

**PROPOSED BEST AVAILABLE RETROFIT
TECHNOLOGY (BART) FOR THE
LAFARGE PLANT IN
SEATTLE, WASHINGTON**



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1.0 EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) published final amendments and guidelines to its 1999 regional haze rule on July 6, 2005 (70 FR 39104). Under this regulation, certain existing stationary sources that emit visibility impairing pollutants must install and operate the Best Available Retrofit Technology (BART). BART is required for sources that fit specific criteria, as discussed below, and that "may reasonably be anticipated to cause or contribute" to visibility impairment in any Class I area. The determination of what constitutes BART is made on a case-by-case basis considering technical feasibility, costs of compliance, energy impacts, and the modeled reduction in visibility impacts.

The BART requirement only applies to sources included in the specific source categories listed in Clean Air Act (CAA) Section 169A(g)(7) that also meet the time frame and emission level thresholds specified in the BART Guidelines found at 40 CFR Part 51, Appendix Y. Once the emission units in the applicable source categories have been identified, the second step is to determine whether the units fall within the 15-year time frame established by the BART Guidelines. Therefore, BART applicability focuses on sources that were "in existence" on August 7, 1977 and not "in operation" before August 7, 1962. The third step of identifying BART-eligible emission sources is determining whether the source meets a 250 ton per year emission threshold. The 250 ton per year threshold is applied facility-wide. To be BART-eligible, the combined potential to emit of the emission units meeting the source category and operational date tests must be in excess of 250 tons per year for any single visibility impairing pollutant. Visibility-impairing pollutants include sulfur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter (PM).

Lafarge owns and operates a portland cement manufacturing plant in Seattle, Washington. Portland cement manufacturing is one of the specific source categories listed in Section 169A. In addition, Lafarge operates a cement kiln that was constructed and, based upon available information, became operational between August 7, 1962



and August 7, 1977. Since the potential to emit of the kiln is in excess of 250 tons per year for one or more visibility impairing pollutants, the kiln is considered to be BART-eligible.

The Lafarge kiln "may reasonably be anticipated to cause or contribute" to a visibility impairment at a Class I area. There are nine Class I areas located within 300 km of the Lafarge site. The closest is Alpine Lakes which is located 53 km to the east. The most distant is Mt. Hood which is located 245 km to the south. Source-specific modeling indicates that the emissions from Lafarge has the potential to change the 24-hour background visibility by more than 0.5 deciviews (the deciview is the accepted metric for expressing visibility and changes in visibility) at one or more Class I areas. The kiln at Lafarge is therefore subject to BART.

Once a source is determined to be subject to BART, a BART review is required for each potential visibility-impairing pollutant emitted. The BART review must identify the best system of continuous emission reduction considering the following five statutory factors: 1) the cost of compliance, 2) energy and non-air quality environmental impacts, 3) any existing pollution control in use at the source, 4) the remaining useful life of the source, and 5) the degree of visibility improvement reasonably anticipated from implementing BART.

This document presents the procedures and results of the BART review conducted for the cement kiln at the Lafarge Seattle plant. The results presented herein demonstrate that duct sorbent injection represents BART for control of SO_2 and that selective non-catalytic reduction (SNCR) represents BART for control of NO_x . No additional control is proposed for emission of particulate matter because the plant is subject to and compliant with Puget Sound Clean Air Agency emissions standards for particulate matter emissions and opacity. Additional control would not result in appreciable reduction in particulate matter emissions. Further, the modeling presented herein demonstrates that current particulate emissions do not adversely contribute to visibility



impacts. For these reasons, no specific PM₁₀ BART limit is proposed (i.e., BART for PM₁₀ is no additional controls and compliance with the Puget Sound Clean Air Agency standards for PM₁₀ represents BART). Table 1-1 presents the proposed SO₂ and NO_x BART limits for the Lafarge Seattle plant.

Table 1-1. Proposed BART for Lafarge Seattle

Emission Unit	Proposed BART	Pollutant(s) Controlled	Proposed BART Emission Limit (TPD)	Visibility Improvement on 98 th Percentile Day (delta deciview) ^a	Class I Area Most Impacted
Kiln	SNCR	NO _x	11.5	1.09	Olympic
	Duct Injection	SO ₂	4.3		

TPD = tons per day
^a2004 meteorology

Lafarge proposes that these limits be expressed as a 30-day rolling average. These proposed limits are based on applying the BART technology control efficiencies outlined in Sections 3.1 and 3.2 to the maximum daily emission rates measured during the 2003-2005 period.



2.0 BACKGROUND INFORMATION

2.1 Plant Location

The Lafarge plant is located in west-central King County. The approximate Lambert Conformal Conic (LCC) coordinates of the plant are -97.398 kilometers east and 154.755 kilometers north. Figure 2-1 shows the location of the plant on the Seattle South 7.5 minute USGS quadrangle.

2.2 Description of Operations

The Seattle plant produces portland cement using a wet process kiln, which means the raw materials are fed to the kiln as a slurry. The primary ingredients in production of portland cement include the following minerals: calcium, alumina, silica, and iron. The raw materials used to supply these minerals include limestone, shale, sand, and iron ore. These minerals are also found in alternate raw materials that do not come directly from the earth. Lafarge can substitute quarry-based raw materials with alternate raw materials depending on their quality and composition. Alternate raw materials used by Lafarge include Petroleum contaminated soil (PCS), Blast & Foundry sands, Fluid catalytic cracking catalyst (FCC), and Vactor.

All raw materials are transported to the plant site. The materials are crushed or milled. Water is added to the raw mill to create a pumpable slurry, or slip, of approximately 70% solids. The slurry is stored in tanks until it is fed to the kiln for pyroprocessing. The plant operates one kiln with a total production capacity of 465,000 tons of clinker per year. The kiln exhaust gases account for all of the gaseous emissions from the plant and the majority of the particulate emissions.

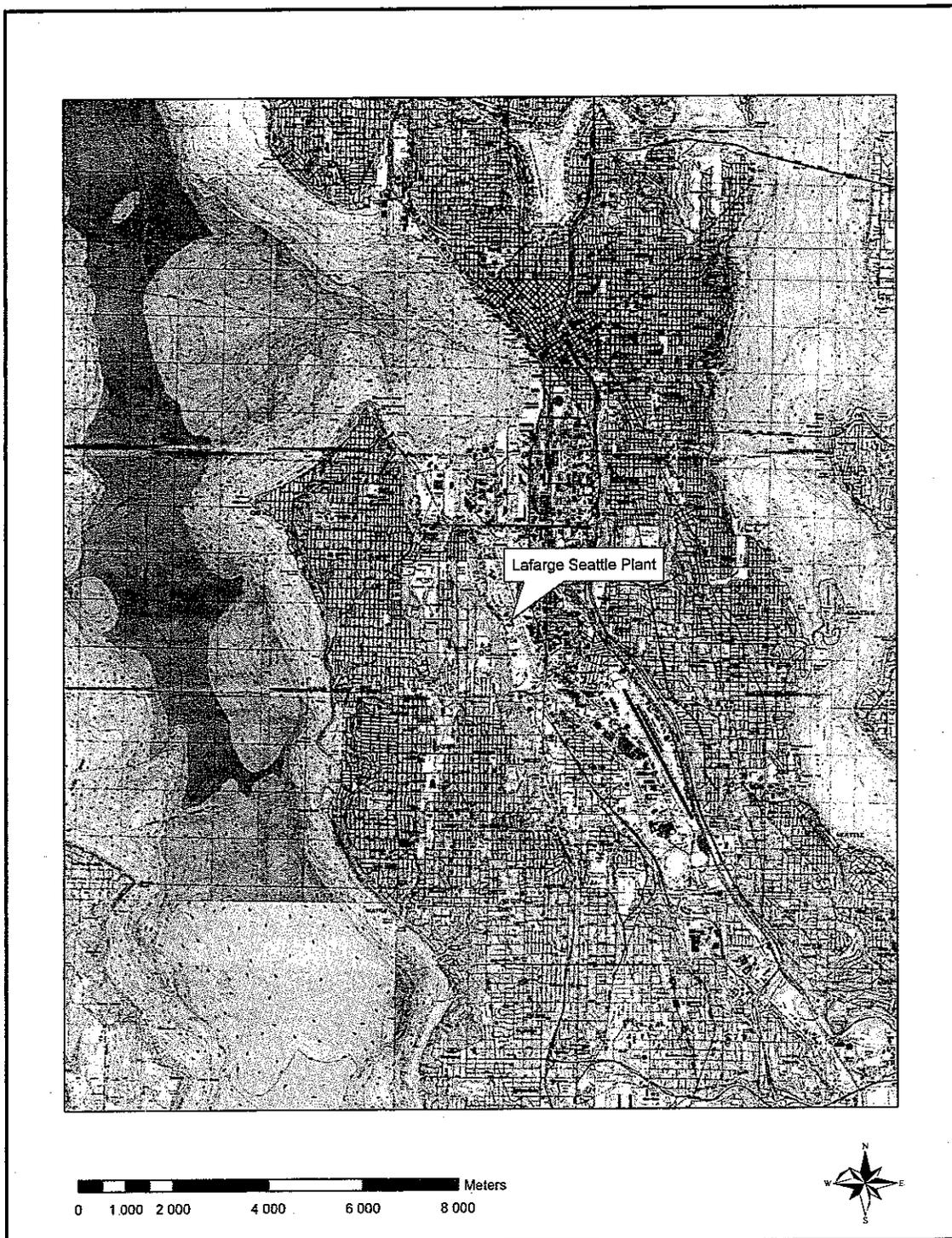


Figure 2-1. Location of the Lafarge Seattle Plant



Once the clinker leaves the kiln, the last component of the pyroprocessing system is the clinker cooler. In this step, the clinker is rapidly cooled using air to lock in desirable product qualities by freezing mineralogy. The clinker cooler also enables the material to be cooled for further processing. The final step in the manufacture of portland cement at Seattle involves a sequence of blending and grinding that transform the clinker into finished portland cement. Gypsum and other materials are added as needed to impart specific product properties. These materials and the clinker are mixed and milled in the finish mills. The final product is then stored in silos prior to shipment. The cement is shipped off-site via trucks, railcars, and barges. Material handling, which consists of numerous conveyor belts and transfer operations, as well as milling activities and roadways also contribute to particulate matter emissions from the plant, although to a much lesser extent.

2.3 Class I Areas Evaluated

Class I areas are national parks and wilderness areas in which visibility is more stringently protected under the CAA than any other areas in the United States. Class I areas that are located within 300 km of a BART-eligible source are required to be evaluated for visibility impacts.¹

There are nine Class I areas located within 300 km of the Lafarge site that required evaluation. In addition, Lafarge evaluated visibility impacts at the Columbia River Gorge. Figure 2-2 shows the location of the Class I areas evaluated with respect to the Lafarge plant. There is no other Class I area located within 300 km of the Lafarge plant. The next closest Class I area is the Mt. Jefferson Wilderness Area which is located 311 km south of the Lafarge Seattle plant.

¹ Washington, Oregon, and Idaho, "Modeling Protocol for the Application of the CALPUFF Modeling System Pursuant to the Best Available Retrofit Technology (BART) Regulation", October 11, 2006.

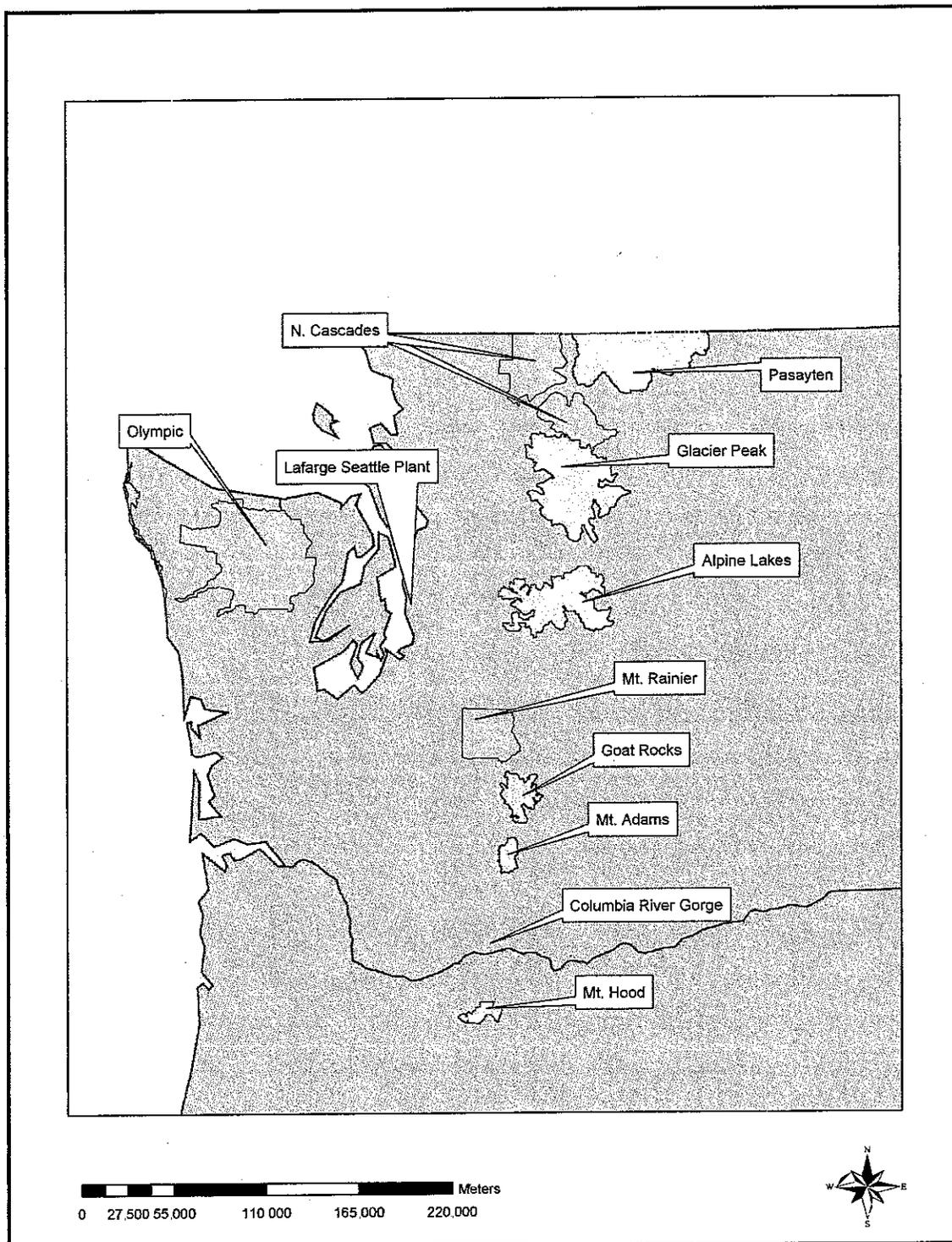


Figure 2-2. Location of the Lafarge Plant and the Class I Areas Evaluated



3.0 BART SELECTION PROCESS

Five basic steps were taken in selecting BART for the Lafarge Seattle plant kiln:

- All available retrofit control technologies were identified;
- Technically infeasible options were eliminated;
- The technically feasible options were ranked in order of control effectiveness;
- The energy, environmental, and economic impacts of each control were evaluated; and
- The visibility impact of each control alternative was determined (see 70 FR 39164).

Based on this process, Lafarge has proposed BART limits for the Seattle kiln as shown in Table 1-1 and Table 3-3 of this report. Detailed control costing calculations can be found in Appendix A.

As discussed previously, the BART analysis for the Seattle plant identified additional SO₂ and NO_x controls for the cement kiln. Since the control options for these pollutants are basically unrelated, each pollutant is addressed individually. However, because the impacts of SO₂ and NO_x on visibility are similar, the proposed BART limits are based on a combined SO₂ and NO_x control strategy (see Section 3.3).²

3.1 PM₁₀ BART Analysis

The Lafarge Seattle plant employs particulate controls on all point sources potentially subject to BART requirements. Table 3-1 lists these emissions units and their controls. Baghouses are used to control PM₁₀ emissions from all sources except the kiln main stack. Baghouses are generally considered the top-performing PM₁₀ control technology available for such sources. Since the top-performing technology is already installed on these sources, there is no potential retrofit technology that can be applied. Further, these units are required to meet an outlet grain loading limit of at least 0.01 gr/dscf.

² Model results indicate that SO₂ and NO_x emissions contributed equally to visibility reduction. Lafarge therefore concluded that both SO₂ and NO_x control strategies would need to be implemented to yield appreciable modeled visibility improvement. Modeling output data supporting this conclusion are provided in Appendix C.



Thus, there are no modifications that could be made that would substantially improve the performance of the existing baghouses.

Table 3-1. Emission Sources of Particulate Matter and Controls

Emission Unit ID	Emission Unit Description	PM ₁₀ Control(s)
EU-1	Rotary Cement Kiln Main Stack	Two Dry Electrostatic Precipitators (ESPs)
EU-2	Clinker Cooler	Baghouses
EU-4	Raw Material, Clinker and Finished Product Storage Bins; Finish Mill Conveying System Transfer Points, Bagging System and Bulk Loading/Unloading System. This unit also includes the general fuel system.	Baghouses
EU-5	Cement Kiln Dust Recycle System	Baghouse

An ESP is used to control the kiln main stack. A properly sized and operated ESP is capable of providing PM₁₀ emissions control efficiencies that are equivalent to the efficiency that can be provided by a new baghouse. In the case of the Seattle plant, there are two ESPs that were originally designed for two kilns to exhaust 400,000 actual cubic foot per minute (acfm), but these ESPs only control one kiln at less than half the design flow. Each ESP has three stages in series. The exhaust duct from the kiln splits (called pant legs) as it enters the two ESPs. The ESP is controlled by three 1,000 kilovolt transformer-rectifiers rated at 1,400 milliamps. The ESPs were originally designed with an internal velocity of about 5 foot per minute (fpm) providing a residence time of about 8.5 seconds. The ESP is currently operated at about 2 feet per second (fps) providing a treatment time of about 20 seconds. Due to this elevated residence time, the capture efficiency of the exhausted kiln dust in the ESPs is above 99.95% which equals or exceeds the efficiency that might be achieved by a baghouse installed on this source.



Because of the excellent level of control provided by the existing ESPs, there is no retrofit technology that might be used to improve performance. For this reason, Lafarge concludes that BART for this source is the existing control system. This system is subject to and compliant with Puget Sound Clean Air Agency emissions standards for particulate matter emissions and opacity. Furthermore, evaluation of the model results indicates that the existing particulate matter emissions do not contribute significantly to visibility impairment. Lafarge therefore proposes that the existing limits be considered BACT for the kiln main stack.

3.2 SO₂ BART Analysis

Step 1 – Identify Potentially Applicable SO₂ Control Options

Lafarge has identified SO₂ control options for retrofit to the kiln at its Seattle plant. Based on review of U.S. EPA's RBLC (RACT, BACT, and LAER Clearinghouse) database, industry practice, recently issued permits for cement kilns, and considering the potential for technology transfer, the SO₂ control technologies potentially available³ for retrofit to the Seattle kiln include:

- Duct Sorbent Injection; and
- Flue Gas Desulfurization.

The following subsections describe each of these technologies and their potential applicability to the Seattle kiln.

Duct Sorbent Injection Systems. In general, sorbent injection systems consist of injecting an alkaline reagent into the exhaust gas duct upstream of a particulate control device. In situations where there is limited ability for the reagent to dry once it is

³ Available retrofit control options are those air pollution control technologies with a practical potential for application to the emissions unit and the regulated pollutant under evaluation [70 FR 39614]. A source owner is not required to purchase or construct a process or control device that has not already been demonstrated in practice. The term "demonstrated in practice" is not specifically defined in the BART rule, but EPA proposed to define this term to include any technology that meets the following criteria: (1) it has been installed and operating continually for at least 6 months on an emissions unit(s) which has been operating at least at 50 percent of design capacity during that period of time; and (2) its performance has been verified during that 6 month period with a performance test or performance data while operating under a load that coincides with either the operation of the emissions units served by the control technology at their PTE, or 90 percent of the control technology's design specifications [61 FR 38249]. This definition is assumed to be relevant for purposes of this BART analysis.



injected, dry reagent powders (typically hydrated lime) are injected. Examples of alkaline reagents used in sorbent injection systems include magnesium hydroxide, hydrated lime, and sodium carbonate. The injected reagent reacts with SO_2 in the gas stream. The byproduct of this reaction consists of fine sulfate and sulfite particles along with unreacted reagent. These particles are collected in a downstream particulate control device and either disposed of or reintroduced into the process.

Duct sorbent injection systems have been applied on cement kilns in recent years to reduce SO_2 emissions. A duct sorbent injection system could be installed upstream of the existing ESP. Such systems are expected to reduce SO_2 emissions by an estimated 25 to 30% when used in combination with an ESP.

Flue Gas Desulfurization (FGD). A review of technical publications and USEPA guidance shows that one of the most effective add-on control technologies for SO_2 control involves scrubbing with an aqueous alkaline slurry or solution. This type of add-on control technology is commonly referred to as wet flue gas desulfurization.

Another type of widely-used flue gas desulfurization technology is known as dry or semi-dry scrubbing. This is also an effective SO_2 control technology because it uses water to enhance the reactions between SO_2 and the alkaline reagent used. It has the advantage of producing a dry byproduct which is may be easier to manage depending on the application. The following subsections provide additional information on wet and semi-dry FGD systems and their potential applicability to the Lafarge Seattle cement kiln.

Wet Flue Gas Desulfurization. Wet flue gas desulfurization (FGD) systems are characterized by low flue gas outlet temperatures, water-saturated flue gas conditions, and a wet sludge reaction product which is dewatered before reuse or disposal. Wet FGD systems on cement kilns are typically installed downstream of a particulate matter control device so that the kiln dust and scrubber reaction



products are collected separately. The following discussion reviews wet scrubbing technologies that are potentially applicable to the Seattle kiln.

Wet Limestone with Forced Oxidation (LSFO) – Limestone with forced oxidation (LSFO) is the type of wet limestone FGD process that is most commonly used today. A conventional wet limestone FGD system forms a scrubber byproduct composed mostly of calcium sulfite (CaSO_3) solids. The LSFO process produces a scrubber byproduct with very little CaSO_3 in the byproduct. Instead, the byproduct from an LSFO FGD system has a calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ or gypsum) content in excess of 90 percent. The high gypsum content of the scrubber byproduct makes the solids easier to dewater, improves the reliability of the scrubbing process, and provides the potential for byproduct reuse. For most applications, these factors result in lower overall costs of control than a conventional, unoxidized limestone scrubbing process.

In the LSFO process, hot flue gas exiting the particulate control device enters an absorber where a slurry of limestone and gypsum is sprayed into the flue gas.⁴ The SO_2 in the flue gas is absorbed into the slurry which is alkaline relative to the absorbed SO_2 . The flue gas exits the absorption tower through a mist eliminator to remove entrained droplets. The absorbed SO_2 (now mostly dissolved sulfite) contained in the slurry drains into a recirculation tank located at the bottom of the scrubber vessel. The sulfite is subsequently oxidized to sulfate in the recirculation tank, and following the oxidation step, it precipitates as calcium sulfate dihydrate. This process is called “forced oxidation,” and involves bubbling

⁴ There are a number of variations on the design of a limestone forced oxidation scrubbing system that may differ slightly from the system described here. However the basic principals of SO_2 control and byproduct formation are the same. The differences are principally due to alternative designs that have different features and benefits and the choice of technology is often a function of site-specific considerations and individual company preferences



air through the slurry to force the oxidation of sulfite to sulfate. The oxidation air is provided by large electric compressors or blowers.

A portion of the slurry in the recirculation tank is pumped back into the scrubber vessel, and a portion is removed. The removed slurry is dewatered, typically using hydrocyclones followed by a horizontal belt filter. The final gypsum product may be used in a number of applications. In the case of the Seattle plant, depending on process chemistry and gypsum quality, it should be possible to reuse the byproduct gypsum by adding it to final cement product.

For this BART analysis, an overall SO₂ removal efficiency of 81% is assumed for the LSFO process. This efficiency represents a short-term 90% SO₂ control efficiency coupled with an estimated system on-stream factor of 90%. The control efficiency is typical of control efficiencies for wet scrubbers applied in this industry. The estimated on-stream factor reflects both limited experience with wet FGD systems in the cement industry along with the expected impacts on reliability of a single-module FGD system. An overall 81% control efficiency is consistent with Lafarge's experience on one of its cement kilns in Europe that has been retrofitted with an FGD system. Lafarge has not been able to identify reliable published control efficiency data on other retrofitted FGD systems on wet process cement kilns.

Wet Lime FGD Process – In the wet lime FGD process, flue gas leaving the particulate control device enters an absorber tower. The SO₂ is removed from the flue gas when the gas comes into contact with an alkaline slurry of hydrated lime and calcium sulfite. The scrubbed flue gas exits the absorption tower through a mist eliminator to remove entrained droplets prior to gas exiting the system. The reaction products (i.e.,



scrubber slurry composed primarily of calcium sulfite) are withdrawn from the absorber and then sent for dewatering and further processing. This dewatering process includes thickening the sulfite sludge and fixating the sludge or filter cake with lime and/or ash. The blend of ash, lime, and filter cake is then conveyed to a truck loading facility for disposal

A significant disadvantage of the wet lime FGD system as compared to the LSFO system is the higher operating costs, primarily due to the high lime reagent costs and higher byproduct disposal costs. The production of lime for this process also has important secondary environmental impacts as compared to the LSFO process, including the consumption of natural gas or other fuels required for calcining raw limestone.

The wet lime FGD process, like the LSFO process, can be designed for short-term SO₂ removal efficiencies of 90%. However, due to the nature of the byproduct produced by this system, it is not considered a good choice for use at the Seattle plant. The production of byproduct gypsum using the LSFO is much better match and it also provides cost advantages. For these reasons, wet lime scrubbing is not considered further in this BART assessment. Because LSFO is the best option from technical and environmental perspective, and because it provides equivalent levels of performance, this is the only wet scrubbing technology that is evaluated in this BART analysis.⁵

Dry or Semi-Dry Flue Gas Desulfurization. Spray dryers (also referred to as "semi-dry" FGD systems) are characterized by flue gas temperatures above the saturation point (i.e., the gas exiting the scrubber is at less than 100% relative humidity). Dry and semi-dry FGD systems are typically use with boilers equipped

⁵ This approach is consistent with the BART rule which states: "It is not necessary to list all permutations of available control levels that exist for a given technology - the list is complete if it includes the maximum level of control each technology is capable of achieving." [70 FR 39164]



with a baghouse system downstream of the FGD system to collect both scrubber byproduct and fly ash such that the fly ash and the FGD reaction products are commingled into a single byproduct stream.

In the spray drying process, hot flue gases enter a spray dryer vessel. Within the spray dryer, a finely atomized slurry of lime and recycled ash is sprayed into the flue gas stream. The SO_2 in the flue gas reacts with the lime and any alkali present in the fly ash to form sulfur salts (mostly CaSO_3). As the SO_2 reacts with the slurry, the water in the droplets evaporates forming solid particles, raising the flue gas moisture content, and lowering the flue gas temperature. A baghouse downstream of the spray dryer removes the dry solid reaction products and residual fly ash before the scrubbed gas is released to the atmosphere. A portion of the collected reaction products and residual fly ash is recycled to the spray dryer reagent feed system. The remaining solids are removed for reuse or disposal.

Other semi-dry technologies involve the use of separate humidification and reagent injection steps in a fluidized bed reactor. In this reactor, the elevated humidity promotes the reaction between gas-phase SO_2 and the semi-dry alkaline reagent. Possible reagents used in this type of system include lime and soda ash. Soda ash is less desirable because the sodium-sulfur byproducts (i.e., sodium sulfate and sodium sulfite) have a high level of solubility and thus, they are more difficult to dispose of in an environmentally sound manner.

Like spray drying, the reaction byproducts from the semi-dry technologies are typically collected in a fabric filter downstream of the reactor vessel. Some of the collected material is recycled to the reactor and a portion is sent to disposal. In the case of the Seattle plant, this reactor would have to be located upstream of a new baghouse (which could replace the existing ESPs).



Step 2 – Eliminate Technically Infeasible Control Options

Of the possible SO₂ control options identified in this BART analysis, duct sorbent injection and wet scrubbing are technically feasible for retrofit application to the cement kiln at the Lafarge Seattle plant. The various dry scrubbing options are a poor choice for the Seattle plant and they are deemed infeasible for several reasons. First, there is insufficient space in the flue gas path for installation of a dry scrubber. While it may be theoretically possible to install dry scrubbers on the Seattle kiln, it is practically infeasible. Construction would involve large, complex duct runs, the need for additional gas fans, and complex duct/control system configurations. The cost of such a system would result in a dry FGD system that costs as much or more as a wet FGD system while providing less effective SO₂ removal. Further, the Seattle plant has extremely limited space and in effect, there is simply no room for a dry scrubber retrofit without significant demolition and relocation of existing equipment.

Second, the Seattle plant uses dry ESPs for particulate control. Retrofitting a dry scrubber upstream of these ESPs is virtually impossible. Instead, the ESPs would need to be replaced with new baghouses. The complexity of this project makes it significantly more expensive than the retrofit of a wet scrubbing system. Because dry scrubbing offers no cost or performance advantages over wet scrubbing, it is not a feasible candidate for this BART evaluation.

Step 3 – Rank Feasible SO₂ Control Options

The most effective, technically feasible SO₂ control option for the Seattle kiln is wet FGD at 81% overall SO₂ control efficiency (90% control and 90% on-stream factor). The second most effective option SO₂ control option identified for the Seattle kiln is the use of duct sorbent injection at an overall SO₂ control efficiency of 25% (27.5% control and 90% on-stream factor).



Step 4 – Evaluate Feasible Control Options

Table 3-2 summarizes the economic, energy, and environmental impacts associated with the use of wet FGD on the Seattle kiln. As this table shows a wet-FGD system has extremely high economic impacts and results in significant energy impacts. For this reason, Lafarge concludes that wet FGD should not be the basis for BART limits on the Seattle kiln.

Table 3-2. FGD Economic, Energy, and Environmental Impacts

Summary of Impacts	Wet Flue Gas Desulfurization
Environmental Impacts	
Uncontrolled SO ₂ Emissions (tpy)	570
Controlled SO ₂ Emissions (tpy)	108
SO ₂ Controlled (tpy)	462
Other Impacts	21 MMgal/yr water use Reduced Plume Buoyancy
Energy Impacts	
Electricity Use (MWh/year)	7,100
Economic Impacts	
Total Capital Cost (\$)	\$77,064,944
Total Annual Cost (\$)	\$15,340,911
Cost Effectiveness (\$/ton)	\$33,227

Since the wet FGD option is not cost effective, Lafarge proposes that the Seattle kiln BART limits be based on the installation of a duct sorbent injection system designed for an annual average SO₂ reduction of 25%.

3.3 NOx BART Analysis

Step 1 – Identify Potentially Applicable NOx Control Options

Lafarge has identified possible NOx control options for retrofit to the Seattle kiln. Based on review of U.S. EPA's RBLC database, industry practice, recently issued permits for



cement kilns, and considering the potential for technology transfer, the available NOx control technologies that are potentially applicable for retrofit to the Seattle kiln include:

- Process Optimization;
- Low NOx Burners;
- Mid-Kiln Fuel Firing;
- Selective non-catalytic NOx reduction (SNCR); and
- Selective catalytic NOx reduction (SCR).

The following subsections describe each of these technologies and their potential applicability to the Seattle kiln.

Process Optimization. Any effort that is related to reducing the amount of fuel fired in a cement kiln can be characterized as process optimization since reduced fuel consumption (e.g., improved fuel efficiency) generally results in reduced NOx emissions. The Seattle kiln has incorporate enhanced process monitoring systems, advanced computer controls, and necessary instrumentation over the years to improve the overall kiln stability and operation. The baseline and projected NOx emission rates from the Seattle kiln reflects the impact that process optimization has had on reducing NOx emissions. Since process optimization is a technically feasible NOx control technique that is currently being used by the plant, it is not considered further in this analysis (i.e., this technology cannot be retrofit to the Seattle kiln, as its effects are already included in the baseline NOx emissions from the plant).

Low NOx Burners. Low NOx burner designs limit NOx formation by lowering the burner flame temperature, minimizing residence time at peak temperatures, and reducing the flame aggressiveness within the combustion zone. These burner designs typically introduce fuel in a sub-stoichiometric (lean) air-to-fuel ratio (generally 6 to 10 percent) at the primary burner inlet to reduce the combustion zone temperature and create an air-starved flame. Secondary air inlets introduce more supplemental air beyond the primary flame to complete combustion. The goal of low NOx burner technology is to create an ignition of the fuel in an oxygen deficient environment, thereby creating less NOx.



In many industries using conventional steam boilers, the implementation of low NOx burners has been very successful. However, in cement manufacturing, the success of low NOx burners is limited because much higher burning zone temperatures (as compared to the combustion temperature range found in industrial and utility boilers) are essential to achieve acceptable product quality.

Mid-Kiln Fuel Firing. Mid-kiln fuel firing is a staged fuel combustion concept that is typically used in conventional wet and long-dry kilns. Mid-kiln fuel firing has been applied in long kilns as a method to reduce the formation of thermal NOx by displacing a percentage of the fuel fired in the primary burning zone. Mid-kiln firing allows part of the fuel to be burned at a temperature which is much lower than the temperature required for clinker formation. In mid-kiln firing systems, solid fuel is introduced into the calcining zone of a rotating kiln using a specially designed feed injection mechanism. Typically whole tires are used as mid-kiln fuel. Since the supply of whole tires cannot be guaranteed, mid-kiln firing is not considered a viable NOx control technique and is not considered further in this analysis.

Selective Non-Catalytic Reduction (SNCR). SNCR is an add-on control technology that involves injection of aqueous or anhydrous ammonia (NH_3), or urea (urea is composed of two attached ammonia molecules) into the gas stream. The injected ammonia is converted by OH^\cdot free radicals to ammonia free radicals (i.e., NH_2^\cdot), which react with NOx to form N_2 and H_2O . The optimum temperature range for this reaction is 1,600°F to 1,900°F. Above 1,900°F, the amount of NH_3 that oxidizes to NOx increases, and, in turn, the NOx reduction performance deteriorates. Both laboratory work and field data show NH_3 slip⁶ to be a strong function of temperature. At temperatures at or above 1,900°F, unreacted NH_3 emissions decrease due to the NH_3 oxidation to NOx. At temperatures at or below 1,600°F, unreacted NH_3 emissions may rapidly increase. At

⁶ "Slip" is a term used to refer to emissions of unreacted ammonia from SNCR and SCR processes



Seattle, NH_3 can be injected into the kiln in a region that operates between 1,600°F and 1900°F. This temperature window is appropriate for SNCR application.

The following factors influence the control effectiveness of SNCR:

- Temperature and oxygen availability (i.e., the NH_3 injection location);
- The baseline, or uncontrolled NO_x concentration;
- Mixing;
- Reagent Ratio (i.e., the NH_3 to NO_x molar ratio at the injection point);
- NH_3 accumulation;
- Excess ammonia emissions; and
- Ammonium salt formation.

Based on the current state of knowledge, these technical differences usually do not result in an SNCR system's "inability to perform" but instead present a "level of performance" question (i.e., generally, the central issue is the exact level of NO_x reduction that can be achieved when SNCR is applied and whether the costs outweigh the benefits).

For SNCR to work effectively, the gas stream being treated must have a relatively high concentration of NO_x as opposed to other potential reactants (e.g., CO) that could also react with the injected NH_3 . The presence of competing reactants in the gas stream may result in less NH_3 to convert NO_x to its non-polluting forms. This would reduce the effectiveness of the SNCR process.

Second, the desirable SNCR chemical reactions are most effective in a temperature range between 1,600°F and 1,900°F. Above the high end of the SNCR temperature range, the NO_x reduction efficiency degrades dramatically; in fact, at higher temperatures, the injected reagent can oxidize and actually increase NO_x emissions. Below the low end of the temperature range, the reaction rates are not rapid enough for the injected reagent to react completely. Therefore, selection of the proper temperature range for ammonia or urea injection is critical to achieving optimum performance of SNCR.



Finally, SNCR requires an oxidizing, or fuel-lean atmosphere to effectively reduce NOx emissions. In a fuel-rich, or reducing environment, partially oxidized fuel (e.g., CO) competes with NH₃ for OH* radicals, thus reducing NOx control effectiveness. In addition, ammonia interferes with the complete oxidation of organic compounds in the fuel, potentially causing a rise in CO emissions. These three conditions must be met for SNCR to be most effective in NOx reduction.

The successful application of SNCR also depends on the accurate injection of the optimum quantity of reagent NH₃. Insufficient reagent will not result in effective control, while excess reagent will result in excessive ammonia slip. Ammonia is typically injected in approximately equal molar quantities relative to the NOx present in the gas stream. While this injection ratio can theoretically result in conversion of 50% or more of the NOx with an ammonia slip of 10 ppm or less, there is a strong potential for the formation of a detached particulate plume resulting from the presence of chlorides and sulfates in the exhaust gas stream. These compounds are present in the raw materials and are released in the kiln system.

In recent years, SNCR has been applied to a number of cement kilns in both the U.S. and internationally. However, nearly all of these applications have been on modern preheater/precalciner kilns and only limited testing has been conducted on kilns similar to the one at the Seattle plant. The key reason for this is the location within the kiln system where reagent injection occurs. In a preheater/precalciner kiln, reagent injection occurs at the exit of the kiln in the lower part of the preheater tower. This injection location is readily accessible using conventional injection technology. In a wet kiln, injection must occur mid-kiln because this is where the gas temperature is in the proper range for the NOx reduction reactions to occur. Specialized injection systems are required to allow reagent injection in a mid-kiln location.



Lafarge has completed an engineering assessment and determined that SNCR can be applied to the Seattle kiln. Based on this assessment, Lafarge estimates that SNCR can achieve a 30 to 40% NOx reduction relative to current baseline NOx emissions. This range of reduction efficiencies is consistent with the reduction efficiencies that have been observed on the limited SNCR testing and operation for other wet kilns.

Selective Catalytic Reduction (SCR). Like SNCR, SCR systems use NH_3 to chemically convert NOx to molecular N_2 (i.e., the same form of nitrogen that comprises 79% of the air we breathe). However, as the name indicates, SCR uses a catalyst to promote the selective reaction of NOx and ammonia. Ammonia injected into the gas stream reacts with NOx and the SCR catalyst enables these reactions to occur at lower temperatures than are possible with SNCR. While catalysts can operate over a range of temperatures, the optimal temperature range for SCR applications is between 570° to 750°F, well below the 1,600°F to 1,900°F temperature range for SNCR reactions discussed previously.

The SCR catalytic reactions occur on the surface of the catalyst structure. However, the catalyst structures are not composed of simple, flat surfaces. The catalyst is designed to have a series of large openings termed "macropores" and small openings termed "micropores." These macropores and micropores maximize the surface area of the catalyst available for reaction with NOx and NH_3 .

A set of SCR catalyst beds is placed in series in a large vessel located in a part of the process where the gas temperatures are in the appropriate range during routine operation. The NH_3 ⁷ is injected at a controlled rate upstream of the catalyst using an injection grid designed to ensure relatively even NH_3 distribution, good mixing, and minimum NH_3 slip. The injected NH_3 reacts with NOx compounds (i.e., NO and NO_2) on

⁷ The NH_3 reagent can be in the form of an aqueous solution (typically 25 wt. % NH_3), anhydrous NH_3 , or as a product of urea decomposition



the surface of the catalyst in equal molar amounts (i.e., one molecule of NH_3 reacts with one molecule of NO_x) to form N_2 and water.

There is only one large scale installation of SCR on a cement plant in the world with any significant operating experience.⁸ This installation is at the Solnhofen Cement Works in Germany. This is a preheater kiln with the SCR system located at the exit of the preheater tower. In this location, the kiln exhaust gas temperature is in excess of 610°F which is in the correct range for SCR to function.⁹ There is no equivalent location for installing an SCR system in the Seattle plant's kiln. The raw materials used in the Solnhofen plant differ significantly from those at Seattle. The Solnhofen kiln raw materials contain minimal amounts of sulfur and alkali while the Seattle kiln raw materials contain appreciable amounts of both. These compounds are significant because they contribute to SCR problems such as catalyst deactivation and fouling. In addition, the presence of sulfur compounds can lead to downstream problems such as increased particulate emissions and plugging and corrosion of heat exchangers and particulate control equipment.

Lafarge has assessed the publicly available information regarding the Solnhofen SCR application and has determined that the long-term demonstrated performance of the SCR system at Solnhofen shows a demonstrated NO_x reduction efficiency that is similar to the reduction efficiencies expected to be achieved using SNCR¹⁰ These data are consistent with the fact that this system is currently not operational and SNCR is being used to meet the NO_x limit for this plant. In other words, over the long-term, the

⁸ A second commercial-scale SCR system has been installed in Europe on a cement kiln at Cementeria di Monselice. This unit began operation in mid-2006. Very little data are available on this application, but what data are available show that it differs significantly from the Seattle kiln. The Monselice SCR system is installed on a preheater, pre-calciner kiln system. There is no equivalent location in the Seattle kiln that would allow installation of such a system.

⁹ When it was operational, the SCR system at the Solnhofen Cement Works would be bypassed if the flue gas temperature dropped below 320°C or about 610°F.

¹⁰ See for example: "Response to Comments, Permit No. 2000-05-077"; Submitted to Missouri Department of Natural Resources by: Holcim (US) Inc.; April 8, 2004.



Solnhofen SCR system has not performed better than the SNCR system and, as of this writing, it is not in operation.

The Solnhofen SCR system did operate over a period of several years, but as described above, its long-term, demonstrated control effectiveness was not measurably different than the expected control effectiveness of SNCR (on the order of 30 to 40% based on publicly available data). In addition, there are a number of significant differences between the Solnhofen application and the Seattle kiln including:

- Kiln design;
- Flue gas sulfur levels; and
- Particulate mass loadings and compositions.

For the above reasons, the European cement plant experience with SCR systems does not meet the test of being "demonstrated in practice".

There are a number of issues that must be considered in evaluating the potential application of SCR to the Seattle kiln. First, as with SNCR, temperature is a critical variable in application of SCR technology to any source. In the case of the Seattle kiln, there is no location in the gas path where SCR could be applied. Second is the long-term viability of SCR technology in cement kiln applications. There are no known applications of SCR to wet cement kilns like the one at the Seattle plant.

It has been theorized that an SCR system could be installed downstream of the dust collection equipment on a wet kiln. Such an application would involve additional fuel combustion to reheat the gas and then the use of heat recovery equipment to limit the additional fuel used. This type of SCR installation has not been tested or demonstrated on a cement kiln (i.e., it has not been "demonstrated in practice") and it presents a number of potential problems including the issue of fine particulate emissions generated by the SCR system itself, the potential for significant production of sulfuric acid mist in SCR system, and the potential for rapid catalyst deactivation due to the fine particulate in the kiln effluent gas. The only U.S. applications of SCR in a low-dust environment



using heat recovery of the SCR effluent to preheat the SCR inlet stream are on very low sulfur applications (i.e., less than 10 ppm SO₂). Any attempt to apply this type of system to the Seattle kiln would be experimental in nature and such experimental technologies are not considered "available" when it comes to determining BART (as this term is described in the BART rule)

Step 2 - Eliminate Technically Infeasible Control Options

Of the NO_x control options identified in this BART analysis, low-NO_x burners and SNCR are feasible options for application to the Seattle kiln.

The application of SCR to the Seattle kiln represents a technology experiment that would require significant time, resources, and risk. The BART process is intended to apply "available" technologies to existing facilities. Thus, SCR is not considered "available" as its application would require significant development and testing before the suitability for application to the Seattle kiln could even be determined.

Step 3 - Rank Feasible NO_x Control Options

The most effective, technically feasible NO_x control option for the Seattle kiln is the application of SNCR. Lafarge estimates that this technology can achieve approximately 40% NO_x reduction on a short-term basis. The next most effective technology that can be applied is low-NO_x burner technology. Lafarge estimates that this technology can achieve a NO_x reduction of approximately 25%.¹¹

Step 4 - Evaluate Feasible Control Options

Lafarge is proposing to install SNCR which is the most effective feasible NO_x control technology on the Seattle kiln. For this reason, no additional evaluation of control options is necessary.

¹¹ See "Alternative Control Techniques Document - NO_x Emissions from Cement Manufacturing", USEPA, March 1994.



3.4 Proposed BART

Lafarge proposes to install duct absorbent injection and SNCR on the Seattle kiln. Consistent with this control plan, Lafarge is proposing BART limits of 4.3 tons of SO₂ per day and 11.5 tons of NO_x per day with each limit expressed on a 30-day rolling average basis. These proposed limits are based on applying the BART technology control efficiencies outlined in Sections 3.1 and 3.2 to the baseline uncontrolled SO₂ and NO_x emissions as determined by analysis of emissions data from the 2003-2005 period. Table 3-3 provides the specific values used to arrive at these proposed BART limits.

Table 3-3. Proposed BART Limits

Compound	BART Control Efficiency (%)	30-day Average Emissions (ton/day)	
		Baseline ^a	Proposed BART Limit
SO ₂	25%	5.74	4.31
NO _x	40%	19.1	11.5

^aThe baseline value is the maximum daily emission rate (as derived from CEMS data) from the period 2003 through 2005.



4.0 BART MODEL PROCEDURE

4.1 Modeled Emissions and Stack Parameters

Maximum, 24-hour actual emission rates during normal operation for 2003-2005 were determined and modeled in CALPUFF to calculate baseline visibility impacts. Baseline NO_x and SO₂ emissions from the kiln were obtained from continuous emission monitors (CEMS) during the 2003-2005 period. Particulate emissions were based upon stack test data. All PM₁₀ emissions were assumed to be filterable and were speciated, using National Park Service (NPS) speciation profiles for wet process cement kilns with ESPs, into PM₁₀ (PMC or PM Coarse), PM_{2.5} (PMF or PM Fine), elemental carbon (EC), and secondary organic aerosols (SOA). As recommended by the NPS, the condensable PM₁₀ fraction was assumed to be 20.8% of the total PM₁₀ emissions rate. The total PM₁₀ rate was calculated from the filterable fraction assuming that the filterable fraction is 79.2% of the total. The condensable fraction was then speciated (again using the NPS recommended speciation profiles) into sulfates and secondary organic aerosols (SOA). The PM speciation calculations are presented in Appendix B.

Based upon guidance from the three-State modeling protocol, Lafarge modeled emissions of PM₁₀, NO_x and SO₂ in calculating baseline visibility impacts. Lafarge did not model emissions of volatile organic compounds (VOCs) or ammonia as these pollutants are not believed to contribute significantly to visibility degradation. Only emissions of NO_x and SO₂ were varied in evaluating the effects of the various control technologies on visibility improvement. Lafarge did not evaluate PM control alternatives because the plant is subject to and compliant with Puget Sound Clean Air Agency emissions standards for particulate matter emissions and opacity. More stringent levels of PM control are generally not considered to be achievable and any calculated improvement in visibility would be inconsequential. The stack parameters and emission rates that were modeled are provided in Tables 4-1 and 4-2, respectively.



Table 4-1. Modeled Stack Parameter Data

Model Source ID	Source Description	LCC E (km) ^a	LCC N (km) ^a	Stack Height (m)	Base Elevation (m)	Stack Diameter (m)	Exit Velocity (m/sec)	Temp. (K)	Sigma Y (m)	Sigma Z (m)	Momentum Flux
Kiln	Kiln Exhaust	-97.398	-154.755	76.20	33.0	4.97	3.28	443.52	0	0	1

^aLambert Conformal Conic (LCC) coordinates are based upon an origin of 49.0N and 121.0W with Standard Parallels of 30.0N and 60.0N (NWS-84 Datum).

Table 4-2. Baseline Modeled Emission Rates (lb/hr)

Model Source ID	Source Description	SO ₂	SO _x	NOx	HNO ₃	NO ₃	PMC	PMF	EC	SOA
Kiln	Kiln Exhaust	478.5	13.35	1595	0.00	0.00	14.29	41.94	1.61	1.82

Notes: PMFine (PMF) or "soil" = PM < 2.5 um in diameter. PMCoarse (PMC) = PM between 2.5 and 10 um in diameter. SOA = secondary organic aerosols. EC = elemental carbon. Kiln PM speciation based upon NPS guidance.



The stack parameters were assumed not to be affected by the controls employed. That is, only stack gas emissions were varied in evaluating BART control alternatives. Stack gas exit temperature and flow as well as the physical parameters (i.e., diameter and height) were held constant in the control technology evaluation.

The post-control emission rates for each of the BART control scenarios evaluated were based upon the anticipated reduction from each control device (expressed as a percentage) and the baseline rates. The post-control emission rates for each modeled BART scenario are presented in Table 4-3.

4.2 Modeling Methodology

The modeling followed EPA's Interagency Workgroup on Air Quality Modeling (IWAQM), Phase 2 recommendations, for long-range transport¹² and the Washington, Oregon, and Idaho BART Modeling Guidance.¹³ The IWAQM guidance was developed to address air quality impacts—as assessed through the Prevention of Significant Deterioration permitting program. The three-state guidance was developed specifically for BART modeling.

¹² Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts, EPA-454/R-98-019, U.S. Environmental Protection Agency, Air Quality Modeling Group, Research Triangle Park, North Carolina December, 1998.

¹³ Washington, Oregon, and Idaho, "Modeling Protocol for the Application of the CALPUFF Modeling System Pursuant to the Best Available Retrofit Technology (BART) Regulation", October 11, 2006.



Table 4-3. Post-Control Modeled Emission Rates (lb/hr)

Source Description	SO ₂	SO ₄	NO _x	HNO ₃	NO ₃	PM ₁₀	PM _{2.5}	EC	SOA
Control Scenario 1: Duct Sorbent Injection & SNCR (Proposed BART)									
Kiln	358.9	12.01	956.8	0.00	0.00	14.29	41.94	1.61	1.82
Reduction from Baseline (%)	25	10	40	0	0	0	0	0	0
Control Scenario 2: Wet Scrubbing & SNCR									
Kiln	47.85	6.674	956.8	0.00	0.00	14.29	41.94	1.61	1.82
Reduction from Baseline (%)	90	50	40	0	0	0	0	0	0



4.3 CALMET

The dispersion modeling used CALMET windfields for the three-year period 2003-2005. These windfields cover the three-state area of Washington, Oregon, and Idaho, and also extent into adjacent states so that all Class I areas within 300 km of any BART-eligible facility could be evaluated. The CALMET data files were provided to Lafarge in a model-ready format. Lafarge utilized the 4 km CALMET data in conducting its BART analysis

4.4 CALPUFF

Output from the CALMET model was input to the CALPUFF model, which simulates the effects of the meteorological conditions on the transport and dispersion of pollutants from an individual source. Version 6.112 of CALPUFF was used in the analysis.

Modeling Domain

The CALPUFF modeling domain was designed to include the Lafarge plant and all the Class I areas within 300 km of the plant. A 50 km buffer zone in each direction was included in establishing the computational modeling domain. The domain dimensions were therefore calculated to be 446 km east-west by 494 km north-south. The modeling (computational) domain is shown in Figure 4-1. One hundred and twelve grid cells were employed on the east-west axis and 124 on the north-south axis.

Class I Area Receptors

Lafarge used the FLM Class I receptors for each Class I area, with elevations, as obtained from the National Park Service.

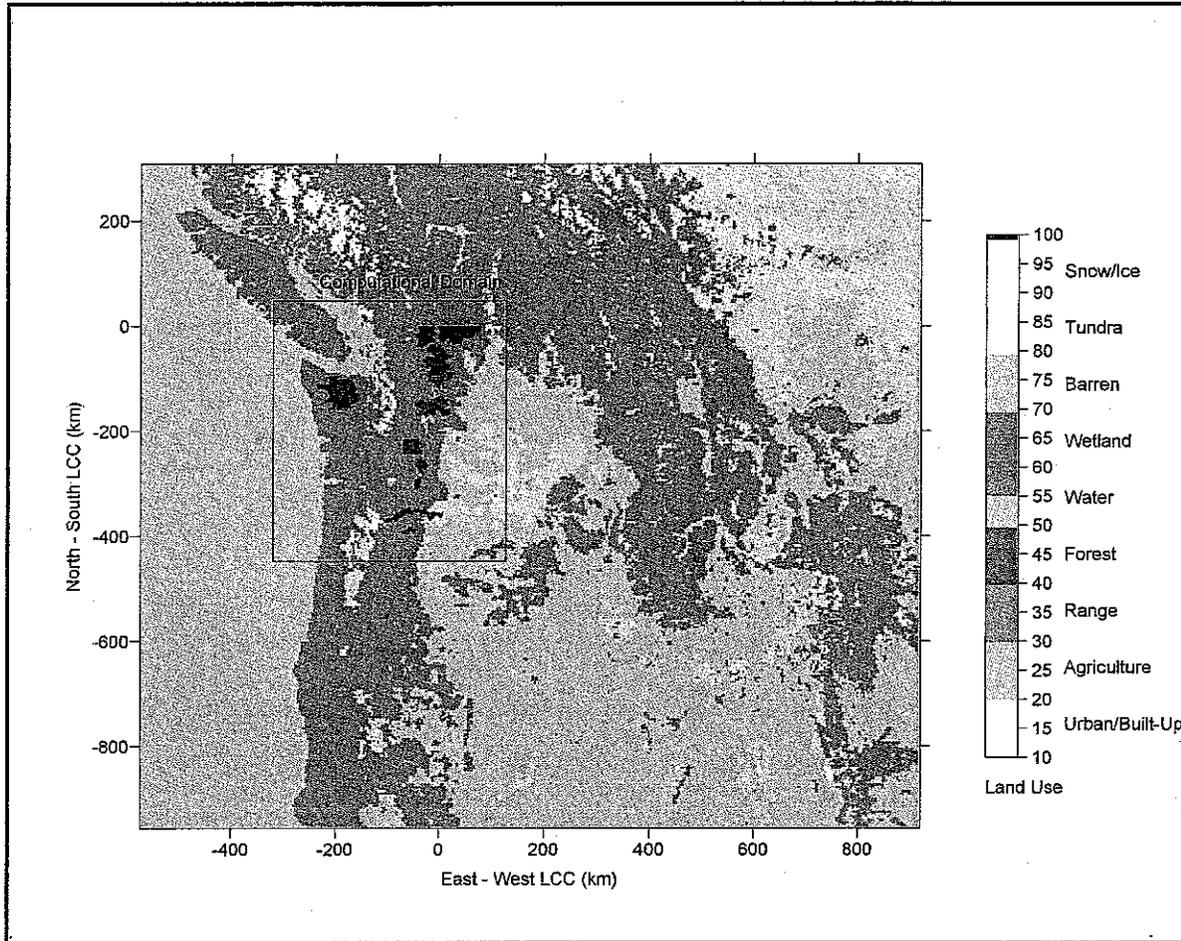


Figure 4-1. CALPUFF Modeling Domain

Control File Settings

In general, Lafarge used the default options in the CALPUFF model.¹⁴ The deviations from the default values are discussed below.

- The MESOPUFF II module was used for chemical transformation (MCHEM=1);
- Pasquill-Gifford dispersion coefficients were used;
- Number of vertical layers (NZ) was set to 10 and cell face heights (ZFACE) of 0, 20, 40, 65, 120, 200, 400, 700, 1200, and 2200 meters were used (to be consistent with CALMET runs);

¹⁴ As defined by pages B-2 through B-8 of the IWAQM Phase 2 Summary Report.



- Building downwash was ignored because all Class I Areas are located greater than 50 km from the source and downwash should not influence concentration estimates; and
- POSTUTIL was not used to speciate modeled PM₁₀ concentrations. In addition, HNO₃/NO₃ partitioning was not used for ammonia limiting.

Ozone and Ammonia Background Values

CALPUFF uses background ozone (O₃) and ammonia (NH₃) values in its chemistry module. Per the three-state BART guidance, Lafarge used constant ozone and ammonia concentration values of 60 and 17ppb, respectively, in the analysis.

4.5 CALPOST

Calculation Methods for Background Light Extinction

Input required by CALPOST includes an input control file and the hourly concentration output file from CALPUFF. The primary settings for the CALPOST control file are associated with the method for calculation of light extinction. The CALPOST control file was set such that the background light extinction calculation Visibility Method 6 (MVISBK=6) was used. This is the default value as described in three-State BART protocol document. As required by Method 6, the Class I area-specific monthly relative humidity values (centroid) for each Class I area were used. These values were obtained from Table A-3 of the EPA's "Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule".¹⁵

In Visibility Method 6, CALPOST also requires monthly background concentrations of ammonium sulfate, ammonium nitrate, coarse particulate mass, organic carbon, soil, and elemental carbon. Annual averages reflective of the 20% best day natural background conditions for these species were obtained from the three-state guidance document.

¹⁵ "Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule", EPA-450/B-03-005, September 2003.



Light Extinction Efficiencies and Rayleigh Scattering Value

The other values required to execute CALPOST include the light extinction efficiencies for the pollutant species identified above (i.e., ammonium sulfate, ammonium nitrate, etc) and the extinction due to Rayleigh scattering (BEXTRAY). Dry extinction efficiencies for the pollutant species were set equal to the Table 2-1 values of the EPA Visibility Guidance Document. The value for Rayleigh scattering was set to 10 Mm^{-1}



5.0 BART MODEL RESULTS

The CALPUFF modeling system was executed with input data and settings as described in Section 4. Delta-deciview results were obtained from the "24HR VISIBILITY (deciview)" table in the CALPOST output files. The regional haze regulation and BART guideline stipulate that the states have flexibility in determining the degree of visibility improvement that should be considered acceptable in assessing appropriate BART controls (see 70 FR 39170). The states may consider the frequency, magnitude, and duration components of visibility impairment. EPA suggests that the states use a comparison threshold, as is done for determining if BART-eligible emission units are subject to BART. States may also compare the 98th percent days for the pre- and post-control runs. Pursuant to the three-state guidance, Lafarge has calculated and has provided the 98th percentile values in two ways: 1) the 8th highest value for each year modeled, and 2) the 22nd highest value for the 3-year modeling period. Results are presented for both the pre- and post-control scenarios. These results are presented in Table 5-1 for the Class I area with the maximum modeled visibility impact, Olympic National Park. Summaries for all Class I areas are provided in Appendix C.

As shown in Table 5-1, the 98th percentile deciview values decrease with each of the control scenarios evaluated. However, the majority of the reduction is realized between the baseline scenario and the control scenario no. 1 (SNCR and Duct Sorbent Injection). The next highest level of control (adding a wet scrubber) results in some degree of visibility improvement. However, the costs of the additional level of control outweigh the small additional improvement in modeled visibility impacts. The addition of a wet scrubber would only improve the combined, three year 98% dv value by 0.31 dv (1.94 – 1.63 dv) at an incremental annualized cost of approximately \$14,000,000 or approximately \$45,000,000/dv.



Table 5-1. 98% Delta Deciview Results - Olympic National Park

Scenario	2003 (8th High)	2004 (8th High)	2005 (8th High)	2003-2005 (22nd High)
Baseline	2.87	3.16	2.98	2.96
Control Scenario 1: SNCR and Duct Sorbent Injection (Proposed BART)	1.88	2.07	1.96	1.94
Control Scenario 2: SNCR and Wet Scrubbing	1.59	1.75	1.67	1.63

The CALPUFF and CALPOST input and output files are provided on the enclosed CD. In addition, an Excel spreadsheet containing the emission calculations, control cost calculations, and model result summaries are provided on the CD.

