Final Report

BART Analysis for Wyodak

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Executive Summary

In response to the Regional Haze Rule and Best Available Retrofit Technology (BART) regulations and guidelines, CH2M HILL was requested to perform a BART analysis for PacifiCorp's Wyodak plant (hereafter referred to as Wyodak). A BART analysis has been conducted for the following criteria pollutants: nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10}). The Wyodak station consists of one unit with a total generating capacity of 335 megawatts (MW). Therefore, the presumptive BART limits do not apply to Wyodak. However, they are being referenced in this analysis, based on the United States Environmental Protection Agency's (EPA) guidelines for units greater than 200 MW. BART emissions limits must be achieved within 5 years after the State Implementation Plan (SIP) is approved by the EPA, and a compliance date of 2014 was assumed for this analysis.

In completing the BART analysis, technology alternatives were investigated and potential reductions in NO_x, SO_2, and PM_{10} emissions rates were identified. The following technology alternatives were investigated, listed below by pollutant:

- NO_x emission controls:
  - Low-NO_x burners (LNBs) with over-fire air (OFA)
  - Rotating opposed fire air (ROFA)
  - LNBs with selective non-catalytic reduction system (SNCR)
  - LNBs with selective catalytic reduction (SCR) system
- SO_2 emission controls:
  - Upgrade existing dry lime flue gas desulfurization (FGD) system
  - Upgrade existing dry FGD system and replace existing electrostatic precipitator (ESP) with a new fabric filter
  - New wet FGD system with ESP
- PM_{10} emission controls:
  - Sulfur trioxide (SO_3) injection flue gas conditioning system followed by the existing ESP
  - New polishing fabric filter
  - New baghouse fabric filter

BART Engineering Analysis

The specific steps in a BART engineering analysis are identified in the *Code of Federal Regulations* (CFR) at 40 CFR 51, Appendix Y, Section IV. The evaluation must include:

- The identification of available, technically feasible, retrofit control options
- Consideration of any pollution control equipment in use at the source (which affects the availability of options and their impacts)
- The costs of compliance with the control options
- The remaining useful life of the facility
- The energy and non-air quality environmental impacts of compliance
- The degree of visibility improvement that is anticipated from the use of BART

The following steps are incorporated into the BART analysis:

- Step 1 – Identify All Available Retrofit Control Technologies
- Step 2 – Eliminate Technically Infeasible Options
  - The identification of available, technically feasible, retrofit control options
  - Consideration of any pollution control equipment in use at the source (which affects the applicability of options and their impacts)
- Step 3 – Evaluate Control Effectiveness of Remaining Control Technologies
- Step 4 – Evaluate Impacts and Document the Results
  - The costs of compliance with the control options
  - The remaining useful life of the facility
  - The energy and non-air quality environmental impacts of compliance
- Step 5 – Evaluate Visibility Impacts
  - The degree of visibility improvement that may reasonably be anticipated from the use of BART

Separate analyses have been conducted for NO_x, SO_2, and PM_{10} emissions. All costs included in the BART analyses are in 2006 dollars, and costs have not been escalated to the assumed 2014 BART implementation date.

Recommendations

CH2M HILL recommends installing the following control devices, which include LNBs with OFA, dry FGD system, and the existing ESP. This combination of control devices is identified as Scenario 1 throughout this report.

NO_x Emission Control

The Wyodak plant burns only Powder River Basin (PRB) coal, a sub-bituminous coal. CH2M HILL recommends new LNBs with over-fire air (LNB with OFA) as BART for

Wyodak, based on the projected significant reduction in NO_x emissions, reasonable control costs, and the advantages of no additional power requirements or non-air quality environmental impacts. This technology is expected to achieve an emission rate of 0.23 pound (lb) per million British thermal units (MMBtu).

SO_2 Emission Control

CH2M HILL recommends upgrading the existing lime spray drying FGD system with the existing ESP as BART for Wyodak, based on the significant reduction in SO_2 emissions, reasonable control costs, and the advantages of minimal additional power requirements and minimal non-air quality environmental impacts. This upgrade approach is projected to have an emission rate of 0.32 lb per MMBtu.

PM_{10} Emission Control

CH2M HILL recommends maintaining the performance of the existing ESP as BART for Wyodak, based on the PM_{10} emissions associated with the current equipment configuration, reasonable control costs, and the advantages of no additional power requirements and no non-air quality environmental impacts.

BART Modeling Analysis

CH2M HILL used the CALPUFF modeling system to assess the visibility impacts of emissions from Wyodak at Class I areas. The Class I areas potentially affected are located more than 50 kilometers (km), but less than 300 km, from the Wyodak Plant.

The Class I areas include the following national parks (NPs):

- Wind Cave NP
- Badlands NP

Because Wyodak will simultaneously control NO_x, SO_2, and PM_{10} emissions, four post-control atmospheric dispersion modeling scenarios were developed to cover the range of effectiveness for combining the individual NO_x, SO_2, and PM_{10} control technologies under evaluation. These modeling scenarios, and the controls assumed, are as follows:

- **Scenario 1**: New LNBs with OFA modifications, upgrading the dry FGD system, and maintaining performance of the existing ESP. As indicated previously, this scenario represents CH2M HILL's BART recommendation.
- **Scenario 2**: New LNBs with OFA modifications, upgrading the dry FGD system, and installing a new fabric filter to replace the existing ESP.
- **Scenario 3**: New LNBs with OFA modifications and SCR, upgrading the dry FGD system, and installing a new fabric filter to replace the existing ESP.
- **Scenario 4**: New LNBs with OFA modifications and SCR, installing a new wet FGD system, and utilizing the existing ESP**.**

Visibility improvements for all emission control scenarios were analyzed, and the results were compared utilizing a least-cost envelope, as outlined in the *New Source Review Workshop Manual*.[1]

Least-cost Envelope Analysis

EPA has adopted the Least-cost Envelope Analysis Methodology as an accepted methodology for selecting the most reasonable, cost-effective controls. Incremental cost-effectiveness comparisons focus on annualized cost and emission reduction differences between dominant alternatives. The dominant set of control alternatives is determined by generating what is called the envelope of least-cost alternatives. This is a graphical plot of total annualized costs for total emissions reductions for all control alternatives identified in the BART analysis.

To evaluate the impacts of the modeled control scenarios on the two Class I areas, the total annualized cost, cost per deciview (dV) reduction, and cost per reduction in number of days above 0.5 dV were analyzed. This report provides a comparison of the average incremental costs between relevant scenarios for the two Class I areas; the total annualized cost versus number of days above 0.5 dV, and the total annualized cost versus 98th percentile ΔdV reduction.

Results of the least-cost envelope analysis validate the selection of Scenario 1, based on incremental cost and visibility improvements. Scenario 2 (LNB with OFA, upgrade dry FGD, and fabric filter) is eliminated, because it is to the left of the curve formed by the “dominant” control alternative scenario, which indicates a scenario with lower improvement and/or higher costs. Scenario 3 (LNB with OFA and SCR, upgrade dry FGD, and replacement of the fabric filter in lieu of the ESP) is not selected due to very high incremental costs, on the basis of both a cost per day of improvement, and cost per dV reduction. While Scenario 4 (LNB with OFA and SCR, wet FGD, and ESP) provides some potential visibility advantage over Scenario 1, the projected improvement is less than 0.5 dV, and the projected costs are excessive. Therefore, Scenario 1 represents BART for Wyodak.

Just-Noticeable Differences in Atmospheric Haze

Studies have been conducted that demonstrate only dV differences of approximately 1.5 to 2.0 dV or more are perceptible by the human eye. Deciview changes of less than 1.5 cannot be distinguished by the average person. Therefore, the modeling analysis results indicate that only minimal, if any, observable visibility improvements at the Class I areas studied would be expected under any of the control scenarios. Thus, the results indicate that even though PacifiCorp will be spending many millions of dollars at this single unit—and over a billion dollars when considering its entire coal fleet—only minimal discernable visibility improvements may result.

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[1] EPA, 1990. *New Source Review Workshop Manual*. Draft. Environmental Protection Agency. October.

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Acronyms and Abbreviations

ºF	Degree Fahrenheit
BACT	Best Available Control Technology
BART	Best Available Retrofit Technology
CALDESK	Program to Display Data and Results
CALMET	Meteorological Data Preprocessing Program for CALPUFF
CALPOST	Post-processing Program for Calculating Visibility Impacts
CALPUFF	Gaussian Puff Dispersion Model
CFR	*Code of Federal Regulations*
CO	Carbon Monoxide
COHPAC	Compact Hybrid Particulate Collector
dV	Deciview
ΔdV	Delta Deciview, Change in Deciview
ESP	Electrostatic Precipitator
EPA	United States Environmental Protection Agency
FGC	Flue Gas Conditioning
FGD	Flue Gas Desulfurization
H_2SO_4	Sulfuric Acid
kW	Kilowatt
kWh	Kilowatt-hour
LAER	Lowest Achievable Emission Rate
lb	Pound
LNB	Low-NO_x Burner
MMBtu	Million British Thermal Units
MM5	Mesoscale Meteorological Model, Version 5
MW	Megawatt
NH_4	Ammonium
$(NH_4)HSO_4$	Ammonium Bisulfate
$(NH_4)_2SO_4$	Ammonium Sulfate
NO_x	Nitrogen Oxide
NP	National Park
NSR Manual	*New Source Review Workshop Manual* (EPA, 1990)
OFA	Over-fire Air

PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than 2.5 Micrometers in Aerodynamic Diameter
PM_{10}	Particulate Matter less than 10 Micrometers in Aerodynamic Diameter
PRB	Powder River Basin
ROFA	Rotating Opposed Fire Air
S&L	Sargent & Lundy
S&L Study	*Multi-Pollutant Control Report* dated October, 2002
SCR	Selective Catalytic Reduction
SIP	State Implementation Plan
SNCR	Selective Non-catalytic Reduction
SO_2	Sulfur Dioxide
SO_3	Sulfur Trioxide
tpy	Tons per Year
TRC	TRC Companies, Inc.
USGS	U.S. Geological Survey
WDEQ	Wyoming Department of Environmental Quality
WDEQ-AQD	Wyoming Department of Environmental Quality – Air Quality Division

1.0 Introduction

Best Available Retrofit Technology (BART) guidelines were established as a result of United States Environmental Protection Agency (EPA) regulations intended to reduce the occurrence of regional haze in national parks (NPs) and other Class I protected air quality areas in the United States. These guidelines provide guidance for states when determining which facilities must install additional controls, and the type of controls that must be used. Facilities eligible for BART installation were built between 1962 and 1977, and have the potential to emit more than 250 tons per year of visibility-impairing pollutants.

The Wyoming Department of Environmental Quality (WDEQ) BART regulations state that each source subject to BART must submit a BART application for a construction permit by December 15, 2006. PacifiCorp received an extension from the WDEQ to submit the BART report for Wyodak on February 2, 2007. The BART report that was submitted to WDEQ in February 2007 included a BART analysis, and a proposal and justification for BART at the source. This revised report—submitted in October 2007—incorporates editorial revisions since the February 2007 version.

The State of Wyoming has identified those eligible, in-state facilities that are required to reduce emissions under BART, and will set BART emissions limits for those facilities. This information will be included in the State of Wyoming State Implementation Plan (SIP), which the State has estimated will be formally submitted to the EPA by early 2008. The EPA BART guidelines also state that the BART emission limits must be fully implemented within 5 years of EPA's approval of the SIP.

Five elements related to BART address the issue of emissions for the identified facilities:

- Any existing pollution control technology in use at the source
- The cost of the controls
- The remaining useful life of the source
- The energy and non-air quality environmental impacts of compliance
- The degree of improvement in visibility that is anticipated from using such technology

This report documents the BART analysis that was performed on Wyodak by CH2M HILL for PacifiCorp. The analysis was performed for nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10}) because they are the primary criteria pollutants that affect visibility.

Section 2 of this report provides a description of the present unit operation, including a discussion of coal sources and characteristics. The BART Engineering Analysis is provided in Section 3 by pollutant type. Section 4 provides the methodology and results of the BART Modeling Analysis, followed by recommendations in Section 5 and references are provided in Section 6. Appendices provide more detail on the economic analysis and the 2006 Wyoming BART Protocol.

2.0 Present Unit Operation

The Wyodak plant consists of one nominal 335-megawatt (MW) unit located near Gillette, Wyoming. Wyodak is equipped with a wall-fired boiler manufactured by Babcock & Wilcox. A Babcock & Wilcox Rothemuhle weighted wire electrostatic precipitator (ESP) is used for particulate control (PM) and a Joy Niro, three-tower, lime-based spray dryer was added for flue gas desulfurization (FGD) in 1986. An Emerson Ovation distributed control system was installed in 2006. Table 2-1 lists additional unit information and the basis of design assumptions.

Coal currently being burned at Wyodak is from the Clovis Point mine, operated by Black Hills Power, and is located near the plant site. The coal is ranked sub-bituminous.

Wyodak was placed in service in 1978. Its current economic depreciation life is through 2042; however, this analysis is based on a 20-year life for BART control technologies—and for purposes of this analysis—will continue operation until 2033. Assuming a BART implementation date of 2014, this will result in an approximate remaining useful life for Wyodak of 20 years from the installation date of any new or modified BART-related equipment. This report does not attempt to quantify any additional life extension costs needed to allow Wyodak to operate until 2042.

TABLE 2-1
Present Unit Operation
Wyodak

General Plant Data	
Site Elevation (feet above mean sea level)	4420
Stack Height (feet)	400
Stack Exit Internal Diameter (feet) /Exit Area (square feet)	20.0 / 314.2
Stack Exit Temperature (degrees Fahrenheit)	185
Stack Exit Velocity (feet per second)	77
Stack Flow (actual cubic feet per minute)	1,451,604
Latitude (degree: minute: second)	44:17:16.36
Longitude (degree: minute: second)	105:23:2.47
Annual Unit Capacity Factor (percentage)	90
Net Unit Output (megawatts)	335
Net Unit Heat Rate (British thermal unit [Btu]/kilowatt hour)(100% load)	12,087 (as measured by fuel throughput)
Boiler Heat Input (million British thermal units [MMBtu]/Hr)(100% load)	4,700 (as measured by continuous emissions monitoring)
Type of Boiler	Wall fired
Boiler Fuel	Coal
Coal Sources	Clovis Point Mine
Coal Heating Value (Btu per pound)[a]	8,050
Coal Sulfur Content (percentage by weight)[a]	0.65
Coal Ash Content (wt. %)[a]	7.46
Coal Moisture Content (wt. %)[a]	30.79
Coal Nitrogen Content (wt. %)	0.57
Current Nitrogen Oxide (NO_x) Controls	Good Combustion Practices
Pre-project NO_x Emission Rate (lb per MMBtu)[(b)]	0.31
Current Sulfur Dioxide (SO_2) Controls	Lime Based Spray Dryer
Pre-project SO_2 Emission Rate (lb per MMBtu)	0.50
Current Particulate Matter less than 10 micrometers (PM_{10}) Controls	Electrostatic Precipitator
Pre-project PM_{10} Emission Rate (lb per MMBtu)[(c)]	0.030

NOTE:
[a]Coal characteristics vary between sources
[b]Emission rates stated on annual average basis
[c]Emission rate stated from test results

3.0 BART Engineering Analysis

This section presents the required BART engineering analysis.

3.1 Applicability

In compliance with regional haze requirements, the State of Wyoming must prepare and submit visibility SIPs to the EPA for Class I areas. The State has estimated that the formal submittal of the SIPs will occur by early 2008. The first phase of the regional haze program is the implementation of BART emission controls on all BART-eligible units, within 5 years after EPA approval of the SIP.

3.2 BART Process

The specific steps in a BART engineering analysis are identified in the *Code of Federal Regulations* (CFR) at 40 CFR 51, Appendix Y, Section IV. The evaluation must include:

- The identification of available, technically feasible, retrofit control options
- Consideration of any pollution control equipment in use at the source (which affects the availability of options and their impacts)
- The costs of compliance with the control options
- The remaining useful life of the facility
- The energy and non-air quality environmental impacts of compliance
- The degree of visibility improvement is anticipated from using BART

The following steps are incorporated into the BART analysis:

- Step 1 – Identify All Available Retrofit Control Technologies
- Step 2 – Eliminate Technically Infeasible Options
  - The identification of available, technically feasible, retrofit control options
  - Consideration of any pollution control equipment in use at the source (which affects the applicability of options and their impacts)
- Step 3 – Evaluate Control Effectiveness of Remaining Control Technologies
- Step 4 – Evaluate Impacts and Document the Results
  - The costs of compliance with the control options
  - The remaining useful life of the facility

  - The energy and non-air quality environmental impacts of compliance

- Step 5 – Evaluate Visibility Impacts
  - The degree of visibility improvement that is anticipated from using BART

To minimize costs in the BART analysis, consideration was made of any pollution control equipment in use at the source, the costs of compliance associated with the control options, and the energy and non-air quality environmental impacts of compliance using these existing control devices. In some cases, enhancing the performance of the existing control equipment was considered. Other scenarios with new control equipment were also developed.

Separate cost analyses have been conducted for NO_x, SO_2, and PM_{10} emissions. All costs included in the BART analysis are in 2006 dollars, and costs have not been escalated to the assumed 2014 BART implementation date.

3.2.1 BART NO_x Analysis

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

Formation of NO_x

During coal combustion, NO_x is formed in three different ways. The dominant source of NO_x formation is the oxidation of fuel-bound nitrogen (also referred to as fuel NO_x). 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 (nitric oxide and nitrogen dioxide) and partially reduced to molecular nitrogen. A smaller part of NO_x formation is due to high temperature fixation of atmospheric nitrogen in the combustion air. A very small amount of NO_x 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 to provide 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.

Coal characteristics directly and significantly impact NO_x emissions from coal combustion. Coal ranking is a means of classifying coals according to their degree of metamorphism in the natural series, from lignite to sub-bituminous to bituminous and on to anthracite. Lower rank coals, such as the sub-bituminous coals from the Powder River Basin (PRB), produce lower NO_x emissions than higher rank bituminous coals, due to their higher reactivity and lower nitrogen content. The fixed carbon to volatile matter ratio (fuel ratio), coal oxygen content, and rank are good relative indices of the reactivity of a coal. Lower rank coals release more organically bound nitrogen earlier in the combustion process than do higher rank bituminous coals. When used with low-NO_x burners (LNBs), sub-bituminous coals create a longer time for the kinetics to promote more stable molecular nitrogen, and hence result in lower NO_x emissions.

Coals from the PRB are classified as sub-bituminous C and demonstrate the high reactivity and low NO_x production characteristics described previously. Based on data from the Energy Information Administration, PRB coals currently represent 88 percent of total U.S. sub-bituminous production and 73 percent of western coal production (Energy Information

Administration, 2006). Most references to western coal and sub-bituminous coal infer PRB origin and characteristics. Emissions standards differentiating between bituminous and sub-bituminous coals are presumed to use PRB coal as the basis for the sub-bituminous standards, due to its dominant market presence and unique characteristics.

Wyodak burns sub-bituminous coal from the PRB. The BART presumptive NO_x limit for sub-bituminous coal combusted in a wall-fired boiler is 0.23 pound (lb) per million British thermal units (MMBtu). The current NO_x emission rate at Wyodak is 0.31 lb per MMBtu.

The BART analysis for NO_x emissions from Wyodak is described in this section.

Step 1: Identify All Available Retrofit Control Technologies

The first step of the BART process is to evaluate NO_x control technologies with practical potential for application to Wyodak, including those control technologies identified as Best Available Control Technology (BACT) or lowest achievable emission rate (LAER) by permitting agencies across the United States. A broad range of information sources have been reviewed in an effort to identify potentially applicable emission control technologies. Wyodak NO_x emissions are currently controlled through the use of good combustion practices.

The following potential NO_x control technology options were considered:

- New/modified LNBs with advanced over-fire air (OFA)
- Mobotec rotating opposed fire air (ROFA)
- Conventional selective non-catalytic reduction (SNCR) system
- Selective catalytic reduction (SCR) system

Step 2: Eliminate Technically Infeasible Options

For Wyodak, a wall-fired configuration burning sub-bituminous coal, technical feasibility will primarily be determined by physical constraints and boiler configuration. Wyodak's current NO_x emission rate is 0.31 lb per MMBtu.

For this BART analysis, information pertaining to LNBs, OFA, SNCR, and SCR were based on the *Multi-Pollutant Control Report* (Sargent & Lundy, 2002, hereafter referred to as the S&L Study). The cost estimates for SCR and SNCR were updated by Sargent & Lundy (S&L) in October 2006. PacifiCorp provided additional emissions data and costs developed by boiler vendors for LNBs and OFA. Also, CH2M HILL solicited a proposal from Mobotec for their ROFA technology.

With SNCR, an amine-based reagent such as ammonia, or more commonly urea, is injected into the furnace within a temperature range of 1,600 degrees Fahrenheit (°F) to 2,100°F, where it reduces NO_x to nitrogen and water. Nitrogen oxide reductions of up to 60 percent have been achieved, although 20 to 40 percent is more realistic for most applications. Selective non-catalytic reduction is typically applied on smaller units. Adequate reagent distribution in the furnaces of large units can be problematic.

Table 3-1 summarizes the control technology options evaluated in this BART analysis, along with projected NO_x emission rates.

TABLE 3-1
NO_x Control Technology Emission Rate Ranking
Wyodak

Technology	Projected Emission Rate (pounds per million British thermal units)
Presumptive Best Available Retrofit Technology (BART) Limit (for reference only)	0.23
Low-NO_x Burners (LNBs) with Over-fire Air (OFA)	0.23
Rotating Opposed Fire Air	0.20
LNBs with OFA and Selective Non-catalytic Reduction (SNCR)	0.18
LNBs with OFA and SCR	0.07

Step 3: Evaluate Control Effectiveness of Remaining Control Technologies

Preliminary vendor proposals, such as those used to support portions of this BART analysis, may be technically feasible and provide expected or guaranteed emission rates; however, the proposals include inherent uncertainties. These proposals are usually prepared in a limited time frame, may be based on incomplete information, may contain overly optimistic conclusions, and are non-binding. Therefore, emission rate values obtained in such preliminary proposals must be qualified, and it must be recognized that contractual guarantees are established only after more detailed analysis has been completed. The following subsections describe the control technologies and the control effectiveness evaluated in this BART analysis.

New LNBs with OFA System. The mechanism used to lower NO_x with LNBs is to stage the combustion process and provide a fuel-rich condition initially; this is so oxygen needed for combustion is not diverted to combine with nitrogen and form NO_x. Fuel-rich conditions favor the conversion of fuel nitrogen to N_2 instead of NO_x. Additional air (or OFA) is then introduced downstream in a lower temperature zone to burn out the char.

Information provided to CH2M HILL by PacifiCorp—based on the S&L Study and data from boiler vendors—indicates that new LNB and OFA retrofit at Wyodak would result in an expected NO_x emission rate of 0.23 lb per MMBtu. PacifiCorp has indicated that this rate corresponds to a vendor guarantee plus an added operating margin, not a vendor prediction, and they believe that this emission rate can be sustained as an average between overhauls. This emission rate represents a significant reduction from the NO_x emission rate of 0.31 lb per MMBtu and meets the presumptive NO_x emission rate of 0.23 lb per MMBtu.

ROFA. Mobotec markets ROFA as an improved second generation OFA system. Mobotec states that: “the flue gas volume of the furnace is set in rotation by asymmetrically placed air nozzles. Rotation is reported to prevent laminar flow, so that the entire volume of the furnace can be used more effectively for the combustion process. In addition, the swirling action reduces the maximum temperature of the flames and increases heat absorption. The combustion air is also mixed more effectively." A typical ROFA installation will have a booster fan(s) to supply the high-velocity air to the ROFA boxes, and Mobotec would propose one 7,000 horsepower fan for Wyodak.

Mobotec expects to achieve a NO_x emission rate of 0.18 lb per MMBtu using ROFA technology. An operating margin of 0.02 lb per MMBtu was added to the expected rate due to Mobotec's limited ROFA experience with western sub-bituminous coals. Under the Mobotec proposal, primarily based on ROFA equipment, the operation of existing LNB and OFA ports will be analyzed. While a typical installation does not require modification to the existing LNB system, and the existing OFA ports are not used, results of computational fluid dynamics modeling will determine the quantity and location of new ROFA ports. The Mobotec proposal includes bent tube assemblies for OFA port installation. Mobotec does not provide installation services because they believe that the Owner can more cost-effectively contract for these services. However, they do provide one onsite construction supervisor during installation and startup.

Because of the expected marginal emission rate improvement, the burden of significant ongoing parasitic costs, the operating difficulties, and the lack of vendor experience with sub-bituminous coals, ROFA was not considered in the post-control modeling scenarios.

SNCR. Selective non-catalytic reduction is generally utilized to achieve modest NO_x reductions on smaller units. With SNCR, an amine-based reagent such as ammonia—or more commonly urea—is injected into the furnace within a temperature range of 1,600°F to 2,100°F, where it reduces NO_x to nitrogen and water. NO_x reductions of up to 60 percent have been achieved, although 20 to 40 percent is more realistic for most applications.

Reagent utilization, which is a measure of the efficiency with which the reagent reduces NO_x, can range from 20 to 60 percent, depending on the amount of reduction, unit size, operating conditions, and allowable ammonia slip. With low-reagent utilization, low temperatures, or inadequate mixing, ammonia slip occurs, allowing unreacted ammonia to create problems downstream. The ammonia may render fly ash unsaleable, react with sulfur to foul heat exchange surfaces, and/or create a visible stack plume. Reagent utilization can have a significant impact on economics, with higher levels of NO_x reduction generally resulting in lower reagent utilization and higher operating cost.

Reductions from higher baseline concentrations (inlet NO_x) are lower in cost per ton, but result in higher operating costs, due to greater reagent consumption. To reduce reagent costs, S&L has assumed that combustion modifications including LNBs and advanced OFA, capable of achieving a projected NO_x emission rate of 0.23 lb per MMBtu. At a further reduction of 20 percent in NO_x emission rates for SNCR would result in a projected emission rate of 0.18 lb per MMBtu.

Because of the expected marginal emission rate improvement, the burden of significant ongoing parasitic costs, the operating difficulties and the potential ammonia slip emission problems; SNCR was not considered in the post-control modeling scenarios.

SCR. SCR works on the same principle as SNCR, but a catalyst is used to promote the reaction. Ammonia is injected into the flue-gas stream, where it reduces NO_x to nitrogen and water. Unlike the high temperatures required for SNCR, the reaction takes place on the surface of a vanadium/titanium-based catalyst at a temperature range between 580°F to 750°F. Due to the catalyst, the SCR process is more efficient than SNCR. The most common type of SCR is the high-dust configuration, where the catalyst is located upstream of the air heater and downstream from the economizer. The high-dust configuration is assumed for Wyodak. In a full-scale SCR, the flue ducts are routed to a separate large reactor containing the catalyst. With in-duct SCR, the catalyst is located in the existing gas duct, which may be expanded in the area of the catalyst to increase flue gas residence time. Due to the higher removal rate, a full-scale SCR was used as the basis for analysis at Wyodak.

S&L prepared the design conditions and cost estimates for SCR at Wyodak. As with SNCR, it is generally more cost effective to reduce NO_x emission levels as much as possible through combustion modifications, in order to minimize the catalyst surface area and ammonia requirements of the SCR. To reduce reagent costs, S&L has assumed that combustion modifications, including LNBs and OFA, providing a NO_x emission rate of 0.23 lb per MMBtu, would be installed in conjunction with the SCR. The S&L design basis results in a projected NO_x emission rate of 0.07 lb per MMBtu. Additional catalyst surface was included in the SCR design to accommodate the characteristics of the coal used at Wyodak.

Level of Confidence for Vendor Post-control Emissions Estimates. In order to determine the level of NO_x emissions needed to achieve compliance consistently with an established goal, a review of typical NO_x emissions from coal-fired generating units was completed. As a result of this review, it was noted that NO_x emissions can vary significantly around an average emissions level. Variations may result for many reasons, including changing coal characteristics, unit load, boiler operation including excess air, boiler slagging, burner equipment condition, coal mill fineness, and so forth.

The steps utilized for determining a level of confidence for the vendor expected value are as follows:

- Establish expected NO_x emissions value from vendor.
- Evaluate vendor experience and historical basis for meeting expected values.
- Review and evaluate unit physical and operational characteristics and restrictions. The fewer variations there are in operations, coal supply, etc., the more predictable and less variant the NO_x emissions are.
- For each technology expected value, there is a corresponding potential for actual NO_x emissions to vary from this expected value. From the vendor information presented, along with anticipated unit operational data, an adjustment to the expected value can be made.

Step 4: Evaluate Impacts and Document the Results

This step involves the consideration of energy, environmental, and economic impacts associated with each control technology. The remaining useful life of the plant is also considered during the evaluation.

Energy Impacts. Installation of LNBs with OFA is not expected to impact the boiler efficiency or forced draft fan power usage significantly. Therefore, these technologies will not have energy impacts.

The Mobotec ROFA system requires installation and operation of one 7,000 horsepower ROFA fan.

Selective catalytic reduction retrofit impacts the existing flue gas fan systems, due to the additional pressure drop associated with the catalyst, which is typically a 6- to 8-inch water gauge increase. Total additional power requirements for SCR installation at Wyodak are estimated at approximately 2,420 kilowatts (kW), based on the S&L Study.

Environmental Impacts. Installation of LNBs with OFA may increase carbon monoxide (CO) emissions and loss on ignition which may result in higher unburned carbon in the ash.

Mobotec has predicted that CO emissions and unburned carbon in the ash, commonly referred to as loss on ignition, would be the same or lower than prior levels for the ROFA system.

The installation of SNCR and SCR systems could impact the saleability and disposal of fly ash due to ammonia levels, and could potentially create a visible stack plume, which may negate other visibility improvements. Other environmental impacts involve the storage of ammonia, especially if anhydrous ammonia is used, and the transportation of the ammonia to the power plant site.

Economic Impacts. Costs and schedules for the LNBs and OFA, SNCR, and SCR were furnished to CH2M HILL by PacifiCorp, developed using S&L's internal proprietary database, and supplemented (as needed) by vendor-obtained price quotes. The relative accuracy of these cost estimates is stated by S&L to be in the range of plus or minus 20 percent. Cost for the ROFA system was obtained from Mobotec to which construction and other costs were added to make a comparable estimate.

A comparison of the technologies on the basis of costs, design control efficiencies, and tons of NO_x removed is summarized in Table 3-2, and the first-year control costs are shown in Figure 3-1. The complete economic analysis is contained in Appendix A.

TABLE 3-2
NO_x Control Cost Comparison
Wyodak

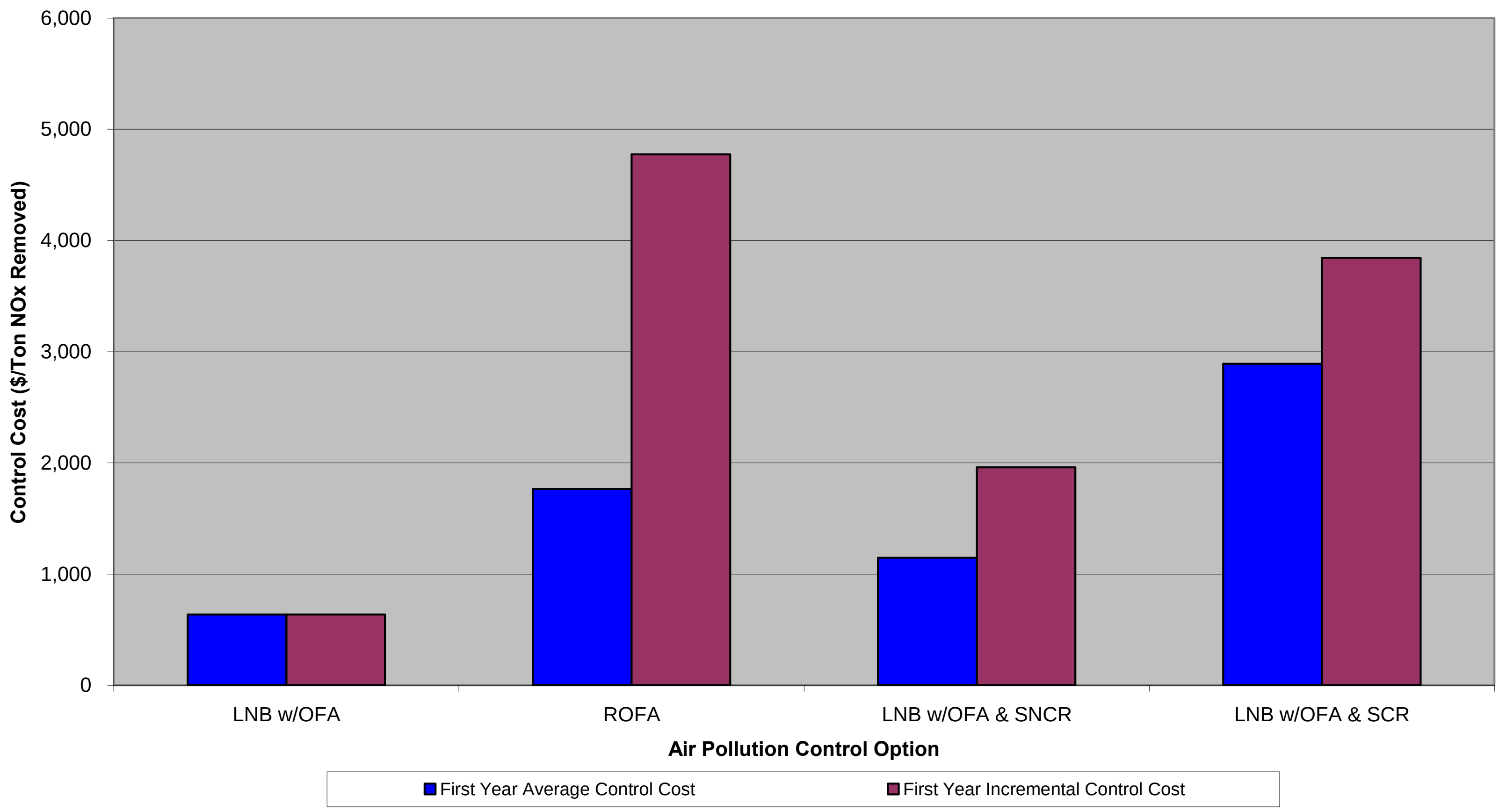
Factor	Low-NO_x Burners (LNBs) with Over-fire Air (OFA)	Rotating Opposed Fire Air (ROFA)	LNB with OFA and Selective Non-catalytic Reduction (SNCR)	LNB with OFA and Selective Catalytic Reduction (SCR)
Total Installed Capital Costs	$9.3 million	$15.3 million	$19.5 million	$108.3 million
Total First-year Fixed and Variable Operation and Maintenance Costs	$0.1 million	$2.1 million	$0.9 million	$2.6 million
Total First-year Annualized Cost	$0.9 million	$3.6 million	$2.8 million	$12.9 million
Power Consumption (megawatt)	NA	5.2	0.34	2.4
Annual Power Usage (1,000 megawatt hours per year)	NA	41.2	2.6	19.0
Nitrogen Oxide (NO_x) Design Control Efficiency	25.8%	35.5%	41.9%	77.4%
Tons NO_x Removed per Year	1,482	2,038	2,409	4,447
First-year Average Control Cost ($/Ton of NO_x Removed)	637	1,766	1,147	2,892
Incremental Control Cost ($/Ton of NO_x Removed)	637	4,775	1,962	3,844

Preliminary BART Selection. CH2M HILL recommends LNBs with OFA as BART for Wyodak based on its significant reduction in NO_x emissions, reasonable control cost, and no additional power requirements or environmental impacts. LNB with OFA is projected to meet the EPA presumptive limit of 0.23 lb per MMBtu for the PRB sub-bituminous coal burned at the facility even though this presumptive limit does not apply.

Step 5: Evaluate Visibility Impacts

Please see Section 4, BART Modeling Analysis.

FIGURE 3-1
First Year Control Cost for NO_x Air Pollution Control Options
Wyodak



3.2.2 BART SO_2 Analysis

Sulfur dioxide forms in the boiler during the combustion process, and is primarily dependent on coal sulfur content. The BART analysis for SO_2 emissions on Wyodak is described below.

Step 1: Identify All Available Retrofit Control Technologies

A broad range of information sources were reviewed, in an effort to identify potentially applicable emission control technologies for SO_2 at Wyodak; this included control technologies identified as BACT or LAER by permitting agencies across the United States.

The following potential SO_2 control technology options were considered:

- Upgrade existing dry lime FGD system
- Upgrade existing dry FGD system and replace existing ESP with a new fabric filter
- New wet FGD system with ESP

Step 2: Eliminate Technically Infeasible Options

Wyodak currently has an uncontrolled SO_2 emission rate of 1.61 lb per MMBtu and meets a state emission limit of 0.50 lb per MMBtu.

Upgrade Dry FGD with Existing ESP. The lime spray dryer injects lime slurry in the top of the absorber vessel with a rapidly rotating atomizer wheel. The rapid speed of the atomizer wheel causes the lime slurry to separate into very fine droplets that intermix with the flue gas. The SO_2 in the flue gas reacts with the calcium in the lime slurry to form calcium sulfate in the form of particulate matter. At Wyodak, this dry particulate matter is captured in the downstream existing ESP, along with the fly ash. The lime spray dryer system produces a dry waste product suitable for landfill disposal.

The dry FGD system at Wyodak currently achieves approximately 69 percent SO_2 removal to achieve an SO_2 outlet emission rate of 0.50 lb per MMBtu. To achieve 80 percent SO_2 removal, the dry FGD system operation would be changed by closing the bypass damper to eliminate bypass flue gas flow, perform modeling to redistribute the flue gas flow to the ESP, adding static mixers to mix the gas prior to the ESP, increase the reagent feed ratio (that is, Ca:S ratio), and increase the recycle ratio. An upgraded dry scrubbing FGD system with the existing ESP is projected to achieve an outlet emission rate of 0.32 lb per MMBtu (80 percent SO_2 removal) based on an average coal sulfur content of 0.65 percent by weight.

Lime Spray Drying FGD with New Fabric Filter. If the existing ESP is replaced with a fabric filter located downstream of the lime spray dryer, then 90 percent SO_2 removal is projected, allowing the facility to achieve an emissions limit of 0.16 lb SO_2 per MMBtu.

Wet Lime/Limestone FGD. Wet SO_2 scrubbers operate by flowing the flue gas upward through a large reactor vessel that has an alkaline reagent (typically a lime or limestone slurry) flowing down from the top. The scrubber mixes the flue gas and alkaline reagent using a series of spray nozzles to distribute the reagent across the scrubber vessel. The calcium in the reagent reacts with the SO_2 in the flue gas to form calcium sulfite and/or calcium sulfate, which are removed from the scrubber with the sludge, and disposed. Most wet FGD systems use forced oxidation to assure that only calcium sulfate sludge is produced. The wet lime/limestone forced oxidation process is used in most new wet FGD installations. Several variations on wet FGD technology are offered by various process developers. These variations include using a jet bubbling reactor as a combination SO_2 absorber and calcium sulfite oxidation vessel and using magnesium enhanced lime as the alkaline reagent.

Wet lime/limestone scrubbing is projected to achieve 90 to 95 percent SO_2 removal. At Wyodak, this removal efficiency is projected to meet the presumptive limit of 0.15 lb of SO_2 per MMBtu used here only as a point of reference.

Step 3: Evaluate Control Effectiveness of Remaining Control Technologies

Table 3-3 summarizes the projected emission rates for the FGD technologies being evaluated for Wyodak.

TABLE 3-3
SO_2 Control Technology Emission Rate Ranking
Wyodak

Control Technology	Short-Term Expected SO_2 Emission Rate (lb per MMBtu)
Presumptive BART Limit (for reference only)	0.15
Wet Lime/Limestone FGD	0.08
Upgrade Dry FGD with Fabric Filter	0.16
Upgrade Dry FGD with Existing ESP	0.32

Step 4: Evaluate Impacts and Document the Results

This step involves the consideration of energy, environmental, and economic impacts associated with each control technology. The remaining useful life of the plant is also considered during the evaluation.

Energy Impacts. An upgraded dry FGD system with the existing ESP has the advantage of requiring less electric power for its operation, compared to a wet FGD system. An upgraded dry FGD system at Wyodak using the existing ESP would require an additional 0.1 MW of power, compared to an additional 1.8 MW for wet FGD. Based on a 90 percent annual plant capacity factor, this would equate to an annual power savings of approximately 12.9 million kilowatt-hour (kWh) for upgraded dry FGD versus wet FGD for Wyodak.

Environmental Impacts. The dry FGD system has the following environmental advantages when compared to wet FGD technology.

- **Sulfuric Acid Mist.** Sulfur trioxide (SO_3) in the flue gas, which condenses to liquid sulfuric acid at temperatures below the acid dew point, is removed efficiently with a lime spray dryer system. Wet scrubbers capture less than 40 to 60 percent of SO_3 and may require the addition of a wet ESP or hydrated lime injection when medium to high sulfur coal is burned in a unit, in order to remove the balance of SO_3. Otherwise, the emission of sulfuric acid mist, if above a threshold value, may result in a visible plume after the vapor plume dissipates.

- **Plume Buoyancy.** Flue gas following a dry FGD system is not saturated with water (30°F to 50°F above dew point), which reduces or eliminates a visible moisture plume. Wet FGD scrubbers produce flue gas that is saturated with water, which would require a gas-gas heat exchanger to reheat the flue gas if it were to operate as a dry stack. Due to the high capital and operating costs associated with heating the flue gas, all recent wet FGD systems in the United States have used wet stack operation.
- **Liquid Waste Disposal**. There is no liquid waste from a dry FGD system. However, wet FGD systems produce a wastewater blow down stream that must be treated to limit chloride buildup in the absorber scrubbing loop. In some cases, a wastewater treatment plant must be installed to treat the liquid waste prior to disposal. The wastewater treatment plant would produce a small volume of solid waste, which may contain toxic metals requiring additional considerations for disposal.
- **Solid Waste Disposal.** The creation of a wet sludge from the wet FGD process creates a solid waste handling and disposal challenge. This sludge needs to be handled properly to prevent groundwater contamination. Wet FGD systems can produce saleable gypsum (if a gypsum market is available), also reducing the quantity of solid waste from the power plant that needs to be disposed.
- **Makeup Water Requirements.** Lime Spray Drying FGD has advantages over a wet scrubber, producing a dry waste material and requiring less makeup water in the absorber. Given that water is a valuable commodity in Wyoming, the reduced water consumption required for dry FGD is a major advantage for this technology.

Economic Impacts. A summary of the costs and amount of SO_2 removed for each technology is provided in Table 3-4 and the first-year control costs are shown in Figure 3-2. The complete economic analysis is contained in Appendix A.

TABLE 3-4
SO_2 Control Cost Comparison
Wyodak

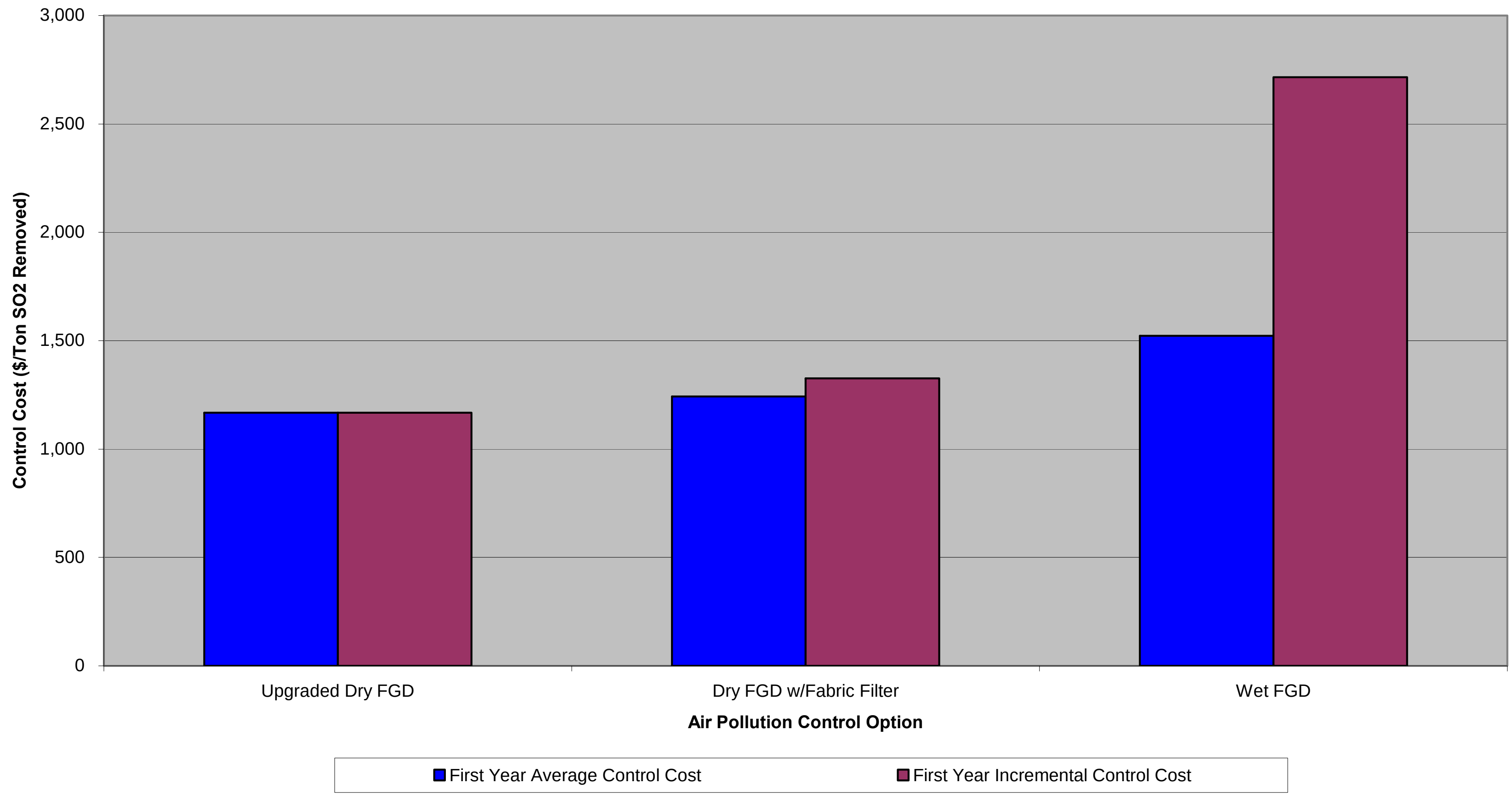
Factor	Upgraded Dry Flue Gas Desulfurization (FGD) with Electrostatic Precipitator (ESP) (Incremental)	Upgraded Dry FGD with Fabric Filter (FF) (Incremental)	Wet FGD (Incremental)
Total Installed Capital Costs	$26.8 million	$66.8 million	$95.1 million
Total First-year Fixed and Variable Operation and Maintenance Costs	$1.3 million	$1.5 million	$2.8 million
Total First-year Annualized Cost	$3.9 million	$7.8 million	$11.8 million
Power Consumption (megawatt)	0.1	0.2	1.8
Annual Power Usage (1000 megawatt hours per year)	0.9	1.2	13.8
Sulfur Dioxide (SO_2) Design Control Efficiency	36.0%	68.0%	84.0%
Tons SO_2 Removed per Year	3,335	6,299	7,782
First-year Average Control Cost (dollars per ton [$/Ton] of SO_2 Removed)	1,167	1,242	1,523
Incremental Control Cost ($/Ton of SO_2 Removed)	1,167	1,326	2.716

Preliminary BART Selection. CH2M HILL recommends upgrading the dry FGD system with the existing ESP as BART for Wyodak, based on the significant reduction in SO_2 emissions, reasonable control costs, and the advantages of minimal additional power requirements and minimal non-air quality environmental impacts.

Step 5: Evaluate Visibility Impacts

Please see Section 4, BART Modeling Analysis.

FIGURE 3-2
First Year Control Cost for SO_2 Air Pollution Control Options
Wyodak



3.2.3 BART PM_{10} Analysis

Wyodak is currently equipped with an ESP. Electrostatic precipitators remove PM from the flue gas stream by charging fly ash particles with a very high direct current voltage, and attracting these particles to grounded collection plates. A layer of collected particulate matter forms on the collecting plates and is removed by periodically rapping the plates. The collected ash particles drop into hoppers below the precipitator and are removed periodically by the fly ash-handling system. The ESP at Wyodak controls PM emissions to 0.030 lb per MMBtu.

The BART analysis for PM emissions on Wyodak is described below. For the modeling analysis to be completed in Section 4, PM_{10} will be used as an indicator for PM, and PM_{10} includes particulate matter less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) as a subset.

Step 1: Identify All Available Retrofit Control Technologies

Two retrofit control technologies have been identified for additional PM control:

- Flue gas conditioning followed by existing ESP
- New polishing fabric filter downstream of existing ESP
- New baghouse fabric filter

Step 2: Eliminate Technically Infeasible Options

Flue Gas Conditioning. If the fly ash from coal has high resistivity, such as fly ash from PRB coal, the ash is not collected effectively in a small ESP. Adding flue gas conditioning (FGC), which is typically accomplished by injection of SO_3, will lower the resistivity of the particles so that they will accept more charge and will allow the ESP to collect the ash more effectively. Adding FGC can account for large improvements in collection efficiency for small ESPs on units burning western low-sulfur coal.

The Wyodak ESP was sized based on a conservative design. It has a large specific collecting area and large residence time in the collection area of the ESP. This ESP operates effectively without the assistance of FGC equipment; thus, a significant improvement in collection efficiency is not expected with the addition of FGC to Wyodak. Therefore, this option will not be carried forward to the next step of the BART analysis.

Polishing Fabric Filter. Fabric filtration has been applied widely to coal combustion sources since the early 1970s, and consists of a number of filtering elements (bags) along with a bag cleaning system and dust hoppers contained in a main shell structure. Fabric filters use fiberglass bags as filters to collect particulate matter. The particulate-laden gas enters a fabric filter compartment and passes through the bags and through a layer of accumulated particulate matter collected on the fabric of the filter bags. The collected particulate matter forms a filter cake layer on the bag that enhances the bag's filtering efficiency. However, excessive caking will increase the pressure drop across the fabric filter. When this occurs, the fabric filter is placed into a cleaning cycle and the dislodged particulate matter is removed by the ash-handling system.

Fabric filters are effective in meeting *New Source Performance Standards* emission requirements on coal-fired boilers. Fabric filters have been used as a control technology of choice on projects where LAER review is required. Unlike precipitators, fabric filter design is not based on any physical properties of the fly ash.

A polishing fabric filter could be added downstream of the existing Wyodak ESP. This technology is licensed by the Electric Power Research Institute, and referred to as a Compact Hybrid Particulate Collector (COHPAC). The COHPAC collects the ash that is not collected by the ESP, thus acting as a polishing device. The ESP needs to be kept in service for the COHPAC fabric filter to work.

The COHPAC fabric filter is about one-half to two-thirds the size of a full-size fabric filter, because the COHPAC has a higher air-to-cloth ratio (7 to 9:1), compared to a full-size pulse jet fabric filter (3.5 to 4:1).

Baghouse Fabric Filter. Another available control technology is replacing the existing ESP with a new fabric filter. However, because the environmental benefits that would be achieved by a replacement fabric filter are also achieved by installing a polishing fabric filter downstream of the existing ESP at lower costs, installation of a full-size fabric filter downstream of the ESP was not considered further in the analysis.

Step 3: Evaluate Control Effectiveness of Remaining Control Technologies

The existing ESP at Wyodak is achieving a controlled PM emission rate of 0.030 lb per MMBtu. Adding a COHPAC fabric filter downstream of the existing ESP would reduce PM emissions to approximately 0.015 lb per MMBtu.

Step 4: Evaluate Impacts and Document the Results

This step involves the consideration of energy, environmental, and economic impacts associated with each control technology. The remaining useful life of the plant is also considered during the evaluation.

Energy Impacts. Energy is required to overcome the additional pressure drop from the COHPAC fabric filter and associated ductwork. Therefore, a COHPAC retrofit will require an induced draft fan upgrade and upgrade of the auxiliary power supply system.

A COHPAC fabric filter at Wyodak would require approximately 2.1 MW of power, equating to an annual power usage of approximately 16.2 million kWh, based on a 90 percent annual plant capacity factor.

Environmental Impacts. There are no negative environmental impacts from the addition of a polishing fabric filter.

Economic Impacts. A summary of the costs and PM removed for the fabric filter are recorded in Table 3-5. The complete economic analysis is contained in Appendix A.

TABLE 3-5
PM_{10} Control Cost Comparison
Wyodak

Factor	Fabric Filter
Total Installed Capital Costs	$32.6 million
Total First-year Fixed & Variable Operation and Maintenance Costs	$1.1 million
Total First-year Annualized Cost	$4.2 million
Power Consumption (megawatt)	2.1
Annual Power Usage (1,000 megawatt hours per year)	16.2
Particulate Matter (PM) Design Control Efficiency	50.0%
Tons PM Removed per Year	278
First-year Average Control Cost (dollars per ton [$/Ton] of PM Removed)	15,202
Incremental Control Cost ($/Ton of Sulfur Dioxide Removed)	15,202

Preliminary BART Selection. CH2M HILL recommends maintaining the ESP downstream of the lime spray dryer as BART for Wyodak, based on the significant reduction in PM_{10} emissions, reasonable control costs, and the advantages of minimal additional power requirements and no non-air quality environmental impacts.

Step 5: Evaluate Visibility Impacts

Please see Section 4, BART Modeling Analysis.

4.0 BART Modeling Analysis

4.1 Model Selection

CH2M HILL used the CALPUFF modeling system to assess the visibility impacts of emissions from Wyodak at nearby Class I areas. The Class I areas potentially affected are located more than 50 kilometers, but less than 300 kilometers, from the Wyodak facility. These National Parks (NP) include:

- Badlands NP
- Wind Cave NP

The CALPUFF modeling system includes the CALMET meteorological model, a Gaussian puff dispersion model (CALPUFF) with algorithms for chemical transformation and deposition, and a post-processor capable of calculating concentrations, visibility impacts, and deposition (CALPOST). The CALPUFF modeling system was applied in a full, refined mode. Version numbers of the various programs in the CALPUFF system used byCH2M HILL were as follows:

- CALMET Version 5.53a, Level 040716
- CALPUFF Version 5.711a, Level 040716
- CALPOST Version 5.51, Level 030709

4.2 CALMET Methodology

4.2.1 Dimensions of the Modeling Domain

CH2M HILL used the CALMET model to generate a three-dimensional wind field and other meteorological parameters suitable for use by the CALPUFF model. A modeling domain was established to encompass the Wyodak facility and allow for a 50-km buffer around the Class I areas that were within 300 km of the facility. Grid resolution was 4 kilometers. Figure 4-1 shows the extent of the modeling domain. Except when specifically instructed otherwise by the Wyoming Department of Environmental Quality – Air Quality Division (WDEQ-AQD), CH2M HILL followed the methodology spelled out in the WDEQ-AQD BART Modeling Protocol, a copy of which is included in this report as Appendix B.

CH2M HILL used the Lambert Conformal Conic map projection for the analysis due to the large extent of the domain. The latitude of the projection origin and the longitude of the central meridian were chosen at the approximate center of the domain. Standard parallels were drawn to represent one-sixth and five-sixths of the north-south extent of the domain to minimize distortion in the north-south direction.

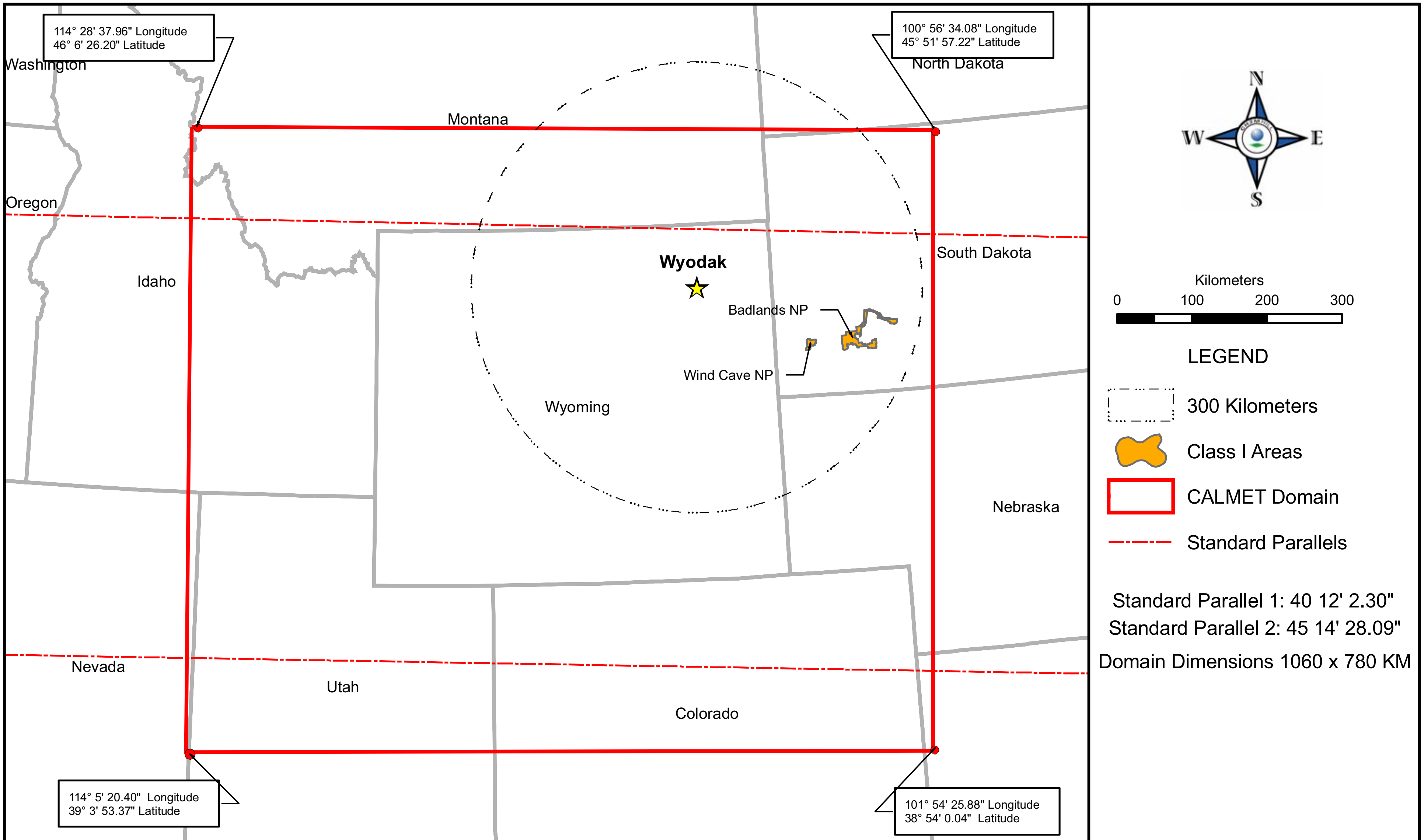


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Figure 4-1
Wyodak Source-Specific
Class I Areas to be Addressed

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The default technical options listed in TRC Companies, Inc.'s (TRC) current example CALMET.inp file were used for CALMET. Vertical resolution of the wind field included 10 layers, with vertical face heights as follows (in meters):

- 0, 20, 40, 100, 140, 320, 580, 1020, 1480, 2220, 3500

Other user-specified model options were set to values established by WDEQ-AQD, which appear in Table 3 of Appendix B. Table 4-1 lists the key user-specified options used for this analysis.

TABLE 4-1
User-specified CALMET Options
Wyodak

CALMET Input Parameter	Value
CALMET Input Group 2	
Map projection (PMAP)	Lambert Conformal
Grid spacing (DGRIDKM)	4
Number vertical layers (NZ)	10
Top of lowest layer (m)	20
Top of highest layer (m)	3500
CALMET Input Group 4	
Observation mode (NOOBS)	0
CALMET Input Group 5	
Prog. Wind data (IPROG)	14
(RMAX1)	30
(RMAX2)	50
Terrain influence (TERRAD)	15
(R1)	5
(R2)	25
CALMET Input Group 6	
Max mixing ht (ZIMAX)	3500

4.2.2 CALMET Input Data

CH2M HILL ran the CALMET model to produce 3 years of analysis: 2001, 2002, and 2003. WDEQ-AQD provided 12-km resolution Mesoscale Meteorological Model, Version 5 (MM5) meteorological data fields that covered the entire modeling domain for each study year that covered the entire modeling domain.

These three data sets were chosen because they are current and have been evaluated for quality. The MM5 data were used as input to CALMET as the “initial guess” wind field. The initial guess wind field was adjusted by CALMET for local terrain and land use effects to generate a Step 1 wind field, and further refined using local surface observations to create a final Step 2 wind field.

Surface data for 2001 through 2003 were obtained from the National Climatic Data Center. CH2M HILL processed the data from the National Weather Service’s Automated Surface Observing System network for all stations that are in the domain. The surface data were obtained in abbreviated DATSAV3 format. A conversion routine available from the TRC Web site was used to convert the DATSAV3 files to CD-144 format for input into the SMERGE preprocessor and CALMET.

Land use and terrain data were obtained from the United States Geological Survey (USGS). Land use data were obtained in Composite Theme Grid format from the USGS, and the Level 1 USGS land use categories were mapped into the 14 primary CALMET land use categories. Surface properties such as albedo, Bowen ratio, roughness length, and leaf area index were computed from the land use values. Terrain data were taken from USGS 1-degree Digital Elevation Model data, which primarily derive from USGS 1:250,000 scale topographic maps. Missing land use data were filled with values that were assumed appropriate for the missing area.

Precipitation data were ordered from the National Climatic Data Center. All available data in fixed-length, TD-3240 format were ordered for the modeling domain. The list of available stations that have collected complete data varies by year, but CH2M HILL processed all available stations/data within the domain for each year. Precipitation data were prepared with the PXTRACT/PMERGE processors in preparation for use within CALMET.

Upper-air data were prepared for the CALMET model with the READ62 preprocessor for the following stations:

- Denver, Colorado
- Salt Lake City, Utah
- Riverton, Wyoming
- Rapid City, South Dakota

Figure 4-2 shows the locations of surface and upper air stations within the MM5 modeling domain.

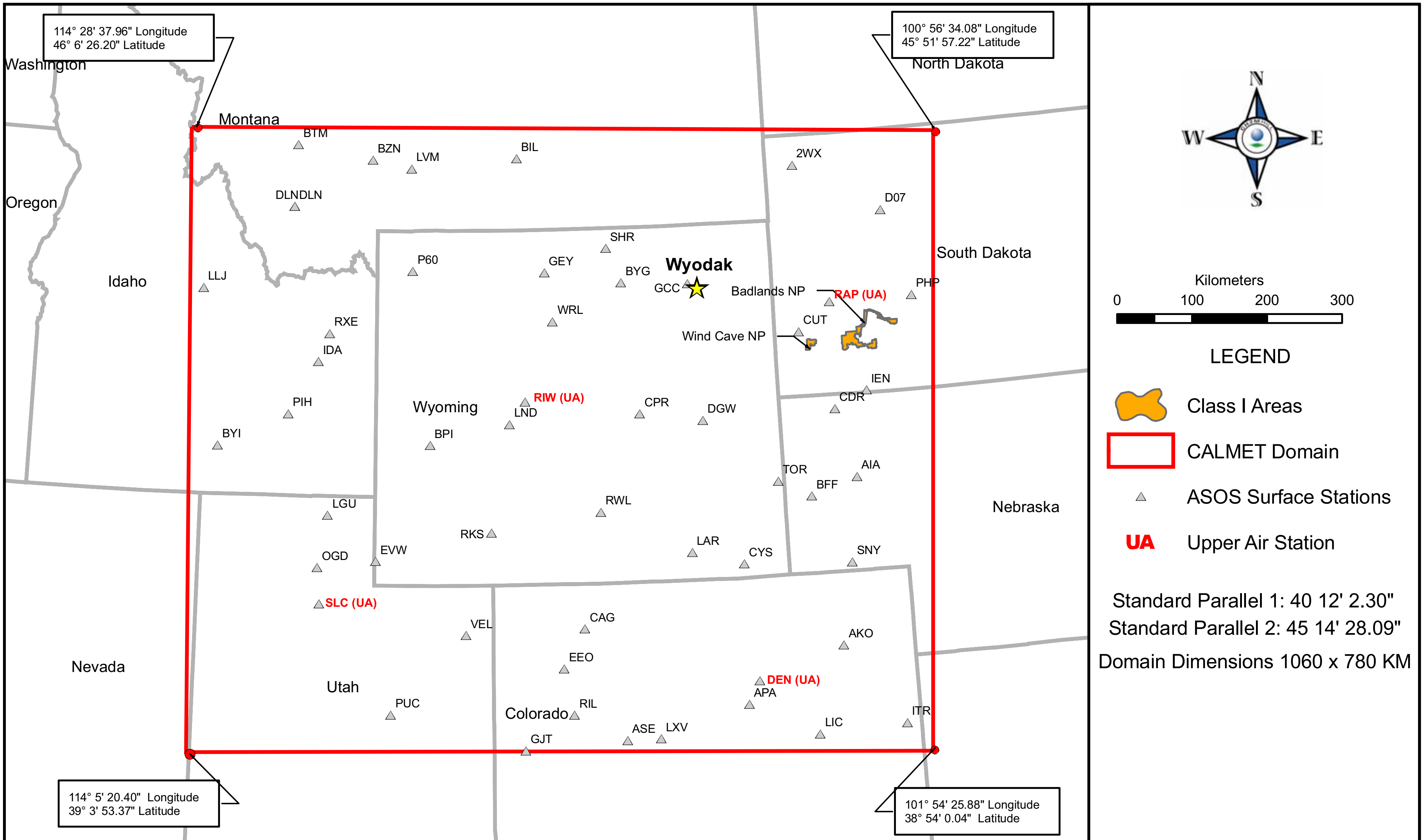

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Figure 4-2
Surface and Upper Air Stations Used in the Wyodak BART Analysis

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4.2.3 Validation of CALMET Wind Field

CH2M HILL used the Program to Display Data and Results (CALDESK) data display and analysis system (v2.97, Enviromodeling Ltd.) to view plots of wind vectors and other meteorological parameters to evaluate the CALMET wind fields. The CALDESK displays were compared to observed weather conditions, as depicted in surface and upper-air weather maps (National Oceanic and Atmospheric Administration, 2006).

4.3 CALPUFF Modeling Approach

For the BART control technology visibility improvement modeling, CH2M HILL followed WDEQ-AQD guidance (WDEQ-AQD, 2006).

CH2M HILL drove the CALPUFF model with the meteorological output from CALMET over the modeling domain described earlier. The CALPUFF model was used to predict visibility impacts for the pre-control (baseline) scenario for comparison to the predicted impacts for post-control scenarios for Wyodak.

4.3.1 Background Ozone and Ammonia

Hourly values of background ozone concentrations were used by CALPUFF for the calculation of SO_2 and NO_x transformation with the MESOPUFF II chemical transformation scheme. CH2M HILL obtained hourly ozone data from the following stations located within the modeling domain for 2001, 2002, and 2003:

- Rocky Mountain National Park, Colorado
- Craters of the Moon National Park, Idaho
- Highland, Utah
- Thunder Basin National Grasslands, Wyoming
- Yellowstone National Park, Wyoming
- Centennial, Wyoming
- Pinedale, Wyoming

For periods of missing hourly ozone data, the chemical transformation relied on a monthly default value of 44 parts per billion. Background ammonia was set to 2 parts per billion. Both of these background values were taken from the guidance document (WDEQ-AQD, 2006).

4.3.2 Stack Parameters

The stack parameters used for the baseline modeling reflect those that are in place under the current permit for Wyodak. Post-control stack parameters reflect the anticipated changes associated with installation of the control technology alternatives that are being evaluated. The maximum heat input rate of 4,700 MMBtu per hour was used to calculate a maximum emission rate. Measured velocities and stack flow rates were used in the modeling to represent a worst-case situation.

4.3.3 Emission Rates

Pre-control emission rates for Wyodak reflect peak 24-hour average emissions that may occur under the source's current permit. The emission rates reflect actual emissions under normal operating conditions, as described by the EPA in the *Regional Haze Regulations and Guidelines for Best Available Retrofit Technology Determinations; Final Rule* (40 CFR Part 51).

CH2M HILL used available continuous emission monitoring data to determine peak 24-hour emission rates. Data reflected operations from the most recent 3- to 5-year period, unless a more recent period was more representative. Allowable short-term (24-hour or shorter period) emissions or short-term emission limits were used if continuous emission monitoring data were not available.

Emissions were modeled for the following pollutants:

- SO_2
- NO_x
- Coarse particulate ($PM_{2.5}$<diameter<PM_{10})
- Fine particulate (diameter<$PM_{2.5}$)
- Sulfates

Post-control emission rates reflect the effects of the emissions control scenario under consideration. Modeled pollutants were the same as those listed for the pre-control scenario.

4.3.4 Post-control Scenarios

Four post-control modeling scenarios were developed to cover the range of effectiveness for the combination of the individual NO_x, SO_2, and PM control technologies being evaluated. The selection of each control device was made based on the engineering analyses described in Section 3 for reasonable technologies that would meet or exceed the presumptive BART levels for each pollutant.

- **Scenario 1**: New LNB with OFA, upgrading the dry FGD system, and maintaining performance of the existing ESP. As indicated previously, this scenario represents CH2M HILL's preliminary BART recommendation.

- **Scenario 2**: New LNB with OFA, upgrading the dry FGD system and a new fabric filter to replace the existing ESP.

- **Scenario 3**: New LNB with OFA and SCR, upgrading the dry FGD system, and a new fabric filter to replace the existing ESP

- **Scenario 4**: New LNB with OFA and SCR, a wet FGD system, and the existing ESP.

Table 4-2 presents the stack parameters and emission rates used for the Wyodak analysis for baseline and post-control modeling.

TABLE 4-2
BART Model Input Data
Wyodak

Model Input Data	Baseline Current Operations with Dry Flue Gas Desulfurization (FGD) and Electrostatic Precipitator (ESP)	Post-control Scenario 1 Low-NO_x Burners (LNB) with OFA, Dry FGD, ESP	Post-control Scenario 2 LNB with OFA, Dry FGD, Fabric Filter	Post-control Scenario 3 LNB with OFA and SCR, Dry FGD, Fabric Filter	Post-control Scenario 4 LNB with OFA and SCR, Wet FGD, ESP
Sulfur Dioxide (SO_2) Stack Emissions (pounds per hour [lb/hr])	2,350	1,518	759	759	380
Nitrogen Oxide (NO_x) Stack Emissions (lb/hr)	1,457	1,081	1,081	329	329
PM_{10} Stack Emissions (lb/hr)	141	141	70.5	70.5	141
Coarse Particulate ($PM_{2.5}$ <diameter< PM_{10}) Stack Emissions (lb/hr)[(a)]	60.6	60.6	40.2	40.2	60.6
Fine Particulate (diameter<$PM_{2.5}$) Stack Emissions (lb/hr)[(b)]	80.4	80.4	30.3	30.3	80.4
Sulfuric Acid (H_2SO_4) Stack Emissions (lb/hr)	5.64	5.64	5.64	9.40	105
H_2SO_4 as Sulfate (SO_4) Stack Emissions (lb/hr)	5.52	5.52	5.52	9.21	103
Ammonium Sulfate [$(NH_4)_2SO_4$] Stack Emissions (lb/hr)				1.08	5.45
$(NH_4)_2SO_4$ as SO_4 Stack Emissions (lb/hr)				0.79	3.96
$(NH_4)HSO_4$ Stack Emissions (lb/hr)				1.93	9.54
$(NH_4)HSO_4$ as SO_4 Stack Emissions (lb/hr)				1.61	7.96
Total Sulfate (SO_4) (lb/hr)	5.52	5.52	5.52	11.6	115
Stack Conditions					
Stack Height (meters)	122	122	122	122	122
Stack Exit Diameter (meters)	6.10	6.10	6.10	6.10	6.10
Stack Exit Temperature (Kelvin)	358	353	350	350	322
Stack Exit Velocity (meters per second)	23.5	23.5	23.5	23.5	23.5

NOTES:
[(a)]Based on AP-42, Table 1.1-6, the coarse particulates are counted as a percentage of PM_{10}. This equates to 43 percent ESP and 57 percent baghouse.
[(b)]Based on AP-42, Table 1.1-6, the fine particulates are counted as a percentage of PM_{10}. This equates to 57 percent ESP and 43 percent baghouse.

Total Sulfate (SO_4) (lb/hr) = H_2SO_4 as Sulfate (SO_4) Stack Emissions (lb/hr) + $(NH_4)_2SO_4$ as SO_4 Stack Emissions (lb/hr) + $(NH_4)HSO_4$ as SO_4 Stack Emissions (lb/hr)

4.3.5 Modeling Process

The CALPUFF modeling for the control technology options for Wyodak followed this sequence:

- Model pre-control (baseline) emissions
- Model preferred post-control scenario (if applicable)
- Determine degree of visibility improvement
- Model other control scenarios
- Determine degree of visibility improvement
- Factor visibility results into the BART five-step evaluation

4.3.6 Receptor Grids

Discrete receptors for the CALPUFF modeling were placed at uniform receptor spacing along the boundary and in the interior of each area of concern. Class I area receptors were taken from the National Park Service database for Class I area modeling receptors. The TRC COORDS program was used to convert all latitude/longitude coordinates to Lambert Conformal Conic coordinates, including receptors, meteorological stations, and source locations.

4.4 CALPOST

The CALPOST processor was used to determine 24-hour average visibility results with output specified in deciview (dV) units. Calculations of light extinction were made for each pollutant modeled. The sum of all extinction values were used to calculate the delta-dV (ΔdV) change relative to natural background. The following default extinction coefficients for each pollutant were used:

- Ammonium sulfate 3.0
- Ammonium nitrate 3.0
- PM coarse (PM_{10}) 0.6
- PM fine ($PM_{2.5}$) 1.0
- Organic carbon 4.0
- Elemental carbon 10.0

CALPOST visibility Method 6 was used to determine the visibility impacts. Monthly relative humidity factors were used in the light extinction calculations to account for the hygroscopic characteristics of nitrate and sulfate particles. Table 5 of the Wyoming *BART Air Modeling Protocol* (Appendix B) lists the monthly relative humidity factors for the Class I areas. These values were used for the particular Class I area being modeled.

The natural background conditions as a reference for determining the ΔdV change represented the 20 percent best natural visibility days. The EPA BART guidance document provided dV values for the 10 percent best days for each Class I area, but did not provide individual species concentration data for the 20 percent best background conditions. Species concentrations corresponding to the 20 percent best days were calculated for each Class I area by scaling back the annual average species concentrations given in Table 2-1 of

Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule (EPA, 2003). A separate scaling factor was derived for each Class I area such that, when multiplied by the Guidance table annual concentrations, the 20 percent best days dV value for that area would be calculated. This procedure was taken from *Protocol for BART-Related Visibility Improvement Modeling Analysis in North Dakota* (North Dakota Department of Health, 2005). However, the Wyoming *BART Air Modeling Protocol* (Appendix B) provided natural background concentrations of aerosol components to use in the BART analysis. Table 4-3 lists the annual average species concentrations from the BART protocol.

TABLE 4-3
Average Natural Levels of Aerosol Components
Wyodak

Aerosol Component	Average Natural Concentration (micrograms per cubic meter) for Wind Cave National Park (NP) and Badlands NP Class I Areas
Ammonium Sulfate	0.047
Ammonium Nitrate	0.040
Organic Carbon	0.186
Elemental Carbon	0.008
Soil	0.198
Coarse Mass	1.191

NOTE:
Source: Table 6 of the Wyoming BART Air Modeling Protocol.

4.5 Presentation of Modeling Results

This section presents the results of the CALPUFF visibility improvement modeling analysis for Wyodak.

4.5.1 Visibility Changes for Baseline vs. Preferred Scenario

CH2M HILL modeled Wyodak for the baseline and four post-control scenarios. The post-control scenarios included emission rates for SO_2, NO_x, and PM_{10} that would be achieved if BART state-of-the-art technology were installed at Wyodak.

Baseline (and post-control) 98^{th} percentile results were greater than 0.5 ΔdV for the Badlands and Wind Cave NPs. The 98^{th} percentile results for each Class I area are presented in Table 4-4.

TABLE 4-4
Costs and Visibility Modeling Results for Baseline vs. Post-control Scenarios at Class I Areas
Wyodak

Scenario	Total First Year Annualized Cost	Class I Area	Modeling Results: Highest ΔdV-	Modeling Results: 98th Percentile ΔdV-	Modeling Results: Number of Days Above 0.5 dV	Cost per dV Reduction	Cost per Reduction in No. of Days Above 0.5 dV	Incremental Cost per dV Reduction	Incremental Cost per Reduction in No. of Days Above 0.5 dV
2001									
Baseline: Current Operation with Dry Flue Gas Desulfurization (FGD), Electrostatic Precipitator (ESP)		Badlands	1.775	0.841	27	--	--		
		Wind Cave	1.723	1.153	41	--	--		
Scenario 1: Low-NO_x Burners (LNBs) with Over-fire Air (OFA), Dry FGD, ESP	$4,836,638	Badlands	1.302	0.595	12	$19,661,130	$322,443		
	$4,836,638	Wind Cave	1.213	0.817	19	$14,394,756	$219,847		
Scenario 2: LNBs with OFA, Dry FGD, Fabric Filter	$8,768,522	Badlands	1.088	0.472	6	$23,762,932	$417,549	$31,966,537	$655,314
	$8,768,522	Wind Cave	0.958	0.671	11	$18,191,954	$292,284	$26,930,712	$491,486
Scenario 3: LNBs with OFA and SCR, Wet FGD, Fabric Filter	$20,682,244	Badlands	0.521	0.254	1	$35,233,806	$795,471	$54,650,101	$2,382,744
	$20,682,244	Wind Cave	0.531	0.333	2	$25,222,249	$530,314	$35,247,698	$1,323,747
Scenario 4: LNBs with OFA and SCR, Wet FGD, ESP	$24,707,516	Badlands	0.641	0.294	1	$45,169,133	$950,289	NA	NA
	$24,707,516	Wind Cave	0.586	0.396	2	$32,638,727	$633,526	NA	NA
2002									
Baseline: Current Operation with Dry FGD, ESP		Badlands	1.859	1.140	34	--	--		
		Wind Cave	2.591	1.323	38	--	--		
Scenario 1: LNBs with OFA, Dry FGD, ESP	$4,836,638	Badlands	1.388	0.829	18	$15,551,891	$302,290		
	$4,836,638	Wind Cave	1.950	0.940	26	$12,628,298	$403,053		
Scenario 2: LNBs with OFA, Dry FGD, Fabric Filter	$8,768,522	Badlands	1.216	0.624	14	$16,993,260	$438,426	$19,179,922	$982,971
	$8,768,522	Wind Cave	1.712	0.788	17	$16,389,761	$417,549	$25,867,658	$436,876
Scenario 3: LNBs with OFA and SCR, Wet FGD, Fabric Filter	$20,682,244	Badlands	0.546	0.331	2	$25,565,197	$646,320	$40,661,167	$992,810
	$20,682,244	Wind Cave	0.777	0.383	5	$22,002,387	$626,735	$29,416,598	$992,810
Scenario 4: LNBs with OFA and SCR, Wet FGD, ESP	$24,707,516	Badlands	0.801	0.405	3	$33,615,668	$797,017	NA	NA
	$24,707,516	Wind Cave	1.085	0.519	9	$30,730,741	$851,983	NA	NA

TABLE 4-4
Costs and Visibility Modeling Results for Baseline vs. Post-control Scenarios at Class I Areas
Wyodak

Scenario	Total First Year Annualized Cost	Class I Area	Modeling Results: Highest ΔdV-	Modeling Results: 98th Percentile ΔdV-	Modeling Results: Number of Days Above 0.5 dV	Cost per dV Reduction	Cost per Reduction in No. of Days Above 0.5 dV	Incremental Cost per dV Reduction	Incremental Cost per Reduction in No. of Days Above 0.5 dV
2003									
Baseline: Current Operation with Dry FGD, ESP		Badlands	2.556	1.070	31	--	--		
		Wind Cave	3.296	1.530	37	--	--		
Scenario 1: LNBs with OFA, Dry FGD, ESP	$4,836,638	Badlands	1.819	0.739	20	$14,612,199	$439,694		
	$4,836,638	Wind Cave	2.370	1.114	28	$11,626,534	$537,404		
Scenario 2: LNBs with OFA, Dry FGD, Fabric Filter	$8,768,522	Badlands	1.319	0.583	13	$18,005,179	$487,140	$25,204,385	$561,698
	$8,768,522	Wind Cave	1.797	0.929	17	$14,589,887	$438,426	$21,253,427	$357,444
Scenario 3: LNBs with OFA and SCR, Wet FGD, Fabric Filter	$20,682,244	Badlands	0.811	0.314	2	$27,357,466	$713,181	$44,288,929	$1,083,066
	$20,682,244	Wind Cave	1.065	0.457	6	$19,275,158	$667,169	$25,240,936	$1,083,066
Scenario 4: LNBs with OFA and SCR, Wet FGD, ESP	$24,707,516	Badlands	0.717	0.340	3	$33,845,912	$882,411	NA	NA
	$24,707,516	Wind Cave	1.028	0.684	10	$29,205,102	$915,093	NA	NA
3-Year Averages									
Baseline: Current Operation with ESP		Badlands		1.017	30.7				
		Wind Cave		1.335	38.7				
Scenario 1: LNBs with OFA, dry FGD, existing ESP	$4,836,638	Badlands		0.721	16.7	$16,339,993	$345,474		
	$4,836,638	Wind Cave		0.957	24.3	$12,784,065	$337,440		
Scenario 2: LNBs with OFA, Dry FGD, Fabric Filter	$8,768,522	Badlands		0.560	11.0	$19,173,153	$445,857	$24,371,182	$693,862
	$8,768,522	Wind Cave		0.796	15.0	$16,258,075	$370,501	$24,421,640	$421,273
Scenario 3: LNBs with OFA and SCR, Dry FGD, Fabric Filter	$20,682,244	Badlands		0.300	1.7	$28,832,125	$713,181	$45,822,008	$1,276,470
	$20,682,244	Wind Cave		0.391	4.3	$21,901,423	$602,395	$29,416,598	$1,116,911
Scenario 4: LNBs with OFA and SCR, Wet FGD, Existing ESP, New Stack	$24,707,516	Badlands		0.346	2.3	$36,840,233	$872,030	NA	NA
	$24,707,516	Wind Cave		0.533	7.0	$30,794,577	$780,237	NA	NA

NOTES:
Scenario 3 produces better results in visibility than Scenario 4. Therefore, Scenario 4 was not further analyzed.
Sample Calculations: Cost per dV Reduction for Scenario 1 for 2001: = $4,836,638 / (0.841 - 0.595) = $19,661,131
Sample Calculations: Cost per Reduction in Number of Days Exceeding 0.5 dV for 2001: = $4,836,638 / (27 - 12) = $322,443

5.0 Preliminary Assessment and Recommendations

As a result of the completed technical and economic evaluations and consideration of the modeling analysis for Wyodak, the preliminary recommended BART controls for NO_x, SO_2, and PM are as follows:

- New LNBs and modifications to the OFA system for NO_x control
- Upgrade lime spray dryer FGD for SO_2 control
- Maintain the existing ESP for PM control

The above recommendations were identified as Scenario 1 for the modeling analysis described in Section 4. Visibility improvements for all emission control scenarios were analyzed, and the results are compared below, utilizing a least-cost envelope, as outlined in the *New Source Review Workshop Manual* (EPA, 1990).

5.1 Least-cost Envelope Analysis

The total annualized cost, cost per dV reduction, and cost per reduction in number of days above 0.5 dV for the scenarios modeled in Section 4 to determine the impact on the two Class I areas are listed in Tables 5-1 and 5-2. A comparison of the incremental costs between relevant scenarios is shown in Tables 5-3 through 5-4. The total annualized cost versus number of days above 0.5 dV, and the total annualized cost versus 98th percentile ΔdV reduction are shown in Figures 5-1 to 5-4 for the two Class I areas.

5.1.1 Analysis Methodology

On page B-41 of the draft New Source Review Manual, the EPA states that "Incremental cost-effectiveness comparisons should focus on annualized cost and emission reduction differences between dominant alternatives. Dominant set of control alternatives are determined by generating what is called the envelope of least-cost alternatives. This is a graphical plot of total annualized costs for a total emissions reductions for all control alternatives identified in the BACT analysis..."

An analysis of incremental cost effectiveness has been conducted. This analysis was performed in the following way. First, the control option scenarios are ranked in ascending order of annualized total costs as shown in Tables 5-1 and 5-2. The incremental cost-effectiveness data, expressed per day and per dV, represents a comparison of the different scenarios, and is summarized in Tables 5-3 and 5-4 for each of the two Class I areas. Then the most reasonable smooth curve of least-cost control option scenarios is plotted for each analysis. Figures 5-1 through 5-4 present the two analyses (cost per dV reduction and cost per reduction in number of days above 0.5 dV) for each of the two Class I areas impacted by the operation of Wyodak.

TABLE 5-1
Badlands Class I Agent Control Data
Wyodak

Scenario	Controls	98th Percentile Deciview (dV) Reduction	Average Number of Days Above 0.5 dV (Days)	Total Annualized Cost (Million$)	Cost per dV Reduction (Million$/dV Reduced)	Cost per Reduction in No. of Days Above 0.5 dV (Million$/Day Reduced)
Base	Current Operation with Dry Flue Gas Desulfurization (FGD), Electrostatic Precipitator (ESP)	0.00	0.0	$0.0	$0.0	$0.0
1	Low-NO_x Burner (LNB) with Over-fire Air (OFA), Dry FGD, ESP	0.30	14.0	$4.8	$16.3	$0.3
2	LNB with OFA, Dry FGD, Fabric Filter	0.46	19.7	$8.8	$19.2	$0.4
3	LNB with OFA and SCR, Dry FGD, Fabric Filter	0.72	29.0	$20.7	$28.8	$0.7
4	LNB with OFA and SCR, Wet FGD, ESP	0.67	28.3	$24.7	$36.8	$0.9

TABLE 5-2
Wind Caves Class I Area Control Data
Wyodak

Scenario	Controls	98th Percentile Deciview (dV) Reduction	Average Number of Days Above 0.5 dV (Days)	Total Annualized Cost (Million$)	Cost per dV Reduction (Million$/dV Reduced)	Cost per Reduction in No. of Days Above 0.5 dV (Million$/Day Reduced)
Base	Current Operation with Dry Flue Gas Desulfurization (FGD), Electrostatic Precipitator (ESP)	0.00	0.0	$0.0	$0.0	$0.0
1	Low-NO_x Burner (LNB) with Over-fire Air (OFA), Dry FGD, ESP	0.38	14.3	$4.8	$12.8	$0.3
2	LNB with OFA, Dry FGD, Fabric Filter	0.54	23.7	$8.8	$16.3	$0.4
3	LNB with OFA and SCR, Dry FGD, Fabric Filter	0.94	34.3	$20.7	$21.9	$0.6
4	LNB with OFA and SCR, Wet FGD, ESP	0.80	31.7	$24.7	$30.8	$0.8

TABLE 5-3
Badlands Class I Area Incremental Data
Wyodak

Options Compared	Incremental Reduction in Days Above 0.5 Deciview (dV) (Days)	Incremental dV Reductions (dV)	Incremental Cost Effectiveness (Million$/Days)	Incremental Cost Effectiveness (Million$/dV)
Baseline and Scenario 1	14.0	0.30	$0.35	$16.3
Scenario 1 and Scenario 2	5.7	0.16	$0.69	$24.4
Scenario 1 and Scenario 3	15.0	0.42	$1.1	$37.6
Scenario 1 and Scenario 4	14.3	0.37	$1.4	$53.0

NOTE:
Because Scenario 3 produces better results in visibility than Scenario 4, Scenario 4 was not analyzed further.

TABLE 5-4
Wind Caves Class I Agent Incremental Data
Wyodak

Options Compared	Incremental Reduction in Days Above 0.5 Deciview (dV) (Days)	Incremental dV Reductions (dV)	Incremental Cost Effectiveness (Million$/Days)	Incremental Cost Effectiveness (Million$/dV)
Baseline and Scenario 1	14.3	0.38	$0.34	$12.8
Scenario 1 and Scenario 2	9.3	0.16	$0.42	$24.4
Scenario 1 and Scenario 3	20.0	0.57	$0.79	$28.0
Scenario 1 and Scenario 4	17.3	0.42	$1.1	$46.9

NOTE:
Because Scenario 3 produces better results in visibility than Scenario 4, Scenario 4 was not analyzed further.

FIGURE 5-1
Least-cost Envelope Badlands Class I Area Reduction
Wyodak

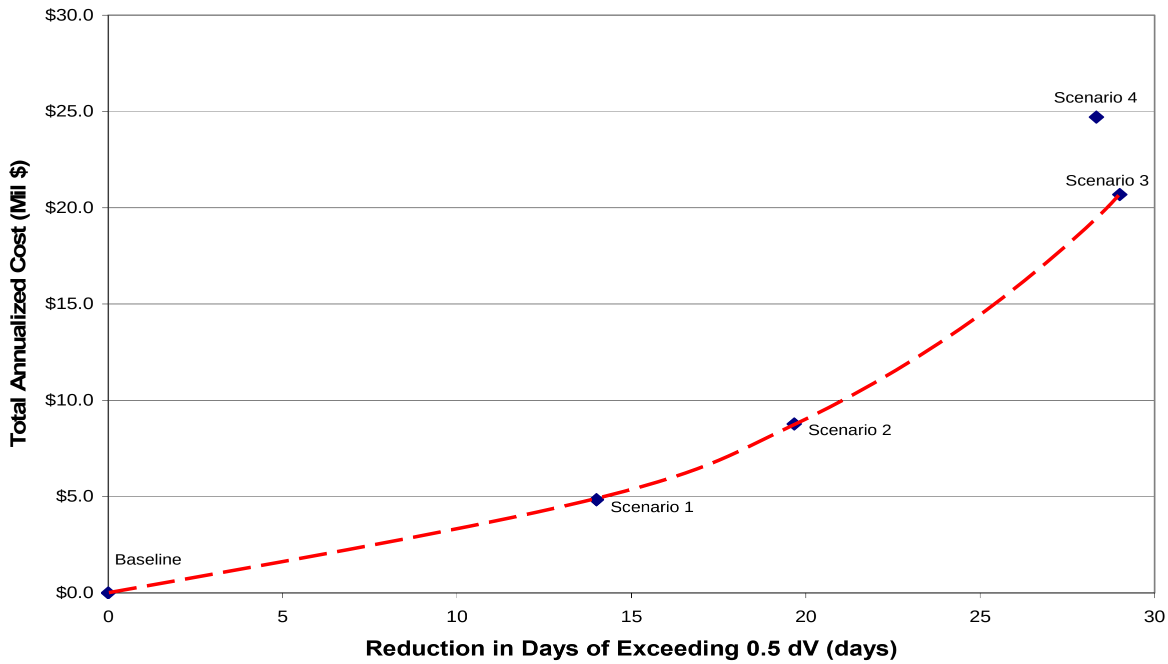


FIGURE 5-2
Least-cost Envelope Badlands Class I Area 98th Percentile
Wyodak

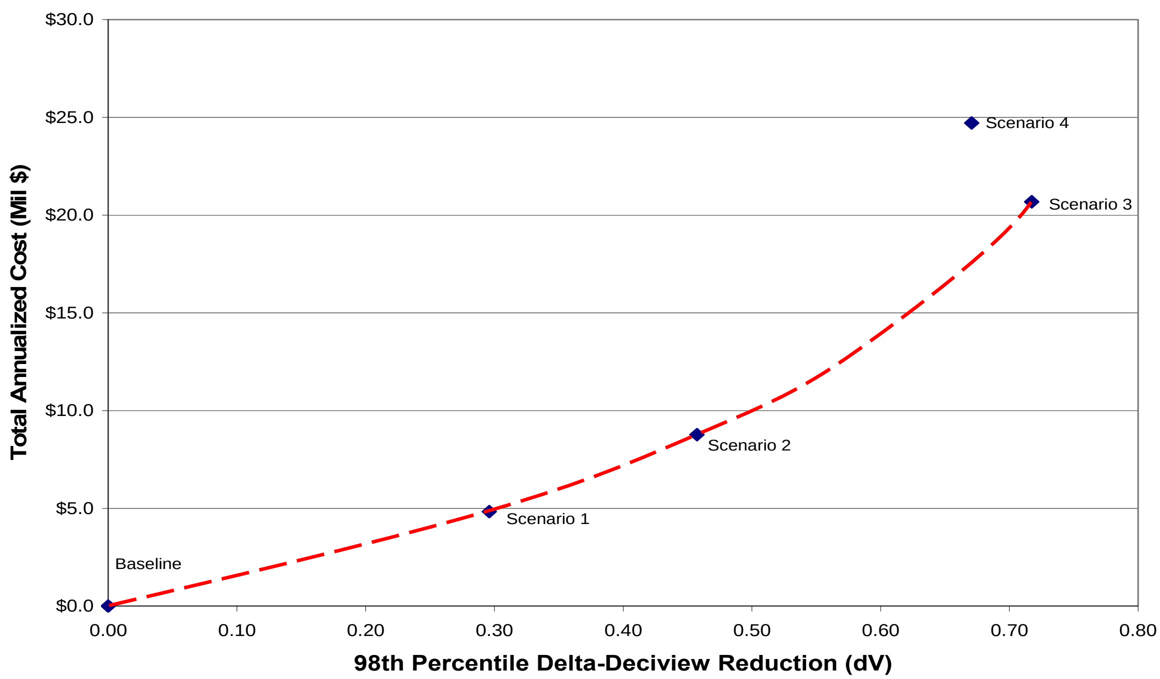


FIGURE 5-3
Least-cost Envelope Wind Caves Class I Area Reduction
Wyodak

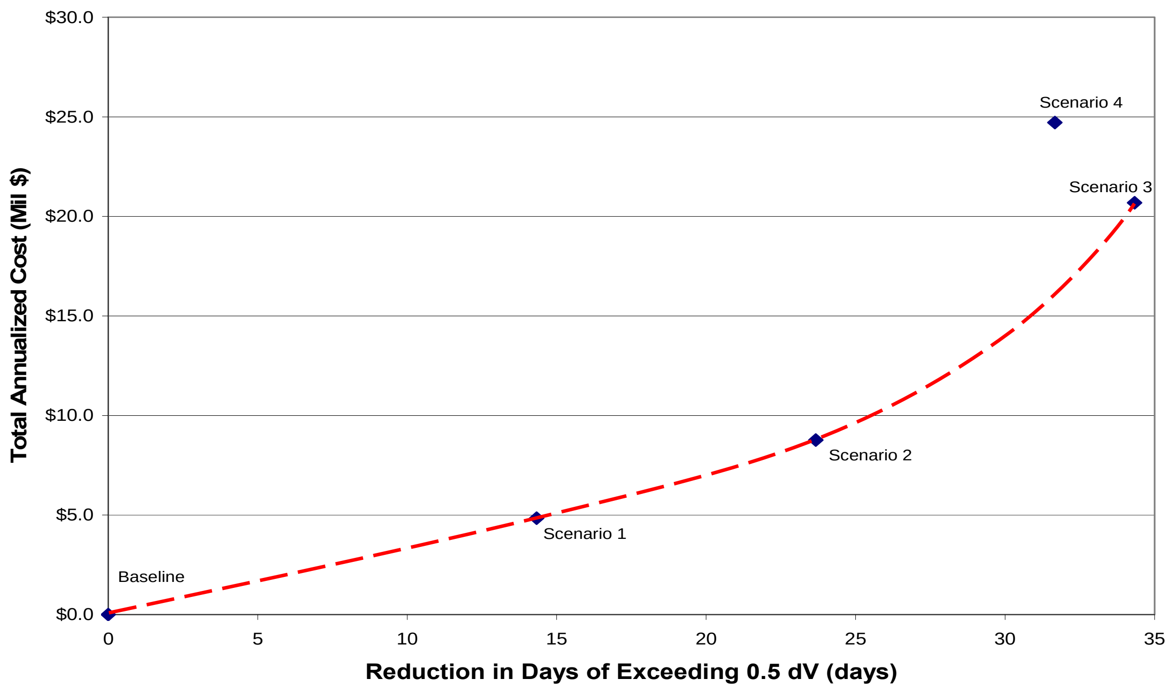
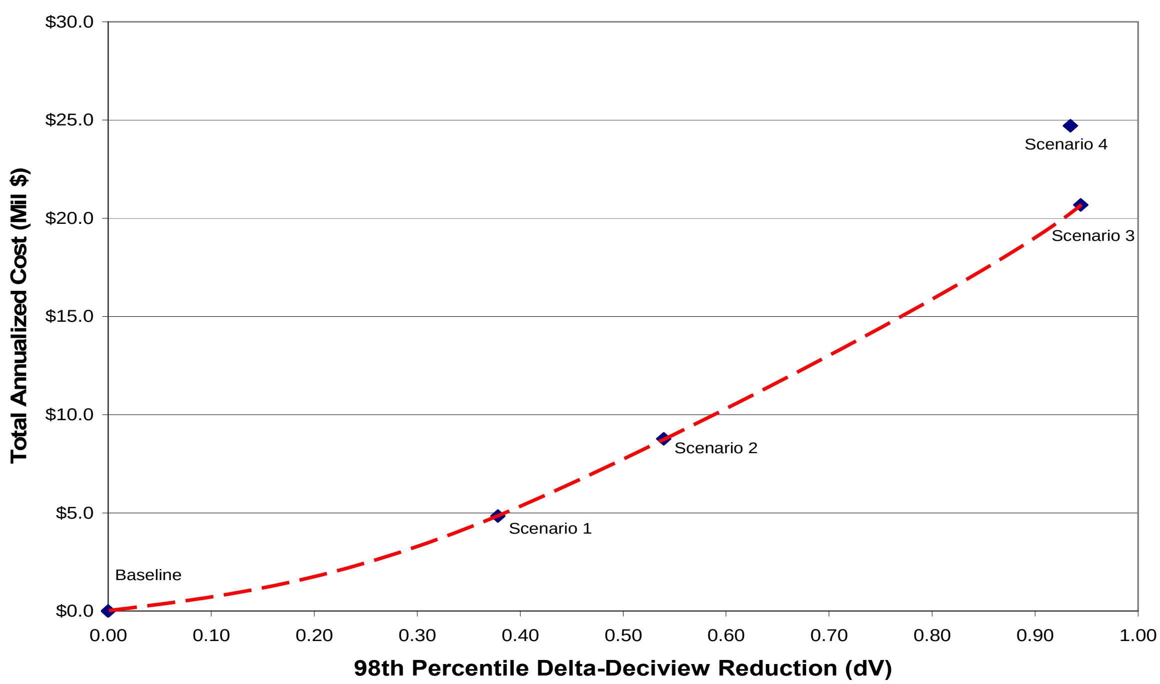


FIGURE 5-4
Least-cost Envelope Wind Caves Class I Area 98th Percentile
Wyodak



5.1.2 Analysis of Results

Results of the least-cost analysis, shown in Tables 5-1 to 5-4 and Figures 5-1 to 5-4, confirm the selection of Scenario 1, based on incremental cost and visibility improvements. In Figure 5-1, the four scenarios are compared as a graph of total annualized cost versus number of days above 0.5 dV. EPA states that, "In calculating incremental costs, the analysis should only be conducted for control options that are dominant among all possible options." In Figure 5-1, the dominant set of control options, Scenarios 1 and 3, represent the least-cost envelope depicted by the curvilinear line connecting them. Scenario 2 is eliminated because, although it lies on the curve formed by the dominant control alternative scenarios, it is an inferior option and should not be considered in the derivation of incremental cost effectiveness. Scenario 2 represents inferior controls because Scenario 1 provides approximately same amount of visibility impact reduction for less cost than Scenario 2. Similarly, Scenario 3 is projected to provide approximately the same amount of visibility impact reduction but at an excessive cost, both a cost per day of improvement and a cost per dV reduction, when compared to Scenario 1. The incremental cost effectiveness is determined by the difference in total annual costs between two contiguous scenarios divided by the difference in emissions reduction.

Analysis of the results for the Badlands NP Class I Area in Tables 5-1 and 5-3 and Figures 5-1 and 5-2 illustrates the conclusions stated above. The greatest reduction in 98^{th} percentile dV and number of days above 0.5 dV is between the Baseline and Scenario 1. Table 5-3 shows that the incremental cost effectiveness for Scenario 1, compared to the Baseline, is at $350,000 per day and $16.3 million per dV to improve visibility at Badlands NP. The incremental cost effectiveness for Scenario 2 compared to Scenario 1 is at $0.69 million/day and $24.4 million per dV. In other words, the additional cost of Scenario 2 is projected to gain only 0.16 dV improvement in visibility. However, Scenario 2 does reduce the number of days where the visibility is above 0.5 dV by 6 days a year. The incremental cost effectiveness for Scenario 3 compared to Scenario 1 is excessive at $1.1 million per day and $37.6 million per dV. A similar conclusion is reached for improving visibility at Wind Caves NP. Therefore, Scenario 1 represents BART for Wyodak.

5.2 Recommendations

5.2.1 NO_x Emission Control

CH2M HILL recommends new LNB with OFA as BART for Wyodak, based on the projected significant reduction in NO_x emissions, reasonable control costs, and the advantages of no additional power requirements or non-air quality environmental impacts. This selection of new LNB with OFA is projected to attain an emission rate of 0.23 lb of NO_x per MMBtu.

5.2.2 SO_2 Emission Control

CH2M HILL recommends upgrading the existing lime spray drying FGD system and the existing ESP as BART for Wyodak, based on the significant reduction in SO_2 emissions, reasonable control costs, and the advantages of minimal additional power requirements and minimal non-air quality environmental impacts.

5.2.3 PM_{10} Emission Control

CH2M HILL recommends maintaining the existing ESP downstream of the lime spray dryer as BART for Wyodak, based on the significant reduction in PM_{10} emissions, reasonable control costs, and the advantages of no additional power requirements and no non-air quality environmental impacts.

5.3 Just-Noticeable Differences in Atmospheric Haze

Conclusions reached in the reference document "Just-Noticeable Differences in Atmospheric Haze" by Dr. Ronald Henry (2002), state that only dV differences of approximately 1.5 to 2.0 dV or more are perceivable by the human eye. Deciview changes of less than 1.5 cannot be distinguished by the average person. Therefore, the modeling analysis results indicate that only minimal, if any, visibility improvements at the Class I areas studied would be expected under any of the scenarios. Thus, the results indicate that even though many millions of dollars will be spent, only minimal visibility improvements may result.

Finally, it should be noted that none of the data were corrected for natural obscuration. During the period of 2001 through 2003, there were several mega-wildfires that lasted for many days and could have had a significant impact on visibility in these Class I areas. If natural obscuration were to reduce the visibility impacts modeled for the Wyodak facility, it would increase the costs per dV reduction that are presented in this report.

6.0 References

40 CFR Part 51. *Regional Haze Regulations and Guidelines for Best Available Retrofit Technology Determinations; Final Rule.* July 6, 2005.

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APPENDIX A

Economic Analysis

PacifiCorp BART Analysis Scenarios

Select Unit:	10	Wyodak

Index No.	Name of Unit
1	Dave Johnston Unit 3
2	Dave Johnston Unit 4
3	Jim Bridger Unit 1
4	Jim Bridger Unit 2
5	Jim Bridger Unit 3
6	Jim Bridger Unit 4
7	Naughton Unit 1
8	Naughton Unit 2
9	Naughton Unit 3
10	Wyodak

Dave Johnston				Naughton					
DJ Unit 3		DJ Unit 4		NTN Unit 1		NTN Unit 2		NTN Unit 3	
Scenario	First Year Cost	Scenario	First Year Cost	Scenario	First Year Cost	Scenario	First Year Cost	Scenario	First Year Cost
Baseline - Current Operation with ESP		Baseline - Current Operation with Venturi Scrubber		Baseline - Current Operation with ESP		Baseline - Current Operation with ESP		Baseline - Current Operation with Wet FGD and ESP	
Scenario 1 - LNB with OFA, Dry FGD, Existing ESP	**N/A** N/A	Scenario 1 - LNB with OFA, Dry FGD, Fabric Filter	**N/A** N/A	Scenario 1 - LNB with OFA, Dry FGD, ESP	**N/A** N/A	Scenario 1 - LNB with OFA, Dry FGD, ESP	**N/A** N/A	Scenario 1 - LNB with OFA, Wet FGD, ESP	**N/A** N/A
Scenario 2 - LNB with OFA, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 2 - LNB with OFA, Wet FGD, New Fabric Filter	**N/A** N/A	Scenario 2 - LNB with OFA, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 2 - LNB with OFA, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 2 - LNB with OFA, Wet FGD, New Fabric Filter	**N/A** N/A
Scenario 3 - LNB with OFA and SCR, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 3 - LNB with OFA and SCR, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 3 - LNB with OFA and SCR, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 3 - LNB with OFA and SCR, Dry FGD, New Fabric Filter	**N/A** N/A	Scenario 3 - LNB with OFA and SCR, Wet FGD, ESP	**N/A** N/A
Scenario 4 - LNB with OFA and SCR, Wet FGD, Existing ESP, New Stack	**N/A** N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, Fabric Filter	**N/A** N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, ESP, New Stack	**N/A** N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, ESP, New Stack	**N/A** N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, Fabric Filter	**N/A** N/A

Jim Bridger								Wyodak	
JB Unit 1		JB Unit 2		JB Unit 3		JB Unit 4		Wyodak	
Scenario	First Year Cost	Scenario	First Year	Scenario	First Year Cost	Scenario	First Year Cost	Scenario	First Year Cost
Baseline - Current Operation with Wet FGD and ESP		Baseline - Current Operation with Wet FGD and ESP		Baseline - Current Operation with Wet FGD and ESP		Baseline - Current Operation with Wet FGD and ESP		Baseline - Current Operation with Dry FGD, ESP	
Scenario 1 - LNB with OFA, Wet FGD, ESP	**N/A** N/A N/A	Scenario 1 - LNB with OFA, Wet FGD, ESP	**N/A** N/A N/A	Scenario 1 - LNB with OFA, Wet FGD, ESP	**N/A** N/A N/A	Scenario 1 - LNB with OFA, Wet FGD, ESP	**N/A** N/A N/A	Scenario 1 - LNB with OFA, Dry FGD, ESP	**$ 4,836,638** $ 4,836,638
Scenario 2 - LNB with OFA, Wet FGD, New Fabric Filter	**N/A** N/A N/A	Scenario 2 - LNB with OFA, Wet FGD, New Fabric Filter	**N/A** N/A N/A	Scenario 2 - LNB with OFA, Wet FGD, New Fabric Filter	**N/A** N/A N/A	Scenario 2 - LNB with OFA, Wet FGD, Fabric Filter	**N/A** N/A N/A	Scenario 2 - LNB with OFA, Dry FGD, Fabric Filter	**$ 8,768,522** $ 8,768,522
Scenario 3 - LNB with OFA and SCR, Wet FGD, ESP	**N/A** N/A N/A	Scenario 3 - LNB with OFA and SCR, Wet FGD, ESP	**N/A** N/A N/A	Scenario 3 - LNB with OFA and SCR, Wet FGD, ESP	**N/A** N/A N/A	Scenario 3 - LNB with OFA and SCR, Wet FGD, ESP	**N/A** N/A N/A	Scenario 3 - LNB with OFA and SCR, Dry FGD, Fabric Filter	**$ 20,682,244** $ 20,682,244
Scenario 4 - LNB with OFA and SCR, Wet FGD, Fabric Filter	**N/A** N/A N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, Fabric Filter	**N/A** N/A N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, Fabric Filter	**N/A** N/A N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, Fabric Filter	**N/A** N/A N/A	Scenario 4 - LNB with OFA and SCR, Wet FGD, ESP	**$ 24,707,516** $ 24,707,516

ECONOMIC ANALYSIS SUMMARY

Wyodak **Boiler Design:** **Opposed Wall-Fired PC**

Parameter	Current Operation	NOx Control				SO2 Control			PM Control
		LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Upgraded Dry FGD	Dry FGD w/Fabric Filter	Wet FGD	Fabric Filter
Case	1	2	3	4	5	6	7	8	10
NOx Emission Control System	LNB	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	LNB	LNB	LNB	LNB
SO2 Emission Control System	Dry FGD	Dry FGD	Dry FGD	Dry FGD	Dry FGD	Upgraded Dry FGD	Dry FGD w/Fabric Filter	Wet FGD	Dry FGD
PM Emission Control System	ESP	ESP	ESP	ESP	ESP	ESP	ESP	ESP	Fabric Filter
TOTAL INSTALLED CAPITAL COST ($)	**0**	**9,300,000**	**15,252,149**	**19,495,654**	**108,280,222**	**26,759,011**	**66,777,531**	**95,136,483**	**32,630,832**
FIRST YEAR O&M COST ($)									
Operating Labor ($)	0	0	0	0	0	0	0	303,677	0
Maintenance Material ($)	0	24,000	36,000	93,000	181,000	21,900	30,660	328,496	48,666
Maintenance Labor ($)	0	36,000	54,000	139,500	271,500	14,600	20,440	218,998	72,999
Administrative Labor ($)	0	0	0	0	0	0	0	0	0
TOTAL FIXED O&M COST	**0**	**60,000**	**90,000**	**232,500**	**452,500**	**36,500**	**51,099**	**851,170**	**121,665**
Makeup Water Cost	0	0	0	0	0	14,388	17,266	47,193	0
Reagent Cost	0	0	0	542,814	673,062	904,412	904,412	704,455	0
SCR Catalyst / FF Bag Cost	0	0	0	0	480,000	0	0	0	186,992
Waste Disposal Cost	0	0	0	0	0	346,184	439,525	506,310	0
Electric Power Cost	0	0	2,057,685	132,057	952,387	44,939	59,130	689,850	812,052
TOTAL VARIABLE O&M COST	**0**	**0**	**2,057,685**	**674,871**	**2,105,449**	**1,309,923**	**1,420,333**	**1,947,808**	**999,044**
TOTAL FIRST YEAR O&M COST	**0**	**60,000**	**2,147,685**	**907,371**	**2,557,949**	**1,346,423**	**1,471,432**	**2,798,979**	**1,120,709**
FIRST YEAR DEBT SERVICE ($)	0	884,689	1,450,904	1,854,579	10,300,462	2,545,526	6,352,401	9,050,127	3,104,100
TOTAL FIRST YEAR COST ($)	**0**	**944,689**	**3,598,588**	**2,761,950**	**12,858,411**	**3,891,949**	**7,823,833**	**11,849,105**	**4,224,809**
Power Consumption (MW)	**0.0**	**0.0**	**5.2**	**0.3**	**2.4**	**0.1**	**0.2**	**1.8**	**2.1**
Annual Power Usage (Million kW-Hr/Yr)	**0.0**	**0.0**	**41.2**	**2.6**	**19.0**	**0.9**	**1.2**	**13.8**	**16.2**
CONTROL COST ($/Ton Removed)									
NOx Removal Rate (%)	**0.0%**	**25.8%**	**35.5%**	**41.9%**	**77.4%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
NOx Removed (Tons/Yr)	**0**	**1,482**	**2,038**	**2,409**	**4,447**	**0**	**0**	**0**	**0**
First Year Average Control Cost ($/Ton NOx Rem.)	**0**	**637**	**1,766**	**1,147**	**2,892**	**0**	**0**	**0**	**0**
Incremental Control Cost ($/Ton NOx Removed)	**0**	**637**	**4,775**	**1,962**	**3,844**	**0**	**0**	**0**	**0**
		2-1	3-2	4-2	5-3				
SO2 Removal Rate (%)	**69.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**36.0%**	**68.0%**	**84.0%**	**0.0%**
SO2 Removed (Tons/Yr)	**0**	**0**	**0**	**0**	**0**	**3,335**	**6,299**	**7,782**	**0**
First Year Average Control Cost ($/Ton SO2 Rem.)	**0**	**0**	**0**	**0**	**0**	**1,167**	**1,242**	**1,523**	**0**
Incremental Control Cost ($/Ton SO2 Removed)	**Base**	**0**	**0**	**0**	**0**	**1,167**	**1,326**	**2,716**	**0**
						6-1	7-6	8-7	
PM Removal Rate (%)	**99.60%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**50.00%**
PM Removed (Tons/Yr)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**278**
First Year Average Control Cost ($/Ton PM Rem.)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**15,202**
Incremental Control Cost ($/Ton PM Removed)	**Base**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**15,202**
									10-1
PRESENT WORTH COST ($)	**0**	**10,033,071**	**41,492,244**	**30,581,776**	**139,532,865**	**43,209,408**	**84,755,271**	**129,333,992**	**46,323,493**

INPUT CALCULATIONS

Wyodak **Boiler Design:** **Opposed Wall-Fired PC**

Parameter	Current Operation	NOx Control				SO2 Control			PM Control	Comments
		LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Upgraded Dry FGD	Dry FGD w/Fabric Filter	Wet FGD	Fabric Filter	
Case	1	2	3	4	5	6	7	8	10	
NOx Emission Control System	LNB	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	LNB	LNB	LNB	LNB	
SO2 Emission Control System	Dry FGD	Dry FGD	Dry FGD	Dry FGD	Dry FGD	Upgraded Dry FGD	Dry FGD w/Fabric Filter	Wet FGD	Dry FGD	
PM Emission Control System	ESP	ESP	ESP	ESP	ESP	ESP	ESP	ESP	Fabric Filter	
Unit Design and Coal Characteristics										
Type of Unit	PC	PC	PC	PC	PC	PC	PC	PC	PC	
Net Power Output (kW)	365,000	365,000	365,000	365,000	365,000	365,000	365,000	365,000	365,000	
Net Plant Heat Rate (Btu/kW-Hr)	12,877	12,877	12,877	12,877	12,877	12,877	12,877	12,877	12,877	
Boiler Fuel	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	Clovis Point Mine	
Coal Heating Value (Btu/Lb)	8,050	8,050	8,050	8,050	8,050	8,050	8,050	8,050	8,050	
Coal Sulfur Content (wt.%)	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%	0.650%	0.65%	
Coal Ash Content (wt.%)	7.46%	7.46%	7.46%	7.46%	7.46%	7.46%	7.46%	7.46%	7.46%	
Boiler Heat Input, each (MMBtu/Hr)	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	4,700	
Coal Flow Rate (Lb/Hr)	583,864	583,864	583,864	583,864	583,864	583,864	583,864	583,864	583,864	
(Ton/Yr)	2,301,592	2,301,592	2,301,592	2,301,592	2,301,592	2,301,592	2,301,592	2,301,592	2,301,592	
(MMBtu/Yr)	37,055,628	37,055,628	37,055,628	37,055,628	37,055,628	37,055,628	37,055,628	37,055,628	37,055,628	
Emissions										
Uncontrolled SO2 (Lb/Hr)	7,583	7,583	7,583	7,583	7,583	2,350	2,350	2,350	7,583	
(Lb/MMBtu)	1.61	1.61	1.61	1.61	1.61	0.50	0.50	0.50	1.61	
(Lb Moles/Hr)	118.36	118.36	118.36	118.36	118.36	36.68	36.68	36.68	118.36	
(Tons/Yr)	29,891	29,891	29,891	29,891	29,891	9,264	9,264	9,264	29,891	
SO2 Removal Rate (%)	69.0%	0.0%	0.0%	0.0%	0.0%	36.0%	68.0%	84.0%	0.0%	
(Lb/Hr)	5,233	0	0	0	0	846	1,598	1,974	0	
(Ton/Yr)	20,627	0	0	0	0	3,335	6,299	7,782	0	
SO2 Emission Rate (Lb/Hr)	2,350	7,583	7,583	7,583	7,583	1,504	752	376	7,583	
(Lb/MMBtu)	0.50	1.61	1.61	1.61	1.61	0.32	0.16	0.08	1.61	
(Ton/Yr)	9,264	29,891	29,891	29,891	29,891	5,929	2,964	1,482	29,891	
Uncontrolled NOx (Lb/Hr)	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	1,457	
(Lb/MMBtu)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	
(Lb Moles/Hr)	48.55	48.55	48.55	48.55	48.55	48.55	48.55	48.55	48.55	
(Tons/Yr)	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	5,744	
NOx Removal Rate (%)	0.0%	25.8%	35.5%	41.9%	77.4%	0.0%	0.0%	0%	0%	
(Lb/Hr)	0	376	517	611	1,128	0	0	0	0	
(Lb Moles/Hr)	0.00	12.53	17.23	20.36	37.59	0.00	0.00	0.00	0.00	
(Ton/Yr)	0	1,482	2,038	2,409	4,447	0	0	0	0	
NOx Emission Rate (Lb/Hr)	1,457	1,081	940	846	329	1,457	1,457	1,457	1,457	
(Lb/MMBtu)	0.31	0.23	0.20	0.18	0.07	0.31	0.31	0.31	0.31	
(Ton/Yr)	5,744	4,261	3,706	3,335	1,297	5,744	5,744	5,744	5,744	
Uncontrolled Fly Ash (Lb/Hr)	34,845	141	141	141	141	141	141	141	141	
(Lb/MMBtu)	7.414	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	
(Lb Moles/Hr)	1,161.1	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	
(Tons/Yr)	137,359	556	556	556	556	556	556	556	556	
Fly Ash Removal Rate (%)	99.60%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	
(Lb/Hr)	34,704	0	0	0	0	0	0	0	71	
(Ton/Yr)	136,803	0	0	0	0	0	0	0	278	
Fly Ash Emission Rate (Lb/Hr)	141	141	141	141	141	141	141	141	71	
(Lb/MMBtu)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.015	
(Ton/Yr)	556	556	556	556	556	556	556	556	278	

Parameter	Current Operation	NOx Control				SO2 Control			PM Control	Comments
		LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Upgraded Dry FGD	Dry FGD w/Fabric Filter	Wet FGD	Fabric Filter	
Case	1	2	3	4	5	6	7	8	10	
General Plant Data										
Annual Operation (Hours/Year)	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	
Annual On-Site Power Plant Capacity Factor	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Economic Factors										
Interest Rate (%)	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	
Discount Rate (%)	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	
Plant Economic Life (Years)	20	20	20	20	20	20	20	20	20	
Installed Capital Costs										
NOx Emission Control System ($2006)	0	9,300,000	15,252,149	19,495,654	108,280,222	0	0	0	0	
SO2 Emission Control System ($2006)	0	0	0	0	0	26,759,011	66,777,531	95,136,483	0	
PM Emission Control System ($2006)	0	0	0	0	0	0	0	0	32,630,832	
Total Emission Control Systems ($2006)	0	9,300,000	15,252,149	19,495,654	108,280,222	26,759,011	66,777,531	95,136,483	32,630,832	
NOx Emission Control System ($/kW)	0	25	42	53	297	0	0	0	0	
SO2 Emission Control System ($/kW)	0	0	0	0	0	73	183	261	0	
PM Emission Control System ($/kW)	0	0	0	0	0	0	0	0	89	
Total Emission Control Systems ($/kW)	0	25	42	53	297	73	183	261	89	
Total Fixed Operating & Maintenance Costs										
Operating Labor ($)	0	0	0	0	0	0	0	303,677	0	
Maintenance Material ($)	0	24,000	36,000	93,000	181,000	21,900	30,660	328,496	48,666	
Maintenance Labor ($)	0	36,000	54,000	139,500	271,500	14,600	20,440	218,998	72,999	
Administrative Labor ($)	0	0	0	0	0	0	0	0	0	
Total Fixed O&M Cost ($)	0	60,000	90,000	232,500	452,500	36,500	51,099	851,170	121,665	
Annual Fixed O&M Cost Escalation Rate (%)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	
Water Cost										
Makeup Water Usage (Gpm)	0	0	0	0	0	25	30	82	0	
Unit Price ($/1000 Gallons)	1.22	1.22	1.22	0.00	1.22	1.22	1.22	1.22	1.22	
First Year Water Cost ($)	0	0	0	0	0	14,388	17,266	47,193	0	
Annual Water Cost Escalation Rate (%)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	
Reagent Cost	None	None	None	Urea	Anhydrous NH3	Lime	Lime	Lime	None	
Unit Cost ($/Ton)	0.00	0.00	0.00	370	400	91.25	91.25	91.25	0.00	
($/Lb)	0.000	0.000	0.000	0.185	0.200	0.046	0.046	0.046	0.000	
Molar Stoichiometry	0.00	0.00	0.00	0.45	1.00	1.10	1.10	1.02	0.00	
Reagent Purity (Wt.%)	100%	100%	100%	100%	100%	90%	90%	90%	90%	
Reagent Usage (Lb/Hr)	0	0	0	372	427	2,514	2,514	1,958	0	
First Year Reagent Cost ($)	0	0	0	542,814	673,062	904,412	904,412	704,455	0	
Annual Reagent Cost Escalation Rate (%)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	
SCR Catalyst / FF Bag Replacement Cost					SCR Catalyst	Bags	Bags	Bags	Bags	
Annual SCR Catalyst (m3) / No. FF Bags	0	0	0	0	160	0	0	0	1,798	
SCR Catalyst ($/m3) / Bag Cost ($/ea.)	3,000	3,000	3,000	3,000	3,000	104	104	104	104	
First Year SCR Catalyst / Bag Replace. Cost ($)	0	0	0	0	480,000	0	0	0	186,992	
Annual SCR Catalyst / Bag Cost Esc. Rate (%)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	
FGD Waste Disposal Cost										
FGD Solid Waste Disposal Rate, Dry (Lb/Hr)	0	0	0	0	0	3,609	4,582	5,278	0	
FGD Waste Disposal Unit Cost ($/Dry Ton)	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	
First Year FGD Waste Disposal Cost ($)	0	0	0	0	0	346,184	439,525	506,310	0	
Annual Waste Disposal Cost Esc. Rate (%)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	
Auxiliary Power Cost										
Auxiliary Power Requirement (% of Plant Output)	0.00%	0.00%	1.43%	0.09%	0.66%	0.03%	0.04%	0.48%	0.56%	
(MW)	0.00	0.00	5.22	0.34	2.42	0.11	0.15	1.75	2.06	
Unit Cost ($2006/MW-Hr)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	
First Year Auxiliary Power Cost ($)	0	0	2,057,685	132,057	952,387	44,939	59,130	689,850	812,052	
Annual Power Cost Escalation Rate (%)	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	

Input Tables

Table 1 - Cases

Index No.	Name of Unit | Case --->	Existing 1	NOx Control 2	3	4	5	SO2 Control 6	7	8	PM Control 9	10
1	Dave Johnston Unit 3	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Dry FGD w/ESP	Dry FGD w/Fabric Filter	Wet FGD w/ESP	N/A	Fabric Filter
2	Dave Johnston Unit 4	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	N/A	Dry FGD w/Fabric Filter	Wet FGD w/Fabric Filter	N/A	Fabric Filter
3	Jim Bridger Unit 1	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	N/A	N/A	Upgraded Wet FGD	Flue Gas Conditioning	Fabric Filter
4	Jim Bridger Unit 2	Current Operation	Exist. LNB w/OFA	ROFA	SNCR	SCR	N/A	N/A	Upgraded Wet FGD	Flue Gas Conditioning	Fabric Filter
5	Jim Bridger Unit 3	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	N/A	N/A	Upgraded Wet FGD	Flue Gas Conditioning	Fabric Filter
6	Jim Bridger Unit 4	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	N/A	N/A	Upgraded Wet FGD	Flue Gas Conditioning	Fabric Filter
7	Naughton Unit 1	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Dry FGD w/ESP	Dry FGD w/Fabric Filter	Wet FGD w/ESP	Flue Gas Conditioning	Fabric Filter
8	Naughton Unit 2	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Dry FGD w/ESP	Dry FGD w/Fabric Filter	Wet FGD w/ESP	Flue Gas Conditioning	Fabric Filter
9	Naughton Unit 3	Current Operation	Exist. LNB w/OFA	ROFA	SNCR	SCR	N/A	N/A	Upgraded Wet FGD	Flue Gas Conditioning	Fabric Filter
10	Wyodak	Current Operation	LNB w/OFA	ROFA	LNB w/OFA & SNCR	LNB w/OFA & SCR	Upgraded Dry FGD	Dry FGD w/Fabric Filter	Wet FGD	N/A	Fabric Filter

Table 2 - Unit Design and Coal Characteristics

		Current Emission Control Systems			Unit Design			Coal Quality			
Index No.	Name of Unit	NOx	SO2	PM	Boiler Design	Net Power Output (kW)	Net Plant Heat Rate (Btu/kW-Hr)	Coal	Heating Value, HHV (Btu/Lb)	Sulfur Content (Wt.%)	Ash Content (Wt.%)
1	Dave Johnston Unit 3	None	None	ESP	3-Cell Burner, Opposed Wall-Fired PC	250,000	11,200	Dry Fork PRB	7,784	0.47%	5.01%
2	Dave Johnston Unit 4	Windbox Mods.	Lime Added to Venturi Scrubber	Venturi Scrubber	Tangential-Fired PC	360,000	11,390	Dry Fork PRB	7,784	0.47%	5.01%
3	Jim Bridger Unit 1	LNCFS-1 & Windbox Mods.	Wet FGD	ESP	Tangential-Fired PC	530,000	11,320	Bridger Mine Underground	9,660	0.58%	10.30%
4	Jim Bridger Unit 2	LNB - TFS 2000	Wet FGD	ESP	Tangential-Fired PC	530,000	11,320	Bridger Mine Underground	9,660	0.58%	10.30%
5	Jim Bridger Unit 3	LNCFS-1 & Windbox Mods.	Wet FGD	ESP	Tangential-Fired PC	530,000	11,320	Bridger Mine Underground	9,660	0.58%	10.30%
6	Jim Bridger Unit 4	LNCFS-1 & Windbox Mods.	Wet FGD	ESP	Tangential-Fired PC	530,000	11,320	Bridger Mine Underground	9,660	0.58%	10.30%
7	Naughton Unit 1	None	None	ESP	Tangential-Fired PC	173,000	10,694	Kemmerer Mine	9,970	0.60%	4.64%
8	Naughton Unit 2	None	None	ESP	Tangential-Fired PC	226,000	10,574	Kemmerer Mine	9,970	0.60%	4.64%
9	Naughton Unit 3	LNCFS II LNB	Wet FGD	ESP	Tangential-Fired PC	356,000	10,336	Kemmerer Mine	9,970	0.60%	4.64%
10	Wyodak	LNB	Dry FGD	ESP	Opposed Wall-Fired PC	365,000	12,877	Clovis Point Mine	8,050	0.65%	7.46%

Table 3 - Emissions

Index No.	Name of Unit	Current Emission Rates (Lb/MMBtu) Controlled SO2	Controlled NOx	Controlled PM	NOx Control Emission Rates (Lb/MMBtu) Case 2	Case 3	Case 4	Case 5	SO2 Control Emission Rates (Lb/MMBtu) Case 6	Case 7	Case 8	PM Emission Rates (Lb/MMBtu) Case 9	Case 10
1	Dave Johnston Unit 3	1.61	0.70	0.030	0.24	0.19	0.19	0.07	0.22	0.15	0.10	N/A	0.015
2	Dave Johnston Unit 4	0.50	0.40	0.061	0.15	0.15	0.12	0.07	N/A	0.15	0.10	N/A	0.015
3	Jim Bridger Unit 1	0.27	0.45	0.045	0.24	0.22	0.20	0.07	N/A	N/A	0.10	0.030	0.015
4	Jim Bridger Unit 2	0.27	0.24	0.074	0.24	0.22	0.20	0.07	N/A	N/A	0.10	0.030	0.015
5	Jim Bridger Unit 3	0.27	0.45	0.057	0.24	0.22	0.20	0.07	N/A	N/A	0.10	0.030	0.015
6	Jim Bridger Unit 4	0.17	0.45	0.030	0.24	0.22	0.20	0.07	N/A	N/A	0.10	0.030	0.015
7	Naughton Unit 1	1.61	0.58	0.056	0.24	0.28	0.18	0.07	0.18	0.15	0.10	0.040	0.015
8	Naughton Unit 2	1.61	0.54	0.064	0.24	0.28	0.18	0.07	0.18	0.15	0.10	0.040	0.015
9	Naughton Unit 3	0.50	0.45	0.094	0.35	0.30	0.25	0.07	N/A	N/A	0.10	0.040	0.015
10	Wyodak	0.50	0.31	0.030	0.23	0.20	0.18	0.07	0.32	0.16	0.08	N/A	0.015

Table 4 - Case 1 O&M Costs (Current Operation)

Index No.	Name of Unit	Annual Fixed O&M Costs Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Variable Operating Requirements Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ -	$ -	$ -	-	None	-	-
2	Dave Johnston Unit 4	$ -	$ -	$ -	$ -	-	None	-	-
3	Jim Bridger Unit 1	$ -	$ -	$ -	$ -	-	None	-	-
4	Jim Bridger Unit 2	$ -	$ -	$ -	$ -	-	None	-	-
5	Jim Bridger Unit 3	$ -	$ -	$ -	$ -	-	None	-	-
6	Jim Bridger Unit 4	$ -	$ -	$ -	$ -	-	None	-	-
7	Naughton Unit 1	$ -	$ -	$ -	$ -	-	None	-	-
8	Naughton Unit 2	$ -	$ -	$ -	$ -	-	None	-	-
9	Naughton Unit 3	$ -	$ -	$ -	$ -	-	None	-	-
10	Wyodak	$ -	$ -	$ -	$ -	-	None	-	-

Table 5 - Case 2 O&M Costs (LNB w/OFA)

Index No.	Name of Unit	Annual Fixed O&M Costs Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Variable Operating Requirements Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ 40,000	$ 60,000	$ -	-	None	-	-
2	Dave Johnston Unit 4	$ -	$ 36,000	$ 54,000	$ -	-	None	-	-
3	Jim Bridger Unit 1	$ -	$ 28,000	$ 42,000	$ -	-	None	-	-
4	Jim Bridger Unit 2	$ -	$ -	$ -	$ -	-	None	-	-
5	Jim Bridger Unit 3	$ -	$ 28,000	$ 42,000	$ -	-	None	-	-
6	Jim Bridger Unit 4	$ -	$ 28,000	$ 42,000	$ -	-	None	-	-
7	Naughton Unit 1	$ -	$ 32,000	$ 48,000	$ -	-	None	-	-
8	Naughton Unit 2	$ -	$ 32,000	$ 48,000	$ -	-	None	-	-
9	Naughton Unit 3	$ -	$ -	$ -	$ -	-	None	-	-
10	Wyodak	$ -	$ 24,000	$ 36,000	$ -	-	None	-	-

Table 6 - Case 3 O&M Costs (Mobotec ROFA)

		Annual Fixed O&M Costs				Variable Operating Requirements			
Index No.	Name of Unit	Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ 60,000	$ 90,000	$ -	-	None	-	2.76
2	Dave Johnston Unit 4	$ -	$ 54,000	$ 81,000	$ -	-	None	-	4.33
3	Jim Bridger Unit 1	$ -	$ 42,000	$ 63,000	$ -	-	None	-	6.41
4	Jim Bridger Unit 2	$ -	$ 42,000	$ 63,000	$ -	-	None	-	6.41
5	Jim Bridger Unit 3	$ -	$ 42,000	$ 63,000	$ -	-	None	-	6.41
6	Jim Bridger Unit 4	$ -	$ 42,000	$ 63,000	$ -	-	None	-	6.41
7	Naughton Unit 1	$ -	$ 48,000	$ 72,000	$ -	-	None	-	1.42
8	Naughton Unit 2	$ -	$ 48,000	$ 72,000	$ -	-	None	-	2.61
9	Naughton Unit 3	$ -	$ 48,000	$ 72,000	$ -	-	None	-	4.47
10	Wyodak	$ -	$ 36,000	$ 54,000	$ -	-	None	-	5.22

Table 7 - Case 4 O&M Costs (LNB w/OFA & SNCR))

		Annual Fixed O&M Costs				Variable Operating Requirements			
Index No.	Name of Unit	Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ 98,000	$ 147,000	$ -	-	Urea	0.41	0.23
2	Dave Johnston Unit 4	$ -	$ 105,000	$ 157,500	$ -	-	Urea	0.45	0.33
3	Jim Bridger Unit 1	$ -	$ 123,000	$ 184,500	$ -	-	Urea	0.45	0.53
4	Jim Bridger Unit 2	$ -	$ 95,000	$ 142,500	$ -	-	Urea	0.45	0.53
5	Jim Bridger Unit 3	$ -	$ 122,000	$ 183,000	$ -	-	Urea	0.45	0.52
6	Jim Bridger Unit 4	$ -	$ 123,000	$ 184,500	$ -	-	Urea	0.45	0.53
7	Naughton Unit 1	$ -	$ 83,000	$ 124,500	$ -	-	Urea	0.45	0.16
8	Naughton Unit 2	$ -	$ 93,000	$ 139,500	$ -	-	Urea	0.51	0.22
9	Naughton Unit 3	$ -	$ 75,000	$ 112,500	$ -	-	Urea	0.45	0.33
10	Wyodak	$ -	$ 93,000	$ 139,500	-	-	Urea	0.45	0.34

Table 8 - Case 5 O&M Costs (LNB w/OFA & SCR))

		Annual Fixed O&M Costs				Variable Operating Requirements				
Index No.	Name of Unit	Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Annual SCR Catalyst Replace. (m3)	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ 155,000	$ 232,500	$ -	-	Anhydrous NH3	1.00	128	1.57
2	Dave Johnston Unit 4	$ -	$ 166,000	$ 249,000	$ -	-	Anhydrous NH3	1.00	123	2.29
3	Jim Bridger Unit 1	$ -	$ 190,000	$ 285,000	$ -	-	Anhydrous NH3	1.00	198	3.28
4	Jim Bridger Unit 2	$ -	$ 162,000	$ 243,000	$ -	-	Anhydrous NH3	1.00	198	3.25
5	Jim Bridger Unit 3	$ -	$ 190,000	$ 285,000	$ -	-	Anhydrous NH3	1.00	200	3.22
6	Jim Bridger Unit 4	$ -	$ 190,000	$ 285,000	$ -	-	Anhydrous NH3	1.00	214	3.36
7	Naughton Unit 1	$ -	$ 132,000	$ 198,000	$ -	-	Anhydrous NH3	1.00	67	0.98
8	Naughton Unit 2	$ -	$ 160,000	$ 240,000	$ -	-	Anhydrous NH3	1.00	101	1.34
9	Naughton Unit 3	$ -	$ 156,000	$ 234,000	$ -	-	Anhydrous NH3	1.00	167	1.99
10	Wyodak	$ -	$ 181,000	$ 271,500	$ -	-	Anhydrous NH3	1.00	160	2.42

Table 9 - Case 6 O&M Costs (Dry FGD)

		Annual Fixed O&M Costs				Variable Operating Requirements				
Index No.	Name of Unit	Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Annual FF Bag Replace.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ 506,128	$ 714,175	$ 476,928	$ -	173	Lime	1.15	-	2.49
2	Dave Johnston Unit 4	$ -	$ -	$ -	$ -	-	Lime	-	-	-
3	Jim Bridger Unit 1	$ -	$ -	$ -	$ -	-	Lime	-	-	-
4	Jim Bridger Unit 2	$ -	$ -	$ -	$ -	-	Lime	-	-	-
5	Jim Bridger Unit 3	$ -	$ -	$ -	$ -	-	Lime	-	-	-
6	Jim Bridger Unit 4	$ -	$ -	$ -	$ -	-	Lime	-	-	-
7	Naughton Unit 1	$ 506,128	$ 587,643	$ 391,762	$ -	120	Lime	1.40	-	1.64
8	Naughton Unit 2	$ 506,128	$ 860,174	$ 573,044	$ -	165	Lime	1.40	-	2.25
9	Naughton Unit 3	$ -	$ -	$ -	$ -	-	Lime	-	-	-
10	Wyodak	$ -	$ 21,900	$ 14,600	-	25	Lime	1.10	-	0.11

Table 10 - Case 7 O&M Costs (Dry FGD w/Fabric Filter)

		Annual Fixed O&M Costs				Variable Operating Requirements				
Index No.	Name of Unit	Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Annual FF Bag Replace.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ 506,128	$ 714,175	$ 476,928	$ -	173	Lime	1.15	1,457	3.88
2	Dave Johnston Unit 4	$ 506,128	$ 1,102,288	$ 734,858	$ -	248	Lime	1.10	1,798	4.54
3	Jim Bridger Unit 1	$ -	$ -	$ -	$ -	-	Lime	-	-	-
4	Jim Bridger Unit 2	$ -	$ -	$ -	$ -	-	Lime	-	-	-
5	Jim Bridger Unit 3	$ -	$ -	$ -	$ -	-	Lime	-	-	-
6	Jim Bridger Unit 4	$ -	$ -	$ -	$ -	-	Lime	-	-	-
7	Naughton Unit 1	$ 506,128	$ 632,660	$ 459,286	$ -	120	Lime	1.15	865	2.66
8	Naughton Unit 2	$ 506,128	$ 905,190	$ 640,568	$ -	165	Lime	1.15	1,193	3.63
9	Naughton Unit 3	$ -	$ -	$ -	$ -	-	Lime	-	-	-
10	Wyodak	$ -	$ 30,660	$ 20,440	-	30	Lime	1.10	-	0.15

Table 11 - Case 8 O&M Costs (Wet FGD)

		Annual Fixed O&M Costs				Variable Operating Requirements				
Index No.	Name of Unit	Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Annual FF Bag Replace.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ 809,804	$ 1,182,587	$ 788,391	$ -	230	Lime	1.02	-	3.45
2	Dave Johnston Unit 4	$ 809,804	$ 1,430,784	$ 953,856	$ -	330	Lime	1.02	1,798	6.29
3	Jim Bridger Unit 1	$ -	$ 25,550	$ 17,033	$ -	53	Soda Ash	1.02	-	0.53
4	Jim Bridger Unit 2	$ -	$ 25,550	$ 17,033	$ -	53	Soda Ash	1.02	-	0.53
5	Jim Bridger Unit 3	$ -	$ 25,550	$ 17,033	$ -	52	Soda Ash	1.02	-	0.52
6	Jim Bridger Unit 4	$ -	$ 25,550	$ 17,033	$ -	27	Soda Ash	1.02	-	0.53
7	Naughton Unit 1	$ 809,804	$ 963,589	$ 642,393	$ -	160	Lime	1.05	-	2.40
8	Naughton Unit 2	$ 809,804	$ 1,226,386	$ 817,591	$ -	220	Lime	1.05	-	3.30
9	Naughton Unit 3	$ -	$ 21,900	$ 14,600	$ -	66	Soda Ash	1.02	-	0.33
10	Wyodak	$ 303,677	$ 328,496	$ 218,998	$ -	82	Lime	1.02	-	1.75

Table 12 - Case 9 O&M Costs (Flue Gas Conditioning)

Index No.	Name of Unit	Annual Fixed O&M Costs				Variable Operating Requirements				
		Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Usage (Lb/Hr)	Annual FF Bag Replace.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ -	$ -	$ -	-	None	-	-	-
2	Dave Johnston Unit 4	$ -	$ -	$ -	$ -	-	None	-	-	-
3	Jim Bridger Unit 1	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	100	-	0.05
4	Jim Bridger Unit 2	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	100	-	0.05
5	Jim Bridger Unit 3	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	100	-	0.05
6	Jim Bridger Unit 4	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	100	-	0.05
7	Naughton Unit 1	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	33	-	0.05
8	Naughton Unit 2	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	43	-	0.05
9	Naughton Unit 3	$ -	$ -	$ 10,000	$ -	-	Elemental Sulfur	67	-	0.05
10	Wyodak	$ -	$ -	$ -	-	-	None	-	-	-

Table 13 - Case 10 O&M Costs (Fabric Filter)

Index No.	Name of Unit	Annual Fixed O&M Costs				Variable Operating Requirements				
		Oper. Labor	Maint. Materials	Maint. Labor	Admin. Labor	Makeup Water Use (Gpm)	Reagent	Reagent Molar Stoich.	Annual FF Bag Replace.	Aux. Power Usage (MW)
1	Dave Johnston Unit 3	$ -	$ 45,016	$ 67,524	$ -	-	None	-	1,457	1.38
2	Dave Johnston Unit 4	$ -	$ 68,133	$ 102,199	$ -	-	None	-	1,798	2.35
3	Jim Bridger Unit 1	$ -	$ 51,099	$ 76,649	$ -	-	None	-	2,885	3.39
4	Jim Bridger Unit 2	$ -	$ 51,099	$ 76,649	$ -	-	None	-	2,885	3.37
5	Jim Bridger Unit 3	$ -	$ 51,099	$ 76,649	$ -	-	None	-	2,827	3.33
6	Jim Bridger Unit 4	$ -	$ 51,099	$ 76,649	$ -	-	None	-	2,885	3.39
7	Naughton Unit 1	$ -	$ 45,016	$ 67,524	$ -	-	None	-	865	1.01
8	Naughton Unit 2	$ -	$ 45,016	$ 67,524	$ -	-	None	-	1,193	1.38
9	Naughton Unit 3	$ -	$ 48,666	$ 72,999	$ -	-	None	-	1,799	2.06
10	Wyodak	$ -	$ 48,666	$ 72,999	$ -	-	None	-	1,798	2.06

Table 14 - Major Materials Design and Supply Costs

Index No.	Name of Unit | Case --->	NOx Control				SO2 Control			PM Control	
		2	3	4	5	6	7	8	9	10
1	Dave Johnston Unit 3	$ 5,449,830	$ 3,556,617	$ 5,773,000	$ 49,355,000	$ 56,379,000	$ 85,647,000	$ 88,913,000	$ -	$ 18,359,000
2	Dave Johnston Unit 4	$ 2,673,501	$ 4,343,192	$ 7,171,085	$ 66,200,000	$ -	$ 137,267,000	$ 178,174,384	$ -	$ 30,853,530
3	Jim Bridger Unit 1	$ 2,981,982	$ 6,056,955	$ 9,528,000	$ 80,923,000	$ -	$ -	$ 8,010,093	$ -	$ 29,814,000
4	Jim Bridger Unit 2	$ -	$ 6,056,955	$ 9,528,000	$ 80,923,000	$ -	$ -	$ 8,010,093	$ -	$ 29,814,000
5	Jim Bridger Unit 3	$ 2,981,982	$ 6,056,955	$ 9,419,000	$ 80,923,000	$ -	$ -	$ 8,010,093	$ -	$ 29,814,000
6	Jim Bridger Unit 4	$ 2,981,982	$ 6,056,955	$ 9,528,000	$ 93,009,000	$ -	$ -	$ 3,549,000	$ -	$ 29,814,000
7	Naughton Unit 1	$ 2,502,123	$ 2,675,792	$ 7,257,000	$ 37,292,000	$ 26,819,000	$ 42,301,000	$ 44,000,000	$ 800,000	$ 15,482,000
8	Naughton Unit 2	$ 2,570,674	$ 3,123,533	$ 8,784,000	$ 47,934,000	$ 39,262,000	$ 57,621,000	$ 56,000,000	$ 800,000	$ 18,359,000
9	Naughton Unit 3	$ -	$ 4,351,377	$ 11,203,578	$ 67,373,000	$ -	$ -	$ 2,963,000	$ 800,000	$ 20,106,000
10	Wyodak	$ 3,187,636	$ 4,500,245	$ 7,234,860	$ 72,479,000	$ 16,487,985	$ 41,146,026	$ 58,619,840	$ -	$ 20,106,000

CAPITAL COST

Wyodak

Parameter	NOx Control								SO2 Control						PM Control			
	LNB w/OFA		ROFA		LNB w/OFA & SNCR		LNB w/OFA & SCR		Upgraded Dry FGD		Dry FGD w/Fabric Filter		Wet FGD		N/A		Fabric Filter	
Case	2		3		4		5		6		7		8		9		10	
NOx Emission Control System	LNB w/OFA		ROFA		LNB w/OFA & SNCR		LNB w/OFA & SCR		LNB		LNB		LNB		LNB		LNB	
SO2 Emission Control System	Dry FGD		Dry FGD		Dry FGD		Dry FGD		Upgraded Dry FGD		Dry FGD w/Fabric Filter		Wet FGD		Dry FGD		Dry FGD	
PM Emission Control System	ESP		ESP		ESP		ESP		ESP		ESP		ESP		N/A		Fabric Filter	
CAPITAL COST COMPONENT	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**	**Factor/Source**	**Cost**
LNB w/OFA or ROFA		**LNB w/OFA**		**ROFA**		**LNB w/OFA**		**LNB w/OFA**										
Major Materials Design and Supply	**Vendor**	**$3,187,636**	**Vendor**	**$4,500,245**	**Vendor**	**$3,187,636**	**Vendor**	**$3,187,636**	**Vendor**	**$0**	**Vendor**	**$0**	**Vendor**	**$0**	**Vendor**	**$0**	**Vendor**	**$0**
Construction	**85.3%**	$2,720,130	**85.3%**	$3,840,228	**85.3%**	$2,720,130	**85.3%**	$2,720,130	**85.3%**	$0	**85.3%**	$0	**85.3%**	$0	**85.3%**	$0	**85.3%**	$0
Balance of Plant	**51.7%**	$1,647,758	**51.7%**	$2,326,273	**51.7%**	$1,647,758	**51.7%**	$1,647,758	**51.7%**	$0	**51.7%**	$0	**51.7%**	$0	**51.7%**	$0	**51.7%**	$0
Electrical (Allowance)	**0.0%**	$0	**30.0%**	$1,350,074	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0
Owner's Costs	**13.2%**	$422,309	**13.2%**	$596,208	**13.2%**	$422,309	**13.2%**	$422,309	**13.2%**	$0	**13.2%**	$0	**13.2%**	$0	**13.2%**	$0	**13.2%**	$0
Surcharge	**16.4%**	$523,585	**16.4%**	$739,187	**16.4%**	$523,585	**16.4%**	$523,585	**16.4%**	$0	**16.4%**	$0	**16.4%**	$0	**16.4%**	$0	**16.4%**	$0
AFUDC	**12.2%**	$389,480	**12.2%**	$549,861	**12.2%**	$389,480	**12.2%**	$389,480	**12.2%**	$0	**12.2%**	$0	**12.2%**	$0	**12.2%**	$0	**12.2%**	$0
Subtotal		**$8,890,897**		**$13,902,076**		**$8,890,897**		**$8,890,897**		**$0**		**$0**		**$0**		**$0**		**$0**
Contingency	**12.8%**	$409,103	**30.0%**	$1,350,074	**12.8%**	$409,103	**12.8%**	$409,103	**12.8%**	$0	**12.8%**	$0	**12.8%**	$0	**12.8%**	$0	**12.8%**	$0
Total Capital Cost for LNB w/OFA or ROFA		**$9,300,000**		**$15,252,149**		**$9,300,000**		**$9,300,000**		**$0**		**$0**		**$0**		**$0**		**$0**
SNCR or SCR						**SNCR**		**SCR**										
Major Materials Design and Supply	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$7,234,860**	**S&L Report**	**$72,479,000**	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$0**
Contingency	**20.0%**	$0	**20.0%**	$0	**20.0%**	$1,446,972	**10.0%**	$7,247,900	**20.0%**	$0	**20.0%**	$0	**20.0%**	$0	**20.0%**	$0	**20.0%**	$0
Labor Premium	**5.6%**	$0	**5.6%**	$0	**5.6%**	$404,646	**5.6%**	$4,053,750	**5.6%**	$0	**5.6%**	$0	**5.6%**	$0	**5.6%**	$0	**5.6%**	$0
EPC Premium	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**8.4%**	$6,122,301	**8.4%**	$0	**8.4%**	$0	**8.4%**	$0	**8.4%**	$0	**8.4%**	$0
Boiler Reinforcement (Allowance)	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0
Sales Tax	**1.1%**	$0	**1.1%**	$0	**1.1%**	$79,728	**1.1%**	$798,719	**1.1%**	$0	**1.1%**	$0	**1.1%**	$0	**1.1%**	$0	**1.1%**	$0
Escalation	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0	**0.0%**	$0
Contingency on Adders	**2.8%**	$0	**2.8%**	$0	**2.8%**	$203,083	**0.0%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0
Surcharge and AFUDC	**11.4%**	$0	**11.4%**	$0	**11.4%**	$826,366	**11.4%**	$8,278,551	**11.4%**	$0	**11.4%**	$0	**11.4%**	$0	**11.4%**	$0	**11.4%**	$0
Total Capital Cost for SNCR or SCR		**$0**		**$0**		**$10,195,654**		**$98,980,222**		**$0**		**$0**		**$0**		**$0**		**$0**
Dry or Wet FGD, FGC or Fabric Filter										**Dry FGD**		**Dry FGD w/FF**		**Wet FGD**		**FGC**		**Fabric Filter**
Major Materials Design and Supply	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$0**	**S&L Report**	**$16,487,985**	**S&L Report**	**$41,146,026**	**S&L Report**	**$58,619,840**	**S&L Report**	**$0**	**S&L Report**	**$20,106,000**
Contingency	**20.0%**	$0	**20.0%**	$0	**20.0%**	$0	**20.0%**	$0	**20.0%**	$3,297,597	**20.0%**	$8,229,205	**20.0%**	$11,723,968	**20.0%**	$0	**20.0%**	$4,021,200
Labor Premium	**5.6%**	$0	**5.6%**	$0	**5.6%**	$0	**5.6%**	$0	**5.6%**	$922,173	**5.6%**	$2,301,297	**5.6%**	$3,278,608	**5.6%**	$0	**5.6%**	$1,124,529
EPC Premium	**8.4%**	$0	**8.4%**	$0	**8.4%**	$0	**8.4%**	$0	**8.4%**	$1,392,740	**8.4%**	$3,475,605	**8.4%**	$4,951,618	**8.4%**	$0	**8.4%**	$1,698,354
Boiler Reinforcement (Allowance)	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$463,972	**2.8%**	$1,157,849	**2.8%**	$1,649,562	**2.8%**	$0	**2.8%**	$565,783
Sales Tax	**1.1%**	$0	**1.1%**	$0	**1.1%**	$0	**1.1%**	$0	**1.1%**	$181,698	**1.1%**	$453,429	**1.1%**	$645,991	**1.1%**	$0	**1.1%**	$221,568
Escalation	**10.1%**	$0	**10.1%**	$0	**10.1%**	$0	**10.1%**	$0	**10.1%**	$1,666,770	**10.1%**	$4,159,452	**10.1%**	$5,925,880	**10.1%**	$0	**10.1%**	$2,032,516
Contingency on Adders	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$0	**2.8%**	$462,818	**2.8%**	$1,154,969	**2.8%**	$1,645,459	**2.8%**	$0	**2.8%**	$564,375
Surcharge and AFUDC	**11.4%**	$0	**11.4%**	$0	**11.4%**	$0	**11.4%**	$0	**11.4%**	$1,883,258	**11.4%**	$4,699,699	**11.4%**	$6,695,558	**11.4%**	$0	**11.4%**	$2,296,507
Total Capital Cost for Dry/Wet FGD, FGC or FF		**$0**		**$0**		**$0**		**$0**		**$26,759,011**		**$66,777,531**		**$95,136,483**		**$0**		**$32,630,832**

Wyodak — LNB w/OFA

Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton NOx Removed)
0	2013										
1	2014	60,000	-	-	-	-	-	-	884,689	944,689	637
2	2015	61,200	-	-	-	-	-	-	884,689	945,889	638
3	2016	62,424	-	-	-	-	-	-	884,689	947,113	639
4	2017	63,672	-	-	-	-	-	-	884,689	948,361	640
5	2018	64,946	-	-	-	-	-	-	884,689	949,635	641
6	2019	66,245	-	-	-	-	-	-	884,689	950,934	642
7	2020	67,570	-	-	-	-	-	-	884,689	952,259	642
8	2021	68,921	-	-	-	-	-	-	884,689	953,610	643
9	2022	70,300	-	-	-	-	-	-	884,689	954,988	644
10	2023	71,706	-	-	-	-	-	-	884,689	956,394	645
11	2024	73,140	-	-	-	-	-	-	884,689	957,828	646
12	2025	74,602	-	-	-	-	-	-	884,689	959,291	647
13	2026	76,095	-	-	-	-	-	-	884,689	960,783	648
14	2027	77,616	-	-	-	-	-	-	884,689	962,305	649
15	2028	79,169	-	-	-	-	-	-	884,689	963,857	650
16	2029	80,752	-	-	-	-	-	-	884,689	965,441	651
17	2030	82,367	-	-	-	-	-	-	884,689	967,056	652
18	2031	84,014	-	-	-	-	-	-	884,689	968,703	654
19	2032	85,695	-	-	-	-	-	-	884,689	970,384	655
20	2033	87,409	-	-	-	-	-	-	884,689	972,097	656
Present Worth		733,071	-	-	-	-	-	-	9,300,000	10,033,071	338
(% of PW)		7.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	92.7%	100.0%	

Wyodak — ROFA

Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton NOx Removed)
0	2013										
1	2014	90,000	-	-	-	-	2,057,685	2,057,685	1,450,904	3,598,588	1,766
2	2015	91,800	-	-	-	-	2,098,838	2,098,838	1,450,904	3,641,542	1,787
3	2016	93,636	-	-	-	-	2,140,815	2,140,815	1,450,904	3,685,355	1,808
4	2017	95,509	-	-	-	-	2,183,631	2,183,631	1,450,904	3,730,044	1,830
5	2018	97,419	-	-	-	-	2,227,304	2,227,304	1,450,904	3,775,627	1,853
6	2019	99,367	-	-	-	-	2,271,850	2,271,850	1,450,904	3,822,121	1,875
7	2020	101,355	-	-	-	-	2,317,287	2,317,287	1,450,904	3,869,545	1,899
8	2021	103,382	-	-	-	-	2,363,633	2,363,633	1,450,904	3,917,918	1,922
9	2022	105,449	-	-	-	-	2,410,905	2,410,905	1,450,904	3,967,259	1,947
10	2023	107,558	-	-	-	-	2,459,124	2,459,124	1,450,904	4,017,586	1,971
11	2024	109,709	-	-	-	-	2,508,306	2,508,306	1,450,904	4,068,919	1,996
12	2025	111,904	-	-	-	-	2,558,472	2,558,472	1,450,904	4,121,280	2,022
13	2026	114,142	-	-	-	-	2,609,642	2,609,642	1,450,904	4,174,687	2,048
14	2027	116,425	-	-	-	-	2,661,834	2,661,834	1,450,904	4,229,163	2,075
15	2028	118,753	-	-	-	-	2,715,071	2,715,071	1,450,904	4,284,728	2,102
16	2029	121,128	-	-	-	-	2,769,373	2,769,373	1,450,904	4,341,404	2,130
17	2030	123,551	-	-	-	-	2,824,760	2,824,760	1,450,904	4,399,214	2,159
18	2031	126,022	-	-	-	-	2,881,255	2,881,255	1,450,904	4,458,181	2,187
19	2032	128,542	-	-	-	-	2,938,880	2,938,880	1,450,904	4,518,326	2,217
20	2033	131,113	-	-	-	-	2,997,658	2,997,658	1,450,904	4,579,675	2,247
Present Worth		1,099,607	-	-	-	-	25,140,488	25,140,488	15,252,149	41,492,244	1,018
(% of PW)		2.7%	0.0%	0.0%	0.0%	0.0%	60.6%	60.6%	36.8%	100.0%	

Wyodak — LNB w/OFA & SNCR

Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton NOx Removed)
0	2013										
1	2014	232,500	-	542,814	-	-	132,057	674,871	1,854,579	2,761,950	1,147
2	2015	237,150	-	553,670	-	-	134,698	688,368	1,854,579	2,780,097	1,154
3	2016	241,893	-	564,743	-	-	137,392	702,135	1,854,579	2,798,608	1,162
4	2017	246,731	-	576,038	-	-	140,140	716,178	1,854,579	2,817,488	1,170
5	2018	251,665	-	587,559	-	-	142,943	730,502	1,854,579	2,836,746	1,178
6	2019	256,699	-	599,310	-	-	145,802	745,112	1,854,579	2,856,390	1,186
7	2020	261,833	-	611,296	-	-	148,718	760,014	1,854,579	2,876,426	1,194
8	2021	267,069	-	623,522	-	-	151,692	775,214	1,854,579	2,896,863	1,203
9	2022	272,411	-	635,993	-	-	154,726	790,719	1,854,579	2,917,708	1,211
10	2023	277,859	-	648,713	-	-	157,820	806,533	1,854,579	2,938,971	1,220
11	2024	283,416	-	661,687	-	-	160,977	822,664	1,854,579	2,960,659	1,229
12	2025	289,085	-	674,921	-	-	164,196	839,117	1,854,579	2,982,780	1,238
13	2026	294,866	-	688,419	-	-	167,480	855,899	1,854,579	3,005,345	1,248
14	2027	300,764	-	702,187	-	-	170,830	873,017	1,854,579	3,028,360	1,257
15	2028	306,779	-	716,231	-	-	174,246	890,477	1,854,579	3,051,835	1,267
16	2029	312,914	-	730,556	-	-	177,731	908,287	1,854,579	3,075,781	1,277
17	2030	319,173	-	745,167	-	-	181,286	926,453	1,854,579	3,100,205	1,287
18	2031	325,556	-	760,070	-	-	184,912	944,982	1,854,579	3,125,117	1,297
19	2032	332,067	-	775,272	-	-	188,610	963,881	1,854,579	3,150,528	1,308
20	2033	338,709	-	790,777	-	-	192,382	983,159	1,854,579	3,176,447	1,319
Present Worth		2,840,651	-	6,632,018	-	-	1,613,453	8,245,471	19,495,654	30,581,776	635
(% of PW)		9.3%	0.0%	21.7%	0.0%	0.0%	5.3%	27.0%	63.7%	100.0%	

Wyodak — LNB w/OFA & SCR

Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton NOx Removed)
0	2013										
1	2014	452,500	-	673,062	480,000	-	952,387	2,105,449	10,300,462	12,858,411	2,892
2	2015	461,550	-	686,523	489,600	-	971,435	2,147,558	10,300,462	12,909,570	2,903
3	2016	470,781	-	700,253	499,392	-	990,864	2,190,509	10,300,462	12,961,752	2,915
4	2017	480,197	-	714,258	509,380	-	1,010,681	2,234,319	10,300,462	13,014,977	2,927
5	2018	489,801	-	728,544	519,567	-	1,030,895	2,279,005	10,300,462	13,069,268	2,939
6	2019	499,597	-	743,114	529,959	-	1,051,512	2,324,586	10,300,462	13,124,644	2,952
7	2020	509,588	-	757,977	540,558	-	1,072,543	2,371,077	10,300,462	13,181,128	2,964
8	2021	519,780	-	773,136	551,369	-	1,093,994	2,418,499	10,300,462	13,238,741	2,977
9	2022	530,176	-	788,599	562,397	-	1,115,873	2,466,869	10,300,462	13,297,506	2,990
10	2023	540,779	-	804,371	573,644	-	1,138,191	2,516,206	10,300,462	13,357,447	3,004
11	2024	551,595	-	820,458	585,117	-	1,160,955	2,566,530	10,300,462	13,418,587	3,018
12	2025	562,627	-	836,867	596,820	-	1,184,174	2,617,861	10,300,462	13,480,950	3,032
13	2026	573,879	-	853,605	608,756	-	1,207,857	2,670,218	10,300,462	13,544,559	3,046
14	2027	585,357	-	870,677	620,931	-	1,232,014	2,723,623	10,300,462	13,609,441	3,061
15	2028	597,064	-	888,090	633,350	-	1,256,655	2,778,095	10,300,462	13,675,621	3,075
16	2029	609,005	-	905,852	646,017	-	1,281,788	2,833,657	10,300,462	13,743,124	3,091
17	2030	621,186	-	923,969	658,937	-	1,307,424	2,890,330	10,300,462	13,811,977	3,106
18	2031	633,609	-	942,449	672,116	-	1,333,572	2,948,137	10,300,462	13,882,208	3,122
19	2032	646,281	-	961,298	685,558	-	1,360,243	3,007,099	10,300,462	13,953,843	3,138
20	2033	659,207	-	980,524	699,269	-	1,387,448	3,067,241	10,300,462	14,026,910	3,154
Present Worth		5,528,579	-	8,223,368	5,864,570	-	11,636,127	25,724,064	108,280,222	139,532,865	1,569
(% of PW)		4.0%	0.0%	5.9%	4.2%	0.0%	8.3%	18.4%	77.6%	100.0%	

Wyodak					Upgraded Dry FGD						
Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton SO2 Removed)
0	2013										
1	2014	36,500	14,388	904,412	-	346,184	44,939	1,309,923	2,545,526	3,891,949	1,167
2	2015	37,230	14,676	922,500	-	353,108	45,838	1,336,122	2,545,526	3,918,878	1,175
3	2016	37,974	14,969	940,950	-	360,170	46,754	1,362,844	2,545,526	3,946,345	1,183
4	2017	38,734	15,269	959,769	-	367,374	47,689	1,390,101	2,545,526	3,974,361	1,192
5	2018	39,508	15,574	978,965	-	374,721	48,643	1,417,903	2,545,526	4,002,938	1,200
6	2019	40,298	15,886	998,544	-	382,216	49,616	1,446,261	2,545,526	4,032,086	1,209
7	2020	41,104	16,203	1,018,515	-	389,860	50,608	1,475,186	2,545,526	4,061,817	1,218
8	2021	41,927	16,527	1,038,885	-	397,657	51,621	1,504,690	2,545,526	4,092,143	1,227
9	2022	42,765	16,858	1,059,663	-	405,610	52,653	1,534,784	2,545,526	4,123,075	1,236
10	2023	43,620	17,195	1,080,856	-	413,722	53,706	1,565,480	2,545,526	4,154,626	1,246
11	2024	44,493	17,539	1,102,473	-	421,997	54,780	1,596,789	2,545,526	4,186,808	1,255
12	2025	45,383	17,890	1,124,523	-	430,437	55,876	1,628,725	2,545,526	4,219,634	1,265
13	2026	46,290	18,248	1,147,013	-	439,046	56,993	1,661,299	2,545,526	4,253,116	1,275
14	2027	47,216	18,613	1,169,953	-	447,827	58,133	1,694,525	2,545,526	4,287,268	1,286
15	2028	48,160	18,985	1,193,352	-	456,783	59,296	1,728,416	2,545,526	4,322,103	1,296
16	2029	49,124	19,365	1,217,219	-	465,919	60,482	1,762,984	2,545,526	4,357,634	1,307
17	2030	50,106	19,752	1,241,564	-	475,237	61,691	1,798,244	2,545,526	4,393,877	1,318
18	2031	51,108	20,147	1,266,395	-	484,742	62,925	1,834,209	2,545,526	4,430,844	1,329
19	2032	52,130	20,550	1,291,723	-	494,437	64,184	1,870,893	2,545,526	4,468,550	1,340
20	2033	53,173	20,961	1,317,557	-	504,325	65,467	1,908,311	2,545,526	4,507,010	1,351
Present Worth		445,947	175,792	11,049,972	-	4,229,631	549,056	16,004,451	26,759,011	43,209,408	648
(% of PW)		1.0%	0.4%	25.6%	0.0%	9.8%	1.3%	37.0%	61.9%	100.0%	

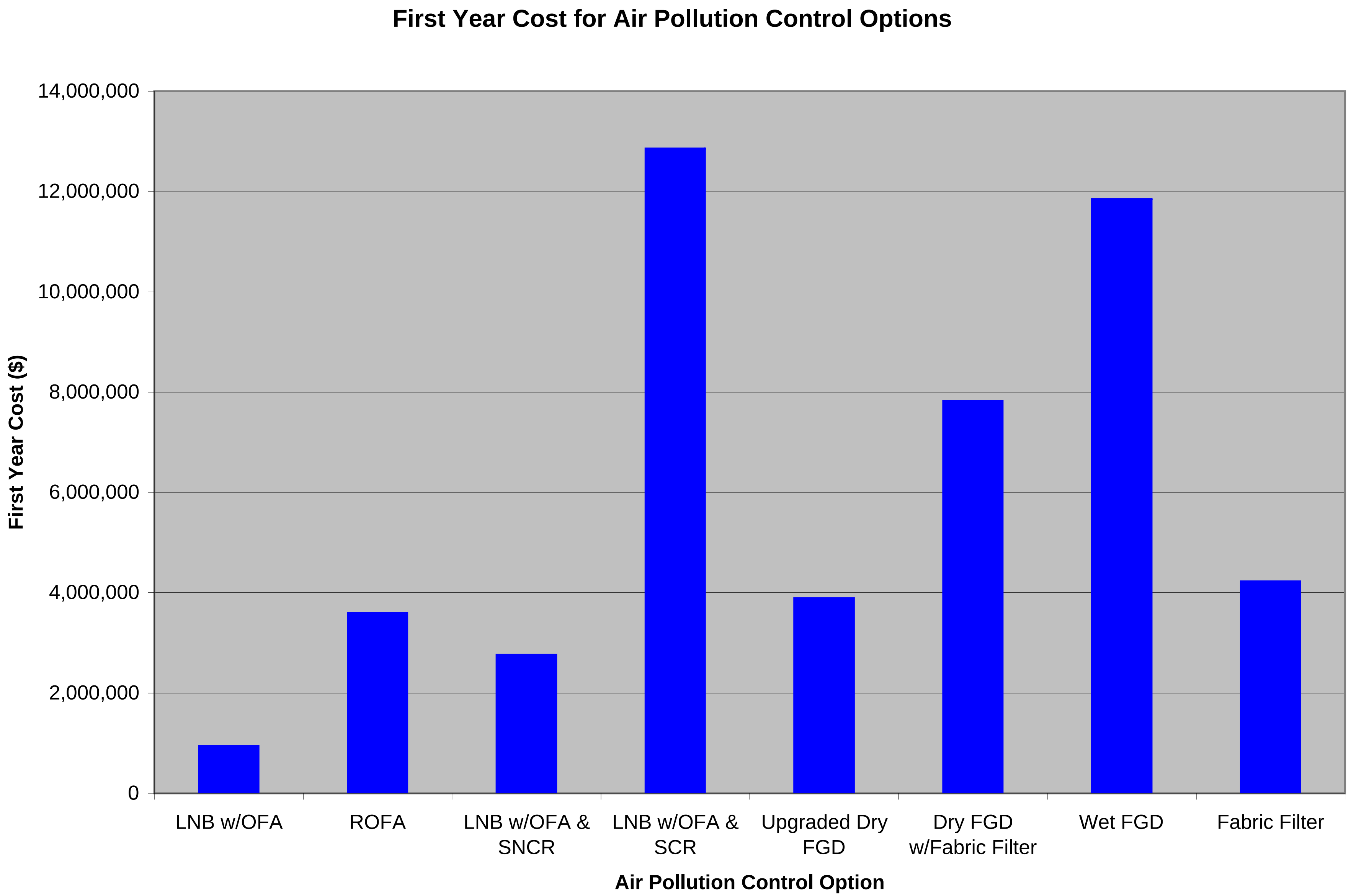
Wyodak					Dry FGD w/Fabric Filter						
Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton SO2 Removed)
0	2013										
1	2014	51,099	17,266	904,412	-	439,525	59,130	1,420,333	6,352,401	7,823,833	1,242
2	2015	52,121	17,611	922,500	-	448,315	60,313	1,448,739	6,352,401	7,853,262	1,247
3	2016	53,164	17,963	940,950	-	457,282	61,519	1,477,714	6,352,401	7,883,279	1,251
4	2017	54,227	18,323	959,769	-	466,427	62,749	1,507,268	6,352,401	7,913,897	1,256
5	2018	55,312	18,689	978,965	-	475,756	64,004	1,537,414	6,352,401	7,945,126	1,261
6	2019	56,418	19,063	998,544	-	485,271	65,284	1,568,162	6,352,401	7,976,981	1,266
7	2020	57,546	19,444	1,018,515	-	494,976	66,590	1,599,525	6,352,401	8,009,473	1,271
8	2021	58,697	19,833	1,038,885	-	504,876	67,922	1,631,516	6,352,401	8,042,614	1,277
9	2022	59,871	20,230	1,059,663	-	514,973	69,280	1,664,146	6,352,401	8,076,418	1,282
10	2023	61,069	20,634	1,080,856	-	525,273	70,666	1,697,429	6,352,401	8,110,899	1,288
11	2024	62,290	21,047	1,102,473	-	535,778	72,079	1,731,377	6,352,401	8,146,069	1,293
12	2025	63,536	21,468	1,124,523	-	546,494	73,521	1,766,005	6,352,401	8,181,942	1,299
13	2026	64,806	21,897	1,147,013	-	557,424	74,991	1,801,325	6,352,401	8,218,533	1,305
14	2027	66,103	22,335	1,169,953	-	568,572	76,491	1,837,352	6,352,401	8,255,855	1,311
15	2028	67,425	22,782	1,193,352	-	579,944	78,021	1,874,099	6,352,401	8,293,924	1,317
16	2029	68,773	23,237	1,217,219	-	591,543	79,581	1,911,581	6,352,401	8,332,755	1,323
17	2030	70,149	23,702	1,241,564	-	603,373	81,173	1,949,812	6,352,401	8,372,362	1,329
18	2031	71,552	24,176	1,266,395	-	615,441	82,796	1,988,808	6,352,401	8,412,761	1,335
19	2032	72,983	24,660	1,291,723	-	627,750	84,452	2,028,585	6,352,401	8,453,968	1,342
20	2033	74,442	25,153	1,317,557	-	640,305	86,141	2,069,156	6,352,401	8,496,000	1,349
Present Worth		624,325	210,951	11,049,972	-	5,370,050	722,442	17,353,415	66,777,531	84,755,271	673
(% of PW)		0.7%	0.2%	13.0%	0.0%	6.3%	0.9%	20.5%	78.8%	100.0%	

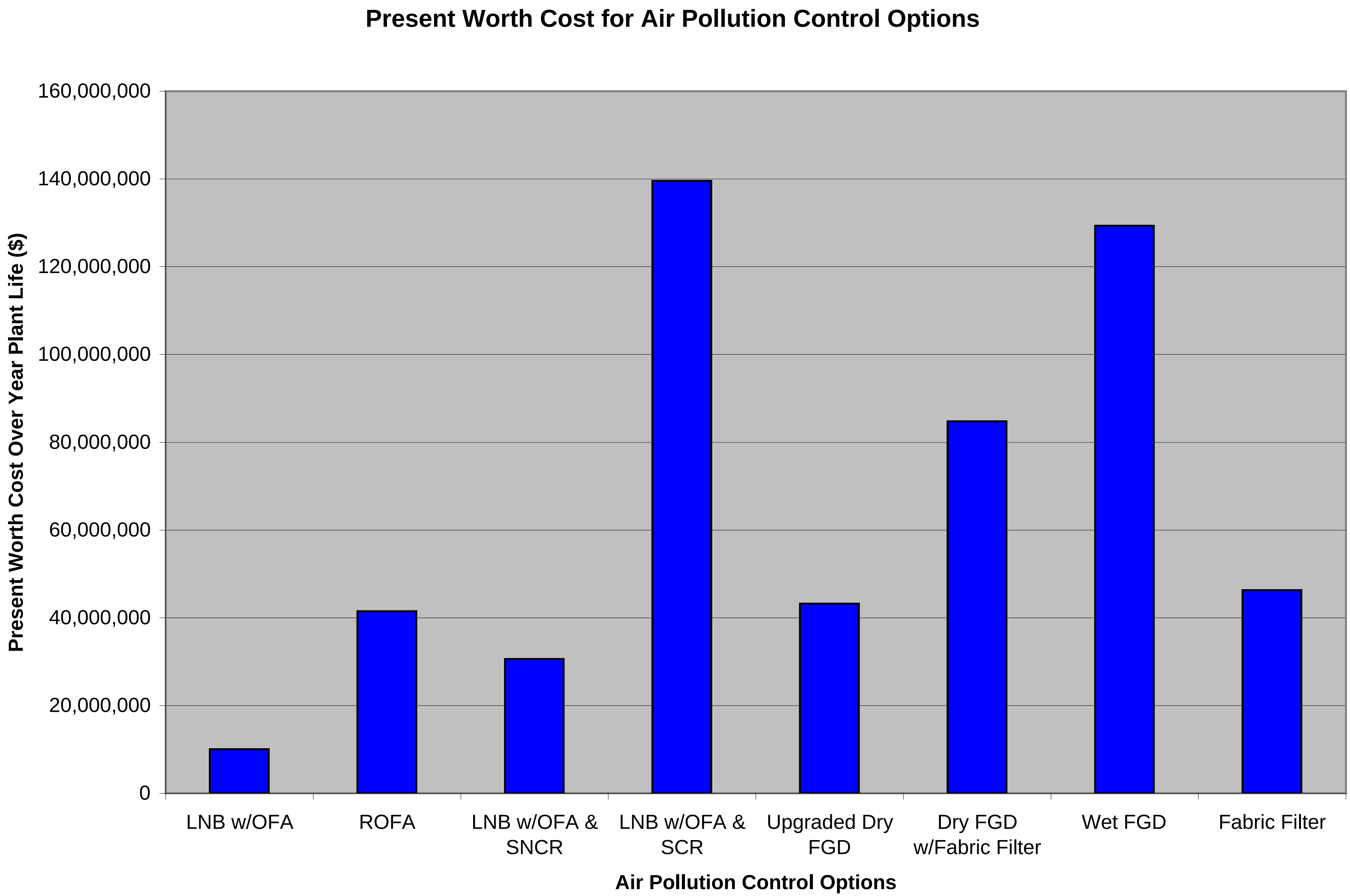
Wyodak — Wet FGD

Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton SO2 Removed)
0	2013										
1	2014	851,170	47,193	704,455	-	506,310	689,850	1,947,808	9,050,127	11,849,105	1,523
2	2015	868,194	48,137	718,544	-	516,437	703,647	1,986,764	9,050,127	11,905,085	1,530
3	2016	885,558	49,100	732,915	-	526,765	717,720	2,026,500	9,050,127	11,962,184	1,537
4	2017	903,269	50,082	747,573	-	537,301	732,074	2,067,030	9,050,127	12,020,425	1,545
5	2018	921,334	51,083	762,524	-	548,047	746,716	2,108,370	9,050,127	12,079,831	1,552
6	2019	939,761	52,105	777,775	-	559,008	761,650	2,150,538	9,050,127	12,140,425	1,560
7	2020	958,556	53,147	793,330	-	570,188	776,883	2,193,548	9,050,127	12,202,231	1,568
8	2021	977,727	54,210	809,197	-	581,592	792,421	2,237,419	9,050,127	12,265,273	1,576
9	2022	997,282	55,294	825,381	-	593,223	808,269	2,282,168	9,050,127	12,329,576	1,584
10	2023	1,017,227	56,400	841,889	-	605,088	824,435	2,327,811	9,050,127	12,395,165	1,593
11	2024	1,037,572	57,528	858,726	-	617,190	840,923	2,374,367	9,050,127	12,462,066	1,601
12	2025	1,058,323	58,679	875,901	-	629,533	857,742	2,421,855	9,050,127	12,530,305	1,610
13	2026	1,079,490	59,852	893,419	-	642,124	874,897	2,470,292	9,050,127	12,599,908	1,619
14	2027	1,101,080	61,049	911,287	-	654,967	892,395	2,519,698	9,050,127	12,670,904	1,628
15	2028	1,123,101	62,270	929,513	-	668,066	910,242	2,570,091	9,050,127	12,743,319	1,638
16	2029	1,145,563	63,516	948,103	-	681,427	928,447	2,621,493	9,050,127	12,817,183	1,647
17	2030	1,168,475	64,786	967,065	-	695,056	947,016	2,673,923	9,050,127	12,892,524	1,657
18	2031	1,191,844	66,082	986,407	-	708,957	965,957	2,727,402	9,050,127	12,969,372	1,667
19	2032	1,215,681	67,403	1,006,135	-	723,136	985,276	2,781,950	9,050,127	13,047,757	1,677
20	2033	1,239,995	68,751	1,026,257	-	737,599	1,004,981	2,837,589	9,050,127	13,127,710	1,687
Present Worth		10,399,475	576,598	8,606,924	-	6,186,026	8,428,486	23,798,034	95,136,483	129,333,992	831
(% of PW)		8.0%	0.4%	6.7%	0.0%	4.8%	6.5%	18.4%	73.6%	100.0%	

Wyodak — Fabric Filter

Year	Date	TOTAL FIXED O&M COST	Makeup Water Cost	Reagent Cost	SCR Catalyst / FF Bag Cost	Waste Disposal Cost	Electric Power Cost	TOTAL VARIABLE O&M COST	DEBT SERVICE	TOTAL ANNUAL COST	Control Cost ($/Ton PM Removed)
0	2013										
1	2014	121,665	-	-	186,992	-	812,052	999,044	3,104,100	4,224,809	15,202
2	2015	124,099	-	-	190,732	-	828,293	1,019,025	3,104,100	4,247,223	15,282
3	2016	126,581	-	-	194,546	-	844,859	1,039,405	3,104,100	4,270,086	15,365
4	2017	129,112	-	-	198,437	-	861,756	1,060,193	3,104,100	4,293,406	15,449
5	2018	131,694	-	-	202,406	-	878,991	1,081,397	3,104,100	4,317,192	15,534
6	2019	134,328	-	-	206,454	-	896,571	1,103,025	3,104,100	4,341,454	15,621
7	2020	137,015	-	-	210,583	-	914,502	1,125,086	3,104,100	4,366,201	15,710
8	2021	139,755	-	-	214,795	-	932,792	1,147,588	3,104,100	4,391,443	15,801
9	2022	142,550	-	-	219,091	-	951,448	1,170,539	3,104,100	4,417,190	15,894
10	2023	145,401	-	-	223,473	-	970,477	1,193,950	3,104,100	4,443,451	15,988
11	2024	148,309	-	-	227,942	-	989,887	1,217,829	3,104,100	4,470,238	16,085
12	2025	151,275	-	-	232,501	-	1,009,685	1,242,186	3,104,100	4,497,561	16,183
13	2026	154,301	-	-	237,151	-	1,029,878	1,267,029	3,104,100	4,525,430	16,283
14	2027	157,387	-	-	241,894	-	1,050,476	1,292,370	3,104,100	4,553,857	16,386
15	2028	160,535	-	-	246,732	-	1,071,485	1,318,217	3,104,100	4,582,852	16,490
16	2029	163,745	-	-	251,667	-	1,092,915	1,344,582	3,104,100	4,612,427	16,596
17	2030	167,020	-	-	256,700	-	1,114,773	1,371,473	3,104,100	4,642,594	16,705
18	2031	170,361	-	-	261,834	-	1,137,069	1,398,903	3,104,100	4,673,364	16,816
19	2032	173,768	-	-	267,071	-	1,159,810	1,426,881	3,104,100	4,704,749	16,929
20	2033	177,243	-	-	272,412	-	1,183,006	1,455,418	3,104,100	4,736,762	17,044
Present Worth		1,486,489	-	-	2,284,641	-	9,921,532	12,206,173	32,630,832	46,323,493	8,334
(% of PW)		3.2%	0.0%	0.0%	4.9%	0.0%	21.4%	26.3%	70.4%	100.0%	


First Year Cost for Air Pollution Control Options
First Year Cost ($)
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
LNB w/OFA
ROFA
LNB w/OFA & SNCR
LNB w/OFA & SCR
Upgraded Dry FGD
Dry FGD w/Fabric Filter
Wet FGD
Fabric Filter
Air Pollution Control Option


Present Worth Cost for Air Pollution Control Options
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
Present Worth Cost Over Year Plant Life ($)
LNB w/OFA
ROFA
LNB w/OFA & SNCR
LNB w/OFA & SCR
Upgraded Dry FGD
Dry FGD w/Fabric Filter
Wet FGD
Fabric Filter
Air Pollution Control Options

APPENDIX B

2006 Wyoming BART Protocol

BART Air Modeling Protocol

Individual Source Visibility Assessments for BART Control Analyses

September, 2006

State of Wyoming
Department of Environmental Quality
Air Quality Division
Cheyenne, WY 82002

Table of Contents

1.0 INTRODUCTION

The U.S. EPA has issued final amendments to the Regional Haze Regulations, along with Guidelines for Best Available Retrofit Technology (BART) Determinations.(1) The guidelines address the methodology for determining which facilities must apply BART (sources subject-to-BART) and the evaluation of control options.

The State of Wyoming used air quality modeling in accordance with the EPA Guidelines to determine the Wyoming sources which are subject-to-BART. This Protocol defines the specific methodology to be used by those sources for determining the improvement in visibility to be achieved by BART controls.

The methodology presented in this Protocol is consistent with EPA guidance and the Air Quality Division (AQD) determination of subject-to-BART sources. It is intended that all Wyoming sources that must conduct BART analyses will use this Protocol for their evaluation of control technology visibility improvement. Any deviations from the procedures described herein must be approved by the Division prior to implementation.

(1) 40 CFR Part 51: Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations; Final Rule. 70 Federal Register, 39103-39172, July 6, 2005.

2.0 OVERVIEW

Wyoming AQD determined that eight facilities (sources) in the state are subject-to-BART. The sources are listed in Table 1. Division modeling indicated that each of these sources causes or contributes to visibility impairment in one or more Class I areas. Each source must conduct a BART analysis to define Best Available Retrofit Technology (BART) applicable to that source, and quantify the improvement in Class I visibility associated with BART controls. This Protocol sets out the procedures for quantifying visibility improvement. Other aspects of the full BART analysis are not addressed here.

There are many Class I areas within and surrounding Wyoming (See Figure 1). On the basis of distance from subject-to-BART sources, topography, meteorology, and prior modeling, the AQD has determined that only five Class I areas need be addressed in BART individual source analyses. These are Badlands and Wind Cave National Parks in South Dakota, Mt. Zirkel Wilderness Area in Colorado, and Bridger and Fitzpatrick Wilderness Areas in Wyoming. Sources in eastern Wyoming have been shown to have greatest visibility impacts at the two South Dakota Class I areas, and western Wyoming sources have maximum impacts at Bridger and Fitzpatrick Wilderness Areas, and Mt. Zirkel. Visibility improvement at these highest impact areas will provide the best measure of the effectiveness of BART controls.

Each facility should carry out modeling with the CALPUFF modeling system for the Class I areas specified in Table 2. The AQD will provide meteorological input for CALMET for the years 2001, 2002, and 2003. The model domain covered by the AQD meteorological data is centered in southwest Wyoming, and extends roughly from Twin Falls, ID in the west to the Missouri River in the east, and from Denver in the south to Helena, MT in the north. The domain is shown, along with Class I areas, in Figure 1.

Sources may wish to utilize a smaller domain for CALPUFF modeling. Smaller domains are acceptable if they provide adequate additional area beyond the specific source and Class I areas being addressed. Figure 1 includes a "southwest Wyoming" domain which represents the minimum acceptable area for sources impacting the Bridger and Fitzpatrick Wilderness Areas, and the Mt. Zirkel Wilderness Area, and a "northeast Wyoming" domain as a minimum area for Badlands and Wind Cave National Parks modeling.

The CALPUFF model should be used with each of the three years of meteorological data to calculate visibility impacts for a baseline (existing emissions) case, and for cases reflecting BART controls. The control scenarios are to include individual scenarios for proposed BART controls for each pollutant (SO_2, NO_x, and particulate matter), and a combined scenario representing application of all proposed BART controls. If desired, additional modeling may be performed for controls that are not selected as BART. This might be done, for example, to provide data useful in identifying the control technologies that represent BART. However, visibility modeling is required only for the proposed BART controls.

Table 1. Wyoming Sources Subject-to-BART

Basin Electric	Laramie River Power Plant	Boilers #1,2,3
FMC Corporation	Granger Soda Ash Plant	Boilers #1,2
FMC Corporation	Green River Sodium Plant	Three boilers
General Chemical Co.	Green River Soda Ash	Two boilers
PacifiCorp	Dave Johnson Power Plant	Boilers #3,4
PacifiCorp	Jim Bridger Power Plant	Boilers #1-4
PacifiCorp	Naughton Power Plant	Boilers #1,2,3
PacifiCorp	Wyodak Power Plant	Boiler

Results of visibility modeling will be presented as a comparison between baseline impacts and those calculated for the BART control scenarios. Quantitative measures of impact will be the 98th percentile deciview change (Δdv) relative to the 20% best days natural background, and the number of days with deciview change exceeding 0.5 (EPA Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations, 70 FR 39103). Results should be presented for each year.

Table 2. Source-Specific Class I Areas to be Addressed

Source	Class I Areas to be Evaluated
Basin Electric Laramie River	Wind Cave NP, Badlands NP
FMC Corporation Granger Soda Ash	Bridger WA, Fitzpatrick WA
FMC Corporation Sodium Products	Bridger WA, Fitzpatrick WA
General Chemical Green River Soda Ash	Bridger WA, Fitzpatrick WA
Pacificorp Dave Johnston	Wind Cave NP, Badlands NP
Pacificorp Jim Bridger	Bridger WA, Fitzpatrick WA, Mt. Zirkel WA
Pacificorp Naughton Plant	Bridger WA, Fitzpatrick WA
Pacificorp Wyodak	Wind Cave NP, Badlands NP

3.0 EMISSIONS DATA FOR MODELING

CALPUFF model input requires source (stack) – specific emission rates for each pollutant, and stack parameters (height, diameter, exit gas temperature, and exit gas velocity). Per EPA BART guidance, these parameters must be representative of maximum actual 24-hour average emitting conditions for baseline (existing) operation, and maximum proposed 24-hour average emissions for future (BART) operations.

3.1 Baseline Modeling

Sources are required to utilize representative baseline emission conditions if data are available; baseline emissions must be documented. Possible sources of emission data are stack tests, CEM data, fuel consumption data, etc. Remember that emissions should represent maximum 24-hour rates. EPA BART guidance states that you should "Use the 24-hour average actual emission rate from the highest emitting day of the meteorological period modeled (for the pre-control scenario)." Thus, baseline conditions should reference data from 2001 through 2003 (or 2004).

As a minimum, modeled emissions must include:

SO_2	sulfur dioxide
NO_x	oxides of nitrogen
$PM_{2.5}$	particles with diameter less than 2.5μm
$PM_{10-2.5}$	particles with diameters greater than 2.5μm but less than or equal to 10 μm

If the fraction of PM_{10} in the $PM_{2.5}$ (fine) and $PM_{10-2.5}$ (coarse) categories cannot be determined all particulate matter should be assumed to be $PM_{2.5}$.

In addition, direct emissions of sulfate (SO_4) should be included where possible. Sulfate can be emitted as sulfuric acid (H_2SO_4), sulfur trioxide (SO_3), or as sulfate compounds; emissions should be quantified as the equivalent mass of SO_4.

When test or engineering data are not available to specify SO_4 emissions or the relative fractions of fine and coarse particles, use can be made of speciation profiles available from Federal Land Managers at the website http://ww2.nature.nps.gov/air/permits/ect/index.cfm. Profiles are available for a number of source type and control technology combinations. The FLM speciation factors are acceptable if data are available for the appropriate source type.

Emissions of VOC (volatile organic compounds), condensable organics measured in stack tests, and elemental carbon components of PM_{10} do not need to be included for BART modeling. The only other pollutant noted in EPA BART guidance is ammonia (NH_3). Though ammonia is not believed to be a significant contributor to visibility impairment in most cases in Wyoming, it could be important for sources with significant ammonia emissions – for example from some NO_x control systems. Sources that are expected to emit ammonia (in pre-or post-control configurations) should include ammonia emissions in their model input.

If quantitative baseline emissions data are unavailable and sources believe that the maximum 24-hour emission rates estimated by the Division (presented in the Subject-to-BART final report) are representative of baseline conditions for their facility, they may be used for baseline modeling. However, emissions of sulfate and ammonia (if applicable) should be included based on the best available test information or speciation factors from current literature.

3.2 Post-Control Modeling

All pollutants described above should be included for each post-control scenario. Post-control emissions (maximum 24-hour average) will generally be the baseline emissions multiplied by a control factor appropriate to the BART control. However, some proposed controls may simply increase the efficiency of existing controls; others may result in an increase in emissions of one pollutant while controlling another. These factors must all be considered in defining emission rates for post-control modeling. Any changes in stack parameters resulting from control application must also be included.

The required visibility assessment will include the effect of each proposed BART control. For example, if a source proposes to add a scrubber for SO_2 control, low NO_x burners for NO_x control, and a baghouse for particulate control, four sets of visibility results should be developed:

- Use of SO_2 control alone
- Use of NO_x control alone
- Use of particulate control alone
- Use of proposed combination of all three controls

All pollutants should be modeled in each CALPUFF model run, but the modeled emissions should reflect only the specific controls or combination of controls addressed in that run.

Additional modeling could be necessary in situations where a facility is comprised of more than one subject-to-BART source, and different BART controls are applicable to different sources. Excessive modeling to address multiple control combinations is not necessary; however, visibility modeling should quantify the effect of BART controls on all affected sources for each pollutant, and of all facility BART controls combined.

4.0 METEOROLOGICAL DATA

Wyoming AQD will provide MM5 meteorological data fields for years 2001, 2002, and 2003 that can be utilized as input to CALMET. The MM5 output will have 12 kilometer resolution and cover the full domain shown in Figure 1.

Mesoscale meteorological data (MM5) were developed and evaluated as part of the AQD's southwest Wyoming NO_2 increment analysis. Three years of MM5 data at 36 km resolution were used to initialize 12 km MM5 simulations. The 12km MM5 modeling used identical physics options to the original 36 km runs. CALMM5 was then used as a preprocessor to produce CALMET – ready MM5 data input files. Quality assurance was performed by comparing the original MM5 output on the 36km national RPO grid to the 12 km MM5 output and observations.

The CALMET model (version 5.53a, level 040716) should be used to prepare meteorological input for CALPUFF. The user may select a domain smaller than the MM5 domain for CALMET and CALPUFF modeling if desired. Figure 1 shows minimum domain areas for modeling of western and eastern Wyoming BART sources. Four kilometer resolution should be specified for CALMET output.

CALMET processing should use the AQD MM5 data, and appropriate surface, upper air, and precipitation data. Figure 2 shows the locations of surface and upper air stations within the MM5 model domain. The MM5 data are used as the initial guess wind field; this wind field is then adjusted by CALMET for terrain and land use to generate a step 1 wind field, and refined using surface and upper air data to create the final step 2 wind field.

Surface, upper air, and precipitation data can be obtained from the National Climatic Data Center. Land use and terrain data are available from the U.S. Geological Survey. Data can be formatted for use in CALMET with standard conversion and processing programs available with the CALMET/CALPUFF software.

Table 3 provides a listing of applicable CALMET input variables for BART meteorological processing. The table includes inputs that are specific to Wyoming BART modeling. Inputs not shown in Table 3 are not relevant to the present application, are dependent on the specific model domain of the user, use model default values, or are obvious from the context.

Table 3. CALMET Control File Inputs

Variable	Description	Value
	Input Group 1	
IBYR	Year	2001
		2002
		2003
IBTZ	Base time zone	7
IRTYPE	Run type	1
LCALGRD	Compute data fields for CALGRID	T
	Input Group 2	
PMAP	Map projection	LCC
DGRIDKM	Grid spacing (km)	4
NZ	Number of layers	10
ZFACE	Cell face heights (m)	0
		20
		40
		100
		140
		320
		580
		1020
		1480
		2220
		3500
	Input Group 4	
NOOBS	No observation Mode	0
	Input Group 5	
IWFCOD	Model selection variable	1
IFRADJ	Froude number adjustment	1
IKINE	Kinematic effects	0
IOBR	Use O'Brien procedure	0
ISLOPE	Slope flow effects	1
IEXTRP	Extrapolate surface wind observations	-4
ICALM	Extrapolate calm surface winds	0
BIAS	Biases for weights of surface and upper air stations	All 0
RMIN2	Minimum distance for extrapolation	-1
IPROG	Use gridded prognostic model output	14
ISTEPPG	Time Step (hours)	1
LVARY	Use varying radius of influence	F

Table 3. CALMET Control File Inputs (continued)

Variable	Description	Value
RMAX 1	Maximum radius of influence (km)	30
RMAX 2	Maximum radius of influence (km)	50
RMIN	Minimum radius of influence (km)	0.1
TERRAD	Radius of influence for terrain (km)	15
R1	Relative weighting of first guess wind field and observations (km)	5
R2	Relative weighting aloft (km)	25
IDIOPT 1	Surface temperature	0
IDIOPT 2	Upper air lapse rate	0
ZUPT	Lapse rate depth (m)	200
IDIOPT 3	Average wind components	0
IUPWND	Upper air station	-1
ZUPWND (1) ZUPWND (2)	Bottom and top of layer for domain scale winds (m)	1, 1000 1, 1000
IDIOPT4	Surface wind components	0
IDIOPT5	Upper air wind components	0
	Input Group 6	
IAVEZI	Spatial averaging	1
MNMDAV	Max search radius	1
HAFANG	Half angle for averaging (deg)	30
ILEVZI	Layer of winds in averaging	1
ZIMAX	Maximum overland mixing height (m)	3500
ITPROG	3D temperature source	1
IRAD	Interpolation type	1
TRADKM	Radius of influence – temperature (km)	500
NUMTS	Maximum number of Stations	5
IAVET	Spatial averaging of temperatures	1
NFLAGP	Precipitation interpolation	2

5.0 CALPUFF MODEL APPLICATION

The CALPUFF model (version 5.711a, level 040716) will be used to calculate pollutant concentrations at receptors in each Class I area. Application of CALPUFF should, in general, follow the guidance presented in the Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 report (EPA – 454/R98-019) and the EPA Regional Haze Regulations and Guidelines for BART Determinations (70 FR 39103).

Appropriate CALPUFF control file inputs are in Table 4. Note should be taken of the basis for several of the recommended CALPUFF inputs.

- Building downwash effects need not be included. Because of the transport distances involved and the fact that most sources have tall stacks, building downwash is unlikely to have a significant effect on model-predicted concentrations

- Puff splitting is not required. The additional computation time necessary for puff splitting is not justified for purposes of BART analyses.

- Hourly ozone files should be used to define background ozone concentration. Data are available from the following sites within the model domain.
  Rocky Mountain NP, CO
  Craters of the Moon NP, ID
  AIRS – Highland UT
  Mountain Thunder, WY
  Yellowstone NP, WY
  Centennial, WY
  Pinedale, WY

  The background ozone concentration shown in Table 4 is used only when hourly data are missing.

- A constant background ammonia concentration of 2.0 ppb is specified. This value is based upon monitoring data from nearby states and IWAQM guidance. Experience suggests that 2.0 ppb is conservative in that it is unlikely to significantly limit nitrate formation in the model computations.

- MESOPUFF II chemical transformation rates should be used.

- The species to be modeled should be the seven identified in CALPUFF: SO_2, SO_4, NO_x, HNO_3, NO_3, $PM_{2.5}$, and $PM_{10-2.5}$. If ammonia (NH_3) is emitted it should be added to the species list. In most cases, all pollutants modeled will also be emitted, except for HNO_3 and NO_3.

Concentration calculations should be made for receptors covering the areas of the Class I areas being addressed. Receptors in each Class I area will be those designated by the Federal Land Managers and available from the National Park Service website.

Table 4. CALPUFF Control File Inputs

Variable	Description	Value
	Input Group 1	
METRUN	Control parameter for running all periods in met file	1
IBYR	Starting year	2001 2002 2003
XBTZ	Base time zone	7
NSPEC	Number of chemical species modeled	7 (or 8)
NSE	Number of species emitted	5 (or 6)
METFM	Meteorological data format	1
	Input Group 2	
MGAUSS	Vertical distribution in near field	1
MCTADJ	Terrain adjustment method	3
MCTSG	Subgrid scale complex terrain	0
MSLUG	Elongated puffs	0
MTRANS	Transitional plume rise	1
MTIP	Stack tip downwash	1
MSHEAR	Vertical wind shear	0
MSPLIT	Puff splitting allowed?	0
MCHEM	Chemical mechanism	1
MAQCHEM	Aqueous phase transformation	0
MWET	Wet removal	1
MDRY	Dry deposition	1
MDISP	Dispersion Coefficients	3
MROUGH	Adjust sigma for roughness	0
MPARTL	Partial plume penetration of inversions	1
MPDF	PDF for convective conditions	0
	Input Group 4	
PMAP	Map projection	LCC
DGRIDKM	Grid spacing	4

Table 4. CALPUFF Control File Inputs (continued)

ZFACE	Cell face heights (m)	0
		20
		40
		100
		140
		320
		580
		1020
		1480
		2220
		3500
	Input Group 6	
NHILL	Number of terrain features Input Group 7	0
Dry Gas Depo	Chemical parameters for dry gas deposition	Defaults
	Input Group 8	
Dry Part. Depo	Size parameters for dry particle deposition SO_4, NO_3, PM25 PM10	 Defaults 6.5, 1.0
	Input Group 11	
MOZ	Ozone Input option	1
BCK03	Background ozone – all months (ppb)	44.0
BCKNH3	Background ammonia – all months (ppb)	2.0
	Input Group 12	
XMAXZI	Maximum mixing height (m)	3500
XMINZI	Minimum mixing height (m)	50

6.0 POST PROCESSING

Visibility impacts are calculated from the CALPUFF concentration results using CALPOST. CALPOST version 5.51, level 030709 should be used; the output from CALPOST will provide the highest deciview impact on each day from all receptors within each Class I area modeled.

For some CALPUFF applications such as deposition calculations, the POSTUTIL program is used prior to CALPOST. POSTUTIL is also used to repartition total nitrate by accounting for ammonia limiting. The ammonia limiting calculation in POSTUTIL should not be applied for Wyoming BART modeling. If you believe that ammonia limiting is appropriate for a specific BART analysis, justification should be discussed with the Division prior to its used.

Visibility calculations by CALPOST for BART purposes use Method 6. This method requires input of monthly relative humidity factors, f(RH), for each Class I area. The EPA guidance document provides appropriate data for each area. Table 5 lists monthly f(RH) factors to use for the Wyoming, Colorado, and South Dakota areas to be addressed in BART modeling. The factors shown in Table 5 include averages for the adjacent Class I areas, and are within 0.2 units of the Guideline table values for the individual Class I areas.

Natural background conditions as a reference for determination of the delta-dv change due to a source should be representative of the 20% best natural visibility days. EPA BART guidance provides the 20% best days deciview values for each Class I area on an annual basis, but does not provide species concentration data for the 20% best background conditions. These concentrations are needed for input to CALPOST.

Annual species concentrations corresponding to the 20% best days were calculated for each Class I area to be addressed, by scaling back the annual average concentrations given in Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule (Table 2-1). A separate scaling factor was derived for each Class I area such that, when multiplied by the Guidance table annual concentrations, the 20% best days deciview value for that area would be calculated. The scaled aerosol concentrations were averaged for the Bridger and Fitzpatrick WAs, and for Wind Cave and Badlands NPs, because of their geographical proximity and similar annual background visibility. The 20% best days aerosol concentrations to be used for each month for Wyoming BART evaluations are listed in Table 6.

Table 7 is a list of inputs for CALPOST. These inputs should be used for all BART visibility calculations. Output from CALPOST should be configured to provide a ranked list of the highest delta-deciview values in each Class I area. The 98th percentile delta-deciview value and the number of values exceeding 0.5 can then be determined directly from the CALPOST output.

Table 5. Monthly f(RH) Factors for Class I Areas

Month	Wind Cave NP Badlands NP	Bridger WA Fitzpatrick WA	Mt. Zirkel WA
January	2.65	2.50	2.20
February	2.65	2.30	2.20
March	2.65	2.30	2.00
April	2.55	2.10	2.10
May	2.70	2.10	2.20
June	2.60	1.80	1.80
July	2.30	1.50	1.70
August	2.30	1.50	1.80
September	2.20	1.80	2.00
October	2.25	2.00	1.90
November	2.75	2.50	2.10
December	2.65	2.40	2.10

Table 6. Natural Background Concentrations of Aerosol Components for 20% Best Days for BART Analyses ($\mu g/m^3$)

Aerosol Component	Wind Cave NP Badlands NP	Fitzpatrick WA Bridger WA	Mt. Zirkel WA
Ammonium Sulfate	.047	.045	.046
Ammonium Nitrate	.040	.038	.038
Organic Carbon	.186	.178	.179
Elemental Carbon	.008	.008	.008
Soil	.198	.189	.190
Coarse Mass	1.191	1.136	1.141

Table 7. CALPOST Control File Inputs

Variable	Description	Value
	Input Group 1	
ASPEC	Species to Process	VISIB
ILAYER	Layer/deposition code	1
A,B	Scaling factors	0,0
LBACK	Add background concentrations?	F
BTZONE	Base time zone	7
LVSO4	Species to be included in extinction	T
LVNO3		T
LVOC		F
LVPMC		T
LVPMF		T
LVEC		F
LVBK	Include background?	T
SPECPMC	Species name for particulates	PM10
SPECPMF		PM25
EEPMC	Extinction efficiencies	0.6
EEPMF		1.0
EEPMCBK		0.6
EESO4		3.0
EENO3		3.0
EEOC		4.0
EESOIL		1.0
EEEC		10.0
MVISBK	Visibility calculation method	6
RHFAC	Monthly RH adjustment factors	Table 5
BKSO4	Background concentrations	Table 6
BKNO3		Table 6
BKPMC		Table 6
BK OC		Table 6
BKSOIL		Table 6
BKEC		Table 6
BEXTRAY	Extinction due to Rayleigh scattering	10.0

7.0 REPORTING

A report on the BART visibility analysis should be submitted that clearly compares impacts for post-control emissions to those for baseline emissions. Data for baseline and BART scenarios should include both the 98th percentile values and the number of days with delta-deciview values exceeding 0.5. Results should be given for each model year.

Table 8 is an example of a recommended format for presentation of model input and model results. The example is for baseline conditions; similar tables should be provided for each control scenario (SO_2, NO_x, and PM10) and for the combination of all BART controls. Your report tables need not follow the exact format shown in Table 8; but the same information should be provided in a concise and clear form. If additional scenarios were modeled or you wish to present supplemental information, they should be provided in an appendix or separate from the specified final results.

Table 8. Example Format for Presentation of Model Input and Results

Baseline Conditions Model Input Data

Source (Unit) Description And ID	SO_2 Emission Rate (lb/day)	NO_x Emission Rate (lb/day)	$PM_{2.5}$ Emission Rate (lb/day)	$PM_{10-2.5}$ Emission Rate (lb/day)	SO_4 Emission Rate (lb/day)	NH_3 Emission Rate (lb/day)	Location Easting UTM (m)	Location Northing UTM (m)	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Gas Temp (deg K)

Baseline Visibility Modeling Results

Name of Facility	Class I Area	2001		2002		2003	
		98^{th} Percentile Value (dv)	No. of days exceeding 0.5 dv	98^{th} Percentile Value (dv)	No. of days exceeding 0.5 dv	98^{th} Percentile Value (dv)	No. of days exceeding 0.5 dv