

## **Appendix N**

**Holcim-Clarksville BART Analysis**

**April 24, 2008**

**BART FIVE FACTOR ANALYSIS ■ HOLCIM (US) INC**  
CLARKSVILLE, MISSOURI

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**Project 081701.0004**

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## 1. EXECUTIVE SUMMARY

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This report documents the determination of the Best Available Retrofit Technology (BART) as proposed by Holcim (US) Inc. (Holcim) for the Portland cement manufacturing plant located in Clarksville, Missouri (Clarksville plant). This analysis is for the kiln system. Currently, particulate matter emissions from the kiln are controlled by an electrostatic precipitator. The Clarksville plant has other lesser emitting BART-eligible emissions units, all of which have Particulate Matter Control Devices (PMCDs) installed. The negligible visibility impairment attributable to these sources concludes that no additional controls are necessary to satisfy the requirements of the BART rule.<sup>1</sup>

Holcim used the U.S. Environmental Protection Agency's (EPA's) guidelines<sup>2</sup> in 40 CFR Part 51 to determine BART for the kiln. Specifically, Holcim conducted a five-step analysis to determine BART for SO<sub>2</sub>, NO<sub>x</sub>, and PM<sub>10</sub> that included the following:

1. Identifying all available retrofit control technologies;
2. Eliminating technically infeasible control technologies;
3. Evaluating the control effectiveness of remaining control technologies;
4. Evaluating impacts and document the results;
5. Evaluating visibility impacts

Based on the five-step analysis, Holcim proposes the following as BART:

### Kiln:

- PM<sub>10</sub> – Holcim has determined that the existing electrostatic precipitator constitutes BART. This control device is effective for controlling PM<sub>10</sub> from a wet kiln.
- NO<sub>x</sub> – Holcim has determined that BART for the Holcim Clarksville Kiln is the installation and operation of a Mid Kiln Firing (MKF) system.
- SO<sub>2</sub> – Holcim proposes that no additional SO<sub>2</sub> controls are required for BART compliance. Additional SO<sub>2</sub> controls would require significant expenditures relative to the visibility improvements and are not justified.

The proposed BART control strategies will result in reductions of the visibility impacts attributable to the Clarksville plant. A summary of the visibility improvement at Class I areas based on the existing emission rates and proposed BART emission rates is provided in Table 1-1.

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<sup>1</sup> Holcim submitted an inventory of all of the BART-eligible emission sources to the MDNR. Based on a review of this information, the MDNR concluded that the contributions from particulate matter from the non-kiln sources to visibility impairment is negligible and further analysis of these smaller particulate matter sources was not required. Meeting with the MDNR dated January 23, 2008.

<sup>2</sup> 40 CFR 51, Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations

**TABLE 1-1. VISIBILITY IMPAIRMENT IMPROVEMENT**

	Mingo National Wildlife Refuge	Hercules Glades Wilderness Area	Upper Buffalo Wilderness Area
Existing 98% Impact ( $\Delta dv$ )	1.01	0.81	0.61
BART 98% Impact ( $\Delta dv$ )	0.92	0.72	0.60
Improvement 98% Impact ( $\Delta dv$ )	8.9%	11.1	1.6%

## 2. INTRODUCTION AND BACKGROUND

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On July 1, 1999, the U.S. EPA published the final Regional Haze Rule (RHR). The objective of the RHR is to improve visibility in 156 specific areas across with United States, known as Class I areas. The Clean Air Act defines Class I areas as certain national parks (over 6000 acres), wilderness areas (over 5000 acres), national memorial parks (over 5000 acres), and international parks that were in existence on August 7, 1977.

On July 6, 2005, the EPA published amendments to its 1999 RHR, often called the Best Available Retrofit Technology (BART) rule, which included guidance for making source-specific BART determinations. The BART rule defines BART-eligible sources as sources that meet the following criteria:

- (1) Have potential emissions of at least 250 tons per year of a visibility-impairing pollutant,
- (2) Began operation between August 7, 1962 and August 7, 1977, and
- (3) Are included as one of the 26 listed source categories in the guidance.

A BART-eligible source is subject to BART if the source is “reasonably anticipated to cause or contribute to visibility impairment in any federal mandatory Class I area.” EPA has determined that a source is reasonably anticipated to contribute to visibility impairment if the 98<sup>th</sup> percentile visibility impacts from the source are greater than 0.5 delta deciviews ( $\Delta dv$ ) when compared against a natural background. Air quality modeling is the tool that is used to determine a source’s visibility impacts.

Once it is determined that a source is subject to BART, a BART determination must address air pollution control measures for the source. The visibility regulations define BART as follows:

*“...an emission limitation based on the degree of reduction achievable through the application of the best system of continuous emission reduction for each pollutant which is emitted by...[a BART-eligible source]. The emission limitation must be established on a case-by-case basis, taking into consideration the technology available, the cost of compliance, the energy and non air quality environmental impacts of compliance, any pollution control equipment in use or in existence at the source, the remaining useful life of the source, and the degree of improvement in visibility which may reasonable be anticipated to result from the use of such technology.*”

Specifically, the BART rule states that a BART determination should address the following five statutory factors:

1. Existing controls
2. Cost of controls
3. Energy and non-air quality environmental impacts
4. Remaining useful life of the source
5. Degree of visibility improvement as a result of controls

Further, the BART rule indicates that the five basic steps in a BART analysis can be summarized as follows:

1. Identify all available retrofit control technologies;
2. Eliminate technically infeasible control technologies;
3. Evaluate the control effectiveness of remaining control technologies;
4. Evaluate impacts and document the results;
5. Evaluate visibility impacts

A BART determination should be made for each visibility affecting pollutant (VAP) by following the five steps listed above for each VAP.

BART applicability was determined for the Clarksville plant based on an applicability analysis performed by the MDNR and a refined applicability analysis performed by Holcim. Both analyses determined that the kiln is subject to BART. The details of the applicability determination can be found in Section 3.

Subsequently, Holcim performed an analysis to determine BART for each VAP for the kiln. The VAPs emitted by the kiln include NO<sub>x</sub>, SO<sub>2</sub>, and particulate matter with a mass mean diameter smaller than ten microns (PM<sub>10</sub>) of various forms (filterable coarse particulate matter [PM<sub>c</sub>], filterable fine particle matter [PM<sub>f</sub>], elemental carbon [EC], inorganic condensable particulate matter [IOR CPM] as sulfates [SO<sub>4</sub>], and organic condensable particulate matter [OR CPM] also referred to as secondary organic aerosols [SOA]). The BART determinations for SO<sub>2</sub> and NO<sub>x</sub> can be found in Sections 4 and 5 respectively.

### 3. BART APPLICABILITY DETERMINATION

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As stated in Section 2, a BART-eligible source is subject-to-BART if the source is “reasonably anticipated to cause or contribute to visibility impairment in any federal mandated Class I area.” EPA has determined that a source is reasonably anticipated to contribute to visibility impairment if the 98<sup>th</sup> percentile of the visibility impacts from the source is greater than 0.5  $\Delta$ dv when compared against a natural background. The MDNR conducted air quality modeling for the kiln to predict the existing visibility impairment attributable to the Clarksville plant in the following Class I areas:

- Mingo National Wildlife Refuge
- Hercules Glade Wilderness Area
- Upper Buffalo Wilderness Area

Based on this modeling, the MDNR concluded that the Clarksville plant was subject to BART since the 98<sup>th</sup> percentile of the visibility impacts attributable to the kiln are greater than 0.5  $\Delta$ dv when compared against a natural background for a Class I area.

The modeling methods and procedures that Holcim followed were consistent with the methods and procedures that were followed in the MDNR’s original modeling. Table 3-1 summarizes the emission rates that were modeled for SO<sub>2</sub>, NO<sub>x</sub>, and PM<sub>10</sub><sup>3</sup>. The SO<sub>2</sub> and NO<sub>x</sub> emission rates are the highest actual 24-hour emission rates based on 2003-2007 continuous emissions monitoring system (CEMS) data. The PM<sub>10</sub> emission rates are based on data included in Holcim’s BART survey.

**TABLE 3-1. MODELED 24-HOUR EMISSIONS (AS AN HOURLY EQUIVALENT)**

SO <sub>2</sub> (lb/hr)	NO <sub>x</sub> (lb/hr)	Total PM <sub>10</sub> (lb/hr)
4889.38	3049.38	51.82

Table 3-2 summarizes the stack parameters that were used to model the kiln.

**TABLE 3-2. SUMMARY OF STACK PARAMETERS**

Parameter	Value
Actual Stack height (ft)	250
Stack Diameter (ft)	21.7
Exhaust Velocity (ft/s)	34.3
Exhaust Temperature (F)	367

The results of the modeling indicate that the 98<sup>th</sup> percentile of the visibility impacts are greater than 0.5  $\Delta$ dv when compared against a natural background. Since the visibility impacts are greater than 0.5  $\Delta$ dv, the kiln is subject to BART. The results of the modeling are summarized in Table 3-3.

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<sup>3</sup> The non-kiln PM<sub>10</sub> emissions were included in the model as part of the kiln PM<sub>10</sub> emissions.

**TABLE 3-3. SUMMARY OF 98<sup>TH</sup> PERCENTILE VISIBILITY IMPACTS AND NUMBER OF DAYS WITH VISIBILITY IMPACT GREATER THAN 0.5 ΔDV**

Class I Area	Visibility Impairment	
	98th % Δdv	Days > 0.5 Δdv
Mingo Wilderness	1.01	75
Hercules Glades Wilderness	0.81	40
Upper Buffalo Wilderness	0.61	33

Table 3-4 provides a breakdown of the visibility impacts listed in Table 3-3 by each VAP for the high (98<sup>th</sup> percentile) day (note that the specific percentiles vary from day to day, and location to location, the breakdown listed is an example of one event only).

**TABLE 3-4. BREAKDOWN OF POLLUTANT SPECIFIC CONTRIBUTIONS TO VISIBILITY FOR THE 98<sup>TH</sup> PERCENTILE DAY.**

Class I Area	Visibility Impairment Attributable to SO <sub>4</sub>	Visibility Impairment Attributable to NO <sub>3</sub>	Visibility Impairment Attributable to SOA	Visibility Impairment Attributable to EC	Visibility Impairment Attributable to PM <sub>c</sub>	Visibility Impairment Attributable to PM <sub>f</sub>	Total Visibility Impairment (Δdv)
	(%)	(%)	(%)	(%)	(%)	(%)	
Mingo Wilderness	98.6	1.2	0	0	0	0.2	1.01
Hercules Glades Wilderness	42.3	57.5	0	0	0	0.2	0.81
Upper Buffalo Wilderness	95.7	4.2	0	0	0	0.1	0.61

As shown in Table 3-4, the most significant contributors to the visibility impairment are sulfates (SO<sub>4</sub>) and nitrates (NO<sub>3</sub>). The SO<sub>4</sub> contribution is from the chemical conversion of SO<sub>2</sub> emitted by the kiln to SO<sub>4</sub>. The NO<sub>3</sub> contribution is entirely from the chemical conversion of NO<sub>x</sub> emitted from the kiln. The contribution of PM<sub>10</sub> to the total visibility impairment can be estimated as the sum of the contributions from SOA, EC, PM<sub>c</sub>, and PM<sub>f</sub>. The PM<sub>10</sub> contribution is much smaller (<1%) than the contribution from SO<sub>2</sub> and NO<sub>x</sub>.

## 4. SO<sub>2</sub> BART EVALUATION

Sulfur, in the form of metallic sulfides (pyrite), sulfate, or organosulfur compounds, is often found in the raw materials used to manufacture cement and in the solid and liquid fuels burned in cement kilns.<sup>4</sup> The raw materials and fuels for the Clarksville plant are no exception. Sulfur dioxide can be generated by the oxidation of sulfur compounds in the raw materials and fuels during operation of the pyroprocess. Constituents found in fuels, raw materials, and in-process materials, such as the alkali metals (sodium and potassium), calcium carbonate, and calcium oxide react with SO<sub>2</sub> formed in the pyroprocess and much of the sulfur leaves the process in the principle product of the kiln system called clinker.

The kiln is the only BART source which emits SO<sub>2</sub>, thus an SO<sub>2</sub> BART evaluation was performed only for the kiln. The maximum actual 24-hour kiln SO<sub>2</sub> emission rate that was modeled for the BART applicability determination is summarized in Table 4-1. .

**TABLE 4-1. EXISTING ACTUAL MAXIMUM 24-HOUR SO<sub>2</sub> EMISSION RATES**

	SO <sub>2</sub> 24-Hour Emission Rate ton/24-hr	SO <sub>2</sub> Hourly Equivalent Emission Rate lb/hr
Kiln	58.67	4889.38

### 4.1 IDENTIFICATION OF AVAILABLE RETROFIT SO<sub>2</sub> CONTROL TECHNOLOGIES

Step 1 of the BART determination is the identification of all available retrofit SO<sub>2</sub> control technologies. A list of control technologies was obtained by reviewing the U.S. EPA's Clean Air Technology Center, publicly-available air permits, applications, and technical literature published by the U.S. EPA, state agencies, and Regional Planning Organizations (RPOs).

The available retrofit SO<sub>2</sub> control technologies are summarized in Table 4-2.

**TABLE 4-2. AVAILABLE SO<sub>2</sub> CONTROL TECHNOLOGIES**

<b>SO<sub>2</sub> Control Technologies</b>
Fuel Substitution Raw Material Substitution Dry Lime Injection/Scrubbing Wet Lime Scrubbing

<sup>4</sup> Miller, F. MacGregor and Hawkins, Garth J., "Formation and Emission of Sulfur Dioxide from the Portland Cement Industry", *Proceedings of the Air and Waste Management Association*, June 18-22, 2000.

## 4.2 ELIMINATE TECHNICALLY INFEASIBLE SO<sub>2</sub> CONTROL TECHNOLOGIES

Step 2 of the BART determination is to eliminate technically infeasible SO<sub>2</sub> control technologies that were identified in Step 1.

### 4.2.1 FUEL SUBSTITUTION

Holcim uses a mixture of coal, petroleum coke, alternative fuels (synfuel), and oil as the primary fuels for the kiln. For example, the 2007 actual fuel usage breakdown on an energy input basis, was 3.4 percent coal, 84 percent petroleum coke, 11.8 percent synfuel, and 0.8 percent oil (the fuel usages are also on an as received basis). The sulfur content of the petroleum coke is approximately 5.72 percent and the sulfur content of the coal is approximately 3.45 percent.

The design of the long wet kiln system is such that some of the SO<sub>2</sub> resulting from fuel combustion may be emitted and the rest is absorbed in clinker or CKD. Therefore, if Holcim reduces sulfur in the fuel input to the kiln, a corresponding reduction in SO<sub>2</sub> emissions from the kiln would be expected. Fuel sulfur content could be reduced by burning a coal with a lower sulfur content of 0.7 percent, in lieu of the current coal/coke, which would result in a lower overall fuel sulfur content.

Determining the specific reduction in SO<sub>2</sub> emissions from a reduction in fuel sulfur is complicated as the reactions in the kiln system are complex. The sulfur is introduced into the system in the fuel as well as the raw materials (pyrites) and the sulfur exits the kiln system in the product (clinker), the cement kiln dust (CKD), and out the stack as SO<sub>2</sub>. Further, although the sulfur in the clinker is small on a percentage basis, the magnitude of the clinker production is extremely large (greater than 1 million tons per year). Consequently, small changes in the amount of sulfur absorbed in the product can dramatically change the amount of SO<sub>2</sub> emitted. The variation in sulfur in the raw materials from the quarry, the clinker quality requirement determined by the market, and the kiln conditions can all cause significant changes in kiln operating parameters, such as kiln burning temperature, kiln excess Oxygen, etc. These changes can have a strong impact on the sulfur absorbed in the clinker and CKD and hence on SO<sub>2</sub> emissions. These operating conditions can also strongly change how the fuel sulfur affects SO<sub>2</sub> emissions. Reviewing the data yields that there is no linear correlation between fuel sulfur and SO<sub>2</sub> emissions. To calculate an SO<sub>2</sub> control effectiveness, based on switching to a lower sulfur fuel, a high number of assumptions must be made with a very low confidence in the accuracy. Regardless, an attempt has been made.

The assumptions, based on long term averages in 2007, which can vary significantly on an annual and short term (24-hr) basis, include that 65 percent of sulfur input in the kiln system is from fuel, 35 percent of sulfur input is from raw materials, and approximately 30-35 percent of total sulfur input is estimated to ultimately be emitted as SO<sub>2</sub> in the stack.

Based on the 2007 data, if all of the current coal and coke is replaced with low sulfur coal, the sulfur input from fuel is calculated to be reduced by approximately 85 percent. Following is a summary of the sulfur input reduction from the use of low sulfur coal. The low sulfur coal has a lower heat content (26 GJ/Metric ton) and higher moisture content

than the coke currently being used (33 GJ/Metric ton), so a higher volume of low sulfur coal is needed than coke reduced.

Current – 2007 Average

Coke Usage:	160,915 metric tons
Low Heat Content	32.510 GJ/Mt
Sulfur Content:	5.72 %
Sulfur Input from Coke:	9,204 metric tons

Current Coal Usage:	9,432 metric tons
Low Heat Content	22.177 GJ/Mt
Sulfur Content:	3.45 %
Sulfur Input from Coal:	325 metric tons

Total Sulfur Input from Coke/Coal: 9,529 metric tons

Low Sulfur Coal Replacement

Coal Usage:	208,546 metric tons
Heat Content	26.266 GJ/Mt
Sulfur Content:	0.7 %

Total Sulfur Input from Coal: 1,459 metric tons

Net reduction in sulfur input from coal:

$$9,529 \text{ metric tons} - 1,459 \text{ metric tons} = 8,070 \text{ metric tons} = 8,893 \text{ tons}$$

The SO<sub>2</sub> reduction calculation, based on the calculated sulfur reduction, is very complicated. The pyrite sulfur from the raw materials can volatilize at relatively low temperatures in the kiln, in an area where the sulfur comes in contact with the kiln feed that has only minimally been calcined into CaO. Consequently, less of this sulfur reacts with the CaO and thus is emitted. Again, if the sulfur reacted with the CaO, it would be absorbed into the clinker and CKD. The fuel sulfur, on the other hand, enters the kiln in the burning zone and travels the entire length of the kiln, coming in contact with much higher concentrations of CaO, thus having a much greater chance of being absorbed. Consequently, there is no simple linear relationship between fuel sulfur and SO<sub>2</sub> emissions that can be used to confidently calculate an SO<sub>2</sub> reduction.

The fuel sulfur reduction of 8,893 tons corresponds with a 54 percent reduction of the total sulfur (fuel and raw material sulfur) input to the kiln system in 2007. As mentioned above, a large fraction of fuel sulfur would have been absorbed by the CaO in the system, and thus would not have been emitted as SO<sub>2</sub>, while SO<sub>2</sub> emitted from the pyrite in the raw materials has less of a chance of being absorbed, so there is not a directly proportional reduction in SO<sub>2</sub> with the sulfur reduction from the fuels, nor with the total sulfur reduction. Holcim estimates that based on the year 2007 data, the actual SO<sub>2</sub> reduction is about 40% - 50%.

These reductions are the maximum reductions in tons of SO<sub>2</sub> that can be expected, especially if overall emissions of SO<sub>2</sub> increase from other sources (such as raw materials). As mentioned previously, the actual reduction will vary significantly, especially on a short term basis. Holcim estimates that the net reduction in SO<sub>2</sub> would be in the range of 40 percent to 50 percent.

Holcim considers this technology to be technically feasible and will consider it further.

#### **4.2.2 RAW MATERIAL SUBSTITUTION / SELECTIVE MINING**

In a long wet kiln, not only the pyritic sulfur, but total sulfur in the raw materials will have an impact on SO<sub>2</sub> emissions.

Part of the pyritic sulfur reacts with oxygen and forms SO<sub>2</sub> at the relatively lower temperature zone of the kiln. The rest of the sulfur, such as sulfates and sulfur compounds, enters the kiln at higher temperature zones, where more SO<sub>2</sub> is volatilized. Some of this SO<sub>2</sub> will pass the length of the kiln without being absorbed and will thus be emitted to the stack.

Using raw materials with lower sulfur content can reduce the potential for SO<sub>2</sub> emissions from a wet kiln system. The limestone, shale, and other raw materials used at the Clarksville plant contain pyrites and total sulfur in varying concentrations. If zones or layers in the on-site quarry could be identified and mined selectively such that lower sulfur content materials are used, the emission rate of SO<sub>2</sub> could be reduced. Holcim has conducted a complete quarry investigation, and based on the quarry scheduling optimization (QSO) model and computation, after 1-2 years of mining, the plant will be facing an area that has an even higher total sulfur content than that currently being used. Thus, there will be a higher total sulfur content in the raw material in the next 3-10 years. The total sulfur in the raw materials is expected to increase by an additional ~30% without selective quarrying, and by ~20% if some form of selective quarrying can be identified. Similarly, no significant reduction of pyritic sulfur from selective mining is anticipated.

Selective mining is not considered a technically feasible SO<sub>2</sub> control technology for the kiln. Moreover, Holcim is concerned that actual annual emissions resulting from normal variability at the plant will lead to an increase in SO<sub>2</sub> emissions as a result of total sulfur increases in the raw materials from the quarry. This variability will need to be considered in any potential BART control strategy.

#### **4.2.3 DRY LIME INJECTION/DRY LIME SCRUBBING**

Dry Lime Injection, or Dry Lime Scrubbing (DLS), consists of injecting hydrated lime, Ca(OH)<sub>2</sub>, into the flue gas. The Ca(OH)<sub>2</sub> reacts with SO<sub>2</sub> in the flue gas stream to create fine particles of CaSO<sub>3</sub> or CaSO<sub>4</sub>. The particles are collected in the particulate matter control device (PMCD) serving the kiln.

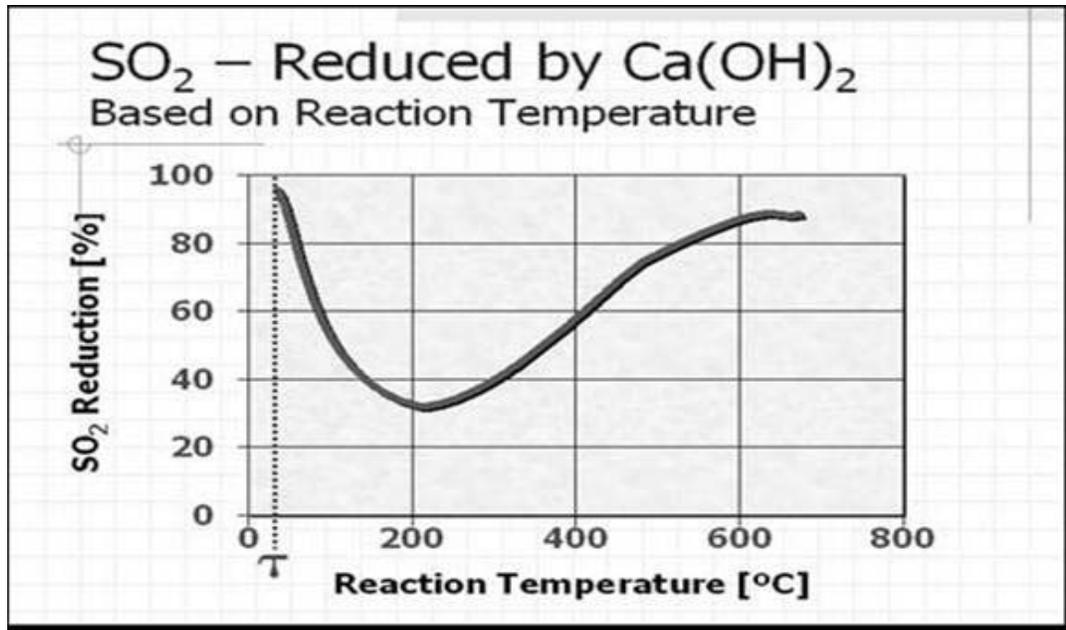
The current PMCD was not sized/designed to handle the additional particulate matter loading that would result from this technology. Consequently, adding DLS could cause

PM emissions and opacity to increase above permitted levels requiring Holcim to replace the existing PMCD (an ESP) with a new PMCD (a Baghouse).

Holcim is aware of only one other long term application of this technology on a wet kiln, which is on a smaller wet kiln in Belgium. Consequently, very little data exists to directly quantify the feasibility or benefit (emission reduction) of such a system. Regardless, Holcim is considering the technology to be technically feasible.

The effectiveness of DLS is impacted by both the temperature and the residence time/air flow rate at the location it is injected. At Clarksville, the injection point would be between the kiln outlet and the PMCD. At this location, the temperature is approximately 200 deg C (415 deg F). The temperature can not be increased at this location as the plant has limitations on the inlet temperature to the PMCD from both the Portland Cement MACT and the Hazardous Waste Combustion MACT in order to meet the Dioxin/Furan (D/F) limit. Further, lowering the temperature would lead to lower ESP efficiency and opacity problems. Figure 4-1 is a plot of SO<sub>2</sub> reduction versus reaction temperature from a commonly used article entitled “What is Achievable with Today’s Technologies”, Mark S. Terry, Krupp Polysius Corp, 2001. As indicated in the figure, at a temperature of 200 deg C (415 deg F), the reduction level is approximately 30 percent, which is the lowest reduction level over the temperature range presented.

**FIGURE 4-1. SO<sub>2</sub> REDUCTION VERSUS REACTION TEMPERATURE FOR HYDRATED LIME**



The molar ratio of lime (calcium source) to SO<sub>2</sub> is much higher than in a typical coal fired boiler due to a number of factors, some of which include the higher CO<sub>2</sub> and dust levels in the cement kiln system exhaust. The CO<sub>2</sub> competes with SO<sub>2</sub> in the reaction with the lime, and the higher dust loading reduces the even distribution of the lime in the gas. Based on a communication with the Obourg plant in Belgium, a molar ratio of between 4:1 and 6:1

has been used. The larger size of the Clarksville kiln will make it more difficult to evenly distribute the lime to the kiln gas and thus Holcim anticipates that a molar ratio of 6:1 will be required to achieve a maximum control efficiency of 20 - 30 percent.

Holcim considers this technology to be technically feasible and will consider it further.

#### **4.2.4 WET LIME SCRUBBING**

Wet lime scrubbing (WLS) is a name for a traditional tailpipe wet scrubber. This process involves passing the flue gas from the main PMCD through a sprayed aqueous suspension of  $\text{Ca}(\text{OH})_2$  or  $\text{CaCO}_3$  (limestone) that is contained in an appropriate scrubbing device. In the case of the Clarksville plant, the basic underlying economics would dictate the use of ground limestone as the scrubbing reagent. Use of the cement kiln dust as a scrubbing reagent was not considered as a viable option for Clarksville due to its high chlorine content and a large amount of inerts. In WLS, the aqueous suspension of scrubbing reagent is not taken to dryness as it is in DLS. The  $\text{SO}_2$  reacts with the scrubbing reagent to form  $\text{CaSO}_3 \cdot \text{H}_2\text{O}$  or gypsum that is collected and retained as aqueous sludge. The sludge is either dewatered and disposed of or used as synthetic gypsum.

The scrubbing efficiency of WLS can vary from an estimated 80 percent to 95 percent of the  $\text{SO}_2$  in the flue gas treated by the scrubber<sup>5</sup>. Further, WLS is a high maintenance process with high rates of downtime expected from build up or plug up of mist-eliminators or spray nozzles and the severe wear and corrosion of components. Holcim has found that high levels of hydrocarbons (THC) in the gas stream have caused significant corrosivity and foam build-up at their Dundee plant. Further, it significantly influences the system availability and the efficiency. The THC levels at the Clarksville plant may also lead to build up and plugging, and thus an availability (uptime) of the WLS of 95 percent is assumed.

Despite these identified drawbacks, WLS is considered a technically feasible BART option.

### **4.3 RANK OF TECHNICALLY FEASIBLE $\text{SO}_2$ CONTROL OPTIONS BY EFFECTIVENESS**

The third step in the BART analysis is to rank the technically feasible options according to effectiveness. Table 4-3 provides the effectiveness of each technology in the form of an annual average efficiency.

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<sup>5</sup> Assessment of Control Technology Options for BART-Eligible Sources Steam Electric Boilers, Industrial Boilers, Cement Plants and Paper and Pulp Facilities. Prepared by Northeast States for Coordinated Air Use Management In Partnership with The Mid-Atlantic/Northeast Visibility Union, March 2005, Page 4-21, Table IV-4. Range of Removal Efficiencies of Wet  $\text{SO}_2$  Scrubbers for Long Wet Kilns.

**TABLE 4-3. RANKING OF TECHNICALLY FEASIBLE KILN SO<sub>2</sub> CONTROL TECHNOLOGIES BY EFFECTIVENESS**

Control Technology	Effectiveness SO <sub>2</sub> Reduction (Percent Reduction – Annual Basis)
Wet Lime Scrubbing	80-95%
Fuel Substitution	40-50%
Dry Lime Scrubbing	20-30%

#### 4.4 EVALUATION OF IMPACTS FOR FEASIBLE SO<sub>2</sub> CONTROLS

Step four of the BART analysis procedure is the impact analysis. The BART determination guidelines list the four factors to be considered in the impact analysis:

- Cost of compliance
- Energy impacts
- Non-air quality impacts; and
- The remaining useful life of the source

Holcim has conducted an impact analysis for the remaining SO<sub>2</sub> control options.

##### 4.4.1 WET LIME SCRUBBING

###### **Cost of Compliance**

Holcim utilized a recent WLS vendor bid as the basis for the economic analysis to determine the annualized cost for WLS. Holcim divided the annualized cost of WLS by the annual tons of SO<sub>2</sub> reduced to determine the cost effectiveness for WLS. The “annual tons reduced” were determined by subtracting the estimated controlled annual emissions from the existing annual emissions. The existing annual emissions should be considered both on a projected actual and a potential to emit (PTE) basis. The projected actual (PA) annual SO<sub>2</sub> emissions provided to the MDNR in the recent Mid Kiln Firing (MKF) permit application was 11,481 tons/year<sup>6</sup>. The PTE listed in the MKF permit is 13,298 tons/year. The estimated controlled annual emissions were calculated by applying an 80 percent to 95 percent control efficiency and a 95 percent control device uptime, to the projected actual annual and PTE emissions. Table 4-4 provides a summary of the cost effectiveness analysis related to WLS. The detailed cost analysis table is provided in Appendix A.

The equipment cost includes both the WLS system and a limestone preparation system. The limestone preparation system includes 2 Ball Mills used to grind the limestone received to a specific fineness.

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<sup>6</sup>The projected actual annual emission rate was determined as part of the construction permit application process to support the August 27, 2007 Mid Kiln Firing construction permit. Permit Number 082007-019.

The cost effectiveness analysis does not include the cost to construct a new exhaust stack, which may be needed to employ the WLS technology, and it does not include the possible additional cost for the equipment relocation on site due to the limited space available for the WLS system.

The control cost factors were obtained from the EPA's Control Cost Manual, 6<sup>th</sup> Edition. Some of the factors have been scaled, as indicated, based on the construction being a retrofit, rather than Greenfield, and company knowledge of the actual cost of similar size/type projects.

Two factors that significantly increase the cost of this technology are the need to reheat the exhaust gas and the cost of sludge disposal.

#### Exhaust Gas Reheat

A common concern of utilizing a wet scrubber on a cement kiln exhaust gas is the probable formation of a detached plume resulting in opacity violations. For a typical cement kiln stack, if the exhaust gas contains NH<sub>3</sub>, HCl, and SO<sub>2</sub>, sub-micron aerosols of NH<sub>4</sub>Cl and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> may form when the gas temperature is reduced after exiting the stack. A detached plume is predicted to occur when the exhaust gas is cooled to the dew point at or near the exit of the stack and prior to the dilution of the aerosol forming constituents. The wet scrubber requires the exhaust gas to be cooled to the dew point at the inlet of the scrubber. As the temperature of the exhaust gas is cooled in the scrubber, a visible plume condition is nearly assured. The sub-micron NH<sub>4</sub>Cl aerosol will be formed and is difficult to remove in the scrubber. This problem has been reported for wet scrubbers used at cement plants. As the plant is subject to a 20 percent opacity limitation from both the PCMACT and HWCMACT, even a small increase in opacity could lead to an exceedance of the standard, which is not acceptable. Based on information from Holcim's Dundee, Michigan plant, Holcim anticipates that the temperature of the exhaust gas at the exit of the scrubber would be approximately 170 deg F. To keep the sub-micron particles from forming at the exit of the stack, reheating the exhaust gas, after the scrubber, is required. Without having any data to determine an optimum outlet temperature for the stack gas (after a scrubber is installed), Holcim has conservatively determined that to counteract this effect, the exhaust gas would need to be reheated to the current gas temperature after the ESP of approximately 380 deg F. This re-heating would most likely be achieved using natural gas combustion. The natural gas combustion would lead to a 97 ton/year increase in NO<sub>x</sub> emissions that would negatively impact visibility gains from the SO<sub>2</sub> reduction.

#### Sludge Disposal

The sludge generated from the WLS system may require disposal. Therefore, Holcim has determined the cost of disposal based on a bid from Area Disposal Services, Inc. for the disposal fee (\$36/ton), as well as the cost for trailer rental (\$120/month) and transportation (\$220/load).

WLS may also lead to an increase in PM emissions because some particles of limestone or CaSO<sub>3</sub> will be entrained in the flue gas and subsequently be emitted from the scrubber. WLS is also known to increase emissions of sulfuric acid mist.<sup>7</sup>

**TABLE 4-4. COST ANALYSIS SUMMARY FOR WET LIME SCRUBBING**

Control Case	Control Effectiveness (%)	Annual Cost (\$/yr)	Existing Annual Emissions (tons/yr)	Pollutant* Removed (tons/yr)	Cost** Effectiveness (\$/ton)	Cost*** Impact (\$/ton clinker)
WLS – PA	80%	\$24,706,548	11,481	8,726	\$2,863	\$20
WLS – PA	95%	\$25,246,115	11,481	10,362	\$2,460	\$21
WLS – PTE	80%	\$25,161,975	13,298	10,106	\$2,514	\$21
WLS – PTE	95%	\$25,786,935	13,298	12,001	\$2,166	\$21

\* Assumes 95% uptime.

\*\* Includes 97 tons of NOx generated.

\*\*\* Based on a maximum historical actual clinker production rate of 1,215,708 tons/year.

The significant increases in cost per ton of clinker produced from using WLS, as shown in Table 4-4, would likely eliminate any profit margin currently realized by the plant. Thus, it would not be economically feasible to operate the plant with WLS.

### **Energy Impacts**

A wet scrubber requires an additional fan of considerable horsepower to move the flue gas through the scrubber. The exhaust gas reheat requirement will utilize approximately 1,000,000 MMcf/year of natural gas, which will itself lead to an increase in NOx emissions of 97 tons/yr.

### **Non Air-Quality Impacts**

Without reheating, a frequent steam plume and/or detached plume can be expected at the discharge of the wet scrubber that would result in visual impairment in the area.

The WLS technology could generate over 50,000 tons per year of waste (sludge) that will require disposal in a landfill.

### **Remaining Useful Life**

The remaining useful life of the kiln does not impact the annualized cost of WLS because the useful life is anticipated to be at least as long as the capital cost recovery period, which is 15 years.

## **4.4.2 FUEL SUBSTITUTION**

### **Cost of Compliance**

<sup>7</sup> *Innovations in Portland Cement Manufacturing*, Portland Cement Association, 2004, pg. 660 & 669

The increased cost of using low sulfur coal includes the relative increase in fuel cost as well as the cost of a new coal mill system. Low sulfur coal is harder than the current coal/coke utilized and has a lower heat content; consequently, a higher volume of coal grinding will be needed than the current mill can achieve. The increased grinding requirement would also have an additional energy requirement. A bid for a new coal mill, classifier, and mill motors, was obtained from GEBR. Pfeiffer USA Inc. Table 4-5 provides a summary of the cost effectiveness analysis related to Fuel Substitution. The detailed cost analysis table is provided in Appendix A.

The cost effectiveness analysis does not include the cost to construct any new storage or handling facilities for the low sulfur coal that may be required.

The control cost factors were obtained from the EPA’s Control Cost Manual, 6<sup>th</sup> Edition. Some of the factors have been scaled, as indicated, based on the construction being a retrofit, rather than greenfield, and company knowledge of the actual cost of similar size/type projects.

**TABLE 4-5. COST ANALYSIS SUMMARY FOR FUEL SUBSTITUTION**

Control Case	Control Effectiveness (%)	Annual Cost (\$/yr)	Existing Annual Emissions (tons/yr)	Pollutant Removed (tons/yr)	Cost Effectiveness (\$/ton)	Cost* Impact (\$/ton clinker)
Fuel Sub – PA	40%	\$27,022,178	11,481	4,592	\$5,884	\$22
Fuel Sub – PA	50%	\$27,022,178	11,481	5,741	\$4,707	\$22
Fuel Sub – PTE	40%	\$27,022,178	13,298	5,319	\$5,080	\$22
Fuel Sub – PTE	50%	\$27,022,178	13,298	6,649	\$4,064	\$22

\*Based on a maximum historical actual clinker production rate of 1,215,708 tons/year

The significant increases in cost per ton of clinker produced from using Fuel Substitution, as shown in Table 4-5, would likely eliminate any profit margin currently realized by the plant. Thus, it would not be economically feasible to operate the plant with Fuel Substitution.

**Energy Impacts**

The low sulfur coal will require additional energy for grinding. The actual increase is difficult to estimate.

**Non Air-Quality Impacts**

None.

**Remaining Useful Life**

The remaining useful life of the kiln does not impact the annualized cost because the useful life is anticipated to be at least as long as the capital cost recovery period, which is 15 years. However, the existing coal mill would need to be replaced at a significant expense.

### 4.4.3 DRY LIME SCRUBBING

#### Cost of Compliance

The increased cost of DLS includes the cost of hydrated lime as well as the injection system and replacing the existing ESP with a new baghouse. As the DLS injection system would likely be a custom application, Holcim's engineering department has estimated that the DLS injection system equipment cost would be approximately \$1,000,000. Holcim obtained a bid for retrofitting the existing ESP with a Baghouse from GE Energy. A detailed analysis has not yet been completed to determine if the retrofit will be capable of handling the additional dust loading from the DLS system.

The quantity of hydrated lime required is calculated below on a PA and PTE basis as follows:

#### Hydrated Lime Requirement.

##### PA Basis:

The projected actual annual emission level of SO<sub>2</sub> is 11,481 tons

A molar ratio of 6:1, Ca(OH)<sub>2</sub> to SO<sub>2</sub>, is required. The Ca(OH)<sub>2</sub> required is calculated by multiplying by the ratio of molecular weights:

$$6 \times 11,481 \text{ tons SO}_2 \times (74 \text{ ton Ca(OH)}_2 / 64 \text{ SO}_2) = 79,649 \text{ tons Ca(OH)}_2$$

The estimated purity of the hydrated lime is 96.8 percent Ca(OH)<sub>2</sub>. Consequently, the amount required is scaled as follows:

$$79,649 \text{ tons Ca(OH)}_2 / 0.968 = 82,282 \text{ tons hydrated lime}$$

##### PTE Basis:

The PTE annual emission level of SO<sub>2</sub> is 13,298 tons

A molar ratio of 6:1, Ca(OH)<sub>2</sub> to SO<sub>2</sub>, is required. The Ca(OH)<sub>2</sub> required is calculated by multiplying by the ratio of molecular weights:

$$6 \times 13,298 \text{ tons SO}_2 \times (74 \text{ ton Ca(OH)}_2 / 64 \text{ SO}_2) = 92,255 \text{ tons Ca(OH)}_2$$

The estimated purity of the hydrated lime is 96.8 percent Ca(OH)<sub>2</sub>. Consequently, the amount required is scaled as follows:

$$92,255 \text{ tons Ca(OH)}_2 / 0.968 = 95,304 \text{ tons hydrated lime}$$

Table 4-6 provides a summary of the cost effectiveness analysis related to DLS. The detailed cost analysis table is provided in Appendix A. The control cost factors were obtained from the EPA's Control Cost Manual, 6<sup>th</sup> Edition. Some of the factors have been

scaled, as indicated, based on the construction being a retrofit, rather than greenfield, and company knowledge of the actual cost of similar size/type projects.

**TABLE 4-6. COST ANALYSIS SUMMARY FOR DRY LIME SCRUBBING**

Control Case	Control Effectiveness (%)	Annual Cost (\$/yr)	Existing Annual Emissions (tons/yr)	Pollutant Removed (tons/yr)	Cost Effectiveness (\$/ton)	Cost* Impact (\$/ton clinker)
DLS – PA	20%	\$15,607,401	11,481	2,181	\$7,155	\$13
DLS – PA	30%	\$15,607,401	11,481	3,272	\$4,770	\$13
DLS – PTE	20%	\$17,638,856	13,298	2,527	\$6,981	\$15
DLS – PTE	30%	\$17,638,856	13,298	3,790	\$4,654	\$15

\*Based on a maximum historical actual clinker production rate of 1,215,708 tons/year

The significant increases in cost per ton of clinker produced from using DLS, as shown in Table 4-6, would likely eliminate any profit margin currently realized by the plant. Thus, it would not be economically feasible to operate the plant with DLS.

**Energy Impacts**

Additional electricity is needed for the pump used to inject the lime into the kiln gas.

**Non Air-Quality Impacts**

Utilizing DLS could also increase the amount of CKD sent to the landfill.

**Remaining Useful Life**

The remaining useful life of the kiln does not impact the annualized cost because the useful life is anticipated to be at least as long as the capital cost recovery period, which is 15 years.

**4.5 EVALUATION OF VISIBILITY IMPACT OF FEASIBLE SO<sub>2</sub> CONTROLS**

A final impact analysis was conducted to assess the visibility improvement for the existing emission rate when compared to the emission rate of WLS, Fuel Substitution, and DLS. The existing emission rates, and emission rates associated with controls, were modeled using CALPUFF. The existing emission rate is the same rate that was modeled for the BART applicability analysis. The SO<sub>2</sub> emission rate associated with WLS, Fuel Substitution, and DLS is the existing emission rates less the average anticipated control of 87.5 percent, 45 percent, and 25 percent respectively. The emission rates are summarized in Table 4-7.

**TABLE 4-7. SUMMARY OF EMISSION RATES MODELED IN SO<sub>2</sub> CONTROL VISIBILITY IMPACT ANALYSIS**

Emission Rate Scenario	Emission Rate		
	SO <sub>2</sub> (lb/hr)	NO <sub>x</sub> (lb/hr)	PM <sub>10</sub> (lb/hr)
WLS – 87.5%	611	3,049	51.82
Fuel Substitution – 45%	2,689	3,049	51.82
DLS – 25%	3,667	3,049	51.82
Base case – Max 24-hr avg.	4,889	3,049	51.82

Comparisons of the existing visibility impacts and the visibility impacts based on WLS, Fuel Substitution, and DLS are provided in Table 4-8. The visibility improvement associated with the controls are also shown in Table 4-8; this value was calculated as the difference between the existing visibility impairment and the visibility impairment for the controlled emission rates as measured by the 98<sup>th</sup> percentile modeled visibility impact.

**TABLE 4-8. SUMMARY OF MODELED IMPACTS FROM SO<sub>2</sub> CONTROL VISIBILITY IMPACT ANALYSIS**

	Mingo National Wildlife Refuge	Hercules Glades Wilderness Area	Upper Buffalo Wilderness Area
Existing 98% Impact ( $\Delta$ dv)	1.01	0.81	0.61
WLS 98% Impact ( $\Delta$ dv)	0.48	0.31	0.21
WLS Improvement 98% Impact ( $\Delta$ dv)	0.53	0.50	0.40
Fuel Subs. 98% Impact ( $\Delta$ dv)	0.70	0.58	0.37
Fuel Subs Improvement 98% Impact ( $\Delta$ dv)	0.31	0.23	0.24
DLS 98% Impact ( $\Delta$ dv)	0.87	0.70	0.48
DLS Improvement 98% Impact ( $\Delta$ dv)	0.14	0.11	0.13

## 4.6 PROPOSED BART FOR SO<sub>2</sub>

In order to determine BART for SO<sub>2</sub>, Holcim reviewed each control option’s availability, as well as its cost of compliance, energy impacts, and non-air quality impacts, as well as the remaining useful life of the kiln. Table 4-9 summarizes the cost effectiveness for the controls based on the tons of SO<sub>2</sub> reduced and the visibility improvement in deciviews.

**TABLE 4-9. SUMMARY OF COST EFFECTIVENESS OF SO<sub>2</sub> CONTROL OPTIONS**

Control Option *	Existing Emissions (tons/yr)	Reduced Annual Emissions (tons/yr)	Annual Cost (\$/yr)	Cost ** Effectiveness (\$/ton)	Cost Impact (\$/ton clinker)
WLS-PA-80%	11,481	8,726	\$24,706,548	\$2,863	\$20
Fuel Sub - PA - 40%	11,481	4,592	\$27,022,178	\$5,884	\$22
DLS - PA - 20%	11,481	2,181	\$15,607,401	\$7,155	\$13

\*The worst case scenario from a cost effectiveness perspective is provided.

\*\*Includes 97 tons of NO<sub>x</sub> generated for WLS

Control Type <b>WLS-PA-80%</b>	Base 98th Percentile Impact (DV)	Controlled 98 <sup>th</sup> Percentile Impact (DV)	98 <sup>th</sup> Percentile Improvement (DV)	98 <sup>th</sup> Percentile Improvement (%)	Cost Effectiveness (\$/DV)
Class I Area					
Mingo	1.01	0.48	0.53	52.5	\$46,616,128
Hercules	0.81	0.31	0.50	61.7	\$49,413,096
Buffalo	0.61	0.21	0.40	65.6	\$61,766,370

Control Type <b>Fuel Subs.</b>	Base 98th Percentile Impact (DV)	Controlled 98 <sup>th</sup> Percentile Impact (DV)	98 <sup>th</sup> Percentile Improvement (DV)	98 <sup>th</sup> Percentile Improvement (%)	Cost Effectiveness (\$/DV)
Class I Area					
Mingo	1.01	0.70	0.31	30.7	\$87,168,317
Hercules	0.81	0.58	0.23	28.4	\$117,487,732
Buffalo	0.61	0.37	0.24	39.3	\$112,592,410

Control Type <b>DLS</b>	Base 98th Percentile Impact (DV)	Controlled 98 <sup>th</sup> Percentile Impact (DV)	98 <sup>th</sup> Percentile Improvement (DV)	98 <sup>th</sup> Percentile Improvement (%)	Cost Effectiveness (\$/DV)
Class I Area					
Mingo	1.01	0.87	0.14	13.9	\$111,481,434
Hercules	0.81	0.70	0.11	13.6	\$141,885,461
Buffalo	0.61	0.48	0.13	21.3	\$120,056,929

Based on the five step analysis outlined by EPA, this analysis demonstrates that the cost of compliance associated with WLS, Fuel Substitution, and DLS is extremely high on a \$/ton of SO<sub>2</sub> removed basis, and especially on a \$/DV of improvement basis. A cost range of \$46 million - \$141 million/DV is well beyond expectations of the BART program. Holcim has concluded that the current inherent scrubbing by the cement kiln process is the only feasible control and no additional BART control option is economically feasible. Notwithstanding, Holcim has been diligently working on capturing SO<sub>3</sub> in clinker and significantly increased SO<sub>3</sub> in the clinker in the past five years. Holcim continues to work on process optimization to further increase the SO<sub>3</sub> capture in the clinker.

## 5. NO<sub>x</sub> BART EVALUATION

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In Portland cement kilns, the NO<sub>x</sub> that is generated is primarily classified into one of two categories, i.e., thermal NO<sub>x</sub> or fuel NO<sub>x</sub><sup>8</sup>. Thermal NO<sub>x</sub> occurs as a result of the high-temperature oxidation of molecular nitrogen present in the combustion air. Fuel NO<sub>x</sub> is created by the oxidation of nitrogenous compounds present in the fuel. It is also possible for nitrogenous compounds to be present in the raw material feed and become oxidized to form additional NO<sub>x</sub> referred to as feed NO<sub>x</sub>.

Due to the high flame temperature in the burning zone of the rotary kiln (3400° F), NO<sub>x</sub> emissions from the kiln tend to be mainly comprised of thermal NO<sub>x</sub>. Although NO<sub>x</sub> emissions from cement kilns include both nitrogen oxide (NO) and nitrogen dioxide (NO<sub>2</sub>), typically, less than 10% of the total NO<sub>x</sub> in the flue gas is NO<sub>2</sub>.<sup>9</sup>

The kiln is the only BART source which emits NO<sub>x</sub>, thus a NO<sub>x</sub> BART evaluation was performed only for the kiln. The maximum actual 24-hour kiln NO<sub>x</sub> emission rate that was modeled for the BART applicability determination is summarized in Table 4-1. The NO<sub>x</sub> 24-hour maximum actual emission rate was determined from analyzer data for November 24, 2007.

**TABLE 5-1. EXISTING ACTUAL MAXIMUM 24-HOUR NO<sub>x</sub> EMISSION RATES**

	NO <sub>x</sub> 24-Hour Emission Rate ton/24-hr	NO <sub>x</sub> Hourly Equivalent Emission Rate lb/hr
Kiln	36.59 (73,185 lbs)	3,049

### 5.1 IDENTIFICATION OF AVAILABLE RETROFIT NO<sub>x</sub> CONTROL TECHNOLOGIES

Step 1 of the BART determination is the identification of all available retrofit NO<sub>x</sub> control technologies. A list of control technologies was obtained by reviewing the U.S. EPA's Clean Air Technology Center, control equipment vendor information, publicly-available air permits, applications, and technical literature published by the U.S. EPA and the RPOs.

The available retrofit NO<sub>x</sub> control technologies are summarized in Table 5-2.

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<sup>8</sup> NO<sub>x</sub> Formation and Variability in Portland Cement Kiln Systems, Penta Engineering, December 1998.

<sup>9</sup> IBID.

**TABLE 5-2. POSSIBLE NO<sub>x</sub> CONTROL TECHNOLOGIES**

Kiln Control Technologies
Low NO <sub>x</sub> Burner
Flue Gas Recirculation
CKD Insufflation
Mid-Kiln Firing of Tires
Selective Noncatalytic Reduction
Selective Catalytic Reduction

## **5.2 ELIMINATE TECHNICALLY INFEASIBLE NO<sub>x</sub> CONTROL TECHNOLOGIES**

Step 2 of the BART determination is to eliminate technically infeasible NO<sub>x</sub> control technologies that were identified in Step 1.

### **5.2.1 LOW-NO<sub>x</sub> BURNER IN THE ROTARY KILN**

Low NO<sub>x</sub> burners (LNBs) reduce the amount of NO<sub>x</sub> formed at the flame. The principle of all LNBs is the same: stepwise or staged combustion and localized exhaust gas recirculation (i.e. at the flame). As applied to the rotary cement kiln, the low-NO<sub>x</sub> burner creates primary and secondary combustion zones at the end of the main burner pipe to reduce the amount of NO<sub>x</sub> initially formed at the flame. In the high-temperature primary zone, combustion is initiated in a fuel-rich environment in the presence of a less than stoichiometric oxygen concentration. The oxygen-deficient condition at the primary combustion site minimizes thermal and fuel NO<sub>x</sub> formation and produces free radicals that chemically reduce some of the NO<sub>x</sub> that is being generated in the flame.

In the secondary zone, combustion is completed in an oxygen-rich environment. The temperature in the secondary combustion zone is much lower than in the first; therefore, lower NO<sub>x</sub> formation is achieved as combustion is completed. CO that has been generated in the primary combustion zone as an artifact of the sub-stoichiometric combustion is fully oxidized in the secondary combustion zone.

Low-NO<sub>x</sub> burners are considered to be a technically feasible option for NO<sub>x</sub> control. As Holcim already has a LNB, the technology will not be considered further.

### **5.2.2 FLUE GAS RECIRCULATION**

Flue gas recirculation involves the use of oxygen-deficient flue gas from some point in the process as a substitute for primary air in the main burner pipe in the rotary kiln. Flue gas recirculation (FGR) lowers the peak flame temperature and develops localized reducing conditions in the burning zone through a significant reduction of the oxygen content of the primary combustion “air.” The intended effect of the lower flame temperature and reducing conditions in the flame is to decrease both thermal and fuel NO<sub>x</sub> formation in the rotary kiln.

While FGR is a practiced control technology in the electric utility industry, Holcim is not aware of any attempt to apply FGR to a cement kiln because of the unique process requirements of the industry, i.e., a hot flame is required to complete the chemical reactions that form clinker minerals from the raw materials. The process of producing clinker in a cement kiln requires the heating of raw materials to about 2700°F for a brief but appropriate time to allow the desired chemical reactions that form the clinker minerals to occur. A short, high-temperature flame of about 3400°F is necessary to meet this process requirement. The long/lazy flame that would be produced by FGR would result in the production of lower or unacceptable quality clinker because of the resulting undesirable mineralogy. Clinkering reactions must take place in an oxidizing atmosphere in the burning zone to generate clinker that can be used to produce acceptable cement. FGR would tend to produce localized or general reducing conditions that also could detrimentally affect clinker quality. Due to these important limitations on the application of FGR and the lack of a successful demonstration on a cement kiln in the United States, FGR is not a technically feasible control option for NO<sub>x</sub> control at this time.

### **5.2.3 CEMENT KILN DUST INSUFFLATION**

Cement kiln dust (CKD) is a residual byproduct that can be produced by any of the four basic types of cement kiln systems. CKD is most often treated as a waste even though there are some beneficial uses. However, as a means of recycling usable CKD to the cement pyroprocess, CKD sometimes is injected or insufflated into the burning zone of the rotary kiln in or near the main flame. The presence of these cold solids within or in close proximity to the flame has the effect of cooling the flame and/or the burning zone thereby reducing the formation of thermal NO<sub>x</sub>. The insufflation process is somewhat counterintuitive because a basic requirement of a cement kiln is a very hot flame to heat the clinkering raw materials to about 2700°F in as short a time as possible. The Clarksville plant already uses this technology and it is already included in the baseline. Therefore, this option is removed from consideration for BART.

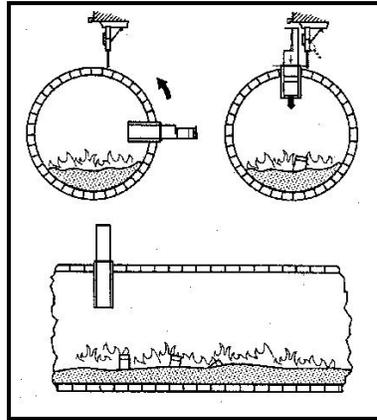
### **5.2.4 MID-KILN FIRING OF SOLID FUEL WITH MIXING AIR FAN**

Secondary combustion is defined as follows: a portion of the fuel is fired in a location other than the burning zone. This reduces thermal NO<sub>x</sub> generation because the temperature in the secondary combustion zone is less than 2100 °F. Mid-kiln firing (MKF) of solid fuels is an example of secondary combustion and includes fuels such as used tires, oil filter fluff, plastics, spent activated carbon and carbon black, asphalt shingles, diaper manufacturing waste, and other combustible solids. MKF improves clinker process energy efficiency, allows for greater operational flexibility with respect to fuel types, and is currently listed as a NO<sub>x</sub> control technology in 10 CSR 10-6.380 Control of NO<sub>x</sub> Emissions from Portland Cement Kilns.

An example of a MKF system is the Cadence feed form MKF technology which was first introduced in 1989. It is comprised of three primary components: (1) a staging arm or “feed fork,” that picks up the fuel modules and positions them for entry into the kiln, (2) two pivoting doors that open to allow the fuel to drop into the kiln, and (3) a drop tube that

extends through the side wall of the kiln. In addition to these basic components, feed fork technology also requires a delivery system which positions the fuel models so they can be picked up by the feed fork and a mechanism for opening the doors so the fuel can enter the kiln. Due to rotation of the kiln, fuel can only be injected once per revolution from the top, as shown in Figure 5-1.

**FIGURE 5-1. MID-KILN FIRING SCHEMATIC<sup>10</sup>**



High-pressure air, in the range of a 2-10 percent replacement of the primary combustion air, could be injected through the shell of the rotary kiln and into the calcining zone to where a mixing air fan mixes the air with the gas and fuel within the rotary kiln for more complete combustion of the solid fuel.

By adding fuel mid-kiln, MKF changes both the flame temperature and flame length. These changes should reduce thermal NO<sub>x</sub> formation by burning part of the fuel at a lower temperature and by creating reducing conditions at the mid-kiln fuel injection point which may destroy some of the NO<sub>x</sub> formed upstream in the kiln burning zone.

Clarksville has the largest long kiln in the world. The kiln has a 7 meter diameter and a very high thermal capacity. Using whole tires to replace 10% of total fuel consumption will require four whole tires being fed to the mid-kiln door per kiln revolution, 12% fuel replacement would require 5 tires per revolution. The maximum tire feed rate per revolution that Holcim is aware of, on similar applications, is three tires per revolution. Holcim is concerned that the greater the number of tires fed per revolution, on a continuous basis, the greater the potential for process upsets from unstable feeding. Holcim has found that kilns being fed even one to three tires per revolution can have problems with stable, uniform feeding. In addition, if too many tires burn at the bottom of the kiln, a high local temperature could result which would disturb the normal operation of the kiln and potentially increase NO<sub>x</sub>. Further, due to the large kiln diameter, the reducing zone created by burning tires may only impact a small cross section of the entire cross section of the kiln, thus having less of an overall reduction in NO<sub>x</sub> than anticipated.

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<sup>10</sup> NO<sub>x</sub> Control Technologies for the Cement Industry, EC/R Incorporated, Chapel Hill, NC, USA, U.S. EPA Contract NO. 68-D98-025, U.S. EPA RTP, September 19, 2000.

In an effort to better understand these uncertainties, Holcim hired CINAR Company, the expert in this field, to conduct modeling of the system and to predict NO<sub>x</sub> reduction. Their study predicted that a 15% NO<sub>x</sub> reduction would occur at 10% replacement (replace 10% of the current fuel with tires) and 27% NO<sub>x</sub> reduction for 15% replacement.

To then determine the thermal substitution rate (TSR) of tires that the Clarksville plant is capable of utilizing, three additional factors must be considered:

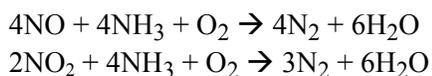
1. Tire availability. The local market only has sustainable resources of 10-12% TSR;
2. Tire feeding limit: 12% TSR equates to five tires being fed per revolution.
3. The thermal stability of operation in a large kiln. 15% TSR is predicted to be the maximum for short term periods, whereas 10-12% TSR is predicted to be achievable on a long term basis.

Based on the lack of experience using MKF of tires on kilns the size of Clarksville, Holcim is relying on the computer modeling (regardless of the general uncertainty that exists with computer models) to estimate the NO<sub>x</sub> reduction. Holcim anticipates that MKF of tires may achieve up to 20% percent NO<sub>x</sub> reduction at a TSR of 12 percent on a long term basis.

MKF is considered to be a technically feasible option for NO<sub>x</sub> control. Further, Holcim has already received a construction permit that would allow the installation of MKF, whereas other technologies would require a new construction permit application process, the result of which is unknown.

## **5.2.5 SELECTIVE NONCATALYTIC REDUCTION**

In the relatively narrow temperature window of 1600 to 1995°F, ammonia (NH<sub>3</sub>) reacts with NO<sub>x</sub> without the need for a catalyst to form water and molecular nitrogen in accordance with the following simplified reactions.



As applied to NO<sub>x</sub> control from cement kilns and other combustion sources, this technology is called selective noncatalytic reduction (SNCR). Above this temperature range, the NH<sub>3</sub> is oxidized to NO<sub>x</sub> thereby increasing NO<sub>x</sub> emissions. Below this temperature range, the reaction rate is too slow for completion and unreacted NH<sub>3</sub> may be emitted from the pyroprocess. This temperature window generally is available at some location within the rotary kiln. The NH<sub>3</sub> could be delivered to the kiln shell through the use of anhydrous NH<sub>3</sub>, or an aqueous solution of NH<sub>3</sub> (ammonium hydroxide) or urea.

A concern about application of SNCR technology is the breakthrough of unreacted NH<sub>3</sub> as “ammonia slip” and its subsequent reaction in the atmosphere with SO<sub>2</sub>, sulfur trioxide (SO<sub>3</sub>), hydrogen chloride (HCl) and/or chlorine (Cl<sub>2</sub>) to form a detached plume of sub-

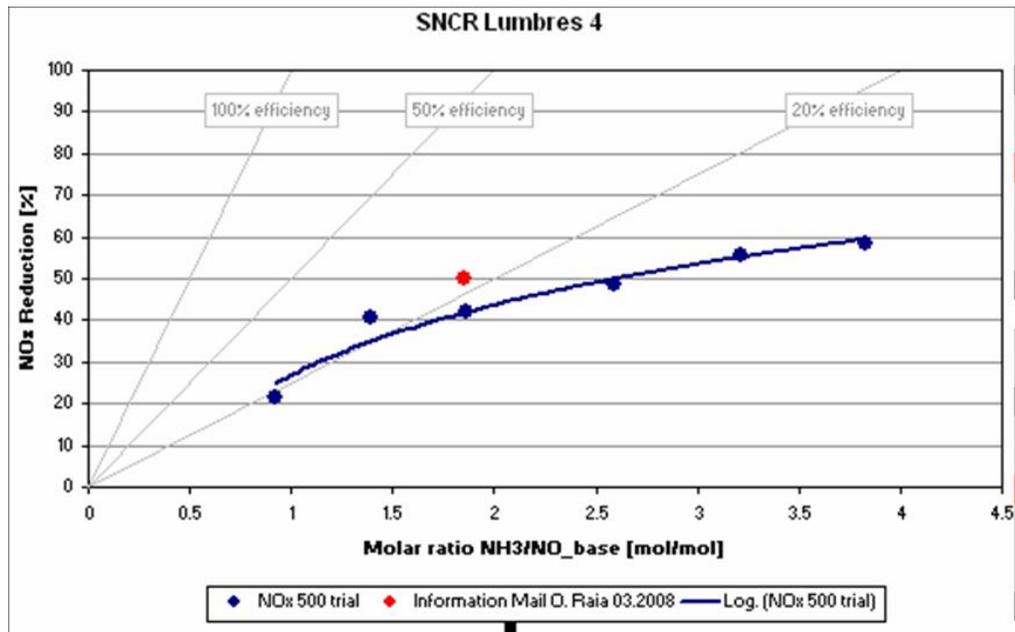
micron particles. As NH<sub>3</sub> or Urea injection rates are increased, to attempt to achieve higher levels of reduction, NH<sub>3</sub> emission levels are increased.

Industry Experience

Ash Grove Cement Company installed a full scale SNCR system on one of its wet kilns in Midlothian, Texas. Ash Grove has reported that it is achieving a 35 to 40% NO<sub>x</sub> reduction; however, as this application has just started, no data is available to verify this reduction is being achieved or on what averaging period or the long term sustainability.<sup>11</sup>

Holcim’s wet plant in Lumbres, France utilizes SNCR. It is the earliest application of SNCR on a long kiln in the world and has been running for multiple years. The plant has found that NH<sub>3</sub> slip increases as the urea injection rate increases especially when the molar ratio is more than 1.0 (i.e. the NH<sub>3</sub> added is more than needed for the reaction). At this level, significant amounts of NH<sub>3</sub> are unreacted. The plant reports achieving 20 percent NO<sub>x</sub> reduction at a 1.0 molar ratio of NH<sub>3</sub>/NO<sub>x</sub> and 40 percent at a molar ratio of 1.5 as shown in Figure 5-2.

**FIGURE 5-2. NO<sub>x</sub> REDUCTION VERSUS NH<sub>3</sub> MOLAR RATIO OBSERVED AT HOLCIM LUMBRES PLANT.**



However, at 20 percent NO<sub>x</sub> reduction, the NH<sub>3</sub> slip is reported to be 10 mg/m<sup>3</sup>, while at 40 percent reduction, the NH<sub>3</sub> slip can be 20 – 30 mg/m<sup>3</sup> (a 50 percent to 100 percent increase). Based on experiences at many cement plants with SO<sub>2</sub> and HCl in the exhaust gas, which is also the case for the Clarksville plant, a 20 mg/Nm<sup>3</sup> NH<sub>3</sub> increase would cause a severe increase in plume visibility. The Lumbres plant is also smaller than

<sup>11</sup> BART Five Factor Analysis. Ash Grove Cement Company Montana City, Montana. Dated June 2007. Page 5-9.

Clarksville, having a diameter of only 3.3 meters versus Clarksville's 7 meter diameter kiln. The larger diameter of Clarksville's kiln would make distribution of the reagent across the kiln more difficult, and would reduce the effectiveness to an unknown degree.

Based on the concerns with NH<sub>3</sub> slip at high molar ratios, and the uncertainty regarding the level of effectiveness of the reagent in Clarksville's large diameter kiln, Holcim anticipates that at a molar ratio of about 1.0, an average annual control efficiency of 20 percent could likely be achieved without excessive NH<sub>3</sub> slip. However, a pilot study would need to be conducted to verify this. Regardless, SNCR is considered to be a technically feasible option for NO<sub>x</sub> control.

### 5.2.6 SELECTIVE CATALYTIC REDUCTION

Selective Catalytic Reduction (SCR) is an add-on control technology for the control of emissions of the oxides of nitrogen (NO<sub>x</sub>) from a combustion process. SCR has been successfully employed in the electric power industry. The basic SCR system consists of a system of catalyst grids placed in series with each other within a vessel that is located in a part of the process where the normal flue gas temperature is in the required range. An ammonia-containing reagent is injected at a controlled rate upstream of the catalyst grids that are designed to ensure relatively even flue gas distribution within the grids, to provide good mixing of the reagent and flue gas, and to result in minimum ammonia (NH<sub>3</sub>) slip.<sup>12</sup> The NH<sub>3</sub> reacts with NO<sub>x</sub> compounds (i.e., NO and NO<sub>2</sub>) on the surface of the catalyst in equal molar amounts (i.e., one molecule of NH<sub>3</sub> reacts with one molecule of NO<sub>x</sub>). Common reagents include aqueous NH<sub>3</sub>, anhydrous NH<sub>3</sub> and urea [(NH<sub>2</sub>)<sub>2</sub>CO]. In the presence of the catalyst, the injected ammonia is converted by OH<sup>-</sup> radicals to ammonia radicals (i.e., NH<sub>2</sub><sup>-</sup>), which, in turn, react with NO<sub>x</sub> to form N<sub>2</sub> and H<sub>2</sub>O. The SCR catalyst enables the necessary reactions to occur at lower temperatures than those required for Selective Non-Catalytic Reduction (SNCR). While catalysts can be effective over a larger range of temperatures, the optimal temperature range for SCR is 570 - 750° F.

The catalyst system used in SCR applications usually consists of (1) a porous honeycomb of a ceramic substrate onto which catalyst has been attached to the surface of the ceramic material, or (2) a flat or corrugated plate onto which catalytic material has been deposited on the surface. A porous metal oxide with a high surface area-to-volume ratio acts as a catalyst base. On this base, typically titanium dioxide (TiO<sub>2</sub>), one or more metal oxide catalysts are deposited in various concentrations. In SCR applications, the active catalyst material typically consists of vanadium pentoxide (V<sub>2</sub>O<sub>5</sub>), tungsten trioxide (WO<sub>3</sub>), and molybdenum trioxide (MoO<sub>3</sub>) in various combinations. The composition, also known as the catalyst formulation, is tailored by the catalyst vendor to best suit a particular SCR application. Catalyst deactivation through poisoning, fouling, masking, sintering and erosion are common problems for SCR catalysts that, without careful process design and operation, could be exacerbated. If not fouled by sulfur dioxide (SO<sub>2</sub>), the catalysts used in SCR have a propensity to oxidize sulfur dioxide (SO<sub>2</sub>) in the flue gas to sulfur trioxide (SO<sub>3</sub>), a more undesirable pollutant.

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<sup>12</sup> Slip refers to the quantity of unreacted reagent that exits the SCR reactor.

Because the reaction rate of  $\text{NH}_3$  and  $\text{NO}_x$  is temperature dependent, the temperature of the flue gas stream to be controlled is the most important consideration in applying SCR technology to any combustion source. The optimum temperature range for SCR application is about  $300^\circ\text{C}$  ( $570^\circ\text{F}$ ) to  $450^\circ\text{C}$  ( $840^\circ\text{F}$ ). This range of normal process temperature would occur within the kiln of a long wet kiln, rather than in the exhaust gas between the wet kiln and the PMCD inlet.

SCR has not been applied to any wet cement plant in the world and is not considered an available technology.

As explained in more detail below, a technology is considered "available" if it can be obtained by the applicant through commercial channels or is otherwise available within the common sense meaning of the term. An available technology is "applicable" if it can reasonably be installed and operated on the source type under consideration. A technology that is available and applicable is technically feasible. Availability in this context is further explained using the following process commonly used for bringing a control technology concept to reality as a commercial product: concept stage; research and patenting; bench scale or laboratory testing; pilot scale testing; licensing and commercial demonstration; and Commercial sales.

A control technique is considered available, within the context presented above, if it has reached the licensing and commercial sales stage of development. A source would not be required to experience extended time delays or resource penalties to allow research to be conducted on a new technique. Neither is it expected that an applicant would be required to experience extended trials to learn how to apply a technology on a totally new and dissimilar source type. Consequently, technologies in the pilot scale testing stages of development would not be considered available. An exception would be if the technology were proposed and permitted under the qualifications of an innovative control device consistent with the provisions of 40 CFR 52.21(v) or, where appropriate, the applicable SIP [in which case it would be considered available].

Therefore, SCR is eliminated from further consideration as BART for  $\text{NO}_x$  control at the Clarksville plant.

### **5.3 RANK OF TECHNICALLY FEASIBLE $\text{NO}_x$ CONTROL OPTIONS BY EFFECTIVENESS**

The third step in the BART analysis is to rank the technically feasible options according to effectiveness. Table 5-3 presents potential  $\text{NO}_x$  technically feasible control technologies by effectiveness.

**TABLE 5-3. RANKING OF TECHNICALLY FEASIBLE KILN NO<sub>x</sub> CONTROL TECHNOLOGIES BY EFFECTIVENESS**

Control Technology	Effectiveness NO <sub>x</sub> Emissions Level (%)
MKF	20%
SNCR	20%
LNB, CKD Insufflation, and Synfuel	Already utilized at Clarksville

### 5.4 EVALUATION OF IMPACTS FOR FEASIBLE NO<sub>x</sub> CONTROLS

Step four for the BART analysis procedure is the impact analysis. The BART determination guidelines list four factors to be considered in the impact analysis:

- Cost of compliance
- Energy impacts
- Non-air quality impacts; and
- The remaining useful life of the source

#### 5.4.1 MKF

##### Cost of Compliance

Holcim anticipates that MKF and SNCR have relatively the same level of effectiveness. Because SNCR would require a pilot study to prove or verify the effectiveness of NO<sub>x</sub> reduction, Holcim is accepting the use of MKF as BART. As Holcim is accepting the most stringent control option available as BART, the cost of compliance is not required to be evaluated.

##### Energy Impacts and Non Air-Quality Impacts

There are no known adverse energy or non-air impacts from MKF. MKF of tires has the benefit of eliminating tires from landfills and illegal dumping. It also reduces CO<sub>2</sub> emissions (a Green House Gas) and reduces fossil fuel use.

##### Remaining Useful Life

The remaining useful life of the kiln does not impact the annualized costs of MKF because the useful life is anticipated to be at least as long as the capital cost recovery period, which would be 15 years.

### 5.5 EVALUATION OF VISIBILITY IMPACT OF FEASIBLE NO<sub>x</sub> CONTROLS

The final impact analysis was conducted to assess the visibility improvement for existing emission rates when compared to the emission rate with MKF. The existing emission rates and emission rates associated with MKF were modeled using CALPUFF. The existing emission rates are the same rates that were modeled for the BART applicability analysis. The NO<sub>x</sub> emission rate associated with MKF

was the existing emission rate less an average reduction of 20 percent. The emission rate is summarized in Table 5-4.

**TABLE 5-4. SUMMARY OF EMISSION RATES MODELED IN NO<sub>x</sub> CONTROL VISIBILITY IMPACT ANALYSIS**

Emission Rate Scenario	Emission Rate		
	SO <sub>2</sub> (lb/hr)	NO <sub>x</sub> (lb/hr)	PM <sub>10</sub> (lb/hr)
MKF,	4,889	2,440	51.82
Base case – High 24 hr average	4,889	3,049	51.82

Comparisons of the 98<sup>th</sup> percentile existing visibility impacts and the visibility impacts based on MKF are provided in Table 5-5. The visibility improvement associated with MKF are also shown in Table 5-5; this was calculated as the difference between the existing visibility impairment and the visibility impairment for the remaining control options as measured by the 98<sup>th</sup> percentile modeled visibility impact.

**TABLE 5-5. NO<sub>x</sub> CONTROL VISIBILITY IMPACT ANALYSIS**

	Existing	MKF	Improvement
	98% Impact (Δdv)	98% Impact (Δdv)	
Mingo	1.01	0.92	8.9%
Hercules	0.81	0.72	11.1%
Upper Buffalo	0.61	0.60	1.6%

As seen in Tables 5-5, the MKF option results in a visibility improvement of up to 11.1 percent in the Hercules Glades Class I area.

## 5.6 PROPOSED BART FOR NO<sub>x</sub>

Based on the five step analysis outlined by EPA, MKF was identified as the highest ranking feasible add-on control technology. Energy and environmental impacts were assessed for this technology and the visibility improvements were evaluated against existing conditions. Consistent with EPA guidance, economic impacts were not assessed as Holcim was willing to utilize the highest ranked control technology. The visibility impact analysis demonstrates that the utilization of MKF to achieve a 2,440 lb/hr NO<sub>x</sub> emission rate results in up to an 11.1 percent visibility improvement. Neither non-air quality nor energy impacts associated with this control technology eliminate it in favor of retaining the existing rates as BART.

Holcim has determined that BART for the facility is MKF. Based on the lack of site specific, or significant industry data, for the use of this technology on wet cement kilns, it is possible that Holcim will further evaluate the MKF system and determine that MKF results in limited or no additional benefit. In the future, an alternative technology or methodology may become feasible and could be implemented as needed. Holcim will continue to utilize the NO<sub>x</sub> controls that are already in place, including LNB, insufflation, and the use of alternative fuels as available.

## **Appendix A. Control Cost Tables**



Table A-1. Wet Limestone Scrubber Control Cost Analysis Based on Projected Actual Emissions and 80% Control.

<b>Direct Costs</b>		
<b>Purchased Equipment Costs</b>		
Wet Scrubber Unit including Limestone Prep System		\$10,524,352
Instrumentation (15% of EC)		\$1,578,653
Sales Tax (5% of EC)		\$526,218
Freight (5% of EC)		\$526,218
	Subtotal, Purchased Equipment Cost (PEC)	\$13,155,441
<b>Direct Installation Costs</b>		
Foundation (10% of PEC)		\$1,315,544
Supports (10% of PEC)		\$1,315,544
Handling and Erection (50% of PEC)		\$6,577,720
Electrical (10% of PEC)		\$1,315,544
Piping (30% of PEC)		\$3,946,632
Extending gas line 1/2 mile to plant		\$500,000
Insulation for Ductwork (5% of PEC)		\$657,772
Painting (1% of PEC)		\$131,554
	Subtotal, Direct Installation Cost	\$15,760,311
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$28,915,752</b>
<b>Indirect Costs</b>		
Engineering (10% of PEC)		\$1,315,544
Construction and Field Expense (15% of PEC)		\$1,973,316
Contractor Fees (10% of PEC)		\$1,315,544
Start-up (1% of PEC)		\$131,554
Performance Test (1% of PEC)		\$131,554
Contingencies (5% of PEC)		\$657,772
	<b>Total Indirect Cost</b>	<b>\$5,525,285</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$34,441,037</b>
<b>Direct Annual Costs</b>		
Hours per Year	(365 days per year, 24 hours per day), 90% Uptime	7,884
<b>Operating Labor</b>		
Operator (8 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$1,073,280
Supervisor (15% of operator)		\$160,992
	Subtotal, Operating Labor	\$1,234,272
<b>Maintenance</b>		
Labor (6 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$804,960
Material (5% of Total Direct Cost)		\$1,445,788
	Subtotal, Maintenance	\$2,250,748
<b>Utilities</b>		
<b>Electricity</b>		
Pump (kW)		2,342
Cost (\$/kW-hr)		\$0.0410
	Subtotal, Electricity	\$757,054
<b>Limestone for slurry</b>		
Amount Required (ton/yr)		13,961
Cost (\$/ton)		\$3.00
	Subtotal, Lime	\$41,883
<b>Water</b>		
Amount Required (gpm)		122.0
Cost (\$/1000 gallons)		\$1.00
	Subtotal, Water	\$64,128
<b>Sludge Disposal</b>		
Amount Generated (tpy)		57,943
Disposal Fee (\$/ton)		\$36.00
Monthly Rent for Trailer @ \$120/month		\$1,440
Cost for Box Transportation @ \$220/load (assume 17 tons/trailer)		\$749,853
	Subtotal, Sludge	\$2,837,247
	Subtotal, Utilities	\$3,700,312
<b>Natural Gas Reheat (assuming a 210 deg F temp drop and reheat)</b>		
Gas Required (MMCF/yr)		1,020,986
Cost (\$/MMBTU)		\$10.06
	Subtotal, Natural Gas	\$10,271,123
	<b>Total Direct Annual Costs</b>	<b>\$17,456,454</b>
<b>Indirect Annual Costs</b>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$2,091,012
Administrative (2% TCI)		\$688,821
Property Tax (1% TCI)		\$344,410
Insurance (1% TCI)		\$344,410
Capital Recovery (15 year life, 7 percent interest)		\$3,781,441
	<b>Total Indirect Annual Cost</b>	<b>\$7,250,094</b>
<b>Conclusion</b>		
<b>Total Annualized Cost</b>		<b>\$24,706,548</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>11,481</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 80%, 95% uptime</b>		<b>8,726</b>
<b>Pollutant Generated - NOx tons/yr</b>		<b>97</b>
<b>Net Pollutant Removed - tons/yr</b>		<b>8,629</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$2,863</b>

Table A-2. Wet Limestone Scrubber Control Cost Analysis Based on Projected Actual Emissions and 95% Control.

<b>Direct Costs</b>		
<b>Purchased Equipment Costs</b>		
Wet Scrubber Unit including Limestone Prep System		\$10,524,352
Instrumentation (15% of EC)		\$1,578,653
Sales Tax (5% of EC)		\$526,218
Freight (5% of EC)		\$526,218
	Subtotal, Purchased Equipment Cost (PEC)	\$13,155,441
<b>Direct Installation Costs</b>		
Foundation (10% of PEC)		\$1,315,544
Supports (10% of PEC)		\$1,315,544
Handling and Erection (50% of PEC)		\$6,577,720
Electrical (10% of PEC)		\$1,315,544
Piping (30% of PEC)		\$3,946,632
Extending gas line 1/2 mile to plant		\$500,000
Insulation for Ductwork (5% of PEC)		\$657,772
Painting (1% of PEC)		\$131,554
	Subtotal, Direct Installation Cost	\$15,760,311
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$28,915,752</b>
<b>Indirect Costs</b>		
Engineering (10% of PEC)		\$1,315,544
Construction and Field Expense (15% of PEC)		\$1,973,316
Contractor Fees (10% of PEC)		\$1,315,544
Start-up (1% of PEC)		\$131,554
Performance Test (1% of PEC)		\$131,554
Contingencies (5% of PEC)		\$657,772
	<b>Total Indirect Cost</b>	<b>\$5,525,285</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$34,441,037</b>
<b>Direct Annual Costs</b>		
Hours per Year	(365 days per year, 24 hours per day), 90% Uptime	7,884
<b>Operating Labor</b>		
Operator (8 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$1,073,280
Supervisor (15% of operator)		\$160,992
	Subtotal, Operating Labor	\$1,234,272
<b>Maintenance</b>		
Labor (6 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$804,960
Material (5% of Total Direct Cost)		\$1,445,788
	Subtotal, Maintenance	\$2,250,748
<b>Utilities</b>		
<b>Electricity</b>		
Pump (kW)		2,342
Cost (\$/kW-hr)		\$0.0410
	Subtotal, Electricity	\$757,054
<b>Limestone for slurry</b>		
Amount Required (ton/yr)		16,579
Cost (\$/ton)		\$3.00
	Subtotal, Lime	\$49,736
<b>Water</b>		
Amount Required (gpm)		122.0
Cost (\$/1000 gallons)		\$1.00
	Subtotal, Water	\$64,128
<b>Sludge Disposal</b>		
Amount Generated (tpy)		68,808
Disposal Fee (\$/ton)		\$36.00
Monthly Rent for Trailer @ \$120/month		\$1,440
Cost for Box Transportation @ \$220/load (assume 17 tons/trailer)		\$890,450
	Subtotal, Sludge	\$3,368,961
	Subtotal, Utilities	\$4,239,878
<b>Natural Gas Reheat (assuming a 210 deg F temp drop and reheat)</b>		
Gas Required (MMCF/yr)		1,020,986
Cost (\$/MMBTU)		\$10.06
	Subtotal, Natural Gas	\$10,271,123
	<b>Total Direct Annual Costs</b>	<b>\$17,996,021</b>
<b>Indirect Annual Costs</b>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$2,091,012
Administrative (2% TCI)		\$688,821
Property Tax (1% TCI)		\$344,410
Insurance (1% TCI)		\$344,410
Capital Recovery (15 year life, 7 percent interest)		\$3,781,441
	<b>Total Indirect Annual Cost</b>	<b>\$7,250,094</b>
<b>Conclusion</b>		
<b>Total Annualized Cost</b>		<b>\$25,246,115</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>11,481</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 95%, 95% uptime</b>		<b>10,362</b>
<b>Pollutant Generated - NOx tons/yr</b>		<b>97</b>
<b>Net Pollutant Removed - tons/yr</b>		<b>10,265</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$2,460</b>

Table A-3. Wet Limestone Scrubber Control Cost Analysis Based on PTE and 80% Control

<b>Direct Costs</b>		
<b>Purchased Equipment Costs</b>		
Wet Scrubber Unit including Limestone Prep System		\$10,524,352
Instrumentation (15% of EC)		\$1,578,653
Sales Tax (5% of EC)		\$526,218
Freight (5% of EC)		\$526,218
	Subtotal, Purchased Equipment Cost (PEC)	\$13,155,441
<b>Direct Installation Costs</b>		
Foundation (10% of PEC)		\$1,315,544
Supports (10% of PEC)		\$1,315,544
Handling and Erection (50% of PEC)		\$6,577,720
Electrical (10% of PEC)		\$1,315,544
Piping (30% of PEC)		\$3,946,632
Extending gas line 1/2 mile to plant		\$500,000
Insulation for Ductwork (5% of PEC)		\$657,772
Painting (1% of PEC)		\$131,554
	Subtotal, Direct Installation Cost	\$15,760,311
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$28,915,752</b>
<b>Indirect Costs</b>		
Engineering (10% of PEC)		\$1,315,544
Construction and Field Expense (15% of PEC)		\$1,973,316
Contractor Fees (10% of PEC)		\$1,315,544
Start-up (1% of PEC)		\$131,554
Performance Test (1% of PEC)		\$131,554
Contingencies (5% of PEC)		\$657,772
	<b>Total Indirect Cost</b>	<b>\$5,525,285</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$34,441,037</b>
<b>Direct Annual Costs</b>		
Hours per Year	(365 days per year, 24 hours per day), 90% Uptime	7,884
<b>Operating Labor</b>		
Operator (8 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$1,073,280
Supervisor (15% of operator)		\$160,992
	Subtotal, Operating Labor	\$1,234,272
<b>Maintenance</b>		
Labor (6 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$804,960
Material (5% of Total Direct Cost)		\$1,445,788
	Subtotal, Maintenance	\$2,250,748
<b>Utilities</b>		
<b>Electricity</b>		
Pump (kW)		2,342
Cost (\$/kW-hr)		\$0.0410
	Subtotal, Electricity	\$757,054
<b>Limestone for slurry</b>		
Amount Required (ton/yr)		16,170
Cost (\$/ton)		\$3.00
	Subtotal, Lime	\$48,511
<b>Water</b>		
Amount Required (gpm)		122.0
Cost (\$/1000 gallons)		\$1.00
	Subtotal, Water	\$64,128
<b>Sludge Disposal</b>		
Amount Generated (tpy)		67,113
Disposal Fee (\$/ton)		\$36.00
Monthly Rent for Trailer @ \$120/month		\$1,440
Cost for Box Transportation @ \$220/load (assume 17 tons/trailer)		\$868,526
	Subtotal, Sludge	\$3,286,046
	Subtotal, Utilities	\$4,155,739
<b>Natural Gas Reheat (assuming a 210 deg F temp drop and reheat)</b>		
Gas Required (MMCF/yr)		1,020,986
Cost (\$/MMBTU)		\$10.06
	Subtotal, Natural Gas	\$10,271,123
	<b>Total Direct Annual Costs</b>	<b>\$17,911,881</b>
<b>Indirect Annual Costs</b>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$2,091,012
Administrative (2% TCI)		\$688,821
Property Tax (1% TCI)		\$344,410
Insurance (1% TCI)		\$344,410
Capital Recovery (15 year life, 7 percent interest)		\$3,781,441
	<b>Total Indirect Annual Cost</b>	<b>\$7,250,094</b>
<b>Conclusion</b>		
<b>Total Annualized Cost</b>		<b>\$25,161,975</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr) - PTE</b>		<b>13,298</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 80%, 95% uptime</b>		<b>10,106</b>
<b>Pollutant Generated - NOx tons/yr</b>		<b>97</b>
<b>Net Pollutant Removed - tons/yr</b>		<b>10,009</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$2,514</b>

Table A-4. Wet Limestone Scrubber Control Cost Analysis Based on PTE and 95% Control

<b>Direct Costs</b>		
<b>Purchased Equipment Costs</b>		
Wet Scrubber Unit including Limestone Prep System		\$10,524,352
Instrumentation (15% of EC)		\$1,578,653
Sales Tax (5% of EC)		\$526,218
Freight (5% of EC)		\$526,218
	Subtotal, Purchased Equipment Cost (PEC)	\$13,155,441
<b>Direct Installation Costs</b>		
Foundation (10% of PEC)		\$1,315,544
Supports (10% of PEC)		\$1,315,544
Handling and Erection (50% of PEC)		\$6,577,720
Electrical (10% of PEC)		\$1,315,544
Piping (30% of PEC)		\$3,946,632
Extending gas line 1/2 mile to plant		\$500,000
Insulation for Ductwork (5% of PEC)		\$657,772
Painting (1% of PEC)		\$131,554
	Subtotal, Direct Installation Cost	\$15,760,311
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$28,915,752</b>
<b>Indirect Costs</b>		
Engineering (10% of PEC)		\$1,315,544
Construction and Field Expense (15% of PEC)		\$1,973,316
Contractor Fees (10% of PEC)		\$1,315,544
Start-up (1% of PEC)		\$131,554
Performance Test (1% of PEC)		\$131,554
Contingencies (5% of PEC)		\$657,772
	<b>Total Indirect Cost</b>	<b>\$5,525,285</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$34,441,037</b>
<b>Direct Annual Costs</b>		
Hours per Year	(365 days per year, 24 hours per day), 90% Uptime	7,884
<b>Operating Labor</b>		
Operator (8 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$1,073,280
Supervisor (15% of operator)		\$160,992
	Subtotal, Operating Labor	\$1,234,272
<b>Maintenance</b>		
Labor (6 men/yr, 2,080 hrs/yr, \$64.50/hr)		\$804,960
Material (5% of Total Direct Cost)		\$1,445,788
	Subtotal, Maintenance	\$2,250,748
<b>Utilities</b>		
<b>Electricity</b>		
Pump (kW)		2,342
Cost (\$/kW-hr)		\$0.0410
	Subtotal, Electricity	\$757,054
<b>Limestone for slurry</b>		
Amount Required (ton/yr)		19,202
Cost (\$/ton)		\$3.00
	Subtotal, Lime	\$57,607
<b>Water</b>		
Amount Required (gpm)		122.0
Cost (\$/1000 gallons)		\$1.00
	Subtotal, Water	\$64,128
<b>Sludge Disposal</b>		
Amount Generated (tpy)		79,697
Disposal Fee (\$/ton)		\$36.00
Monthly Rent for Trailer @ \$120/month		\$1,440
Cost for Box Transportation @ \$220/load (assume 17 tons/trailer)		\$1,031,374
	Subtotal, Sludge	\$3,901,910
	Subtotal, Utilities	\$4,780,698
<b>Natural Gas Reheat (assuming a 210 deg F temp drop and reheat)</b>		
Gas Required (MMCF/yr)		1,020,986
Cost (\$/MMBTU)		\$10.06
	Subtotal, Natural Gas	\$10,271,123
	<b>Total Direct Annual Costs</b>	<b>\$18,536,841</b>
<b>Indirect Annual Costs</b>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$2,091,012
Administrative (2% TCI)		\$688,821
Property Tax (1% TCI)		\$344,410
Insurance (1% TCI)		\$344,410
Capital Recovery (15 year life, 7 percent interest)		\$3,781,441
	<b>Total Indirect Annual Cost</b>	<b>\$7,250,094</b>
<b>Conclusion</b>		
<b>Total Annualized Cost</b>		<b>\$25,786,935</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr) - PTE</b>		<b>13,298</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 95%, 95% uptime</b>		<b>12,001</b>
<b>Pollutant Generated - NOx tons/yr</b>		<b>97</b>
<b>Net Pollutant Removed - tons/yr</b>		<b>11,904</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$2,166</b>

Table A-5. Fuel Substitution Control Cost Analysis Based on Projected Actual Emissions and 40% Control .

<b>Direct Costs</b>	
<b>Purchased Equipment Costs</b>	
New Coal Mill and associated equipment	\$3,864,000
Instrumentation (15% of EC)	\$579,600
Sales Tax (5% of EC)	\$193,200
Freight (5% of EC)	\$193,200
Subtotal, Purchased Equipment Cost (PEC)	\$4,830,000
<b>Direct Installation Costs</b>	
Foundation (10% of PEC)	\$483,000
Supports (10% of PEC)	\$483,000
Handling and Erection (50% of PEC)	\$2,415,000
Electrical (10% of PEC)	\$483,000
Piping (30% of PEC)	\$1,449,000
Insulation for Ductwork (5% of PEC)	\$9,660
Painting (1% of PEC)	\$48,300
Subtotal, Direct Installation Cost	\$5,370,960
Site Preparation	N/A
Buildings	N/A
<b>Total Direct Cost</b>	<b>\$10,200,960</b>
<b>Indirect Costs</b>	
Engineering (10% of PEC)	\$483,000
Construction and Field Expense (15% of PEC)	\$724,500
Contractor Fees (10% of PEC)	\$483,000
Start-up (1% of PEC)	\$48,300
Performance Test (1% of PEC)	\$48,300
Contingencies (5% of PEC)	\$241,500
<b>Total Indirect Cost</b>	<b>\$2,028,600</b>
<b>Total Capital Investment (TCI)</b>	<b>\$12,229,560</b>
<b>Direct Annual Costs</b>	
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage by the ratio of maximum annual clinker production (1,215,708 tons) to 2007 actual clinker production (1,035,283 tons))</b>	
Reduction in coke usage (metric ton/yr)	188,959
Heat Value (Gj / Mt)	32.510
Heat (Gj / yr)	6,143,045
Cost (\$/Gj)	\$1.74
Subtotal, reduction in coke cost	-\$10,688,898
Reduction in coal usage (metric ton/yr)	11,076
Heat Value (Gj / Mt)	22.177
Heat (Gj / yr)	245,627
Cost (\$/Gj)	\$2.41
Subtotal, reduction in coal cost	-\$591,962
Increase in low sulfur coal usage - Amount Required (metric ton/yr)	244,891
Heat Value (Gj / Mt)	26.266
Heat (Gj / yr)	6,432,296
Cost (\$/Gj)	\$5.67
Subtotal, increase in Low Sulfur Coal cost	\$36,471,116
<b>Total Direct Annual Cost (increase)</b>	<b>\$25,190,256</b>
<b>Indirect Annual Costs</b>	
Administrative (2% TCI)	\$244,591
Property Tax (1% TCI)	\$122,296
Insurance (1% TCI)	\$122,296
Capital Recovery (15 year life, 7 percent interest)	\$1,342,740
<b>Total Indirect Annual Cost</b>	<b>\$1,831,922</b>
<b>Conclusion</b>	
<b>Total Annualized Cost</b>	<b>\$27,022,178</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>	<b>11,481</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 40%</b>	<b>4,592</b>
<b>Cost Per Ton of Pollutant Removed</b>	<b>\$5,884</b>

Table A-6. Fuel Substitution Control Cost Analysis Based on Projected Actual Emissions and 50% Control .

<b>Direct Costs</b>	
<b>Purchased Equipment Costs</b>	
New Coal Mill and associated equipment	\$3,864,000
Instrumentation (15% of EC)	\$579,600
Sales Tax (5% of EC)	\$193,200
Freight (5% of EC)	\$193,200
Subtotal, Purchased Equipment Cost (PEC)	\$4,830,000
<b>Direct Installation Costs</b>	
Foundation (10% of PEC)	\$483,000
Supports (10% of PEC)	\$483,000
Handling and Erection (50% of PEC)	\$2,415,000
Electrical (10% of PEC)	\$483,000
Piping (30% of PEC)	\$1,449,000
Insulation for Ductwork (5% of PEC)	\$9,660
Painting (1% of PEC)	\$48,300
Subtotal, Direct Installation Cost	\$5,370,960
Site Preparation	N/A
Buildings	N/A
<b>Total Direct Cost</b>	<b>\$10,200,960</b>
<b>Indirect Costs</b>	
Engineering (10% of PEC)	\$483,000
Construction and Field Expense (15% of PEC)	\$724,500
Contractor Fees (10% of PEC)	\$483,000
Start-up (1% of PEC)	\$48,300
Performance Test (1% of PEC)	\$48,300
Contingencies (5% of PEC)	\$241,500
<b>Total Indirect Cost</b>	<b>\$2,028,600</b>
<b>Total Capital Investment (TCI)</b>	<b>\$12,229,560</b>
<b>Direct Annual Costs</b>	
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage by the ratio of maximum annual clinker production (1,215,708 tons) to 2007 actual clinker production (1,035,283 tons))</b>	
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage to maximum actual production levels)</b>	
Reduction in coke usage (metric ton/yr)	188,959
Heat Value (Gj / Mt)	32.510
Heat (Gj / yr)	6,143,045
Cost (\$/Gj)	\$1.74
Subtotal, reduction in coke cost	-\$10,688,898
Reduction in coal usage (metric ton/yr)	11,076
Heat Value (Gj / Mt)	22.177
Heat (Gj / yr)	245,627
Cost (\$/Gj)	\$2.41
Subtotal, reduction in coal cost	-\$591,962
Increase in low sulfur coal usage - Amount Required (metric ton/yr)	244,891
Heat Value (Gj / Mt)	26.266
Heat (Gj / yr)	6,432,296
Cost (\$/Gj)	\$5.67
Subtotal, increase in Low Sulfur Coal cost	\$36,471,116
<b>Total Direct Annual Cost (increase)</b>	<b>\$25,190,256</b>
<b>Indirect Annual Costs</b>	
Administrative (2% TCI)	\$244,591
Property Tax (1% TCI)	\$122,296
Insurance (1% TCI)	\$122,296
Capital Recovery (15 year life, 7 percent interest)	\$1,342,740
<b>Total Indirect Annual Cost</b>	<b>\$1,831,922</b>
<b>Conclusion</b>	
<b>Total Annualized Cost</b>	<b>\$27,022,178</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>	<b>11,481</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 50%</b>	<b>5,741</b>
<b>Cost Per Ton of Pollutant Removed</b>	<b>\$4,707</b>

Table A-7. Fuel Substitution Control Cost Analysis Based on PTE and 40% Control.

<b>Direct Costs</b>		
<b>Purchased Equipment Costs</b>		
New Coal Mill and associated equipment		\$3,864,000
Instrumentation (15% of EC)		\$579,600
Sales Tax (5% of EC)		\$193,200
Freight (5% of EC)		\$193,200
	Subtotal, Purchased Equipment Cost (PEC)	\$4,830,000
<b>Direct Installation Costs</b>		
Foundation (10% of PEC)		\$483,000
Supports (10% of PEC)		\$483,000
Handling and Erection (50% of PEC)		\$2,415,000
Electrical (10% of PEC)		\$483,000
Piping (30% of PEC)		\$1,449,000
Insulation for Ductwork (5% of PEC)		\$9,660
Painting (1% of PEC)		\$48,300
	Subtotal, Direct Installation Cost	\$5,370,960
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$10,200,960</b>
<b>Indirect Costs</b>		
Engineering (10% of PEC)		\$483,000
Construction and Field Expense (15% of PEC)		\$724,500
Contractor Fees (10% of PEC)		\$483,000
Start-up (1% of PEC)		\$48,300
Performance Test (1% of PEC)		\$48,300
Contingencies (5% of PEC)		\$241,500
	<b>Total Indirect Cost</b>	<b>\$2,028,600</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$12,229,560</b>
<b>Direct Annual Costs</b>		
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage by the ratio of maximum annual clinker production (1,215,708 tons) to 2007 actual clinker production (1,035,283 tons))</b>		
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage to maximum actual production levels)</b>		
Reduction in coke usage (metric ton/yr)		188,959
Heat Value (Gj / Mt)		32.510
Heat (Gj / yr)		6,143,045
Cost (\$/Gj)		\$1.74
	Subtotal, reduction in coke cost	-\$10,688,898
Reduction in coal usage (metric ton/yr)		11,076
Heat Value (Gj / Mt)		22.177
Heat (Gj / yr)		245,627
Cost (\$/Gj)		\$2.41
	Subtotal, reduction in coal cost	-\$591,962
Increase in low sulfur coal usage - Amount Required (metric ton/yr)		244,891
Heat Value (Gj / Mt)		26.266
Heat (Gj / yr)		6,432,296
Cost (\$/Gj)		\$5.67
	Subtotal, increase in Low Sulfur Coal cost	\$36,471,116
	<b>Total Direct Annual Cost (increase)</b>	<b>\$25,190,256</b>
<b>Indirect Annual Costs</b>		
Administrative (2% TCI)		\$244,591
Property Tax (1% TCI)		\$122,296
Insurance (1% TCI)		\$122,296
Capital Recovery (15 year life, 7 percent interest)		\$1,342,740
	<b>Total Indirect Annual Cost</b>	<b>\$1,831,922</b>
<b>Conclusion</b>		
<b>Total Annualized Cost</b>		<b>\$27,022,178</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>13,298</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 40%</b>		<b>5,319</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$5,080</b>

Table A-8. Fuel Substitution Control Cost Analysis Based on PTE and 50% Control.

<b>Direct Costs</b>		
<b>Purchased Equipment Costs</b>		
New Coal Mill and associated equipment		\$3,864,000
Instrumentation (15% of EC)		\$579,600
Sales Tax (5% of EC)		\$193,200
Freight (5% of EC)		\$193,200
	Subtotal, Purchased Equipment Cost (PEC)	\$4,830,000
<b>Direct Installation Costs</b>		
Foundation (10% of PEC)		\$483,000
Supports (10% of PEC)		\$483,000
Handling and Erection (50% of PEC)		\$2,415,000
Electrical (10% of PEC)		\$483,000
Piping (30% of PEC)		\$1,449,000
Insulation for Ductwork (5% of PEC)		\$9,660
Painting (1% of PEC)		\$48,300
	Subtotal, Direct Installation Cost	\$5,370,960
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$10,200,960</b>
<b>Indirect Costs</b>		
Engineering (10% of PEC)		\$483,000
Construction and Field Expense (15% of PEC)		\$724,500
Contractor Fees (10% of PEC)		\$483,000
Start-up (1% of PEC)		\$48,300
Performance Test (1% of PEC)		\$48,300
Contingencies (5% of PEC)		\$241,500
	<b>Total Indirect Cost</b>	<b>\$2,028,600</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$12,229,560</b>
<b>Direct Annual Costs</b>		
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage by the ratio of maximum annual clinker production (1,215,708 tons) to 2007 actual clinker production (1,035,283 tons))</b>		
<b>Increased Fuel Cost (calculated by scaling 2007 annual average fuel usage to maximum actual production levels)</b>		
Reduction in coke usage (metric ton/yr)		188,959
Heat Value (Gj / Mt)		32.510
Heat (Gj / yr)		6,143,045
Cost (\$/Gj)		\$1.74
	Subtotal, reduction in coke cost	-\$10,688,898
Reduction in coal usage (metric ton/yr)		11,076
Heat Value (Gj / Mt)		22.177
Heat (Gj / yr)		245,627
Cost (\$/Gj)		\$2.41
	Subtotal, reduction in coal cost	-\$591,962
Increase in low sulfur coal usage - Amount Required (metric ton/yr)		244,891
Heat Value (Gj / Mt)		26.266
Heat (Gj / yr)		6,432,296
Cost (\$/Gj)		\$5.67
	Subtotal, increase in Low Sulfur Coal cost	\$36,471,116
	<b>Total Direct Annual Cost (increase)</b>	<b>\$25,190,256</b>
<b>Indirect Annual Costs</b>		
Administrative (2% TCI)		\$244,591
Property Tax (1% TCI)		\$122,296
Insurance (1% TCI)		\$122,296
Capital Recovery (15 year life, 7 percent interest)		\$1,342,740
	<b>Total Indirect Annual Cost</b>	<b>\$1,831,922</b>
<b>Conclusion</b>		
<b>Total Annualized Cost</b>		<b>\$27,022,178</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>13,298</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 50%</b>		<b>6,649</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$4,064</b>

Table A-9. Dry Lime Scrubbing - Control Cost Analysis Based on Projected Actual Emissions and 20% Control.

<b>Direct Costs</b>		
<u>Purchased Equipment Costs</u>		
Dry Lime Injection System		\$1,000,000
Retrofit ESPs with Baghouse		\$3,000,000
Total Equipment Cost		\$4,000,000
Instrumentation (15% of EC)		\$600,000
Sales Tax (5% of EC)		\$200,000
Freight (5% of EC)		\$200,000
	Subtotal, Purchased Equipment Cost (PEC)	\$5,000,000
<u>Direct Installation Costs</u>		
Foundation (10% of PEC)		\$500,000
Supports (10% of PEC)		\$500,000
Handling and Erection (50% of PEC)		\$2,500,000
Electrical (10% of PEC)		\$500,000
Piping (30% of PEC)		\$1,500,000
Insulation for Ductwork (5% of PEC)		\$10,000
Painting (1% of PEC)		\$50,000
	Subtotal, Direct Installation Cost	\$5,560,000
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$10,560,000</b>
<u>Indirect Costs</u>		
Engineering (10% of PEC)		\$500,000
Construction and Field Expense (15% of PEC)		\$750,000
Contractor Fees (10% of PEC)		\$500,000
Start-up (1% of PEC)		\$50,000
Performance Test (1% of PEC)		\$50,000
Contingencies (5% of PEC)		\$250,000
	<b>Total Indirect Cost</b>	<b>\$2,100,000</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$12,660,000</b>
<u>Direct Annual Costs</u>		
<u>Operating Labor</u>		
Operator (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Supervisor (15% of operator)		\$1,314
	Subtotal, Operating Labor	\$10,074
<u>Maintenance</u>		
Labor (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Material (5% of Total Direct Cost). Increased to account for high rate of damaged bags that is expected.	\$	528,000
	Subtotal, Maintenance	\$536,760
<u>Lime</u>		
Hydrated lime/Sulfur molar ratio, min. Ca/S		6.0
MW of Ca(OH) <sub>2</sub>		74
MW of SO <sub>2</sub>		64
Purity of the Comercial lime %		96.8
Lime Required - Short Tons		82282
Cost (\$/short ton)	\$	156.00
	Subtotal, Lime	\$12,836,066
	<b>Total Direct Annual Costs</b>	<b>\$13,382,900</b>
<u>Indirect Annual Costs</u>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$328,100
Administrative (2% TCI)		\$253,200
Property Tax (1% TCI)		\$126,600
Insurance (1% TCI)		\$126,600
Capital Recovery (15 year life, 7 percent interest)		\$1,390,000
	<b>Total Indirect Annual Cost</b>	<b>\$2,224,500</b>
<u>Conclusion</u>		
<b>Total Annualized Cost</b>		<b>\$15,607,401</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>11,481</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 20% removal, 95% uptime</b>		<b>2,181</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$7,155</b>

Table A-10. Dry Lime Scrubbing - Control Cost Analysis Based on Projected Actual Emissions and 30% Control.

<b>Direct Costs</b>		
<u>Purchased Equipment Costs</u>		
Dry Lime Injection System		\$1,000,000
Retrofit ESPs with Baghouse		\$3,000,000
Total Equipment Cost		\$4,000,000
Instrumentation (15% of EC)		\$600,000
Sales Tax (5% of EC)		\$200,000
Freight (5% of EC)		\$200,000
	Subtotal, Purchased Equipment Cost (PEC)	\$5,000,000
<u>Direct Installation Costs</u>		
Foundation (10% of PEC)		\$500,000
Supports (10% of PEC)		\$500,000
Handling and Erection (50% of PEC)		\$2,500,000
Electrical (10% of PEC)		\$500,000
Piping (30% of PEC)		\$1,500,000
Insulation for Ductwork (5% of PEC)		\$10,000
Painting (1% of PEC)		\$50,000
	Subtotal, Direct Installation Cost	\$5,560,000
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$10,560,000</b>
<u>Indirect Costs</u>		
Engineering (10% of PEC)		\$500,000
Construction and Field Expense (15% of PEC)		\$750,000
Contractor Fees (10% of PEC)		\$500,000
Start-up (1% of PEC)		\$50,000
Performance Test (1% of PEC)		\$50,000
Contingencies (5% of PEC)		\$250,000
	<b>Total Indirect Cost</b>	<b>\$2,100,000</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$12,660,000</b>
<u>Direct Annual Costs</u>		
<u>Operating Labor</u>		
Operator (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Supervisor (15% of operator)		\$1,314
	Subtotal, Operating Labor	\$10,074
<u>Maintenance</u>		
Labor (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Material (5% of Total Direct Cost). Increased to account for high rate of damaged bags that is expected.	\$	528,000
	Subtotal, Maintenance	\$536,760
<u>Lime</u>		
Hydrated lime/Sulfur molar ratio, min. Ca/S		6.0
MW of Ca(OH) <sub>2</sub>		74
MW of SO <sub>2</sub>		64
Purity of the Comercial lime %		96.8
Lime Required - Short Tons		82282
Cost (\$/short ton)	\$	156.00
	Subtotal, Lime	\$12,836,066
	<b>Total Direct Annual Costs</b>	<b>\$13,382,900</b>
<u>Indirect Annual Costs</u>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$328,100
Administrative (2% TCI)		\$253,200
Property Tax (1% TCI)		\$126,600
Insurance (1% TCI)		\$126,600
Capital Recovery (15 year life, 7 percent interest)		\$1,390,000
	<b>Total Indirect Annual Cost</b>	<b>\$2,224,500</b>
<u>Conclusion</u>		
<b>Total Annualized Cost</b>		<b>\$15,607,401</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>11,481</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 30% removal, 95% uptime</b>		<b>3,272</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$4,770</b>

Table A-11. Dry Lime Scrubbing - Control Cost Analysis Based on PTE and 20% Control.

<b>Direct Costs</b>		
<u>Purchased Equipment Costs</u>		
Dry Lime Injection System		\$1,000,000
Retrofit ESPs with Baghouse		\$3,000,000
Total Equipment Cost		\$4,000,000
Instrumentation (15% of EC)		\$600,000
Sales Tax (5% of EC)		\$200,000
Freight (5% of EC)		\$200,000
	Subtotal, Purchased Equipment Cost (PEC)	\$5,000,000
<u>Direct Installation Costs</u>		
Foundation (10% of PEC)		\$500,000
Supports (10% of PEC)		\$500,000
Handling and Erection (50% of PEC)		\$2,500,000
Electrical (10% of PEC)		\$500,000
Piping (30% of PEC)		\$1,500,000
Insulation for Ductwork (5% of PEC)		\$10,000
Painting (1% of PEC)		\$50,000
	Subtotal, Direct Installation Cost	\$5,560,000
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$10,560,000</b>
<u>Indirect Costs</u>		
Engineering (10% of PEC)		\$500,000
Construction and Field Expense (15% of PEC)		\$750,000
Contractor Fees (10% of PEC)		\$500,000
Start-up (1% of PEC)		\$50,000
Performance Test (1% of PEC)		\$50,000
Contingencies (5% of PEC)		\$250,000
	<b>Total Indirect Cost</b>	<b>\$2,100,000</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$12,660,000</b>
<u>Direct Annual Costs</u>		
<u>Operating Labor</u>		
Operator (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Supervisor (15% of operator)		\$1,314
	Subtotal, Operating Labor	\$10,074
<u>Maintenance</u>		
Labor (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Material (5% of Total Direct Cost). Increased to account for high rate of damaged bags that is expected.	\$	528,000
	Subtotal, Maintenance	\$536,760
<u>Lime</u>		
Hydrated lime/Sulfur molar ratio, min. Ca/S		6.0
MW of Ca(OH) <sub>2</sub>		74
MW of SO <sub>2</sub>		64
Purity of the Commercial lime %		96.8
Lime Required - Short Tons		95305
Cost (\$/short ton)	\$	156.00
	Subtotal, Lime	\$14,867,521
	<b>Total Direct Annual Costs</b>	<b>\$15,414,355</b>
<u>Indirect Annual Costs</u>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$328,100
Administrative (2% TCI)		\$253,200
Property Tax (1% TCI)		\$126,600
Insurance (1% TCI)		\$126,600
Capital Recovery (15 year life, 7 percent interest)		\$1,390,000
	<b>Total Indirect Annual Cost</b>	<b>\$2,224,500</b>
<u>Conclusion</u>		
<b>Total Annualized Cost</b>		<b>\$17,638,856</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>13,298</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 20% removal, 95% uptime</b>		<b>2,527</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$6,981</b>

Table A-12. Dry Lime Scrubbing - Control Cost Analysis Based on PTE and 30% Control.

<b>Direct Costs</b>		
<u>Purchased Equipment Costs</u>		
Dry Lime Injection System		\$1,000,000
Retrofit ESPs with Baghouse		\$3,000,000
Total Equipment Cost		\$4,000,000
Instrumentation (15% of EC)		\$600,000
Sales Tax (5% of EC)		\$200,000
Freight (5% of EC)		\$200,000
	Subtotal, Purchased Equipment Cost (PEC)	\$5,000,000
<u>Direct Installation Costs</u>		
Foundation (10% of PEC)		\$500,000
Supports (10% of PEC)		\$500,000
Handling and Erection (50% of PEC)		\$2,500,000
Electrical (10% of PEC)		\$500,000
Piping (30% of PEC)		\$1,500,000
Insulation for Ductwork (5% of PEC)		\$10,000
Painting (1% of PEC)		\$50,000
	Subtotal, Direct Installation Cost	\$5,560,000
Site Preparation		N/A
Buildings		N/A
	<b>Total Direct Cost</b>	<b>\$10,560,000</b>
<u>Indirect Costs</u>		
Engineering (10% of PEC)		\$500,000
Construction and Field Expense (15% of PEC)		\$750,000
Contractor Fees (10% of PEC)		\$500,000
Start-up (1% of PEC)		\$50,000
Performance Test (1% of PEC)		\$50,000
Contingencies (5% of PEC)		\$250,000
	<b>Total Indirect Cost</b>	<b>\$2,100,000</b>
	<b>Total Capital Investment (TCI)</b>	<b>\$12,660,000</b>
<u>Direct Annual Costs</u>		
<u>Operating Labor</u>		
Operator (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Supervisor (15% of operator)		\$1,314
	Subtotal, Operating Labor	\$10,074
<u>Maintenance</u>		
Labor (0.5 hr/shift, 3 shifts/day, 365 d/yr, \$16/hr)		\$8,760
Material (5% of Total Direct Cost). Increased to account for high rate of damaged bags that is expected.	\$	528,000
	Subtotal, Maintenance	\$536,760
<u>Lime</u>		
Hydrated lime/Sulfur molar ratio, min. Ca/S		6.0
MW of Ca(OH) <sub>2</sub>		74
MW of SO <sub>2</sub>		64
Purity of the Comercial lime %		96.8
Lime Required - Short Tons		95305
Cost (\$/short ton)	\$	156.00
	Subtotal, Lime	\$14,867,521
	<b>Total Direct Annual Costs</b>	<b>\$15,414,355</b>
<u>Indirect Annual Costs</u>		
Overhead (60% of sum of operating, supervisor, maintenance labor & materials)		\$328,100
Administrative (2% TCI)		\$253,200
Property Tax (1% TCI)		\$126,600
Insurance (1% TCI)		\$126,600
Capital Recovery (15 year life, 7 percent interest)		\$1,390,000
	<b>Total Indirect Annual Cost</b>	<b>\$2,224,500</b>
<u>Conclusion</u>		
<b>Total Annualized Cost</b>		<b>\$17,638,856</b>
<b>Pollutant Emission Rate Prior to Scrubber (tons SO<sub>2</sub>/yr)</b>		<b>13,298</b>
<b>Pollutant Removed (tons SO<sub>2</sub>/yr) - 30% removal, 95% uptime</b>		<b>3,790</b>
<b>Cost Per Ton of Pollutant Removed</b>		<b>\$4,654</b>