatilization and Coal Char Combustion versus Coal Type

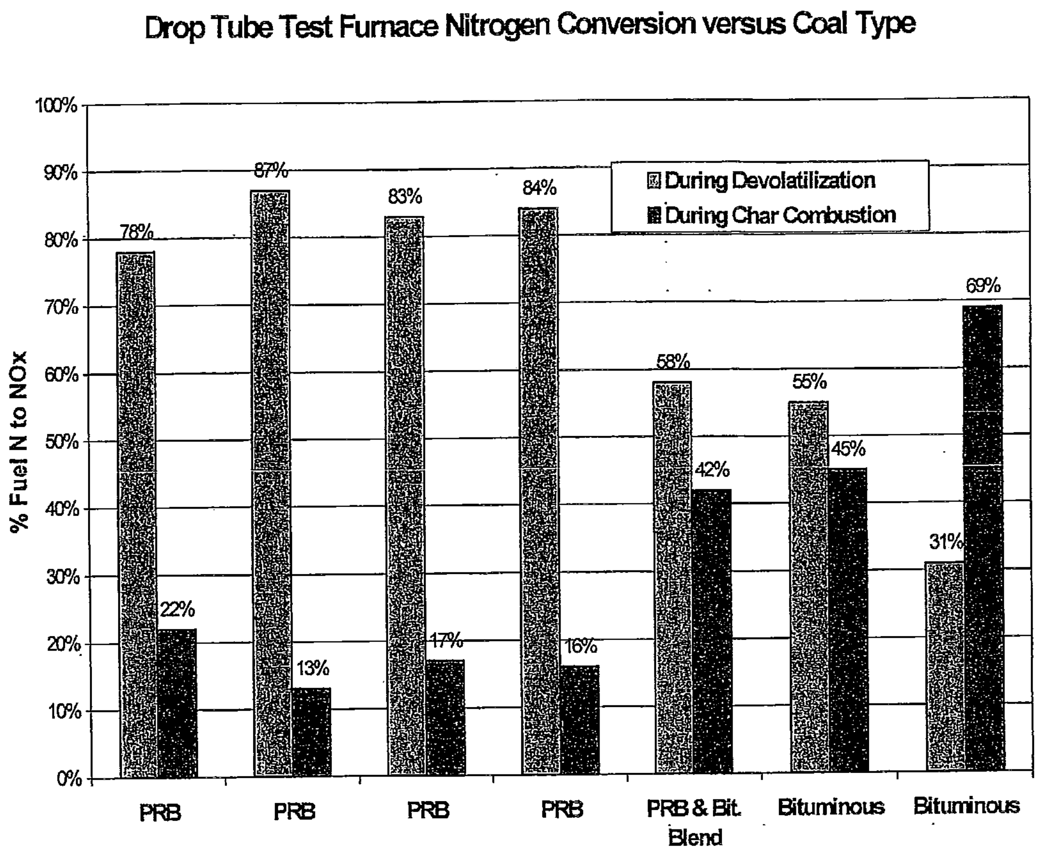

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FIGURE 4
ALSTOM Experience on Western High Volatile Bituminous B and C and Subbituminous B

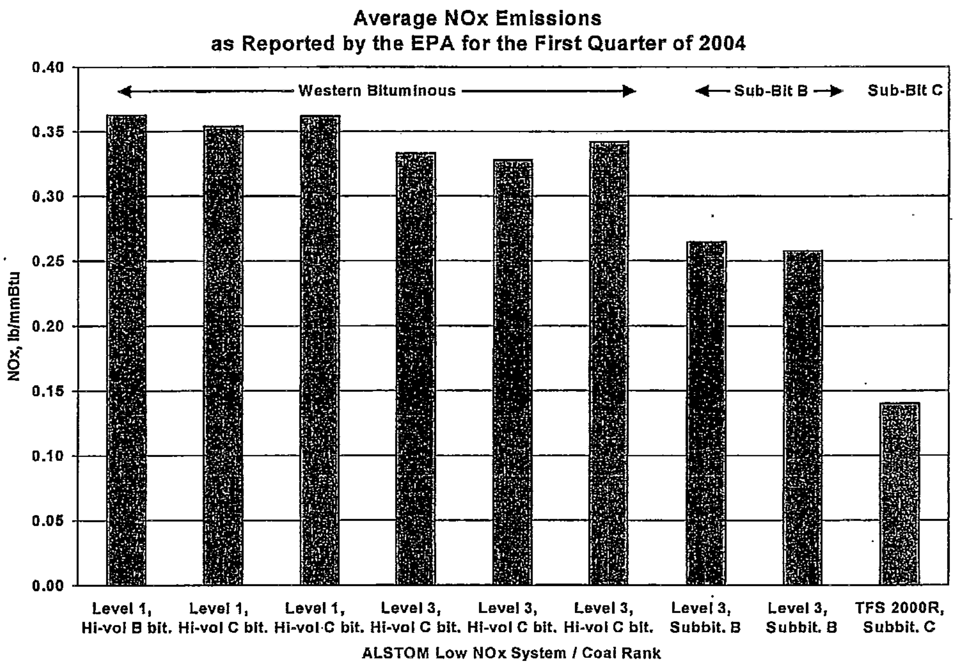

FIGURE 5
Illustration of the Effect of Agglomeration on the Speed of Coal Combustion

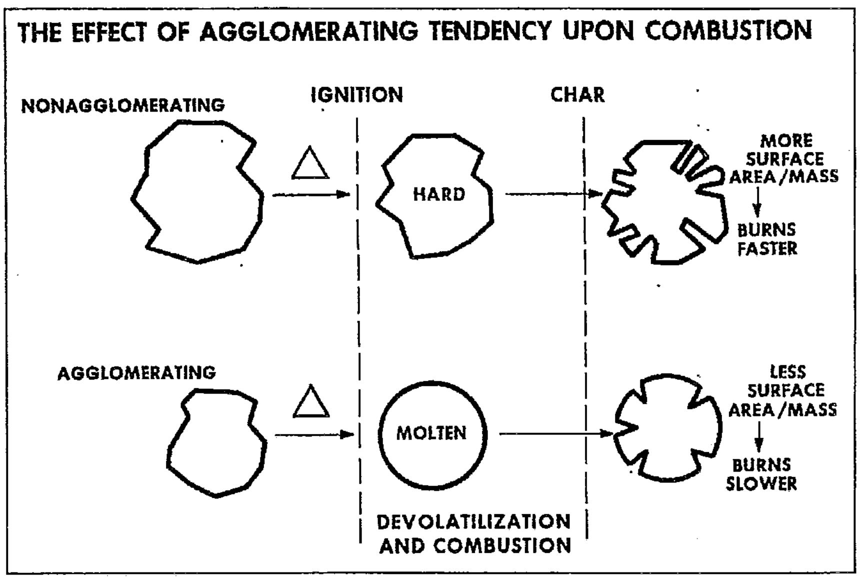

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FIGURE 6
Plot of Typical Nitrogen Content of Various Coals and Applicable Presumptive BART NO_x Limits—Jim Bridger 2

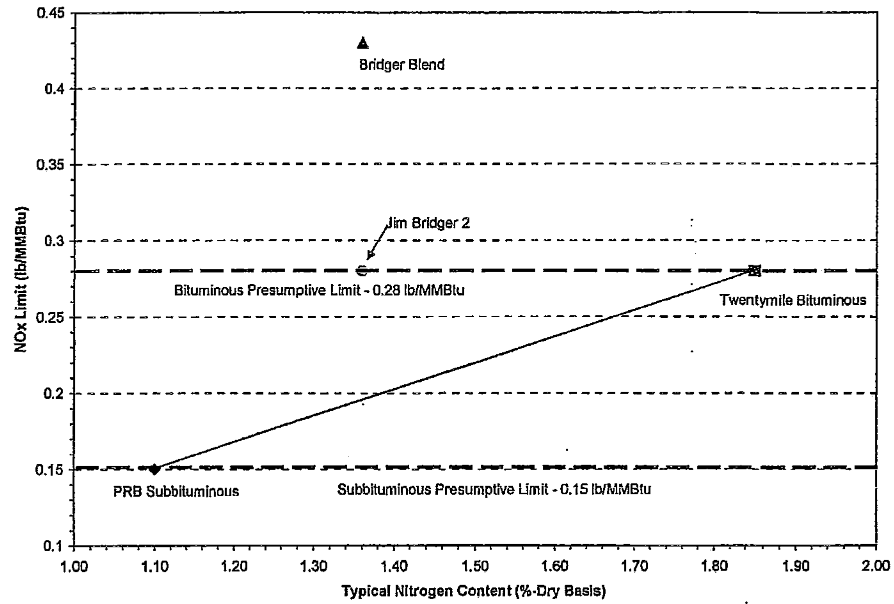
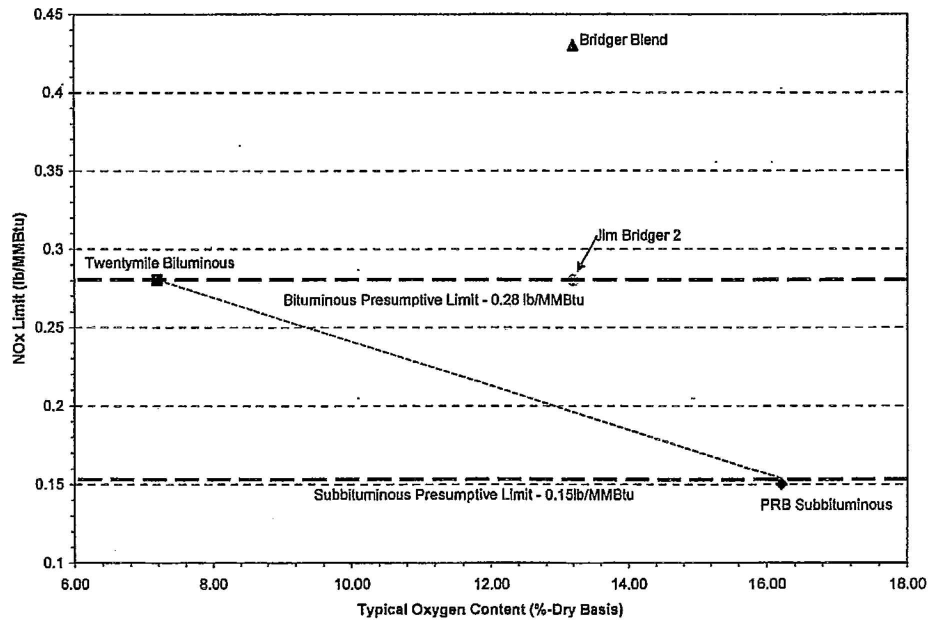


FIGURE 7
Plot of Typical Oxygen Content of Various Coals and Applicable Presumptive BART NO_x Limits—Jim Bridger 2



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Reference

ALSTROM, 2005. NO_x Variation with Western U.S. Sourced Coals Fired in PacifiCorp Utility Boilers. Prepared for PacifiCorp. February 4.

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ATTACHMENT A

NO_X Variation with Western U.S. Sourced Coals Fired in PacifiCorp Utility Boilers

NOx VARIATION WITH WESTERN U.S. SOURCED COALS FIRED IN PACIFICORP UTILITY BOILERS

Prepared For

PacifiCorp

February 4, 2005

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NOx VARIATION WITH WESTERN U.S. SOURCED COALS FIRED IN PACIFICORP UTILITY BOILERS

ALSTOM, Inc
Windsor, CT
February 4, 2005

ABSTRACT

ALSTOM is a world leader in low NOx firing system technology, with over 380 boilers converted globally to low NOx firing on a wide range of coals. In the US, ALSTOM has provided low NOx firing systems to over 50 utility boilers that fire Powder River Basin (PRB), lignite, and a variety of Western bituminous and subbituminous coals. These units firing Western US coals account for over 21,000 MW of electrical generation. From this extensive field experience, as well as fundamental laboratory study, it is clear that each western US coal has unique variations in chemistry and characteristics that directly affect combustion, NOx formation, and NOx reduction potential. As such, ALSTOM maintains that NOx emissions predictions for specific Western U.S. sourced coals must carefully consider the fundamental properties unique to each coal. This paper will focus on ALSTOM's experience burning lignite, subbituminous and Western bituminous coals under low NOx conditions, and outline how NOx generated in Western US coal fired utility boilers can be expected to vary significantly based on each coal's unique characteristics.

NOx Formation Mechanisms

NOx formation and reduction in a utility boiler sources from the following three basic chemical mechanisms:

1) **Thermal NOx**

Thermal NOx, also known as Zel'dovich mechanism NOx, is formed from high temperatures (> 2700 F) in the combustion zone and furnace. Simply stated, nitrogen in the atmospheric air used for combustion combines with oxygen at these high temperatures to form NOx. Thermal NOx can be affected exponentially by local temperatures and can be proportional to the square root of oxygen availability. The key to minimizing thermal NOx is to stage fuel/air mixing in a controlled way, using low NOx firing systems and overfire air, to minimize excessive combustion temperatures. Boiler design, in terms of heat transfer characteristics, also plays a major role in thermal NOx formation. For a retrofit application these design parameters are fixed by the boiler size and configuration, and cannot be easily changed. **In a typical coal fired utility boiler, approximately 20% to 40% of the total NOx comes from thermal NOx.**

2) **Fuel NOx**

Fuel NOx is formed during combustion of fuels (like coal) containing inherent fuel bound nitrogen. Fuel NOx is affected by the total percentage of nitrogen contained in the coal, but there are other equally important factors. The release rate (reactivity) of nitrogen from volatile fractions of the coal in the early stages of combustion, and the nitrogen release rate from the solid coal char (in the later stages of combustion) have a direct impact on NOx. Coal chemistry factors such as coal porosity and fuel oxygen to nitrogen ratio also influence NOx formation. In addition, Fuel NOx can be affected by local oxygen availability. Low NOx firing systems reduce, but cannot eliminate fuel NOx generated from coal types that have high fuel NOx characteristics. **In summary, coal chemical composition and physical properties all directly affect Fuel NOx, which typically represents approximately 60% to 80% of the total NOx from a coal fired utility boiler.**

3) **Prompt NOx**

Prompt NOx, also known as Fenimore NOx, is formed by fractionation of hydrocarbons (CH) in the presence of atmospheric nitrogen (N2) when combusting fuels. Complex interactions between CH and N2 form HCN and N, which can combine with atmospheric oxygen and evolve into additional NOx generated beyond thermal and fuel NOx mechanisms. **Prompt NOx is normally less than 5 % of total NOx in coal fired boilers** and can be controlled by optimized low NOx firing system design, as temperature and oxygen availability can affect hydrocarbon reaction rates.

This brief description of NOx formation fundamentals provides a simplistic overview of the NOx generation process. ALSTOM has a wide NOx experience base of over twenty years of R&D, including US Government-sponsored projects, as well as designing and providing commercial Low NOx firing systems. It is ALSTOM's position that these mechanisms interact in complex ways that are specific to each individual coal and boiler.

In the 1980's ALSTOM began developing NOx prediction tools and design methods for firing eastern U.S. bituminous coals in order to provide commercial guarantees to utilities mandated to comply with the Clean Air Act of 1990. Some of these predictive tools are laboratory based, while others are based on compilation and analysis of extensive field emissions data. In the 1990's, electric utility units east of the Mississippi installed low NOx systems in response to the Clean Air Act Amendments. Many of these units, particularly in the Midwest, have since converted to Powder River Basin (PRB) coals for economic or sulfur emissions reasons. In the late 1990's Texas regulations resulted in many PRB and lignite units being converted to low NOx firing. In addition to these units, other plants in Western states have or are in the process of implementing NOx controls. Many of these units are mine mouth units that fire coals that are unique to each unit. ALSTOM's predictive methodology has evolved over the years as the unit experience base and range of fuels tested has grown. These field experiences and further laboratory testing of Western fuels have proven to ALSTOM that NOx emissions can vary substantially between these differing Western coals.

Western Coal Analysis and ASTM Rank

Coal is a complex fuel with wide variations in chemical analysis, physical characteristics, and combustion reactivity. The American Society for Testing Materials (ASTM) has developed a system for generally classifying coals based on their heating value, volatile content, moisture, reactivity and other properties. Eastern U.S. coals (high volatile bituminous) tend to be high rank fuels with high heating values and low moisture. At the other end of the spectrum, U.S. lignite coals tend to be low rank, as their heating values are low, and moisture content high. Western U.S. coals, like Powder River Basin, tend to be categorized in the lower rank Subbituminous "C" range, while other Western fuels tend to be categorized as higher rank bituminous or subbitbuminous coals.

Coal from the Powder River Basin in Wyoming accounts for approximately 35% of the total coal production in the United States. Due to the significant amount of PRB fuel fired, ALSTOM has expended significant time and effort studying all aspects of the firing system and boiler effects from the combustion of these coals. It is important to note that there are different mines within the PRB region, each with its own unique properties. The main focus of ALSTOM's work on PRB coals has been on the mines south of Gillette, Wyoming, as these produce the largest volume of coal.

In the Western United States, the lignite fields in North Dakota and Texas combine to produce approximately 7% of the total coal mined in the US. Due to the high moisture and ash content, and subsequent low heating value, lignite is not economical to transport long distances. Therefore, all lignite is consumed relatively close to the mine source.

	E. bit.	Hi-vol B bit.	Hi-vol C bit.	Sub bit. A	Sub bit. B	Sub bit. C	TX Lignite
H_2O	5.00	6.28	13.12	14.09	25.00	27.30	33.06
VM	33.10	37.49	34.91	33.75	32.43	31.90	26.75
FC	53.50	46.35	45.78	37.58	38.23	36.40	27.47
Ash	8.40	9.88	6.19	14.58	4.00	4.40	12.72
Hydrogen	5.00	4.68	4.22	4.12	3.72	3.49	3.02
Carbon	71.70	67.70	61.58	55.70	53.88	51.18	39.45
Sulfur	1.30	0.48	0.36	0.48	0.34	0.21	1.99
Nitrogen	1.60	1.38	1.23	0.98	0.72	0.73	0.67
Oxygen	7.10	9.60	13.30	10.05	12.32	12.71	9.09
HHV	12959	12000	10861	9674	9350	8800	6935
FC/VM	1.62	1.24	1.31	1.11	1.18	1.14	1.03
HHVdaf	14964	14313	13461	13562	13169	12884	12790
lb S/mmBtu	1.00	0.40	0.33	0.50	0.36	0.24	2.87
lb N/mmBtu	1.23	1.15	1.13	1.01	0.77	0.83	0.97
Ash Load	6.5	8.2	5.7	15.1	4.3	5.0	18.3

Table 1 - Typical Coal Analysis

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There are also locally significant coal fields in Utah, Colorado, Montana, Wyoming, New Mexico, and Arizona. These fuels are also not transported as far as the coal from the Southern PRB. These coals rank between subbituminous A, B, and C and high volatile bituminous B and C. Combined, these six states account for approximately 15% of the total coal production in the US. Typical fuel analyses of various domestic ASTM ranked coals are shown in Table 1.

The coals fired at Jim Bridger Station are generally classified (ranked) by ASTM Standards as Western Sub-Bituminous "B" and "C" coals as seen on the attached Coal Classification Chart. Coals fired at Huntington Canyon are generally ranked as high volatile "B" or "C" bituminous. Coals at Naughton are typically ranked as sub bituminous "B". The coals fired at Hunter Station are classified as High Volatile Bituminous "B" and "C". Typical coal analyses are attached in Table 2 below.

	Hunter	**Huntington Canyon**	**Bridger**	**Naughton 1&2**	**Naughton 3**
H_2O	8.56	9.95	19.1	20.8	21.1
VM	36.74	35.39	30.1	34.2	34.1
FC	44	47.11	40.4	40.6	39.7
Ash	10.71	7.55	10.1	4.5	5.2
Hydrogen	4.58	4.48	3.5	4.04	3.95
Carbon	64.12	65.3	54	56.87	55.78
Sulfur	0.4	0.33	0.6	0.56	1.1
Nitrogen	1.15	1.04	1.1	1.03	1.03
Oxygen	10.44	11.35	11.4	12.2	11.84
HHV	11489	11499	9428	10012	9900
FC/VM	1.2	1.33	1.34	1.19	1.15
HHV daf	14231	13938	13373	13403	13495
Ash Load	9.3	6.6	10.7	4.49	5.28

Table 2 - Coals Fired at PacifiCorp Stations

Several of the Pacificorp stations, such as Jim Bridger, are mine mouth plants and fire coals that are unique to those units. These coals have very limited distribution outside of the specific plants, and as such, there are no operating low NOx systems firing these coals. Supporting data detailing the limited distribution of these coals is provided in the Appendix of this paper.

Comparing the above PacifiCorp coal analysis to that of the well-studied Power River Basin coals, it can be generally stated that these coals tend to be somewhat higher rank than PRB coals. It is expected that these fuels have somewhat different combustion characteristics than PRB coals.

Influence of Coal Analysis and Rank on NOx

Since over 60% of total stack NOx can be attributed to fuel NOx, ALSTOM's Power Plant Laboratory has studied the conversion of fuel bound nitrogen to NOx, as a function of fuel type and Burner Zone Stoichiometry. Burner Zone Stoichiometry is the ratio of combustion air admitted to the furnace versus the theoretical amount of air required for complete combustion. Most units are designed to operate between 1.14 and 1.25 stoichiometry, where 1.0 is the theoretical amount of air required for combustion. When operating for low NOx the Burner Zone Stoichiometry is reduced by the air staged through the Separated Overfire Air (SOFA) system. Aggressive low NOx firing systems typically are typically designed to operate with Burner Zone Stoichiometries less than theoretical (1.0).

This testing clearly showed the influence of both fuel type and stoichiometry on NOx emissions as illustrated in Figure 1. As expected, as the stoichiometry decreases the percentage of the fuel bound nitrogen converted to NOx decreases. This testing also shows the trend that as the fuel rank decreases, the rate at which the fuel nitrogen converts to NOx also decreases.

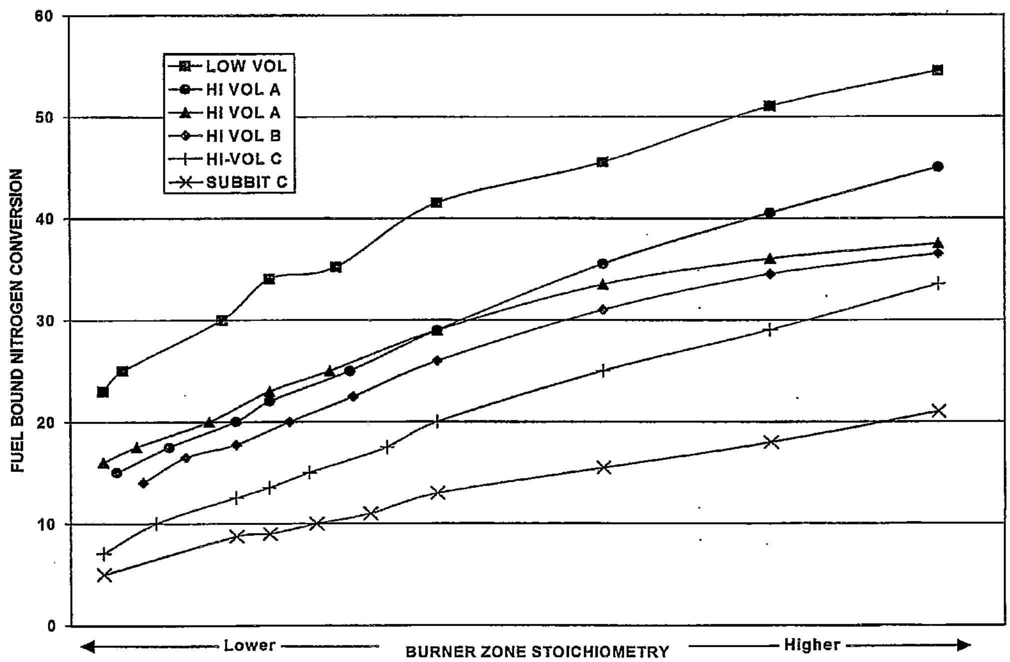

Figure 1 - Nitrogen Conversion to NOx

Subsequent testing in the laboratory identified some of the key characteristics of the coals and mechanisms for this nitrogen conversion efficiency. In general, the lower the fuel rank, , the faster the coal is devolatilized and the faster the fuel bound nitrogen is released. Based on the chemical kinetics under staged conditions, nitrogen preferentially bonds together to

form inert molecular nitrogen N_2 instead of NO or NO_2. Therefore, the more nitrogen that can be released earlier in the combustion process, the lower the NOx emissions can be. Low rank coals show favorable behavior with regard to greater fuel nitrogen release during the devolatilization phases of the combustion process; this is conducive to greater NOx reduction. This is one of the reasons coals like PRB tend to react favorably to staged combustion, producing some of the lowest levels of NOx observed on U.S. coals.
The PacifiCorp coals tend to be higher rank than typical PRB coals. As such, they will have less fuel nitrogen released during devolatilization, and thus will have somewhat higher NOx than true PRB coals when fired under low NOx staged conditions.

A second major factor in fuel NOx is related to how the fuel bound nitrogen evolves from the solid coal char that is produced once the volatile component of the coal is combusted. Generally speaking, approximately 20-40% of the Fuel NOx can source from fuel bound nitrogen associated with the solid char. Control of NO from this char nitrogen component cannot be directly controlled by air staging since under staged low NOx combustion (reducing or pyrolysis conditions), char nitrogen conversion to NO remains relatively constant. Typically, lower rank (more reactive) fuels have more fuel bound nitrogen associated with the volatiles than the char, so low rank coals overall have the lowest NOx potential.

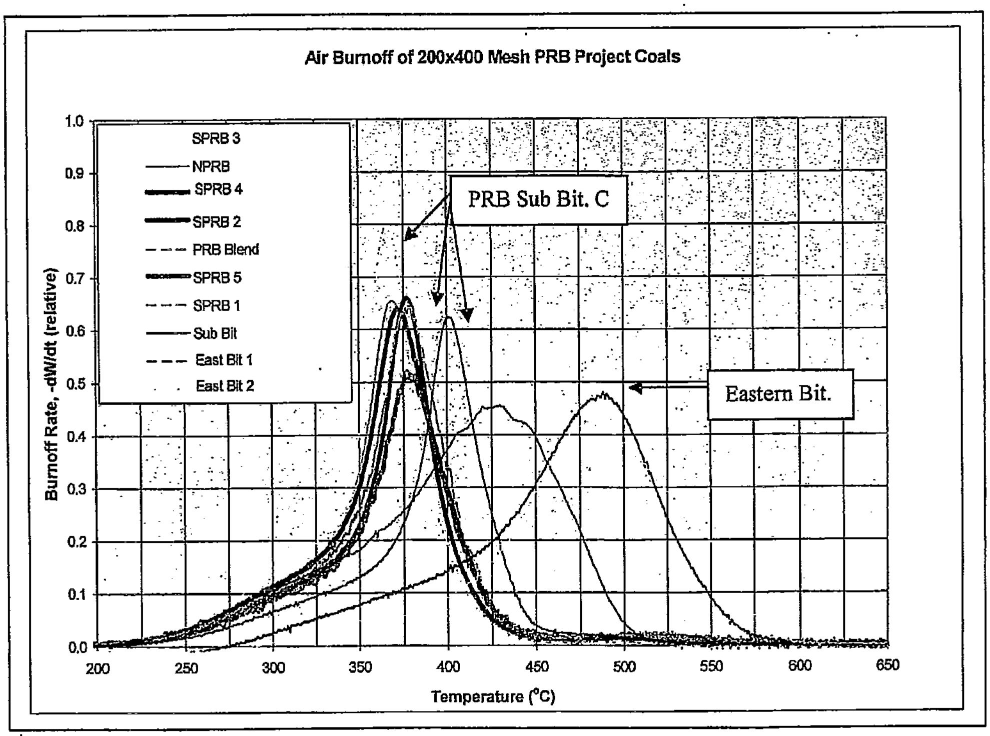

Figure 2 - Air Burnoff of PRB Coals and Reference Coals

In order to better understand how fuel bound nitrogen in both the volatile and char components of different rank coals affects total NOx reduction potential, coals and their char components are tested in a laboratory instrument known as the Thermal Gravimetric Analyzer, or TGA. Under this analysis the burn-off rate (change in weight/unit time) for various coals or coal chars can be shown as a function of temperature. An example of a TGA analysis for a wide variety of coals in shown in Figure 2. As can be seen, all of the PRB coals tested have similar rapid burn-off rates as compared to bituminous coals. This indicates that low rank PRB coals potentially have high volatile fuel nitrogen conversion rates and therefore lower NOx potential as compared to high rank Eastern bituminous coals. The performance of the PacifiCorp coals tends to fall between the PRB coals and Eastern bituminous coals shown. This would support the conclusion that the PacifiCorp coals have a NOx reduction potential well below Eastern bituminous coals, but not as low as true Powder River Basin coals.

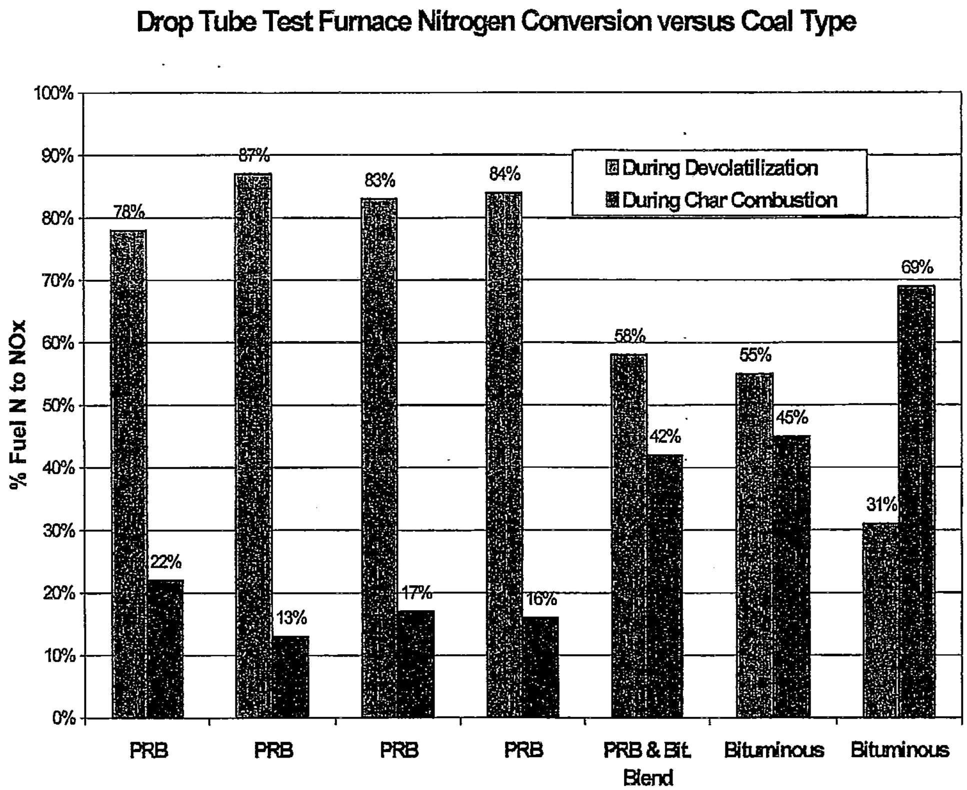

Figure 3 - Fuel Nitrogen Conversion During Coal Devolatilization and Coal Char Combustion versus Coal Type.

This conclusion is supported by additional ALSTOM laboratory data shown in Figure 3. Testing in ALSTOM's bench scale Drop Tube Furnace can determine the relative percentage of fuel bound nitrogen converted to NOx in both the devolatilization and char phases of combustion. It is clear that PRB coals can have greater than 78% of fuel bound nitrogen converted to NOx during devolatilization, which is far greater than that measured for bituminous coals. As a result of these observations, the performance of the PacifiCorp coals, in terms of total fuel NOx emissions would tend to fall between the PRB coals and Eastern bituminous coals shown.

As mentioned earlier, NOx formed by fixation of atmospheric nitrogen to oxygen (thermal NOx) is the other main component of total NOx emissions for a boiler. The other two primary factors are unit design and operating procedures, and are therefore very unit specific. Unit design affects both the residence time of the combustion process, as well as the thermal aspects of combustion. Unit design determines how "hot" a furnace is, which influences the thermal NOx contribution for both the baseline and post-retrofit NOx emissions. From its extensive retrofit experience, ALSTOM developed a series of thermal NOx prediction methodologies based on the physical unit dimensions and the thermal conditions firing Eastern and Midwestern fuels. These site-specific predictive methodologies are used in combination with the fuel NOx prediction methodologies described above to make overall stack NOx emission predictions and commercial guarantees.

Field Experience with Western U.S. Coals

To date, ALSTOM has retrofitted over 50 units firing Western U.S.coals since 1995. Tangentially fired units burning low rank fuels consistently produce the lowest NOx emissions levels in the country on a yearly basis.

Figure 4 shows the experience on coals from the West that rank either as high volatile bituminous B or C or as subbituminous B coals. The coals that PacifiCorp is currently firing generally fall in these categories. Considering the data presented in Figure 4, the NOx emission levels of the PacifiCorp coals will be higher than those of PRB coals.

A recently published ALSTOM technical paper on Western coal firing experience is attached in the Appendix section of this paper. This technical paper was presented at the EERC Western Fuels Symposium in 2004.

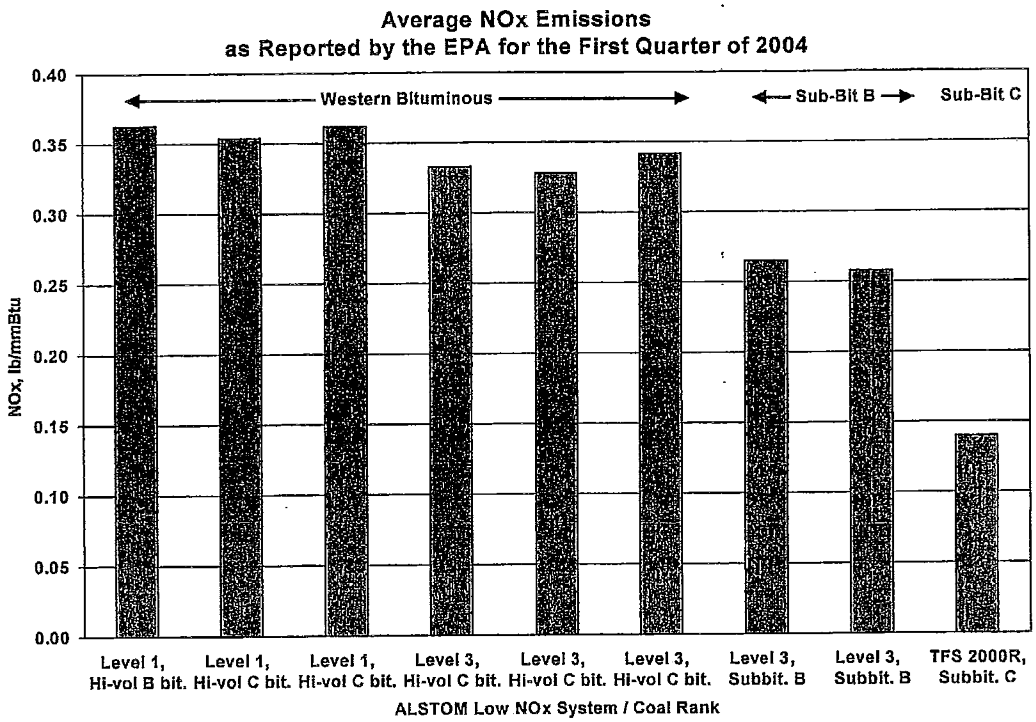

Figure 4 – ALSTOM Experience on Western high volatile bituminous B and C, and subbituminous B

CONCLUSIONS

Both laboratory data and field experience indicate that Western low rank fuels are conducive to low NOx firing. The laboratory data from carefully controlled small scale experiments has documented that the lower rank subbituminous C (PRB) and lignite coals typical of the West will generate low NOx due to the high volatility and quick yield of fuel bound nitrogen. The field experiences from these fuels match the predictions from the laboratory data. Based on ALSTOM's experience to date, most other Western bituminous coals such as those fired by PacifiCorp will produce NOx levels somewhere between PRB coals and Eastern bituminous coals.

APPENDIX

List of Contents

A. PacifiCorp Coal Supply Data
B. *"ALSTOM's Low NOx Firing Experience on Western Fuels"*, Jennings, Patrick and Hart, Doug. Presented at EERC Western Fuels Symposium, 2004

A PacifiCorp Coal Supply

The PacifiCorp units that are located in Wyoming and Utah include the following sites with ALSTOM "Tangential –fired" boilers:

Wyoming Units
Dave Johnston Station
Jim Bridger Station
Naughton Station

Utah Units
Carbon Station
Hunter Station
Huntington Canyon Station

The coals fired at the Jim Bridger and Naughton Stations are classified as Sub-Bituminous "B" coals while the coals fired at Dave Johnston Station as Sub-Bituminous "C" form the Powder River Basin. The coals fired at Carbon, Hunter and Huntington Canyon Stations are classified as high Volatile "C" to high Volatile "B" Bituminous coals.

The coal data below is from "*RDI – Coal.dat*" (U.S. Plants and Coal Sources). This data will show that Jim Bridger Station and Naughton Station are the prominent users of the coals that are fired at these stations, while the other units fire coals that are used at multiple locations.

Jim Bridger Station

The coal that has been fired at Jim Bridger Station since 2000 comes from the following mines in Sweetwater County, WY:

Jim Bridger
Black Butte & Leucite Hills

The other plants that have received coal form these mines are:

Naughton Station - 454,000 tons in 2000
North Valmy Station – 68,000 tons in 2001

Naughton Station

The coal that has been fired at Naughton Station since 2000 comes from the following mines in Lincoln County, WY and Sweetwater County, WY:

Kemmerer (Elkol & Sorenson)
Black Butte & Leucite Hills – 454 tons in 2000.

No other plants are listed as receiving coal from the mines in Lincoln County, WY

Carbon Station

The coal that has been fired at Carbon Station since 2000 comes from the following mines in Emery County, Carbon and Sevier Counties in UT:

Deer Creek (C)
Crandall Canyon
Bear Canyon No. 2
Bear Canyon No. 1
Sufco
Skyline No. 3
Dug Out
Whiskey Creek (Synfuel)
West Ridge

The other plants that have received 50,000 or more tons of coal from these mines from 2000 or later are:

Hunter – PacifiCorp (UT)*
Huntington Canyon – PacifiCorp (UT)*
Grand River Terminals –TVA (IL)
Asbury – Empire District Electric Co. (MO)
Cora Transfer Terminal – TVA (IL)
Genoa – Dairyland Power Coop (WI)*
Intermountain Generating – Los Angeles Dept. of Water and Power (UT)
Sibley – Aquila (MO)
Boardman – Portland General Electric – (OR)
ACE Cogeneration – Ace Cogeneration Co. (CA)
Argus – IMC Chemicals – (CA)*
Edgewater – Wisconsin Power & Light – (WI)
Gardner – Nevada Power Co. – (NV)
Michigan City – Northern Indiana Public Service Co. - (IN)
North Valmy – Sierra Pacific Power Co. – (NV)
Stockton CoGen Co. – Air Products & Chemicals, Inc. - (CA)
Alma - Dairyland Power Coop - (WI)
J.P. Madgett - Dairyland Power Coop – (WI)
Manitowoc – Manitowoc Public Utilities – (WI)
Mount Poso Cogeneration – Mount Poso Cogeneration (CA)

Hunter Station

The coal that has been fired at Hunter Station since 2000 comes from the following mines in Emery County, Carbon and Sevier Counties in UT:

Deer Creek (C)
Trail Mountain
Dug Out
Sufco
West Ridge

The other plants that have received 50,000 or more tons of coal from these mines from 2000 or later are:

Carbon Station – PacifiCorp (UT)*
Huntington Canyon Station – PacifiCorp (UT)*
Grand River Terminals –TVA (IL)
Asbury Station – Empire District Electric Co. (MO)
Cora Transfer Terminal – TVA (IL)
Genoa Station – Dairyland Power Coop (WI)*
Intermountain Generating – Los Angeles Dept. of Water and Power (UT)
Sibley Station – Aquila (MO)
Boardman Station – Portland General Electric – (OR)
ACE Cogeneration – Ace Cogeneration Co. (CA)
Argus – IMC Chemicals – (CA)*
Edgewater Station – Wisconsin Power & Light – (WI)
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J.P. Madgett - Dairyland Power Coop – (WI)
Manitowoc – Manitowoc Public Utilities – (WI)
Mount Poso Cogeneration – Mount Poso Cogeneration (CA)

Huntington Canyon Station

The coal that has been fired at Huntington Canyon Station since 2000 comes from the following mines in Emery County, Carbon and Sevier Counties in UT:

Deer Creek (C)
Emery
Dug Out
Sufco
West Ridge

The other plants that have received 50,000 or more tons of coal from these mines from 2000 or later are:

Carbon Station – PacifiCorp (UT)*
Hunter Station – PacifiCorp (UT)*
Grand River Terminals –TVA (IL)
Asbury Station – Empire District Electric Co. (MO)
Cora Transfer Terminal – TVA (IL)
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Manitowoc – Manitowoc Public Utilities – (WI)
Mount Poso Cogeneration – Mount Poso Cogeneration (CA)

* ALSTOM, Inc. - "Tangential-fired" units

Dave Johnston Station

The coal fired at Dave Johnston Station is a sub-bituminous coal from the Powder River Basin (PRB). This coal is fired at numerous units that fire the coals from the PRB region:

Dave Johnston receives coal from the following mines since the year 2000:

Black Thunder
Coal Creek
Cordero (Caballo Rojo)
Dave Johnston
Dry Fork
Wyodak
Jacobs Ranch
Caballo
Buckskin
Rawhide

There are many units that fire coals from the PRB region.

Coal Quality and Nitrogen Oxide Formation

Nitrogen Oxide (NOx) formation in coal-fired boilers is a complex process that is dependant on a number of variables, including operating conditions, equipment design, and coal characteristics.

Coal Combustion

During coal combustion, NO_x is formed in three different ways, fuel NOx, thermal NOx, and prompt NOx. The dominant source of NO_x formation (approximately 60% to 80%) is the oxidation of fuel-bound nitrogen (fuel NO_x). The amount of nitrogen contained in the coal directly impacts the amount of fuel NOx formed. During combustion, part of the fuel-bound nitrogen is released from the coal with the volatile matter, and part is retained in the solid portion (char). The nitrogen chemically bound in the coal is partially oxidized to nitrogen oxides (NO and NO_2) and partially reduced to molecular nitrogen (N_2). The release rate of nitrogen from the volatile fractions of the coal in the early stages of combustion and the release of nitrogen in the char portion later in the combustion process also impact NOx formation. In addition, the availability of oxygen in the combustion air to combine with nitrogen affects fuel NOx formation.

A smaller part of NO_x formation (20% to 40%) is due to high temperature fixation of atmospheric nitrogen in the combustion air (thermal NO_x). Thermal NOx can be affected exponentially by local temperatures and can be proportional to the square root of oxygen availability.

A very small amount of NO_x (< 5 %) is called "prompt" NO_x. Prompt NO_x results from an interaction of hydrocarbon radicals, nitrogen, and oxygen.

In a conventional pulverized coal burner, air is introduced with turbulence to promote good mixing of fuel and air, which provides stable combustion. However, not all of the oxygen in the air is used for combustion. Some of the oxygen combines with the fuel nitrogen to form NO_x. Low NOx burners (LNBs) in combination with overfire air (OFA) are designed to reduce the amount of air introduced during initial combustion when the volatiles are driven off and introduce air downstream to combust the remaining unburned char. Hence, LNBs result in less conversion of fuel-bound nitrogen to NOx and lower combustion temperatures limiting thermal NOx. In addition, lower temperatures and oxygen availability can reduce hydrocarbon reaction rates resulting in less prompt NOx formation. For retrofit of existing boilers, boiler size and configuration can limit the effectiveness of LNBs and OFA.

Coal Ranking

Coal ranking is a means of classifying coals according to their degree of metamorphism in the natural series, from lignite to subbituminous to bituminous and on to anthracite.

The American Society for Testing Materials (ASTM) has developed a system for for generally classifying coals based on their heating value, volatile content, moisture, reactivity and other properties. Eastern U.S. coals (high volatile bituminous) tend to be high rank fuels with high heating values and low moisture. At the other end of the spectrum, U.S. lignite coals tend to be low rank, as their heating values are low, and moisture content high. Western U.S. coals, like Powder River Basin (PRB), tend to be categorized in the lower rank Subbituminous "C" range, while other Western fuels tend to be categorized as higher rank bituminous or subbituminous coals. Figure 1 shows the criteria for ASTM's coal rankings.

Table 3
Classification of Coals by Rank[a] (ASTM D 388)

Class	Group	Fixed Carbon Limits, % (Dry, Mineral-Matter-Free Basis): Equal or Greater Than	Fixed Carbon Limits, % (Dry, Mineral-Matter-Free Basis): Less Than	Volatile Matter Limits, % (Dry, Mineral-Matter-Free Basis): Greater Than	Volatile Matter Limits, % (Dry, Mineral-Matter-Free Basis): Equal or Less Than	Calorific Value Limits, Btu/lb (Moist,[b] Mineral-Matter-Free Basis): Equal or Greater Than	Calorific Value Limits, Btu/lb (Moist,[b] Mineral-Matter-Free Basis): Less Than	Agglomerating Character
I. Anthracitic	1. Meta-anthracite	98	—	—	2	—	—	Nonagglomerating
	2. Anthracite	92	98	2	8	—	—	
	3. Semianthracite[c]	86	92	8	14	—	—	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	—	—	Commonly agglomerating[e]
	2. Medium volatile bituminous coal	69	78	22	31	—	—	
	3. High volatile A bituminous coal	—	69	31	—	14,000[d]	—	
	4. High volatile B bituminous coal	—	—	—	—	13,000[d]	14,000	
	5. High volatile C bituminous coal	—	—	—	—	11,500	13,000	
						10,500[e]	11,500	Agglomerating
III. Subbituminous	1. Subbituminous A coal	—	—	—	—	10,500	11,500	Nonagglomerating
	2. Subbituminous B coal	—	—	—	—	9,500	10,500	
	3. Subbituminous C coal	—	—	—	—	8,300	9,500	
IV. Lignitic	1. Lignite A	—	—	—	—	6,300	8,300	
	2. Lignite B	—	—	—	—	—	6,300	

[a]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high volatile bituminous and subbituminous ranks. All of these coals either contain less than 48% dry, mineral-matter-free Btu/lb.

[b]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c]If agglomerating, classify in low volatile group of the bituminous class.

[d]Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile C bituminous group.

Figure 1 – Coal Classification

Most coals from the PRB are classified as subbituminous C and demonstrate high reactivity and low NO_x production characteristics. Based on data from the Energy Information Administration (EIA), PRB coals currently represent 88 percent of total U.S. subbituminous production and 73 percent of western coal production. Most references to "western "coal and subbituminous coal infer PRB origin and characteristics. Emissions standards differentiating between bituminous and subbituminous coals are presumed to use PRB coal as the basis for the subbituminous standards, due to their dominant market presence and unique characteristics.

Coal Characteristics

Coal characteristics directly and significantly affect NO_x emissions from coal combustion and play an important role in the ability to design and operate LNBs and OFA systems. As previously discussed, of paramount significance is the ability to control the introduction of air into the burner zone. Burner Zone Stoichiometry is the ratio of combustion air admitted to the furnace versus the theoretical amount of air required for complete combustion. Most units are designed to operate between 1.14 and 1.25 stoichiometry, where 1.0 is the theoretical amount of air required for combustion. When operating for low NOx the Burner Zone Stoichiometry is reduced by the air staged through the OFA system. Aggressive low NOx firing systems typically are typically designed to operate with Burner Zone Stoichiometries less than theoretical (1.0).

Tests run by the boiler manufacturer ALSTOM showed the influence of both fuel type and stoichiometry on NOx emissions as illustrated in Figure 2 below. As expected, as the stoichiometry decreases the percentage of the fuel bound nitrogen converted to NOx decreases. This testing also shows the trend that as the fuel rank decreases, the rate at which the fuel nitrogen converts to NOx also decreases.

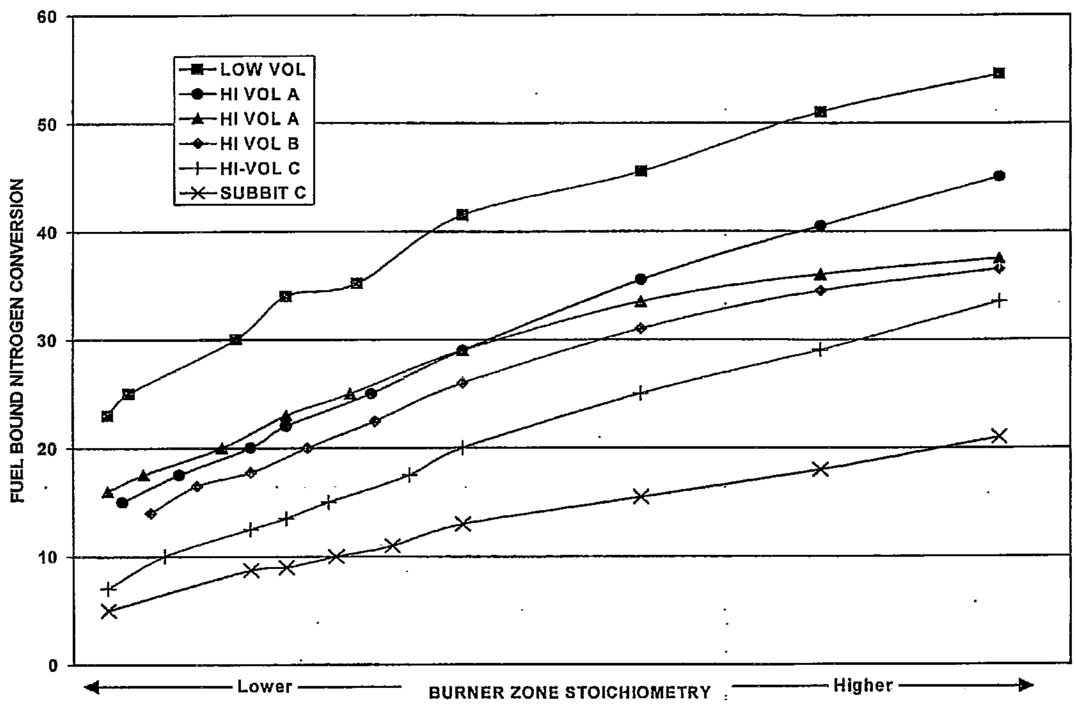

Figure 2 - Nitrogen Conversion to NOx

Subsequent testing in ALSTOM's laboratory identified some of the key characteristics of the coals and mechanisms for this nitrogen conversion efficiency. In general, the lower the fuel rank, the faster the coal is devolatilized and the faster the fuel bound nitrogen is released. Based on the chemical kinetics under staged conditions, nitrogen preferentially bonds together to form inert molecular nitrogen N_2 instead of NO or NO_2. Therefore, the more nitrogen that can be released earlier in the combustion process, the lower the NOx emissions can be. Low rank coals show favorable behavior with regard to greater fuel nitrogen release during the devolatilization phases of the combustion process; this is conducive to greater NOx reduction. This is one of the reasons coals like PRB tend to react favorably to staged combustion, producing some of the lowest levels of NOx observed on U.S. coals.

The coals used at Bridger and Naughton tend to be higher rank than typical PRB coals. As such, they will have less fuel nitrogen released during devolatilization, and thus will have somewhat higher NOx than true PRB coals when fired under low NOx staged conditions.

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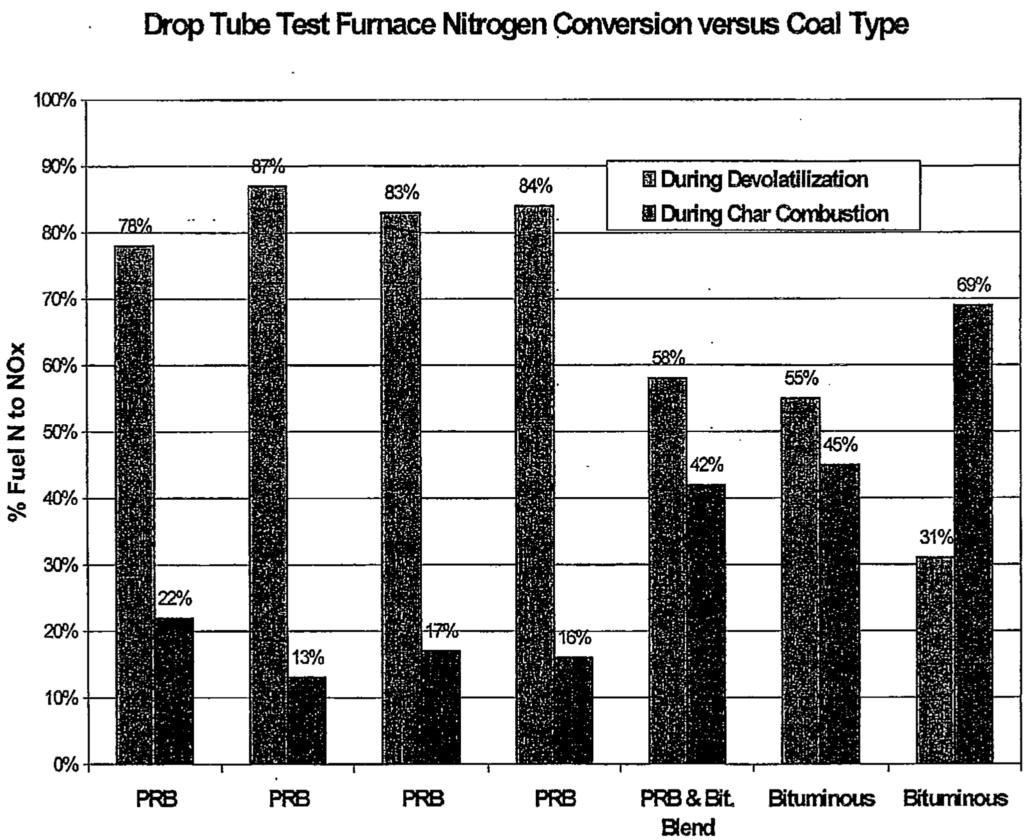

Figure 3 - Fuel Nitrogen Conversion During Coal Devolatilization and Coal Char Combustion versus Coal Type.

This conclusion is supported by additional ALSTOM laboratory data shown in Figure 3. Testing in ALSTOM's bench scale Drop Tube Furnace can determine the relative percentage of fuel bound nitrogen converted to NOx in both the devolatilization and char phases of. combustion. It is clear that PRB coals can have greater than 78% of fuel bound nitrogen converted to NOx during devolatilization, which is far greater than that measured for bituminous coals. As a result of these observations, the performance of the Bridger and Naughton coals, in terms of total fuel NOx emissions would tend to fall between the PRB coals and Eastern bituminous coals shown.

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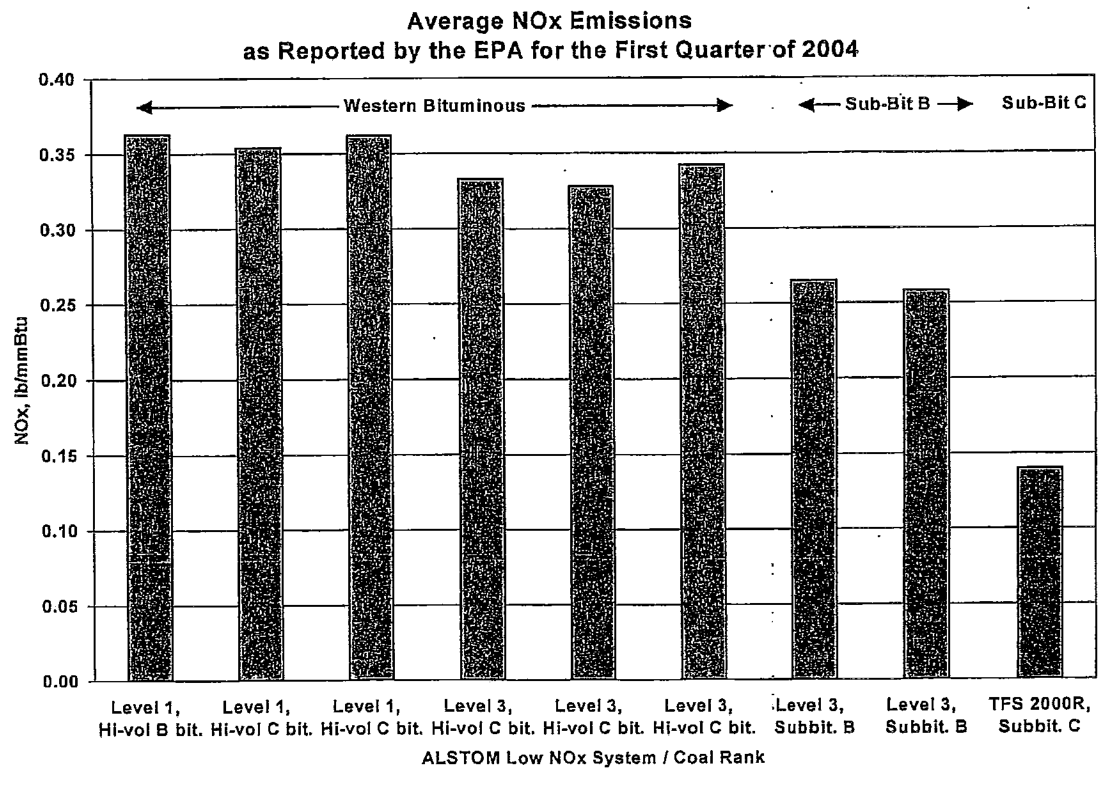

Figure 4 – ALSTOM Experience on Western high volatile bituminous B and C, and subbituminous B

As discussed above, there are a number of western coals that are classified as subbituminous, however, they border on being ranked as bituminous and do not display many of the qualities of PRB coals including most of the low NO_x forming characteristics. The coals from the Bridger, Black Butte, Leucite Hills, and Naughton mines fall into this category.

As defined by ASTM, the only distinguishing characteristic that classifies the coals used at Jim Bridger and Naughton as subbituminous rather than bituminous – that is, they are "non-agglomerating" as compared to "agglomerating". While each of these coals is considered non-agglomerating, they either do not exhibit those properties of non-agglomerating coals or exhibit them to only a minor degree. Agglomerating as applied to coal is "the property of softening when it is heated to above about 400° C in a non-oxidizing atmosphere, and then appearing as a coherent mass after cooling to room temperature." Since the agglomerating property of coals is the result of particles transforming into a plastic or semi-liquid state when heated, it reflects a change in surface area of the particle. As shown by Figure 5, the increased porosity provides more particle surface area resulting in more favorable combustion conditions. This non-agglomerating property assists in making subbituminous coals more amenable to controlling NO_x by allowing less air to be introduced during the initial ignition portion of the combustion process.

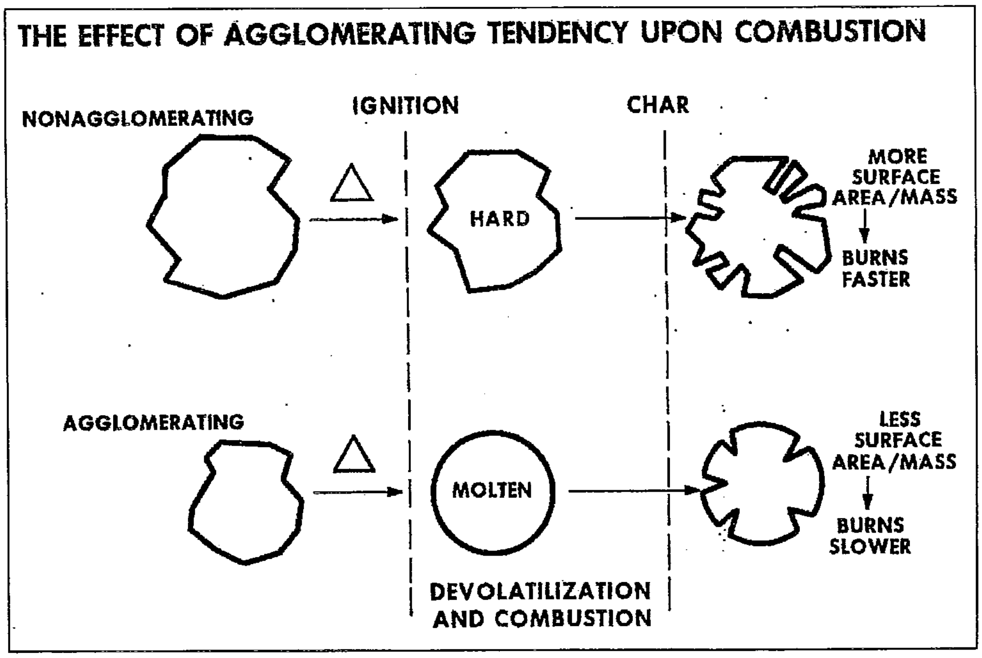

FIGURE 5 -ILLUSTRATION OF THE EFFECT OF AGGLOMERATION ON THE SPEED OF COAL COMBUSTION

Table 1 compares key NOx forming characteristics of the Bridger Mine, Black Butte, Leucite Hills, Naughton, a typical PRB coal, and Twentymile, a representative western bituminous coal.

Parameter	PRB	Bridger Mine	Black Butte	Leucite Hills	Naughton	Twentymile
Nitrogen (% dry)	1.10	1.26	1.47	1.48	1.24	1.85
Oxygen (% dry)	16.2	13.2	13.4	13.2	15.4	7.19
Moisture (%)	27.3	19.1	20.7	19.0	20.9	9.85
Coal rank	Sub C	Sub A	Sub A	Sub A	Sub A	Bit high vol B

Table1 – NOx Characteristics Comparison

As shown in Table 1, although Bridger, Black Butte, Leucite Hills, and Naughton are classified as subbituminous, they all exhibit higher nitrogen content, lower moisture content, and lower oxygen content than the PRB coal. The higher nitrogen content is an indication that more nitrogen is available to the combustion process and higher NO_x emissions are likely. Oxygen content can be correlated to the reactivity of the coal with more reactive coals – generally containing higher levels of oxygen. As previously stated, more reactive coals tend to produce lower NO_x emissions and are also more conducive to reduction of NO_x emissions, through use of combustion control measures such as LNBs and OFA. These characteristics indicate that higher NO_x formation is likely with Bridger, Black Butte, Leucite Hills, and Naughton rather than with PRB coal. The Bridger, Black Butte, Leucite Hills and Naughton coals all contain quality characteristics that fall between a typical PRB coal and Twentymile, a clearly bituminous coal that produces higher NO_x – as has been demonstrated at power plants burning Twentymile coal.

Using Jim Bridger 2 for illustrative purposes, Figures 6 and 7 graphically illustrate the relationship of nitrogen and oxygen content to related BART presumptive NO_x limits for the coals listed in Table 1. Twentymile is used to graphically illustrate achievement of the BART presumptive NO_x limit for a bituminous coal and the PRB coal corresponds to the subbituminous BART presumptive NO_x limit. The Bridger blend consists of a representative combination of coals from the Bridger Mine, Black Butte, and Leucite Hills that has been used at Jim Bridger 2, and indicates the average NO_x emission rate achieved during 2003-2005. Jim Bridger 2 represents the NO_x emission rate achieved after installation of ALSTOM's current state of the art TFS2000 LNB and OFA System. This NO_x emission level of 0.28 lb/MMBtu corresponds to the BART presumptive limit for bituminous coal and underscores the difference in ability to reduce NO_x while burning non-PRB subbituminous coals such as those from the Bridger Mine.

Figures 6 and 7 both demonstrate that with the TFS2000 low NO_x emission system installed and burning a combination of the Bridger, Black Butte, and Leucite Hill coals, the likely NO_x emission rate will be closer to the bituminous end (0.28) of the BART presumptive NO_x limit range than to the BART presumptive NO_x limit of 0.15 lb/MMBtu.

Jim Bridger 2

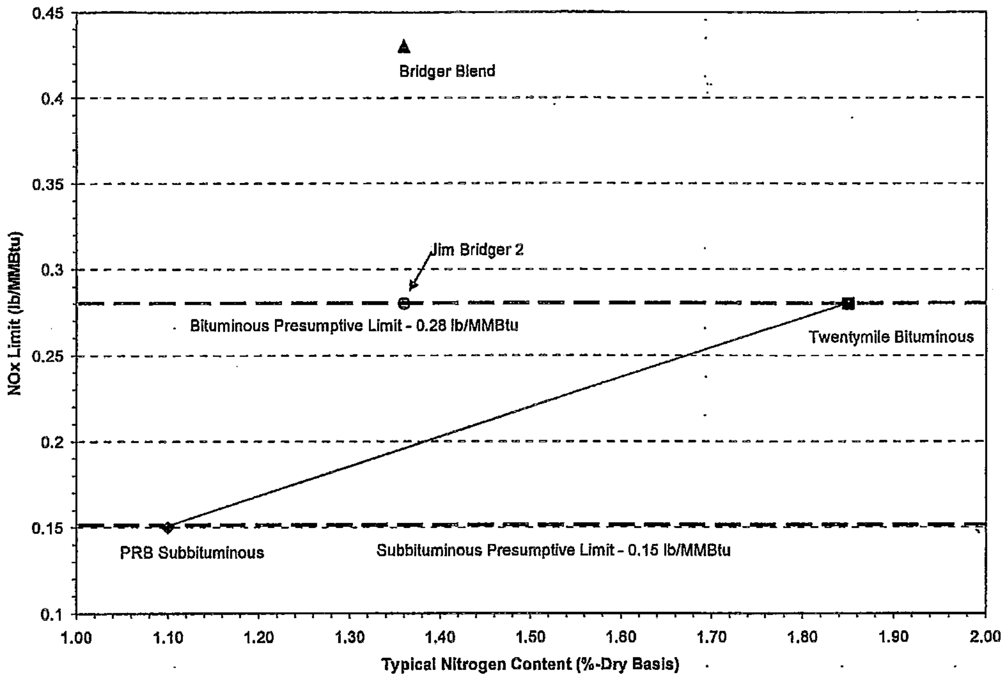

FIGURE 6

Plot of Typical Nitrogen Content of Various Coals and Applicable Presumptive BART NOx Limits

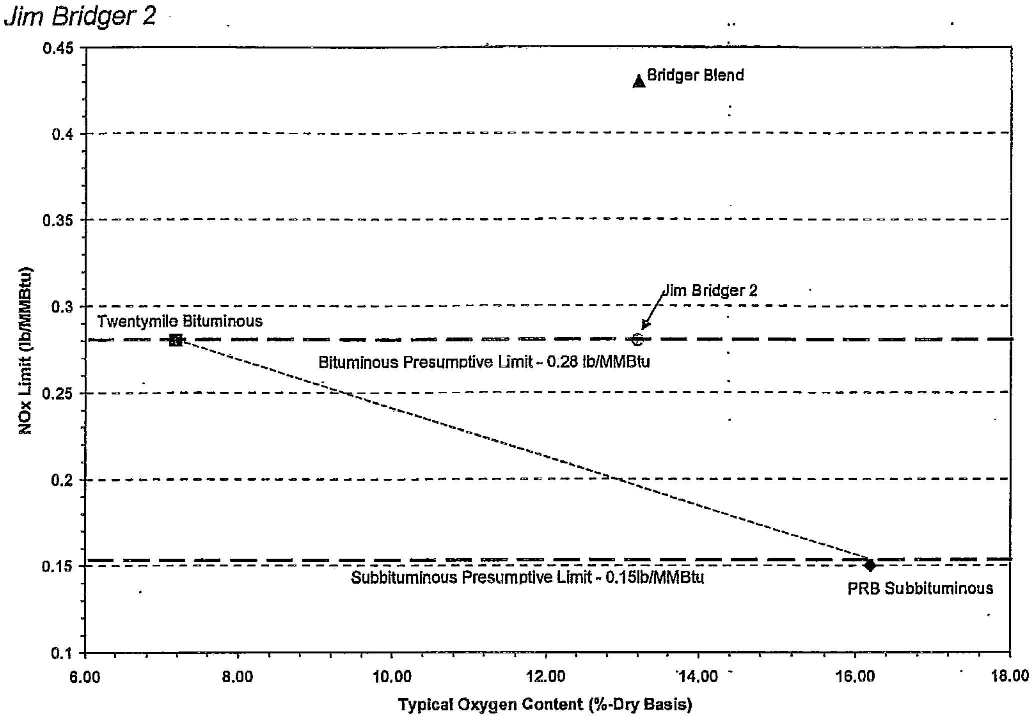

FIGURE 7

Plot of Typical Oxygen Content of Various Coals and Applicable Presumptive BART NO_x Limits

Coal quality characteristics also impact the design and operation of the boiler and associated auxiliary equipment. Minor changes in quality can sometimes be accommodated through operational adjustments or changes to equipment. It is important to note, however, that consistent variations in quality or assumptions of "average" quality for performance projections can be problematic. This is particularly troublesome when dealing with performance issues that are very sensitive to both coal quality and combustion conditions, such as NO_x formation. There is significant variability in the quality of coals burned at Jim Bridger and Naughton. For example, n addition to burning coal from Black Butte and Leucite Hills, Jim Bridger burns coal supplied from the Bridger Mine consisting of three sources: underground, surface, and highwall operations. Each of these coal sources has different quality characteristics as well as inherent variability.

Several of the coal quality characteristics and their effect on NO_x formation have been previously discussed. There are some additional considerations that illustrate the complexity of achieving and maintaining low NO_x emissions with pulverized coal on a consistent shorter term, such as a 30-day rolling average basis.

Good combustion is based on the "three Ts": time, temperature and turbulence. These parameters along with a "design" coal are taken into consideration when designing a boiler and associated firing equipment such as fans, burners, and pulverizers. If a performance requirement such as NO_x emission limits is subsequently changed, conflicts with other performance issues can result.

Jim Bridger is located at an altitude of 6,669 feet above sea level and Naughton is at an elevation of 6,396 feet above sea level. At these elevations, atmospheric pressure is lower (11.5 pounds per square inch) as compared with sea level pressure of 14.7 pounds per square inch. This lower pressure means that less oxygen is available for combustion for each volume of air. In order to provide adequate oxygen to meet the requirements for efficient combustion, larger volumes of air are required. When adjusting air flows and distribution to lower NO_x using LNBs and OFA, original boiler design restrictions again limit the modifications that can be made and still achieve satisfactory combustion performance.

Another significant factor in controlling NO_x emissions is the fineness of the coal entering the burners. Fineness is influenced by the grindability index (Hardgrove) of the coal. Finer coal particles promote release of volatiles and assist char burnout due to more surface area exposed to air. NO_x reduction with high volatile coals is improved with greater fineness and with proper air staging. The lower rank subbituminous coals such as PRB coals are quite friable and easy to grind. Coals with lower Hardgrove Grindability Index values, such as those used at Jim Bridger and Naughton are more difficult to grind and can contribute to higher NO_x levels. In addition, coal fineness can deteriorate over time periods between pulverizer maintenance and service as pulverizer grinding surfaces wear.