Abstract

THEILING, BRENT JASON. Some Cost Effective Techniques for Reducing NOx Emissions at Blue Ridge Paper Company. (Under the direction of Herbert M. Eckerlin and James W. Leach)

The purpose of this paper is to aid in the understanding of why various manufacturers in the State of North Carolina have been forced to reduce their emissions of nitrogen oxides (NOx) and how these emissions might be reduced in a cost effective way. Ultimately, it is focused on aiding a paper plant in the western part of the state to obtain a better understanding of the recent legislation that has impacted the plant pertaining to its emissions. The paper begins by offering background information on types of NOx and the health effects they can cause. A more in depth look at the history of pollution control legislation is then considered. Topics such as the Clean Air Act, its amendments in 1990, the National Ambient Air Quality Standards, and the NOx SIP Call are all considered. The State of North Carolina's NOx SIP is assessed, and specific details are quoted as they pertain to industries across the State. Finally, a case study on Blue Ridge Paper is done in an attempt to show how the Federal and State legislation affects individual manufacturers. This case study includes descriptions of various NOx reduction techniques and, identifies those that have particular relevance to Blue Ridge Paper.

Some Cost Effective Techniques for Reducing NOx Emissions at Blue Ridge Paper Company

By

Brent Jason Theiling

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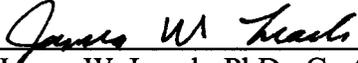Master of Science

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The completion of this work as a final requirement of my master's degree is dedicated to my family. Mom, Dad, and Megan (Maggie and Cooper too), I love you. Your prayers, thoughts, and words of encouragement have helped carry me through the past few years and towards my chosen career of "Professional Student".

Biography

Brent "Jason" Theiling was born in Frankfurt, West Germany on the 14th of October 1977 to his loving parents Brent and Jane Theiling. Throughout his childhood, he and his parents moved to a number of locations across the southeast United State until finally spending his middle school and high school years in Dyersburg, TN.

Jason graduated Magna cum Laude from Furman University with a Bachelor of Science in Physics in August of 1999. In August of 2000 he began pursuing a Masters of Science in Mechanical Engineering from North Carolina State University in Raleigh, NC. His graduate work has been enhanced with the experience of working in the Industrial Assessment Center at the University until his graduation in August of 2002.

Acknowledgments

The completion of this paper and the research involved in its production could not have been done without the assistance of the North Carolina State University's Industrial Assessment Center and all those associated with it. Specifically, I would like to acknowledge the professors who have worked diligently with me throughout my graduate education and who have served on my defense committee. Dr. James Leach, Dr. Herb Eckerlin, and Dr. Kevin Lyons, I thank you. Finally, I would like to thank Dan Meyer and the other employees of Blue Ridge Paper Products who assisted in the IAC assessment of their facility.

Without even one of you, this paper would not have been possible.

Table of Contents

List of Tables

Chapter 13 (cont)

Appendix

List of Figures

Chapter 1

The Background of NOx

Introduction

The term NOx is actually a shortened name for Nitrogen Oxides, which is a generic term that refers to a group of pollutant gases in which Nitrogen and oxygen combine to form stable oxides [1]. There are seven different compounds that fall under the umbrella of NOx (including intermediary forms of the oxides). Despite this, the Environmental Protection Agency (EPA) regulates only Nitrogen Dioxide (NO_2) as a representative from this group. This is done for multiple reasons. Nitrogen Dioxide is the most abundantly produced anthropogenic (man made) Nitrogen Oxide in the atmosphere, and it is generally considered that all Nitric Oxide (NO) produced in combustion will ultimately be converted into NO_2 [2]. Furthermore, NO_2 is not considered to be an important air pollutant in its own right, but it does react in the atmosphere to form acid rain, photochemical smog, and tropospheric ozone (O_3). In general, NOx gases are considered hazardous to both humans and the environment. Combustion, be it from mobile or stationary sources, is the leading cause of anthropogenic NOx production.

Types of NOx Gases and Their Properties

Nitric Oxide (NO)

Nitric Oxide is the major oxide of Nitrogen formed during the combustion process. It is odorless and absorbs light outside of the visible spectrum only, and thus is colorless as well. NO is considered almost completely insoluble in water (0.0006g/100g of water at 25° C). Most often it is formed from the interaction of the Nitrogen released from the fuel and the Oxygen present in the air used for combustion. In general the formation of NO is generated via a simple chemical mechanism.

$$N_2 + O_2 \leftrightarrow 2NO$$
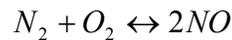
Depending on several factors including the thermodynamic and kinetic properties of the elements involved, as well as the flame temperature and gas flow rate through various temperature zones, the concentration of Nitric Oxide may vary from very minimal to several thousand parts per million (ppm) during combustion[1].

Nitrogen Dioxide (NO$_2$)

Nitrogen Dioxide is the second most abundant NOx gas formed during the combustion process. It possesses a pungent odor and is very corrosive. Unlike Nitric Oxide (NO), Nitrogen Dioxide absorbs light over a wide band of the visible spectrum and thus tends to vary from yellowish-orange to reddish-brown depending on the concentration. The higher the concentration of NO$_2$, the darker and richer its color appears. The concentration of Nitrogen Dioxide created during combustion also increases as the combustion temperature rises, just not as dramatically as that of NO.

If allowed to cool slowly from combustion temperatures to ambient atmospheric temperature, NOx produced in flame maintained equilibrium would revert almost completely back to molecular Nitrogen and Oxygen. No additional harmful compounds would be added to the air. Unfortunately, machines designed around combustion quickly channel the noxious gases through a turbine or some other device that utilizes the thermal energy supplied through combustion to do work. Doing this deprives the NOx of the energy necessary to return to their ambient states spontaneously. This leads the NOx gases to be "frozen out" at or near concentrations normally seen only at combustion temperatures. Even with this, the concentration of Nitrogen Dioxide in the flue gas is still considered relatively low at between six and ten ppm. The problem occurs when both Nitric Oxide and Nitrogen Dioxide are vented out the stack to atmosphere as exhaust fumes. Here the abundant Nitric Oxide undergoes oxidation (usually with atmospheric air) to produce the much more hazardous Nitrogen Dioxide (NO_2). The NO_2 reacts with sunlight and Volatile Organic Compounds (VOCs), to create such environmental and health hazards as photochemical smog, acid rain and tropospheric ozone. Coupling these known hazards of Nitrogen Dioxide with the fact that most NO is eventually converted to NO_2, the EPA issues its emissions standards not on the more combustion abundant NO but rather on the more atmospherically abundant and harmful NO_2.   The formation of Nitrogen Dioxide and the effects and regulations affecting it will all be addressed later in the paper[1].

Nitrous Oxide (N_2O)

Commonly known as laughing gas, nitrous oxide is a colorless gas that possesses a slightly sweet taste and odor. It has been used for years as an anesthetic in dentistry and

medicine. The majority of nitrous oxide gas found in the atmosphere is attributed to the

decomposition of Nitrogen compounds in the soil rather than through formation reactions

taking place in atmospheric conditions[1]. Nitrous oxide is non-flammable and bacteriostatic

(i.e. it stops bacteria from growing). N_2O is commonly used in the dairy industry as a mixing

and foaming agent. Due to its composition, Nitrous Oxide may also be used for increasing

horsepower in automobile engines. Since N_2O contains one atom of oxygen per molecule of

gas as opposed to air that contains 0.4 atom per molecule, combustion in gasoline engines is

aided by the use of nitrous oxide instead of atmospheric air[3]. In general, low concentrations

of N_2O are relatively harmless.

Nitrogen Trioxide [Symmetrical and Non- Symmetrical] (NO_3)

Generally, this oxide is considered an intermediate in other reactions, specifically the

oxidation of Nitrogen Oxide to Nitrogen Dioxide, and as such it is mainly considered a

hypothetical entity. As a transient species, the trioxides are usually found to be blue in color

and important to the formation of air pollutants[1].

Dinitrogen Trioxide [Nitrogen Sesquioxide] (N_2O_3)

Dinitrogen Trioxide is formed through the association of Nitric Oxide and Nitrogen

Dioxide. Under atmospheric conditions, equilibrium is established between this molecule

and the two formed through its dissociation.

$$NO + NO_2 \leftrightarrow N_2O_3$$

 In polluted air, the concentration of this molecule is far less than either NO or NO_2. As of

yet, no important role for Dinitrogen Trioxide has been found in atmospheric chemistry[1].

Dinitrogen Tetroxide (N_2O_4)

Dinitrogen Tetroxide is formed through the association of two Nitrogen Dioxide molecules. It too readily dissociates to establish an equilibrium with its forming moluclues.

$$2NO_2 \leftrightarrow N_2O_4$$
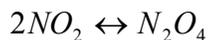
Unlike its composite gas, Nitrogen Dioxide, N_2O_4 absorbs light waves outside the visible spectrum and thus is colorless. Like Dinitrogen Trioxide, this compound has been found not to be of high concentration at atmospheric conditions, nor is it a valuable constituent in atmospheric chemistry. The concentrations of N_2O_3 and N_2O_4 in equimolar mixtures of NO and NO2 ppm are shown below to better identify the contributions of these two oxides in equilibrium with the know pollutants NO and NO_2[1].

Table 1. Theoretical Concentrations of N_2O_3 and N_2O_4 in Equilibrium with NO and NO_2 at 20°C [1]

NO	NO_2	N_2O_3	N_2O_4
Concentratrion, ppm			
0.05	0.05	1.3×10^{-9}	1.7×10^{-8}
0.10	0.10	5.2×10^{-9}	6.8×10^{-8}
0.50	0.50	$13. \times 10^{-7}$	1.7×10^{-6}
1.00	1.00	5.2×10^{-7}	6.8×10^{-6}

Dinitrogen Pentoxide (N_2O_5)

The formation of this oxide of Nitrogen is dependant on the association of the intermediary Nitrogen Trioxide and Nitrogen Dioxide, and is more favored at atmospheric conditions than symmetrical Dinitrogen Tetroxide or Dinitrogen Trioxide with concentrations around 10^{-4} ppm as a contributor to photochemical smog. N_2O_5 exists as a colorless gas and can react with water to form Nitric Acid[1].

Chapter 2

NOx Formation

Introduction

Over 90 percent of all anthropogenic Nitrogen Dioxide that enters the atmosphere is produced by combustion processes. It is generally accepted that about 60% of the NOx produced come from stationary sources, such as furnaces, while the other 40% percent is generated by mobile sources such spark ignition or automobiles. A more detailed breakdown of sources can be found in the table below.

Table 2. NOx Contributions From Various Sources[4]

Source	Thousands of Tons	Percent
Transportation	7,300	36.6
Fuel Combustion, Stationary Sources	11,680	58.5
Industrial Processes	660	3.3
Solid Waste Management	110	0.5
Miscellaneous	220	1.1
	19,970	100

In total these sources produced some 19,970 thousands tons of NOx in per a year. This tremendous amount is dwarfed by the almost 500 million tons of NOx commonly produced in the natural Nitrogen cycle. Even though this natural pattern creates a .001 ppm concentration of Nitrogen Dioxide in normal unpolluted tropospheric air, the compounds are hydrolyzed and precipitated out as Nitrates, and return back to the ground essentially as fertilizers[4]. Problems occurs when the natural concentrations are supplemented by

combustion emitted NOx and the intensity of pollutants reach dangerous levels which cannot be recycled back to the earth in non-hazardous forms. These situations are considered later in this paper for the specific situations of health related hazards as well as environmental concerns.

NOx Formation

There are three main NOx formation mechanisms that are important during combustion and after combustion. The mechanisms depend on the air/fuel ratio, chemical composition of fuel fired, and the temperature. Mechanisms used to describe the process of NOx formation require the description of the release of Nitrogen from the fuel, which includes both the rate of reaction and form in which the Nitrogen is accessible. The Nitrogen in coal is thought to occur primarily in aromatic ring structures, and is released at various rates depending on the coal particle size and the flame temperature. For fluidized bed combustors, the heating rates are typically 10^3-10^4 K/s and the peak temperatures are around 1100-1200K. Typical particle size for these devices are around 1-5 mm. Pulverized coal combusters on the other hand typically burn much smaller sized coal particles, around 1μm, and thus incinerate at peaktemperatures from 1700-1800 K with heating rates of 10^4-10^5 K/s. Studies have shown that Nitrogen release and thus NOx production is a function of both the increased heating rate and final combustion temperature, making pulverized coal boilers a greater source of NOx[5].

Thermal NOx

Thermal NOx production relies on the oxidation of Nitrogen found naturally in the atmosphere and takes place at relatively high temperatures in fuel-lean (that is abundant

excess air) combustion environments[5]. The mechanism for thermal NOx production was discovered by Zeldovich and is based primarily on two reactions.

$$N_2 + O \underset{k_{1-}}{\overset{k_{1+}}{\longleftrightarrow}} NO + N$$

$$N + O_2 \underset{k_{2-}}{\overset{k_{2+}}{\longleftrightarrow}} NO + O$$
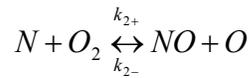
Here k_{1+}, k_{1-}, k_{2+}, and k_{2-} are the forward and reverse rate constants that govern the reaction. These equations show how one molecule of Nitrogen gas, N_2, reacts with an oxygen atom, found in the excess air present in combustion, to form one molecule of NO and a single Nitrogen atom. This Nitrogen atom can then react with molecular Oxygen gas, O_2, in the second reaction to form another NO molecule and a single oxygen atom which feeds the forward reaction of the first equation. In fuel rich combustion, there is often a third equation that is considered in the production of NO.

$$N + OH \underset{k_{3-}}{\overset{k_{3+}}{\longleftrightarrow}} NO + H$$
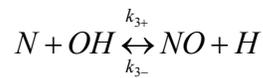
From these three equations it is possible to determine the rate at which NO formation occurs in this combustion process.

$$\frac{d[NO]}{dt} = k_{1+}[O][N_2] - k_{1-}[N][NO] + k_{2+}[O_2][N] - k_{2-}[NO][O] + k_{3+}[N][OH] - k_{3-}[NO][H]$$

This is a general form of the equation, but can be reduced by expressing variables in terms of each other. Specifically, it can be assumed that the monatomic Nitrogen concentration is constant. This is a normal measure when a species (Nitrogen) is present in very small amounts in comparison to a major species (Oxygen).

Thus:

$$\frac{d[N]}{dt} = k_{1+}[O][N_2] - k_{1-}[N][NO] + k_{2-}[NO][O] - k_{2+}[N][O_2] + k_{3-}[NO][H] - k_{3+}[N][OH]$$

Where

$$\frac{d[N]}{dt} = 0.$$

Thus

$$k_{1+}[O][N_2] + k_{2-}[NO][O] + k_{3-}[NO][H] = [N]\{k_{1-}[NO] + k_{2+}[O_2] + k_{3+}[OH]\}$$

which yields a final steady state concentration expression for Nitrogen of

$$[N]_{ss} = \frac{k_{1+}[O][N_2] + k_{2-}[NO][O] + k_{3-}[NO][H]}{\{k_{1-}[NO] + k_{2+}[O_2] + k_{3+}[OH]\}}$$

At this point it is possible to place this expression for Nitrogen concentration back into the original equation for NO formation to receive a complete and relatively simplified expression for the entire mechanism of thermal NOx production. Doing this produces:

$$\frac{d[NO]}{dt} = 2[O]\left\{\frac{k_{1+}[N_2] - \dfrac{k_{-1}k_{-2}[NO]^2}{k_2[O_2]}}{1 + \dfrac{k_{-1}[NO]}{k_2[O_2] + k_3[OH]}}\right\}, \text{ g mol cm}^{-3}\text{s}^{-1}.$$

In a combustion situation, the initial concentrations of both NO and OH are so low that only the forward reactions of the Zeldovich reaction are considered.

$$\frac{d[NO]}{dt} = 2k_{1+}[O][N_2] \text{ g mol cm}^{-3}\text{s}^{-1}$$

If there comes a time when the concentration of NO and OH molecules begins to overtake the concentration of O_2 molecule, which is unlikely, this assumption will no longer hold. This equation reflects the idea that for formation of NOx through the thermal

mechanism, only the concentrations of free Oxygen and molecular Nitrogen are important. At the flame temperatures usually experienced in pulverized coal boilers (i.e. < 1800 K) this mechanism for NOx formations is unimportant due to its extreme dependence on high temperatures to push the reaction. Likewise, the environment in PC boilers tends to be a fuel rich environment, which is lacking in free oxygen atoms and thus results in the dampening of the effectiveness of this mechanism[5].

Prompt NOx

Prompt NOx is NO formed through the reaction of atmospheric Nitrogen with hydrocarbons found in the fuel. The intake reaction produces a HCN functional group. This HCN molecule is then oxidized to form Nitrogen Oxide. The mechanism was first studied by Fenimore who described the following mechanism for this reaction.

The first step in the reaction involves the reaction of molecular Nitrogen with hydrocarbons.

$$N_2 + CH \leftrightarrow HCN + N$$

and

$$N_2 + CH_2 \leftrightarrow HCN + NH$$
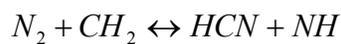
Next, HCN reacts with molecular oxygen to form a NO molecule

$$O_2 + HCN \leftrightarrow NO + COH \, .$$
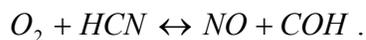
Since this mechanism requires the presence of a hydrocarbon to initiate the NO formation, it tends to be more prevalent in flames where fuel is abundant rather than in fuel-lean flames. Because of this, very little of the NO formed in normal combustion comes from this mechanism. However, with the fuel rich zones prevalent in pulverized coal combustion tends to promote prompt NOx formation.[5]

Fuel NOx

Fuel NOx if formed from the Nitrogen that is already bound into the fuel itself. Usually, it is assumed that the mechanism proceeds through the formation of HCN and NH_3, which are in turn oxidized with molecular Oxygen to form NO. Environments with high concentrations of O_2 form NO while environments with exceptionally high NO concentrations tend to form molecular Nitrogen N_2.

This fuel NOx mechanism is the dominant NO forming reaction in flames from fuels like coal that contains bound Nitrogen. Typically, some 75-80 percent of the NO formed in such flames are due to of one reaction sequence. Thus, by controlling the local environment of combustion means the possibility of controlling total NOx formation.

It is generally accepted that the formation of HCN from a portion of the fuel Nitrogen (α) occurs quickly and the remaining fraction of Nitrogen ($1-\alpha$) reacts slowly in the formation of NH_3. Thus the formation of fuel NOx may be seen in a schematic representation as below[5]. The lower reactions show the formation of NO and N_2 from fuel bound Nitrogen while the top reactions restate the reactions from thermal mechanisms.

Figure 1. Schematic of NO Reaction Process in Coal Systems [5]

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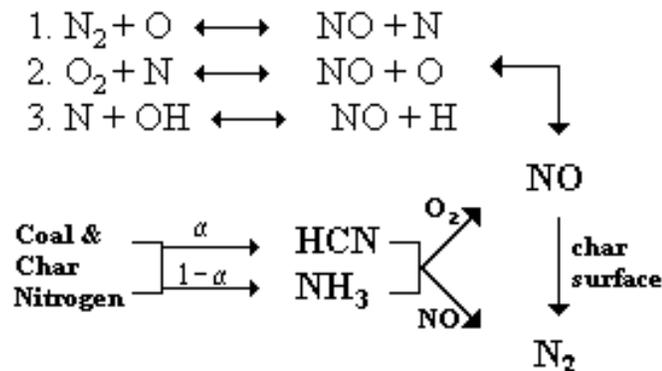
Chapter 3

NOx and the Influence on Ozone and Smog

NOx and Ozone

In addition to the hazards of Nitrogen Oxides themselves, an additional threat to public health and welfare exists because of the role that they play in the development of the pollutant ozone. Molecular ozone (O_3) resides in the upper level of the atmosphere and serves to protect the surface of the planet from the harmful ultraviolet rays that the sun emits. At the ground level (or troposphere) however, the physical effects of ozone are not only unhelpful, but to humans they can be deadly. In an attempt to alleviate the negative effects of this chemical, certain air quality standards have been established that affect not only ozone concentrations, but also its precursor, NOx.

The triple Oxygen molecule of ozone is typically formed when molecular Oxygen (O_2) reacts with another single Oxygen atom to form the larger O_3 molecule. NOx enters the picture as the donator of this single Oxygen atom. NO_2 is acted upon by sunlight and is dissociated into NO and O. These reactions occur as follows.

$$NO_2 + hv \rightarrow NO + O$$

and

$$O_2 + O + M \rightarrow O_3 + M$$
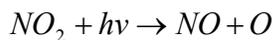
Where *M* is any inert, non-reacting molecule.

This newly formed NO and O_3 can undergo the reverse reaction to again form NO_2 and O_2 with no additional energy input from the sun.

$$O_3 + NO \rightarrow NO_2 + O_2$$
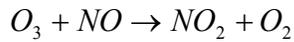
It would seem that equilibrium would be established in this cycle, and the concentration of ozone would stay relatively unchanged. Unfortunately, this is not the case. NO formed by the dissociation of NO_2 in the first reaction rapidly joins with the Volatile Organic Compounds (VOCs) in the atmosphere (which are also emitted from manufacturing plants) to reform NO_2. This prevents the decomposition of ozone and continuously feeds the first reaction causing the production of an increasing amount of ozone in the ground level atmosphere[6]. Legislation discussed later has been adopted in an attempt to reduce ozone and smog through the reduction of NOx. The basic idea of these laws is that by reducing NOx, specifically NO_2, the reaction series can be stopped before it even starts.

Chapter 4

Health Effects

Introduction

With considerable time and effort being put into legislation to reduce the amount of Nitrogen Oxides in the atmosphere, it is important to understand why such measures are being put into place. The presence of NOx, tropospheric Ozone, and their successor, smog, can lead to terrible health problems or even death in animals and humans. Though extensive studies have been conducted on the numerous types of pollutants derived from NOx and their effects on health, only a brief overview of these effects follows. An extensive study may be found in the Assembly of Life Sciences' Committee on Medical and Biologic Effects of Environmental Pollutants reference report[1] as well as in various other documents.

Effects of Nitrogen Oxide

Nitrogen Dioxide is the main NOx gas that has been found to cause health problems in humans. NO_2 has been shown to cause sensory problems as well as cardiovascular and pulmonary/cardiovascular difficulties. Adaptation to light and dark as well as odor detection has been affected with exposures to this gas. Similarly, chronic respiratory disease has been linked to high exposure to Nitrogen Dioxide. Currently, no conclusive results have stemmed from short term exposure tests[1]

Ozone

   While NOx has been linked to some health effects itself, more problems arise from its role in the development of ozone and smog. When ozone is inhaled, even small amounts of the gas may cause acute respiratory problems and aggravate asthma. In fact, it can inflame lung tissue and has been shown to decrease lung capacity in some otherwise healthy adults. Finally, ozone may suppress the immune defenses of body, which leaves victims susceptible to illnesses like bronchitis and pneumonia.

   Children are most at risk from exposure to ozone. As will be discussed later, NOx and ozone are summertime problems. During this time, active children are outside playing and exercising in neighborhood parks, on playgrounds, and at summer camps. In addition, children tend to breath more air than adults per pound. Finally, because children's respiratory systems are still developing as they grow, they are more susceptible than adults to these pollutants. Even in adults, prolonged exposure to ozone can lead to chronic respiratory illness and premature aging of the lungs.[20]

Chapter 5

Clean Air Act History

Historical Overview

From the 1940's to the 1970's, NOx emissions in the United States increased threefold. This increase resulted in an average on 24 million tons of uncontrolled emissions from a variety of sectors. Approximately one third of the NOx was (and still is) generated by utility boilers and another third came from road automobiles. The remaining third is composed of almost equal portions of non-road vehicles (earth movers, construction vehicles, etc.), industrial equipment (process heat burners and blast furnaces), and a various conglomerate of other sectors[7]. With the increase of emissions, it soon became evident that smog, especially in and around industrial cities, was also increasingly dramatically. In an attempt to combat this growing problem and hopefully stop the spread of pollution, local and state governments began developing and implementing legislation. In 1955 the federal government decided that the issue needed to be dealt with on a national level. In that year Congress passed the Air Pollution Control Act of 1955. This marked the first time air pollution was addressed by federal legislation.

The Air Pollution Control Act of 1955 was a self-described "Act to provide research and technical assistance relating to air pollution control". It granted some $5 million dollars a year for nine years (the original Act granted a five year funding period, and an amendment added an additional four years) to fund research to be conducted by the United States Surgeon General's Office on the effect of pollution on in the nation's health. In reality, the

Act did very little in combating pollution from a source. However it was successful in recognizing pollution as a national problem that posed a threat to the nation's health and welfare. The research was also responsible for introducing the idea that pollution can affect agriculture, livestock and personal property as well.

As public and governmental knowledge about pollution grew, new policies were soon needed that focusing on the prevention and/or reduction in hazardous emissions and air pollution were needed. In an attempt to provide at least a partial solution, The Clean Air Act of 1963 was born. The Act was designed to "improve, strengthen, and accelerate programs" that actively pursued solutions to the nationwide air pollution problem. Granting some $95 million dollars to state and local governments for the establishment of air control agencies, the Act encouraged the development of emissions standards for both motor vehicle exhaust and stationary sources. Special attention was paid to reducing harmful sulfur emissions caused by the combustion of certain fossil fuels like coal and oil. Research projects aimed at developing techniques to remove sulfur from fuels were also funded.

Throughout the 1960's, amendments and additions were added to the original Clean Air Act. In 1967, a major amendment know as the Air Quality Act (AQA) introduced two key ideas that govern air pollution control to this day. The first was the development of Air Quality Control Regions (AQCRs) as a means of monitoring ambient air masses around the nation. With these regions, the federal government was able to develop the first set of emissions standards for stationary sources such as utility boilers. These standards led to the development of the second major influence on current pollution control, the State Implementation Plans or SIPs. Despite much debate about a single national standard, the AQA placed the responsibility of meeting the pollution control standards back on the states

while supplying information about recommended control techniques and technologies. The CAA of 1963 with all of its amendments, proved to be a revolutionary step in the battle against pollution.

After the passage of four amendments in the last five years of the 1960's, Congress decided that simply continuing to amend the Clean Air Act from 1963 was not effective in accomplishing the goals set forth by this radical piece of pollution legislation. Thus, in 1970, the CAA was completely rewritten in an attempt to focus the direction of the law "to provide for a more effective program to improve the quality of the Nation's air." In the early 1970's, when pollution was as high as it had ever been in the United States, this meant attempting to protect the public's health by not only setting reduced standards for emissions from existing sources, but also strictly regulating the emissions from new sources. Motor vehicles also came under intense scrutiny as new standards were placed on motor vehicle emissions. The most innovative principle to come out of the CAA of 1970 was for citizens to take legal action against anyone who was in violation of their emissions limits, including not only large corporations but also the government itself.

The CAA of 1970 grew, and changed, and was amended, and even laid dormant for almost a decade as the United States past through the 1970's and into the 1980's. Finally, motivated by growing environmental concerns, Congress created the Clean Air Act of 1990. Deemed the "Act to amend the Clean Air Act"; this new version of an old favorite took aggressive measures toward seeking solutions to some of the nations biggest environmental concerns. The five main areas addressed were air-quality standards, toxic air pollutants, acid rain, stratospheric ozone depletion, and motor vehicle emissions. With an ambitious agenda the CAA granted the creation of new subcommittees which enacted a comparable number of

regulations. This last draft of the CAA is so comprehensive and widespread that its

standards, regulations and various offshoots still regulate air pollution in the United States

today[8].

Chapter 6

Clean Air Act of 1990

Clean Air Act of 1990 and Its Amendments

The Clean Air Act in its present form is broken down into six large sections:

- Title I - Air Pollution Prevention and Control
- Title II - Emission Standards for Mobile Sources
- Title III – General Air Toxins
- Title IV - Acid Deposition Control
- Title V – Permits
- Title VI - Stratospheric Ozone Protection.

A brief overview of the topics discussed under each title is presented below.

Title I: Air Pollution Prevention and Control

The main concern of the Clean Air Act is quite simply the quality of the air the population of the United States breaths and lives in on a daily basis. While great strides were made (prior to 1990) in the reduction of air pollutants like photochemical smog (caused by excessive tropospheric ozone), Carbon Monoxide, and particulate matter, over one hundred million people in the densely populated urban areas still lived with air pollution levels above set limits.

In general, the most widespread and persistent pollution problem is ground level ozone and the smog it causes. Under the 1990 CAA amendments, smog is being addressed

with a new, balanced strategy. The Act sets high expectations for pollution and emissions control, and again places the responsibility of reaching these lofty goals squarely upon the shoulders of the states. It requires the states to continually make a conscious effort to lower emissions (with the Federal government providing assistance through technical research and specialized monetary grants).

Specifically, Title I deals directly with the ambient air quality through the establishment of the NAAQS (National Ambient Air Quality Standards). As a part of this program the Act addresses and defines terms like "attainment" and "non-attainment" areas, and outlines the procedure for redesignation -- as the air quality in an area changes. It addresses the specific problem of ozone by establishing a procedure for ranking geographical areas as marginal, moderate, serious, severe, or extreme. Any area that doesn't meet the set air quality standard is designated as non-attainment, thus setting forth regulations that provide stringent requirements with which the areas must comply in order to meet the ozone standard.

As with any law, the regulations set forth must be regulated by means of sanctions for violators, and this too is outlined in the 1990 CAA. In general violators will be required to implement various control methods while continuously logging emissions and ozone quantities. Obviously, plants residing in areas with poor air quality may be requested to install more stringent control methods.

Title II: Emission Standards for Mobile Sources

Half of the emitted air pollutants come from mobile sources (i.e. cars and trucks). Consequently, the Act focused considerable attention on the reduction of hazardous toxins generated by automobiles. Title II notes that the rapid increase in the number of vehicles on the road coupled with the longer distances most cars travel per trip has greatly offset the previous automobile emission controls. Therefore the CAA of 1990 established even more stringent pollution controls for automobiles aimed at reducing vehicle emissions of hydrocarbons, Carbon Monoxide and most importantly Nitrogen Oxides.

To supplement these actions, the CAA of 1990 also imposed greater control on the quality of vehicular fuel while, at the same time, piloting a new clean fuel automobile program. Specifically, new "formulated" fuel types were specified for several cities where ozone has a problem since 1995. Automobile emissions for cars produced since 1996 have faced much more stringent emissions criteria in the state of California, with other states opting into the program voluntarily. These acts have had significant impact on organizations that employ fleets of cars for business purposes.

Title III: General Air Toxins

In Titles I and II, the CAA focuses primarily on reducing air pollutants that result from combustion. Title III, however, addresses those pollutants that may not be produced explicitly from a combustive process, but are just as damaging to the environment and to the population on a whole. It is estimated that some 1000 to 3000 carcinogenic deaths occur every year due to the 2.7 billion pounds of toxic pollutants produced in the United States. Because of this, the Clean Air Act established the so-called "Right to Know" rule (SARA

title 313) that requires the reduction of some 189 toxic air pollutants. These toxins include solvents like toluene and xylene, as well as consumer emitters like ammonia and sodium fluoride (found in toothpaste).   The rule also requires the publication of known source emitters based on their annual toxin production (i.e. a list of 10 tons/year, 25 tons/year, etc.)

The CAA also introduced the idea of the "Maximum Achievable Control Technology" that sets emissions standards for toxins, based on the sources ability to implement the best technology available on the market at that time (for that specific industry). The EPA passed regulations for some 40 different industries, so that the standards for sources in that industry are the same (i.e. one printing plant will meet the same standards as all the other printing plants).   Simply put, Title III provides for the control and monitoring of toxic substances that maybe just a harmful as NOx and CO, but are less likely to be physically observed.

Title IV: Acid Deposition Control

The National Ambient Air Quality Standards, established under Title I, define the role of Nitrogen Oxides and Sulfur Oxides in the production of ozone and smog for various regions of the nation. Title IV begins to focus on the role of these pollutants on the production of acid rain around the nation. The CAA seeks a 50 percent reduction in NOx and SOx emissions in two phases. The first phase, implemented in 1995, focuses on reducing the SOx emissions to 2.5 lbs /MMBTU (for 110 utility plants in the U.S). The second phase, enacted in 2000, affects approximately 2000 plants and requires another 50 percent reduction of SOx emissions (i.e. to 1.2 lbs SO_2/MMBTU). The implementation of

both Phase I and Phase II requires the installation of continuous monitoring systems in order to track the plants' progress and to ensure regulation compliance.

These new regulations allow plants to participate in allowance trading programs that afford utilities the opportunity to buy or sell allowances to and from other affected sources. That is to say, a utility that easily meets or exceeds the proposed standards could sell its extra allotted emissions units to other plants that may have a more difficult time meeting the imposed limit. This allows some plants to emit more pollutants while others may emit less, provided that the total emissions for all sources are kept below a total cap. It also allows plants to avoid the $2,000 per excess ton emissions fee imposed by the EPA and national government. Furthermore, if a state's emissions average remains below the 0.8lb/ton limit, additional allowances may be awarded to plants to allow for expansion.

Along with the sulfur oxide regulations, Title IV also imposes limits on the production and release of Nitrogen oxides. These standards were enacted in 1992 for some boilers, but by 1997 all boilers in operation were brought under emissions regulations. Specific regulations and limits will be considered later.

Title V: Permits

With all the new regulations enacted through the Clean Air Act, a system had to be established to ensure compliance and to give the EPA a way to enforce the laws. This may have been the most important addition to CAA of 1977. It allowed the national government to install and enforce a national standard and program if states fail to implement their own. The Title outlines procedures for applying for a permit, length of time permit will be

effective, and how long the EPA has to accept or reject the permit request, as well as other administrative procedures.

Title VI: Stratospheric Ozone Protection

Despite the fact the ozone in the troposphere (ground level air we breath) is considered extremely harmful to anyone breathing the substance, ozone in the stratosphere (upper atmosphere) serves to protect the Earth from the harmful effects of the sun. Title VI seeks to eliminate any substance that may lead to the depletion of ozone in the upper atmosphere. Chlorofluorocarbons (CFCs) and halons are specific concerns. Title VI proposes the staged phasing out of these substances, with complete elimination occurring by 2030. The CAA also establishes the need for a list of all hazardous and non-hazardous Class I and Class II chemicals, and bans the continued use of hazardous chemicals[9].

Chapter 7

Clean Air Act and NOx

Pollution Regulations and NOx

With literally volumes of information contained in and published on the Clean Air Act and all of its corresponding legislation, it is important to establish a good background on the history of the regulations as well as a basic understanding of the vast depth and breadth of this Act. With this information, it is possible to investigate the limitations and regulations the Clean Air Act imposes on the emission of the oxides of Nitrogen (which in turn affects the production of troposhperic ozone and photochemical smog) from large stationary sources like utility boilers and large industrial boilers.

The Clean Air Act and NOx

In The Clean Air Act Amendments of 1990, Congress based the need for more advanced air pollution regulations on four major findings. These conclusions may be simply stated as:

1. Most of the nation's population can be found in rapidly expanding urban and metropolitan areas that may extend over multiple states.

2. This population growth has caused an increase in air pollution that has the potential to pose hazards to public health, the environment, and to property and livestock, as well.

3. State and local governments, not the Federal government, will ultimately be held responsible for the prevention and reduction of the afore mentioned pollution.

4. The Federal Government must provide leadership and financial assistance for the establishment of programs to control and prevent air pollution.

With the need for a solution to the ever advancing problem of air pollution as described above, Congress revised the Clean Air Act in 1990 to accomplish the following goals found in section 101 of the CAA.

1. The quality of the Nation's air must be protected and even enhanced so that the health and welfare of the people are protected.

2. Research into solving the air pollution problem must be accelerated. Programs must be developed to prevent and control air pollution.

3. The Federal Government will supply financial and technical assistance to the States to promote the execution of their pollution control and prevention programs.

4. The Act will promote the development of regional air pollution prevention and control programs[9].

Though the goals of the Act seem reasonably straightforward and easy to meet, the enormous size of the air pollution problem makes attacking it a formidable task. By narrowing the scope of the problem of air pollution from all toxic airborne substances to just NOx (and ozone formed from the emission of NOx), it is possible to focus on just four sections of the CAA. Sections 107-110 outline the development of the National Ambient Air Quality Standards (NAAQS) and State Implemented Plans (SIPs), the two major programs involved in the battle against Nitrogen oxide emissions.

CAA: Sec 107

Section 107 of the Clean Air Act begins with the establishment of the idea of air pollution control regions as well as clarifying the role of the "State" as it pertains to air pollution. Section 107 asserts that a state will be responsible for assuring air quality within the geographic boundaries of the state through the submittal of an implementation plan that meets the national primary and secondary ambient air quality standards. It gives the states, through gubernatorial submission and EPA approval, the ability to designate geographical regions that will fall under the attainment guidelines of air quality regulations. Each area of the state is to be classified in one of three ways.

1. Non-attainment: any area that does NOT meet the primary or secondary air quality standards for the pollutant (NOx).

2. Attainment: any area that meets both the primary or secondary air quality standards for the pollutant (NOx).

3. Unclassifiable: any areas that cannot be found to either meet or exceed the primary or secondary standards for the pollutant (NOx) (based on current information).

The section goes on to describe the ability and requirement of the governor to redesignate areas based on their current compliance with emissions standards. Although NOx is not explicitly mentioned in this section, it is understood that NOx is a major player in the formation of ground level ozone. Therefore any regulation imposed on the concentration of ozone in the atmosphere will ultimately effect the emission of NOx as well.

Section 107 begins to lay the groundwork for controlling ozone. It explicitly lists the substance as one for which the state must classify regions as attainment or non-attainment (based on compliance with air quality standards). Lead and particulate matter (PM-10) are

also mentioned, but it is ozone that is of direct concern to those states that producing large quantities of Nitrogen Oxides[9].

CAA: Sec 108 and 109

Sections 108 and 109 develop the idea of a National Ambient Air Quality Standard (NAAQS). These sections state that the Administrator (Director of the EPA) shall issue air quality criteria for a pollutant that the "emissions of which, in his judgment, cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare."[9] These criteria, as well as techniques to control the emissions, are to be published in the national register and are to be made public record. Ultimately, it is Section 108 that establishes that need for a certified and explicit NAAQS. Section 109 begins to outline specific definitions for primary and secondary air quality standards.

Section 108 also allows for continuous review and modification for the reissuance of "criteria for" or "information on" control of known pollutants. Specifically, the code states that the criteria relating to NO_2 must be revised and reissued. "Such criteria shall include a discussion of Nitric and Nitrous Acids, Nitrites, Nitrates, Nitro Amines, and other carcinogenic and potentially carcinogenic derivatives of oxides of Nitrogen."[9]

CAA: Sec 110

Section 110 of the Clean Air Act introduces the idea of State Implemented Plans (SIPs). The plans are to be designed and enforced in such a fashion that upon implementation, all areas, attainment and non-attainment alike, will meet the criteria set forth in the NAAQS.

As prescribed in Section 110 a2, each SIP shall:

1. Include limitations on emissions that can be enforced so as to ensure compliance with the appropriate air quality standards.

2. Establish a way to monitor compliance and collect data that may be requested by the administrator.

3. Require any new source to be in compliance with NAAQS (upon completion of construction)

4. Require that all facilities be properly maintained to ensure constant compliance with the NAAQS and periodic reporting of results.

5. Provide for revision of each plan to reflect improved technologies and more stringent air quality standards.

6. Provide for adequate air quality modeling that accurately predicts how air quality standards will affect stationary sources.

Section 110 also provides rules and standards for the revision of SIPs. It also outlines the requirements for plans as they relate to mobile sources. Initially, it was determined that "State[s] shall adopt and submit to the Administrator…within 3 years… after the promulgation [i.e., publication] of a National Ambient Air Quality Secondary Standard … a plan [that] provides for implementation, maintenance, and enforcement of such secondary standard in each air quality control region within such State."[9] More recently, updated regulations have extended deadlines for review and compliance of certain parts of many states' SIP. These cases will be discussed later.

Chapter 8

National Ambient Air Quality Standards

The National Ambient Air Quality Standards

As prescribed in Sections 107-109 the Clean Air Act of 1990, the Environmental Protection Agency published a set of guidelines for air pollution regulations known as the National Ambient Air Quality Standards. On July 18, 1997 the EPA issued an update of the rules based on a periodic review (as required in Section 109 of the CAA). This updated version of the NAAQS specifically targets the standards for ozone and its transport from region to region across the nation. Since NOx plays a major role in the formation of tropospheric ozone, any new limits on ozone directly affect the emissions on Nitrogen oxides. In fact, these new ozone limits (in the NAAQS) eventually led to the development of legislation known as the NOx SIP Call. This new ruling requires 22 different states to spend millions of dollars to adhere compliance**.**

Primary verses Secondary Standards

Section 109 of the Clean Air Act requires that primary and secondary air quality standards be established as a part of the NAAQS. The primary standards are defined as ones that "the attainment and maintenance of which in the judgment of the Administrator based on

[the] criteria and allowing an adequate margin of safety, are requisite to protect the public health."[9] in section 109 of the CAA.   Simply put, primary standards are required to protect the public health to a level that the Administrator sees fit. These standards are not intended to be set at a zero risk level. In fact, the standards are allowed to have a certain amount of latitude ("margin of safety") built into them, that allows for new discoveries in research for hazards that are already known to exist, as well as those not defined at the time of publication[10].

Secondary standards were developed to protect public welfare, as contrasted to primary standards that focused on public health. Secondary standards as stated in section 109 of the CAA are "specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator, based on [the] criteria, [are] requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air."[9] Where public health may be thought of as observable physical and medical effects on the population or any portion thereof, public welfare may also include effects on wildlife, agriculture, deterioration of property, and personal comfort and well-being.

The New Standards

Until the revisions of the NAAQS, both the primary and secondary standards for ozone in ambient air for any region were set at a level of 0.12 ppm time averaged over 1-hour. That is to say, the average of the concentration of ozone is not to exceed 0.12 ppm for any 1-hour period throughout the day. Furthermore, when averaged over any three consecutive years, only 1 day a year may exceed the 0.12 ppm standards. In 1996, the EPA

announced that it would revise these standards to more accurately reflect the most recent

research developments, as well as the current public opinion. The EPA solicited over 50,000

written and verbal comments regarding the limits of the primary standards. Taking into

consideration the comments collected by the agency as well as research on the subjet, the

EPA developed a new set of standards that imposed greater limitations on the concentration

of tropospheric ozone in the atmosphere in 1997.

The afore mentioned 1-hour primary standard was soon replaced with a much stricter

regulation of 0.08 ppm over an average of 8-hours over a three-year period. This means that

"when the 3-year average of the annual third-highest daily maximum 8-hour average [ozone]

concentrations is less than or equal to 0.08 ppm" at an ambient air quality measuring station,

the standard is met. It was found that exposure to 0.08 ppm for up to 8-hours actually causes

less health effects than exposure to 0.12 ppm for even as short a time as 1-hour (not to

mention the fact that the 8-hour average was also believed to reduce both the 1-hour and 8-

hour ozone concentrations)[10].

As for the secondary standard, a few possibilities were considered as substitutes to the

existing 1-hour standard. The new rule would either be set at the same level as the primary

standard (just as it had been in the past) or it would be expressed as a sum of hourly ozone

concentrations over 12-hours during just the ozone season. After considerable investigation

and public input, the administration decided to opt for implementing a secondary standards

that is identical in all respects to the newly adopted primary standards (i.e. 0.08 ppm over a

8-hour average). It was determined that setting the secondary standard at this level will

substantially improve protection to vegetation while allowing time for additional research

into the development of a more complete rural ambient air quality standard. It was decided

33

that the small benefit to public welfare that would be experienced by implementing a

seasonal standard would not be significant enough to impose such a standard on the nation as

a whole[10].

Chapter 9

NOx and Ozone Transport

NOx and Ozone Transport

As a major part of the 1990 amendments to the Clean Air Act, sections 126, 184, and 176A were added in an attempt to define and investigate the phenomenon known as ozone transport. In these amendments, EPA acknowledges that NOx and the subsequent ozone it helps form may be transported via wind and air flow patterns to areas far away from the emission source. Because of this, states that are downwind from areas that are heavy NOx emitters will repeatedly experience elevated ozone concentrations regardless of the local attempts to reduce NOx (and thus ozone). To help study the effects of this regular environmental occurrence, the EPA established the OTC (Ozone Transport Commission). The Commission not only studied the problem of ozone transport in the northeast, but it was also charged with establishing Ozone Transport Regions (OTR) in other parts of the country, as well.

Notwithstanding substantial measures by the states in the northeast, it was found that due to the inability to address the ozone transport from upwind states, the states downwind were unable to meet the standards set forth in their own State Implemented Plans. In March of 1995, Mary D Nichols, Assistant Administrator for Air and Radiation for the United States EPA, published a memorandum addressing the issue of recurring ozone non-attainment for

areas in the northeast. In it, the EPA recognized "the efforts made by States [as well as] the remaining difficulties in making the ROP [rate of progress] and attainment."[11]   This memorandum went on to lay the groundwork for legislation that would eventually recall the SIPs from 22 States and Washington, D.C. and then impose more stringent requirements. The State Implementation Plans outlined in section 110 of the Clean Air Act requires that states establish reasonable limits for emissions that would be approved by the EPA on a national level, These were implemented in the early 1990s.

On October 27, 1998 the EPA published a ruling that required the submittal of revisions to the SIPs for the states of Alabama, Connecticut, Delaware, Georgia, Illinois, Indiana, Kentucky, Massachusetts, Maryland, Michigan, Missouri, North Carolina, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, West Virginia, Wisconsin, and the District of Columbia. The revisions were aimed at reducing the amount of ozone transported across state lines for the entire eastern half of the United States. It was found that every one of these states contributed significantly to the non-attainment of one or more of the states downwind of it as prescribed by the NAAQS. The following tables show the downwind states affected by the emissions of each of the 22 states for either 8-hour or 1-hour attainment[11].

Table 3. Downwind States to Which Sources in Upwind State Contribute Significantly for the 8-hour NAAQ Standard[11]

Upwind State	Downwind States
Alabama	GA, IL, IN, MI, TN, WI
Connecticut	ME, MA, NH
Delaware	CT, ME, MA, NH*, NJ, NY, PA, RI, VA
Georgia	AL, TN
Illinois	CT, IN, MD, NJ, NY, MI, MO, WI
Indiana	CT, DE, DC, IL, KY, MD, NJ, NY, MI, OH, VA, WI
Kentucky	AL, CT, DC, GA, IL, IN, MD, MI,NJ, NY, MO, OH, VA, WI
Maryland	CT, ME, MA, NH, NJ, NY, PA, RI, VA
Massachusetts	ME, NH
Michigan	CT, DC, MD, NJ, NY, VA
Missouri	IL, IN, MI, WI
New Jersey	CT, ME, MA, NH, NY, PA, RI
New York	CT, ME, MA, NH, NJ, RI
North Carolina	CT, DC, GA, KY, MD, NJ, NY, OH, PA, VA
Ohio	CT, DE, DC, KY, MD, MA, NH, NJ, NY, PA, RI, VA
Pennsylvania	CT, DE, DC, ME, MD, MA, NH, NJ, NY, RI, VA
Rhode Island	ME, MA, NH
South Carolina	AL, GA, TN
Tennessee	AL, GA, IL, IN, KY, MI, OH, WI
Virginia	CT, DE, DC, KY, MD, MA, NH, NJ, NY, PA, RI
West Virginia	CT, DE, DC, MD, MA, NJ, NY, PA, RI, VA
Wisconsin	IL, IN, MI
Distric of Columbia	CT, ME, MA, NH, NJ, NY, PA, RI, VA

Table 4. Downwind States to Which Sources in Upwind State
Contribute Significantly for the 1-hour NAAQ Standard[11]

Upwind State	Downwind States
Alabama	GA, IL, IN, KY, MI, MO, NC, OH, PA, SC, TN, VA
Connecticut	ME, MA, NH, RI
Delaware	CT, ME, MA, NH, NJ, NY, PA, RI, VA
Georgia	AL, IL, IN, KY, MI, MO, NC, SC, TN, VA
Illinois	AL, CT, DC, DE, IN, KY, MD, MI, MO, NJ, NY, OH, PA, RI, TN, WV, WI
Indiana	DE, IL, KY, MD, MI, MO, NJ, NY, OH, PA, TN, VA, WV, WI
Kentucky	AL, DC, DE, GA, IL, IN, MD, MI, MO, NJ, NY, NC, OH, PA, SC, TN, VA, WV, WI
Maryland	CT, DE, DC, ME, MA, NH, NJ, NY, PA, RI, VA
Massachusetts	ME, NH
Michigan	CT, DC, DE, MD, MA, NJ, NY, OH, PA, WV
Missouri	IL, IN, KY, MI, OH, PA, TN, WI
New Jersey	CT, ME, MA, NH, NY, PA, RI
New York	CT, ME, MA, NH, NJ, PA, RI
North Carolina	AL, CT, DE, GA, IN, KY, ME, MD, MA, NJ, NY, OH, PA, RI, SC, TN, VA, WV
Ohio	CT, DC, DE, IN, KY, MD, MA, MI, NJ, NY, NC, PA, RI, TN, VA, WV
Pennsylvania	CT, DC, DE, ME, MD, MA, NH, NJ, NY, OH, RI, VA
Rhode Island	ME, MA, NH
South Carolina	AL, GA, IN, KY, NC, TN, VA
Tennessee	AL, DC, DE, GA, IL, IN, KY, MD, MI, MO, NC, OH, PA, SC, VA, WV, WI
Virginia	CT, DE, DC, ME, MD, MA, NJ, NY, NC, OH, PA, RI, SC, WV
West Virginia	CT, DC, DE, IN, KY, MD, MA, NJ, NY, NC, OH, PA, RI, SC, TN, VA
Wisconsin	MI
Distric of Columbia	CT, ME, MD, MA, NH, NJ, NY, PA, RI, VA

To illustrate the point ability of NOx and ozone to be transported across state lines
and to observe a visual interpretation of this phenomenon, the following animated graphic is
presented. There are three major trends that can be easily observed from this animation.
First, notice how the ozone concentrations begin to increase starting within some of the afore
mentioned states (specifically, Georgia, South Carolina, North Carolina, Tennessee, Illinois,
and Wisconsin) and as the days pass, the northeast United States begins to become infected
and polluted as the air flow carries the ozone to that region. The second animation illustrates
how the jet stream tends to stagnate over areas that are high NOx emissions areas. The red

area on the map designates high emissions areas, and the arrows demonstrate airflow patterns. Notice how that air swirls in areas (like the Appalachian Mountains) where NOx concentrations are high. The third and final animation helps to demonstrate how the wind transports the ozone from one area of the country, over State borders, into another area consisting of different states. This animation helps clarify the EPA's stand point on the need for reduction in NOx and ozone transport, and thus NOx emissions[11]. Simply click on the screen shot below to begin the animation.

Figure 2 NOx Animation [12]
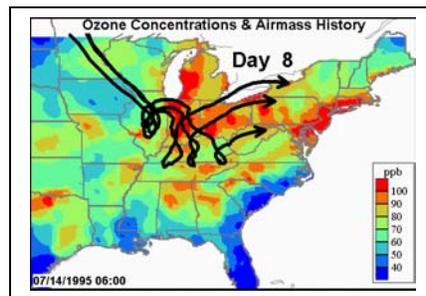
The proposed ruling required that each of the 22 states involved in ozone transport report their emissions for a full year as well as "the ozone season".   This latter term identifies those months for which the ozone and thus its transport is the highest. The ozone season was defined as being from May 1 to September 30. These summer months are typically times when electrical demand is highest (because of a high air conditioning equipment load). This increase in electrical demand requires utility boilers to generate more electricity, thus requiring more fuel combustion, and consequently more NOx and higher ozone levels (either in the local area, or often times, in downwind states.)

For the purpose of defining the total NOx budget, this ruling allowed states to define different emission values for the different types of units. It also set up different standards for

determining the limits depending on the size of the boiler. For budget purposes, the NOx

allowed each Electric Generating Unit (EGU) to produce 0.15 lb of NOx /mmBtu.. Heat

input data calculated in 1995 and 1996 served as the baseline heat input rates for the federal

register. For non-EGU sources, the limits used were as follows:

- 60 percent reduction from uncontrolled emissions for boilers and turbines

- 90 percent reduction from uncontrolled emissions for stationary internal combustion
  engines

- 30 percent reduction from uncontrolled emissions for cement manufacturing plants

These values were used to define a total annual NOx emissions budget for the states[11].

Using these measures an overall budget for each state was calculated. The results are given

in Table 5 below.

Table 5. Final NOx Base, Budget, and Percent
Reduction by State[13]

	Final Base for EGUs Final Budget tons/season	Final Budget for EGUs tons/season	Final Base for non-EGU Pt. Sources tons/season	Final Budget for non-EGU Pt. Sources tons/season	Total Final Base All Affected Sources tons/season	Total Final Budget all Affected Sources tons/season	Total Reduction Reduciton All Affected Sources tons/season	Total Reduction All Affected Sources % tons/season
Alabama	76,900	29,051	49,781	37,696	126,681	77,108	49,572	39%
Connecticut	5,600	2,583	5,273	5,056	10,873	8,198	2,675	25%
Delaware	5,800	3,523	1,781	1,645	7,581	5,585	1,996	26%
Washington DC	0*	207	310	292	310	499	-189	-61%
Georgia	86,500	30,255	33,939	27,026	120,439	68,199	52,240	43%
Illinois	119,300	32,045	55,721	42,011	175,021	91,511	83,509	48%
Indiana	136,800	49,020	71,270	44,881	208,070	113,639	94,431	45%
Kentucky	107,800	36,753	18,956	14,705	126,756	64,476	62,280	49%
Maryland	32,600	14,807	10,982	7,593	43,582	26,062	17,520	40%
Massachusetts	16,500	15,033	9,943	9,763	26,443	25,081	1,363	5%
Michigan	86,600	28,165	79,034	48,627	165,634	92,151	73,483	44%
Missouri	82,100	23,923	13,433	11,054	95,533	45,445	50,088	52%
New Jersey	18,400	10,863	22,228	19,804	40,628	32,389	8,238	20%
New York	39,200	30,273	25,791	24,128	64,991	56,232	8,759	13%
North Carolina	84,800	31,394	34,027	25,984	118,827	68,002	50,826	43%
Ohio	163,100	48,468	53,241	35,145	216,341	106,560	109,781	51%
Pennsylvania	123,100	52,000	73,748	65,510	196,848	131,226	65,622	33%
Rhode Island	1,100	1,118	327	327	1,427	1,445	-18	-1%
South Carolina	36,300	16,290	34,740	25,469	71,040	46,821	24,219	34%
Tennessee	70,900	25,386	60,004	35,568	130,904	73,047	57,857	44%
Virginia	40,900	18,258	39,765	27,076	80,665	51,441	29,224	36%
West Virginia	115,500	26,439	40,192	31,286	155,692	74,662	81,030	52%
Wisconsin	52,000	17,972	22,796	17,973	74,796	42,662	32,134	43%
Total	1,501,800	543,825	757,281	558,618	2,259,081	1,302,443	956,638	42%

The key to understanding what this data means to each state lies in the knowing the intention the EPA has for developing such numbers. The purpose of these budgets is to define the total annual NOx emissions for an enforced state. It is then up to the individual states to define which sources must be regulated and by how much. It is believed that electric utility boilers, large industrial boilers, and large combustion turbines will bear the brunt of the required reductions. Though the ruling defines that all limits must be met for the ozone season of 2007, all sources affected by the ruling will need to have control measures in place by May 1, 2003. To fully understand how each state handles these limits, it is necessary to examine the new SIP for each individual state.

Chapter 10

North Carolina State Implementation Plan

With the announcement of the new rule concerning the emissions of NOx and the restrictive budget placed on the designated 22 states (and Washington, D.C.), the states were forced to define which facilities were and were not to be included in the new regulations. As anexample of how theses regulations can affect a manufacturing facility, this study examines at the implementation plan (SIP) for the State of North Carolina, and how it affects a large paper plant in the western parts of the state.

North Carolina SIP

North Carolina's laws regarding emissions and air quality (especially as they pertain to the NOx SIP Call) are a matter of public record and can be found in the North Carolina Register as Rule 15A NCAC 02D sections .1401 to .1423. In this rule, North Carolina defines the types of sources that are to be regulated, identifies specific facilities, and appropriates the allowed emissions for these facilities during the ozone season.

The ozone season is defined as the periods between May 31 and September 30 for the year 2004, and May 1 through September 30 all years thereafter. The code characterizes facilities and sources depending on the size and function of the affected sources they include.

In doing so it also explicitly lists the individual sources that fall under each specific heading. These categories and sources, as they are defined and listed by the State of North Carolina, may be found in the following sections.

Electrical Utilities

Upon final revision and approval by the EPA, the State of North Carolina has classified the following facilities as Electrical Utilities. Both Duke and Carolina Power and Light have facilities the fall under this category.   The following CP&L facilities are affected.

Table 6. CP&L Electric Utilities[14,15]

CP&L Coal Fired Facility	Location
Asheville	Buncombe County
Cape Fear	Chatham County
Lee	Wayne County
Mayo	Person County
Roxboro	Person County
L V Sutton	New Hanover County
Weatherspoon	Robeson County

For all the facilities listed above, the State of North Carolina has set the following limits on emissions from all coal boilers and combustion turbines at those facilities to:

(A) 12,019 tons per season in 2004;

(B) 15,024 tons per season in 2005;

(C) 11,320 tons per season in 2006 and each year after that;

Duke Power's facilities were similarly restricted. Their facilities emissions totals from all coal boilers and combustion turbines are restricted to

(A) 17,816 tons per season in 2004;

(B) 22,270 tons per season in 2005;

(C) 16,780 tons per season in 2006 and each year after that;

for all facilities listed below.

Table 7. Duke Power Electric Utilities[14,15]

Duke Coal Fired Facility	Location
G G Allen	Gaston County
Belews Creek	Stokes County
Buck	Rowan County
Cliffside	Cleveland County
Dan River	Rockingham County
Marshal	Catawba County
Riverbend	Gaston County

For each facility listed above the State has named each point affected and allocated specific NOx emission limits that apply specifically to that source. For a complete listing of sources by facility and of the allocated NOx emissions for said sources please see the table in Appendix A-1 and A-2[14,15].

Non-Utility Electrical Generating Units

This category includes large stationary boilers, combustion turbines and combined cycle systems whose main purposes are:

(i)   to produce electricity (nameplate rating in excess of 25 MW)

(ii)   to sell some of the electricity generated, and

(iii)   to not be listed with the Duke and CP&L facilities.

The following units meet these criteria and are thus categorized as Non-Utility Electrical

Generating Units.

Table 8. Non-Utility Electrical Generating Units[14,15]

Facility Name	Location
Butler Warner Generating	Cumberland County
Cogentrix-Rocky Mount	Edgecombe County
Cogentrix-Elizabethtown	Bladen County
Cogentrix-Kenansiville	Duplin County
Cogentrix-Lumberton	Robeson County
Cogentrix-Roxboro	Person County
Cogentrix-Southport	Brunswick County
Duke Power	Lincoln County
Halifax-Rosemary	Halifax County
Roanoke Valley	Halifax County
RJ Reynolds Tobbaccoville Facility	Forsyth County
UNC-CH	Orange County
CP&L, Lee Plant	Wayne County
Dynegy	Rockingham County
CP&L Woodleaf	Rowan County
CP&L Mark's Creek	Richmond County
CP&L Asheville	Buncombe County

For a complete listing of sources by facility and of the allocated NOx emissions for

said sources please see the table in Appendix A-3.[14,15]

Affected Non-EGU

Fossil fuel fired industrial boilers, combustion turbines, and combined cycle systems

(not generating electricity for sale) with a maximum design heat input greater than 250

million Btu per hour, are classified as Non-EGUs (Electrical Generating Units). Large paper

plants with large steam loads typically fall under this heading. The following units meet these criteria and are thus categorized as Affected Non- Electrical Generating Units.

Table 9. Affected Non-EGUs[14,15]

Facility Name	Location
Weyerhaeuser Paper Company	Martin County
Blue Ridge Paper Products	Haywood County
International Paper Corporation	Halifax County
Weyerhaeuser Company, New Bern Mill	Craven County
International Paper	Columbus County
Fieldcrest-Cannon, Plant 1	Cabarrus County

A complete listing of budgeted NOx for these facilities is also available in the Table A-4 in the appendix[14,15].

Internal Combustion Units (ICUs)

Large ICUs are regulated under the North Carolina NOx SIP approved in November of 2001. Point sources are classified as ICUs if they meet any of the following characteristics:

1. Rich burn stationary internal combustion engines rated at equal to or greater than 2,400 brake horsepower,

2. Lean burn stationary internal combustion engines rated at equal to or greater than 2,400 brake horsepower,

3. Diesel stationary internal combustion engines rated at equal to or greater than 3,000 brake horsepower, or

4. Dual fuel stationary internal combustion engines rated at equal or to greater than 4,400 brake horsepower

46

Examples if units that fit into these categories are:

Table 10. Large Internal Combustion Units[14,15]

Facility Name	Location
Transcontinental Gas Pipeline Company, 160	Rockingham County
Transcontinental Gas Pipeline Company, 150	Iredell County
Transcontinental Gas Pipeline Company, 155	Davidson County

NOx Emissions during Non-Ozone Season

The EPA as has approved the above classifications and regulations as satisfactory as a part of the North Carolina SIP during the ozone season. However, until their implementation in May 2004 and during all times not classified as ozone season [from October 1 to April 30 (May 30 when applicable) after 2004] North Carolina rule 15A NCAC 2D .0519 remains in effect. A copy of this ruling may be found in Appendix A-5.

Chapter 11

Case Study: Blue Ridge Paper

Background

As a part of a United States Department of Energy Program, the Industrial Assessment Center (IAC) at North Carolina State University conducted an energy assessment of Blue Ridge Paper Products in Canton, NC beginning on May 22, 2001. The main objective of this assessment was to identify and quantify process savings by maximizing energy efficiency, reducing waste, and improving productivity. One goal of the assessment was to evaluate the five coal-fired boilers at Blue Ridge Paper from an Energy Efficiency and NOx reduction point of view. By utilizing the data taken and analyzed by Dr. Herb Eckerlin, Dr. James Leach and members of the IAC staff from NC State University, it is possible to gain a better understanding of:

1. How a manufacturing facility in full operation is affected by the NOx SIP Call and

2. The scale of the improvements necessary to bring a facility into complete compliance of the North Carolina SIP.

The Units

Blue Ridge Paper has five coal-fired boilers on site to supply the plant with steam for co-generation and process purposes. The coal fuel for these boilers costs the plant approximately 14.8 million dollars a year. The following tables gives some key information

concerning the type and amount of coal fired on site in a year and some background information concerning the boilers themselves.

Table 11. Boiler Fuel Usage Information[16]

Boiler No.	1	2	3	4	5
Boiler Name	"Big Bill"	"Peter G"	3Riley Coal	CE	Riley Bark
Coal Type	13	13	15	32	33
	nut & slack	nut & slack	nut & slack	low sulfur	stoker
Heating Value — BTU/lb	13,035	13,035	13,035	13,014	13,493
Fuel Fired — tons/yr	70,071	70,071	93,427	114,939	54,447
Fuel Fired — MMBTU/yr	1,826,751	1,826,751	2,435,642	2,991,632	1,469,307
Fuel Cost — $Million/yr	2.484	2.484	3.312	4.287	2.223
Percent of Total Cost — %	16.80%	16.80%	22.40%	29.00%	15.00%

Table 12. Boiler Specifications[16]

Boiler No.	1	2	3	4	5
Boiler Name	"Big Bill"	"Peter G."	Riley Coal	CE	Riley Bark
Manufacturer	Heine	Heine	Riley	CE	Riley
Type	watertube	watertube	watertube	watertube	watertube
Year of Manufacture	1928	1929	1945	1986	1955
Type of Firing	tangential	tangential	front fired	tangential	stoker
Rated Steam Flow, lb/hr	250,000	250,000	280,000	400,000	200,000
Outlet Steam Conditions	700°F 400 psig	700°F 400 psig	700°F 400 psig	700°F 400 psig	700°F 400 psig
Final Heat Traps	Economizer, Tubular Air Heater	Economizer, Tubular Air Heater	Tubular Air Heater only	Economizer, Tubular Air Heater	Economizer, Tubular Air Heater

49

Boiler NOx Production

With almost 403 thousand tons of coal being burned in the five boilers, this facility generates some 10.5 million MMBTU every year in the burning of coal. The pure size and age of the boilers themselves subjects the units to situations like excess air in combustion and carbon in the fly ash which all work together in increasing the amount of NOx found in the emissions from the boilers. Furthermore, none of the units currently have any NOx control measures installed on them. Because of this, the NOx emissions for these units typically average around 3,900 tons of NOx per year, or about 1,500 tons during what is defined the "Ozone Season". Emissions for each boiler can be found in the table below.

Table 13. NOx Production by Boiler[16]

Boiler Number		1	2	3	4	5
Boiler Name		"Big Bill"	"Peter	Riley Coal	CE	Riley Bark
Fuel		nut & slack	nut & slack	nut & slack	low sulfur	stoker
Boiler Load	lb/hr	187,000	195,000	210,000	343,000	214,000
	%	75%	78%	75%	86%	107%
Type of NOx Control		none	none	none	none	none
Actual NOx Concentration in Flue Gas	ppm	366	256	210	510	159
	lb/MMBTU	1	0.687	0.666	0.754	0.562
Fuel Fired May 1 → Sept 30	tons	26,637	26,637	35,516	43,256	21,491
	MMBTU	694,427	694,427	925,902	1,125,867	579,943
Total NOx May 1 → Sept 30	tons	347	239	308	425	163
Total NOx Emissions May 1 → Sept 30, tons						1,482

The Blue Ridge Budget

Because of the size of the boilers and their relatively high NOx emissions, it is easy to understand why the EPA and the North Carolina Division of Air Quality have targeted this facility as a major candidate for the revised limitations imposed by the NOx SIP Call. According to the new NOx SIP submitted to and approved by the EPA for the State of North Carolina, Blue Ridge Paper will be allocated a total of 1,257 tons of NOx for the ozone season of 2004. The Ozone Season for that year is defined as May 31 through September 30, with the May 1 deadline taking affect in 2005 and beyond. Because of this extension in the ozone season, the facility is allotted 314 additional tons for 2005. By 2006, however all point sources affected by the SIP NOx regulations are expected to be in compliance, and thus meet the final emissions limits. For Blue Ridge, this means a final total allotment of 839 tons for its five operating units. A budget for the entire facility and each unit may be found in Table 14.

Table 14. Currently NOx Production and NOx Allocations by Boiler for 2004 –2006[16]

Facility	Source	NOx Production (tons/ozone season) 2002	NOx Allocations (tons/ozone season) 2004	NOx Allocations (tons/ozone season) 2005	NOx Allocations (tons/ozone season) 2006
Blue Ridge Paper Products Haywood County	Pulverized coal dry bottom boiler- "Big Bill"	347	212	265	141
	Pulverized coal dry bottom boiler- "Peter G"	239	187	234	125
	Pulverized coal dry bottom boiler- "Riley Coal"	308	358	447	239
	Pulverized coal wet bottom boiler- "No. 4"	425	365	456	244
	Wood/Coal- Riley Bark	163	135	169	90
	Total for all Five Units	1482	1257	1571	839

NC SIP CALL verses NOx Production

With the published SIP for the State of North Carolina finally being approved by the

EPA and adherence to said legislation mandated by the courts, some action must be

established to move towards ensuring compliance by May 30, 2004. To understand the

improvements needed to begin to establish a plan of action, it is necessary to compare the

actual NOx production with the allotted NOx emissions as specified by the State of North

Carolina.

The values presented in Table are the actual NOx production numbers measured by

the IAC in the summer of 2001, corrected to 3 percent oxygen, and based upon the total heat

input for each boiler during the Ozone Season. McBurney[16] conducted a similar study,

during the summer of 2001, which showed similar results (see table 10). For completeness

sake, both of these studies were compared to numbers expected by AP-42. A comparative

table follows.

Table 15. Comparative NOx Levels[16]

Boiler Name	1 "Big Bill"	2 "Peter G."	3 Riley Coal	4 CE	5 Riley Bark
IAC NOx lb/MMBTU	1.000	0.687	0.666	0.754	0.562
McBurney NOx lb/MMBTU	1.000	1.000	1.000	0.680	0.450
AP-42 NOx lb/MMBTU	0.832	0.832	0.832	0.553	0.508

Note on AP-42

As a point of reference, it may be helpful to look at the regulatory limits established for Blue Ridge Paper using AP-42 emissions factors and inventories. These factors are typically used as a guide for air quality and management. They provide emission estimates for various control techniques on different types of combustion units. Usually, they are listed in terms of weight of pollutant per unit volume or per unit weight. The emissions factors are determined by averaging data collected on multiple studies conducted by numerous consultants to generate emissions rates that are typical for the various types of units and their reduction technologies. Because these numbers are averages, it stands to reason that half of the units tested were above this mean number, which would imply that half the units are always out of compliance. Obvious this cannot be true, and by the EPA's own admission, "Emission factors in AP-42 are neither EPA-recommended emission limits…nor standards. Use of these factors as source-specific permit limits and/or as emission regulation compliance determinations is not recommended by the EPA"[17]. Therefore, use of the AP-42 emission factors is for a reference only rather than a limit imposed by the government.

Chapter 12

Control Techniques

With the publication of the stringent new NOx emission standards and the relative short time before these standards are to be implemented, it is worth noting the various types of control technologies that are available today. To promote the transfer of information on existing technologies that are on the market, the EPA has published a number of documents explaining not only the type of equipment available, but also the effectiveness of each method and its applicability to various combustion devices. In general there are two types of NOx control/reduction technologies available: combustion modification and post-combustion treatments. A brief description of each of these technologies follows.

Combustion Technologies

Less Excess Air (LEA)

As shown earlier, atmospheric oxygen is a key component in the production of NOx during combustion. In fuel lean environments (i.e. high excess air), NOx production tends to increase. Therefore, reducing excess air greatly reduces the NOx content of flue gas. It should be noted, however, that low excess air operation can lead to incomplete combustion (i.e. CO in the flue gas). A practical minimum for excess air firing of a coal unit is 18-25 percent excess air[18].

Overfire Air (OFA)

Though too much excess air in combustion is not desirable from a NOx production standpoint, fuel-rich environments can often lead to incomplete combustion and an increase of Carbon Monoxide (CO) and unburned hydrocarbons. To aid in the complete combustion of the fuel, a small amount of secondary air added to the primary zone. This secondary air generally ensures complete combustion[18].

Low NOx Burners (LNB)

Low NOx Burners are designed to control the mixing of fuel and combustion air to produce a kind of staged combustion. The burners create combustion zones that act together to reduce the NOx produced from combustion. For example, the first zone may be primary combustion, the second may develop fuel reburning, and a third may be final combustion in low excess air conditions to optimize NOx reduction[18].

Flue Gas Recirculation (FGR)

With flue gas recirculation, up to 20 percent of the exhaust flue gases is returned to the burner windbox and mixed with the combustion air. In a sense, low O_2 flue gas (e.g., 4 percent O_2) displaces Oxygen rich air (i.e. 20.9 percent O_2) in the combustion chamber, thus reducing the flame temperature and the production of NOx. FGR systems can reduce NOx levels by 20-50 percent[18].

Water Injection

The injection of water or steam into the combustion zone acts in a similar way to flue gas recirculation. This method changes the stoichiometric mixture in the combustion zone and ultimately reduces the flame temperature. By providing additional mass (water) into the equation, energy is absorbed as water is converted into steam, thus reducing flame temperature, and consequently the production of NOx[18].

Post-Combustion Treatments

While combustion technologies are used to reduce the actual production of NOx during combustion, post-combustion treatments attempt to remove NOx from the flue gases after the NOx has been produced. As opposed to altering combustion itself, the latter approach involves adding additional materials to the gases at various temperature levels of the boiler.

Selective Catalytic Reduction (SCR)

In SCR, ammonia is injected into the flow downstream from combustion to reduce NOx as the gases pass over catalysts. These catalysts help to promote the reaction of NOx and NH_3 (ammonia) into harmless Nitrogen and water vapor. Generally, precious metals have been used as the catalysts, but alternatives like base metals are now being considered to help reduce cost. Unfortunately, this technology has generally been expensive (mainly due to the use of precious metals) while allowing a portion of the injected ammonia to "slip through" unreacted. Because of this, these technologies are usually not favored despite reported 94 percent reductions in NOx levels[18].

Selective Non-Catalytic Reduction (SNCR)

Similar to SCR, SNCR injects ammonia or urea directly into the flue gas stream at specific flue gas temperatures. These temperatures help to ionize the injected liquids and thus provide for easier reaction with NOx in the reduction to Nitrogen and water. This "slip through" continues to be a problem for this technology as well, despite the fact that no catalysts are used [18].

A table comparing the various types of control techniques available may be found on the following page.

Table 16. NOx Control Techniques

Control Technique	Description of Technique	Advantages of Technique	Disadvantages of Technique	NOx Reduction Potential
Less Excess Air	Reduces oxygen avalability	Easy modificationn	Low NOx reduction	10-20
Over Fire Air	Stages Combustion	Low Cost	Higher Air Flow for increased CO	20-30
Low NOx Burners	Internally Stages Combustion	Low Operating Cost, Compatible FGR	Moderately High Capitol Cost	35-55
Flue Gas Recirculation	<30% of Flue Gas Recirculates With Air, Decreases Temperature	Potentiallly High NOx Reduction for Low Nitrogen Fuels	High Operating and Capitol Cost, Affects Heat Transfer and System Pressures	20-50
Water Injection	Reduces Flame Temperature	Moderate Capitol Costs	Efficiency Penalty	10
Selective Catalytic Reduction	Catalyst Located in Air Flow Promotes Reacion Between Ammonia and NOx	High NOx Removal	High Capitol and Operating Cost, Catalyst Siting, Possible Need of Water Wash	75-85
Selective Non-Catalytic Rduction	Injected Urea or Ammonia Ionizes to React with NOx	ModerateNox Removal, Low Capitol and Operating Cost	Temperature Dependant, Ammonia Storage, Handling, and Injection System	30-60

Columns A, B, C, and D from Reference [18]

Rows 1, 2, 3, 6, 7, and 8 in column E from Reference [17]

Rows 5 and 6 in column E from Reference [19]

Chapter 13

Plan for Blue Ridge to come into Compliance

Introduction

Now that the techniques available for NOx reduction have been discussed, it is possible to see how these techniques may be used to help bring Blue Ridge Paper into compliance with the NOx SIP Call. Currently, the boilers at the plant produce 1,482 tons of NOx during the five-month ozone season. While a reduction to 1,257 tons is necessary for compliance in 2004, a reduction to 839 tons will be required by 2006. This is equivalent to a NOx reduction of 643 tons from current operating conditions. While this seems like a truly formidable task, the goal may be reached with the implementation of but a few corrective measures. In particular, by reducing excess air in the boiler after combustion and installing low NOx burners on all the units the total NOx emissions can be reduced to acceptable levels for the years through 2005. In fact, the implementation of these techniques should bring the NOx production to levels close to those required by the NOx SIP Call (839 tons) by 2006. Nonetheless, once these recommendations are implemented it will be possible to reassess the situation, and if additional measures need to be taken, they can be done at that time.

Less Excess Air (LEA)

During their assessment, the Industrial Assessment Center evaluated the operation of the five power boilers and identified some energy saving opportunities that would also help to reduce NOx. All the boilers were found to be operating at high excess air levels, one as high as 200 percent[16]. As discussed earlier, atmospheric air contributes to the formation of NOx. By reducing the excess air it is possible to reduce NOx levels by 10-20 percent. While some excess air is necessary to assure complete combustion, it best to keep it at a reasonable level. Because of the age and size of the boilers at Blue Ridge, 30 percent (50 percent for Riley Coal) would be acceptable. The net effect of an excess air reduction program is a lowering of NOx production by 263 tons for the five-month NOx season.

Table 17 shows the current O_2 and corresponding excess air levels for four of the five boilers at Blue Ridge Paper. It should be noted that the No 4 CE boiler currently operates at 27 percent excess air (4.4 percent O_2) and does not require any excess air modifications.

Table 17. Flue Gas Readings by Boiler[16]

Boiler: Big Bill		Present	Target
O2	%	12	5
Excess Air	%	140	30
Stack Losses	%	18.47	12.3
Resulting Efficiency	%	81.53	87.7

Boiler: Riley Coal		Present	Target
O2	%	13.2	5
Excess Air	%	170	30
Stack Losses	%	21.08	12.77
Resulting Efficiency	%	78.92	87.23

Boiler: Peter G		Present	Target
O2	%	11.8	5
Excess Air	%	135	30
Stack Losses	%	18.78	12.64
Resulting Efficiency	%	81.22	87.36

Boiler: Riley Bark		Present	Target
O2	%	14	7
Excess Air	%	200	50
Stack Losses	%	22.4	13.58
Resulting Efficiency	%	77.6	86.42

As indicated above, high excess air levels contribute to high stack losses and lower boiler efficiency. In older boilers, one of the causes of high excess air is "tramp air". Tramp

air is atmospheric air that has been sucked in through the boiler casing or tubular air heater after combustion has occurred. Because it occurs in the post-combustion zone of the boiler, it serves no useful purpose in the firing process and only contributes to the stack loss and a lowering of the overall boiler efficiency.

To correct the tramp air problem, it is necessary to first locate the source of the tramp air leak. If a significant increase in O_2 concentrations is found between the entrance and exit of the tubular air heater, it is likely that the tramp air has entered here. Measures can then be taken to replace the faulty tubes. If no significant increase in O_2 is found across the air heater, the air is probably entering through the boiler casing itself. Measures should then be taken to refurbish the casing of the boiler itself.

Once the excess air has been reduced, it will be possible to realize significant reductions in NOx from these boilers. These reductions will come in two forms. First, the amount of fuel burned will decrease due to the higher efficiency of the units. Less coal used for combustion reduces the production of NOx. Secondly, the reduction of excess air reduces the amount of atmospheric air available for the production of thermal NOx.

The amount of NOx reduction expected from the simple reduction of coal burned can be determined from the following. From Table 8 it is possible to determine the amount of fuel (in MMBTU) is currently being fired. With the increase in boiler efficiency expected from reducing the tramp air, less fuel will be needed to be burned to maintain the current steam load. This, in turn, will reduce the fuel NOx.

Using Big Bill as an example, we can calculate the annual fuel input in terms of MMBTU/yr.

Current Fuel Usage   =   70,071 tons/yr x 2,000 lb/ton x 13035 BTU/lb
(for Big Bill)

                            =   1,826,751 MMBTU/yr

This procedure can be used to determine the fuel input to each power boiler, thus yielding the following results.

Table 18. Heat Output by Boiler[16]

Boiler No.		1	2	3	4	5
Name		Big Bill	Peter G	Riley Coal	CE	Riley Bark
Fuel Fired	tons/yr	70,071	70,071	93,427	114,939	54,447
	MMBTU	1,826,751	1,826,751	2,435,642	2,991,632	1,469,307

The fuel savings associated with the improvements in boiler efficiency can now be calculated:

Fuel Savings   =   Fuel Usage x (1-present efficiency/target efficiency)
(for Big Bill)

                            =   1,826,751/yr x (1-81.53%/87.70%)

                            =   128,512 MMBTU/yr

Repeating this for each boiler, the total predicted reduction in annual fuel consumption is 638,898 MMBTU/yr (6.1 percent of total). It should be noted that since no efficiency increase is expected for the No. 4 CE boiler, the fuel consumption for this boiler was not reduced. Reducing fuel usage will correspond directly to a reduction in fuel NOx production (remember, 75 percent of NOx formed in combustion of coal is fuel NOx). Thus a 7 percent reduction in fuel will correspond to a 7 percent reduction in fuel NOx. Results can be found in the table below.

Table 19. Reductions from LEA[16]

Boiler Name	Fuel Saved MMBTU	Fuel Reduction (%)	Present NOx (tons/season)	Fuel NOx (tons/season)	Fuel NOx reduction (tons/season)
Big Bill	128,518	7.0	347	260	18.2
Peter G	128,391	7.0	239	179	12.5
Riley Coal	232,032	9.5	308	231	21.9
CE	0	0.0	425	319	0
Riley Bark	149,957	10.2	163	122	12.5
Total	638,898	6.1	1482	1112	65.1

In chapter 11, it was shown that the five power boilers generated 1,482 tons of NOx during the ozone season (May 1 to September 30). Of this total, 1,112 tons is projected to be fuel NOx. A decrease in fuel usage will then reduce the NOx by 65.1 tons during this critical season.

Low NOx Burners

Low NOx Burners have proven to be one of the best available NOx reduction techniques. While the cost is considerable, the results can be quite good, with some installations reporting reductions as large as 70 percent. While results like this may be possible, more typical results range between 35-55 percent.

Since the boilers at Blue Ridge have various types of burners, it is important to find estimates that pertain specifically to each type of burner, as opposed to simply assuming a 35 percent reduction for all burner types. Three of the boilers have tangential burners, one is wall fired and No. 5 is stoker fired. It is important to note that low NOx burners are applicable to the tangential and wall fired units only. Thus both the Environmental

63

Protection Agency's published AP-42 emissions factors and a Department of Energy publication on case studies done on the burner's effects for various types of burners were consulted. Table 20 summarizes the information in these publications.

Table 20. Expected Reduction Amounts

Type of Burner	Emission Factors		
	Regular Burner AP-42 lb/ton	Low NOx Burners	
		AP-42 Guidelines lb/ton	DOE Publication[21] %
Wall	22	11 (50%)[1]	(48%)[1]
Tangential	15	9.7 (35%)[1]	(37%)[1]

[1] % reduction

Conservatively, the lower of the two reduction estimates for each type of burner was used to determine the reduction that may be expected for the instillation of LNB (35 percent for tangential burners, 48 percent for wall fired boilers).

The overall effects of (i) tramp air reduction and (ii) low NOx burners can be seen in table 21 below.

Table 21. Reduction by Burner Type

Type of Firing	Present NOx Levels (tons/season)	NOx Reduction		New NOx Levels (tons/season)
		Tramp Air Reduction (tons/season)	Low NOx Burners (tons/season)	
Tangential Burners	749	31	251	467
Wall-Fired Burners	308	22	137	149
Stoker-Fired Burner	425	12	N/A	413
Total	1482	65	388	1029

Thus, the overall effect of minimizing tramp air and introducing low NOx burners is a net reduction of 453 tons of NOx per ozone season. This is equivalent to a 30.5 percent reduction in total NOx for the season.

Conclusion

The NC SIP calls for Blue Ridge Paper to reduce their total NOx emissions during the shortened ozone season of 2004 (May 30 to September 30) to 1,257 tons and to 1,571 tons for the 2005 full length five-month ozone season. By simply implementing the reduction steps described above, it is expected that the plant's NOx emissions during the ozone season will be reduced by a total of 449 tons. By removing this 453 tons of NOx, Blue Ridge Paper will reduce their ozone season NOx emissions to 1,033 tons (May 1st to September 30th) .

Emissions of this amount will easily bring the plant into compliance for the 2004 season as well as the 2005 season. What's more, these reductions techniques will reduce NOx significantly throughout the year, not just during the NOx season. As opposed to installing gas units to burn during the summer months, these techniques, once implemented, will allow the plant to continue with normal day to day operations from January, through May and October, and straight on to December of every year.

Unfortunately, it is expected that by May 2006, Blue Ridge Paper will have to reduce their NOx emissions to 839 tons per ozone season, and to maintain this level for the five month NOx season for the years to come. While the reduction techniques described above will certainly make great strides towards reaching this mark, additional measures will need to be taken if the plant is to become compliant by May 2006. Currently, there are a number of different technologies available (such as Over Fire Air, Selective Catalytic Reduction or Selective Non-Catalytic Reduction) that may be implemented in conjunction with the LNB that can help reduce emissions by the remaining 190 tons necessary to reach the required 839 tons/season. It is recommended that these techniques be considered and evaluated only after the plant has come into compliance for the 2004 season. Furthermore, the projections made here are conservative. Therefore, it is recommended that Blue Ridge first implement the above measures and evaluate the results before making any decisions on implementing additional technologies.

References

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Appendix

The appendix gives the tables showing the State of North Carolina's final NOx emissions allocations for Utilities, EGUs and NON-EGUs. It also includes a copy of the North Carolina Rule that governs NOx emissions for all times not designated as "Ozone Season". While this information is relevant and pertinent to topics covered in the preceding pages, their bulk or verbatim quotation of legal documentation has found them here.

Table A-1 CP&L Electric Utilities
Complete NOX Budget[14,15]

Facility	Source	NOx Allocations (tons/ozone season) 2004	NOx Allocations (tons/ozone season) 2005	NOx Allocations (tons/ozone season) 2006
Asheville,	1	551	689	519
Buncombe Co	2	538	672	507
Cape Fear	5	286	358	270
Chatham Co.	6	406	508	382
Lee	1	145	182	137
Wayne Co	2	159	199	150
	3	465	582	438
Mayo	1	1987	2483	1872
Person Co	1	861	1076	811
Roxboro	2	1602	2003	1509
Person Co	3	1773	2215	1669
	4	1698	2122	1599
	1	182	228	171
L V Sutton	2	198	247	186
New Hanover	3	806	1007	759
Co	1	85	107	80
Weatherspoon	2	97	121	91
Robeson Co		180	225	170

Table A-2 Duke Power Electric Utilities
Complete NOx Budget[14,15]

Facility	Source	NOx Allocations (tons/ozone season) 2004	NOx Allocations (tons/ozone season) 2005	NOx Allocations (tons/ozone season) 2006
G G Allen Gaston Co	1	350	437	329
	2	355	444	334
	3	590	737	556
	4	528	660	497
	5	578	722	544
Belows Creek Stokes Co	1	2591	3239	2441
	2	3020	3775	2846
Buck Rowan Co	5	66	83	63
	6	73	91	69
	7	78	97	73
	8	319	399	300
	9	337	422	318
Cliffside Cleveland Co	1	76	95	71
	2	82	102	77
	3	107	134	101
	4	120	150	113
	5	1326	1658	1249
Dan River RockinghamCo	1	132	165	124
	2	144	180	135
	3	304	380	286
Marshal Catawba Co	1	1011	1263	252
	2	1056	1320	994
	3	1784	2230	1680
	4	1764	2206	1662
Riversbend Gaston Co	10	299	374	282
	7	216	270	204
	8	225	281	212
	9	285	256	268

Table A-3 Non-Utility Electrical Generating Units
Complete NOX Budget[14,15]

Facility	Source	NOx Allocations (tons/ozone season) 2004	NOx Allocations (tons/ozone season) 2005	NOx Allocations (tons/ozone season) 2006
Butlar Warner Generating, Cumberland Co	Combustion Turbine 1	27	33	49
	Combustion Turbine 2	27	33	49
	Combustion Turbine 3	27	33	49
	Combustion Turbine 4	34	23	63
	Combustion Turbine 5	35	43	63
	Combustion Turbine 6	28	35	52
	Combustion Turbine 7	27	33	49
	Combustion Turbine 8	27	33	49
Cogentrix-Rocky Mount, Edgecombe Co	Boiler ST-unt	319	398	351
Cogentrix-Elizabethtown, Bladen Co	Bcoal Boiler ST-OWN	115	143	126
Cogentrix-Keanansville, Duplin Co	Stoker Boiler ST-LLE	103	128	113
Cogentrix-Lumberton, Robeson Co	Coal Boiler ST-TON	114	142	125
Cogentrix-Roxboro, Person Co	ST-ORO	175	218	192
Cogentrix-Southport, Brunswick Co	ST-ORT	356	444	392

Duke Power, Lincoln	Combustion Turbine 1	18	23	26
	Combustion Turbine 2	18	23	26
	Combustion Turbine 3	18	23	26
	Combustion Turbine 4	18	23	26
	Combustion Turbine 5	18	23	26
	Combustion Turbine 6	18	23	26
	Combustion Turbine 7	18	23	26
	Combustion Turbine 8	18	23	26
	Combustion Turbine 9	18	23	26
	Combustion Turbine 10	18	23	26
	Combustion Turbine 11	18	23	26
	Combustion Turbine 12	18	23	26
	Combustion Turbine 13	18	23	26
	Combustion Turbine 14	18	23	26
	Combustion Turbine 15	18	23	26
	Combustion Turbine 16	19	24	27
Panda- Rosemary, Halifax Co	CT-ary	35	43	32
	CW-ary	25	31	23
Roanoke Valley, Halifax Co	1	447	558	493
	2	142	178	167
RJ Reynolds Tobbaccoville Facility Forsyth Co	Boiler 1	194	243	64
	Boiler 2	218	273	64
	Boiler 3	178	223	64
	Boiler 4	190	238	64
UNC-CH, Orange Co.	Boiler 5,6,7	116	145	128
	Boiler 8	120	150	113
CP&L, Lee Plant, Wayne Co	Combustion Turbine 1	25	31	31
	Combustion Turbine 2	25	31	31
	Combustion Turbine 3	92	115	115
	Combustion Turbine 4	92	115	115

Dynegy, Rockingham Co	Combustion Turbine 1	34	42	42
	Combustion Turbine 2	33	42	42
	Combustion Turbine 3	33	42	42
	Combustion Turbine 4	33	41	41
	Combustion Turbine 5	33	41	41
CP&L, Woodleaf Rowan Co	Combustion Turbine 1	22	27	27
	Combustion Turbine 2	22	27	27
	Combustion Turbine 3	22	27	27
	Combustion Turbine 4	21	27	27
	Combustion Turbine 5	22	28	28
CP&L, Mark's Creek Richmond Co	Combustion Turbine 1	22	27	27
	Combustion Turbine 2	22	27	27
	Combustion Turbine 3	22	27	27
	Combustion Turbine 4	22	27	27
	Combustion Turbine 5	21	27	27
	Combustion Turbine 6	21	27	27
	Combustion Turbine 7	22	28	28
CP&L, Asheville, Buncombe Co	Combustion Turbine 1	60	75	75
	Combustion Turbine 2	60	75	75

Table A-4 Affected Non-EGU
Complete NOx Budget

Facility	Source	NOx Allocations (tons/ozone season) 2004	NOx Allocations (tons/ozone season) 2005	NOx Allocations (tons/ozone season) 2006
Weyerhaeuser Paper Company, Martin Co	Riley Boiler	566	708	379
	Package Boiler	20	25	25
BlueRidge Paper Products, Haywood Co	Big Bill	212	265	141
	Peter G	187	234	125
	Riley Coal	358	447	239
	No 4	365	456	244
	Riley Bark	135	169	90
International Paper Corp Halifax Co	Wood/bark no 6 oil pulverized coal dry bottom boiler	518	648	346
Weyerhaeuser Co New Bern Mill Craven Co	No 1 power boiler	181	226	121
	No 2 power boiler	58	72	72
International Paper Columbus Co	No 3 power boiler	126	158	84
	No 4 power boiler	334	418	223
Fieldcrest-Cannon, Plant 1 Cabarrus Co	boiler	174	217	116

As contained in the North Carolina SIP approved from the EPA this means:

a) The emissions of Nitrogen dioxide shall not exceed:
(1) 0.6 pounds per million BTU of heat input per hour from any oil or gas fired boiler with a capacity of 250 million BTU per hour or more,
(2) 1.3 pounds per million BTU of heat input per hour from any coal-fired boiler with a capacity of 250 million btu per hour or more;
(3) 5.8 pounds per ton of acid produced from any nitric acid manufacturing plants,
(4) 5.8 pounds per ton of acid produced from any sulfuric acid manufacturing plant.
(b) The emissions of nitrogen oxides shall not exceed:
(1) 0.8 pounds per million BTU of heat input from any oil or gas fired boiler with a capacity of 250 million BTU per hour or more.
(2) 1.8 pounds per million of BTU of heat input from any coal-fired boiler with a capacity of 250 million BTU per hour or more.
(c) The emission limit for a boiler that burns both coal and oil or gas in combination shall be calculated by the equation $E = [(E_C) (Q_C) + (E_O) (Q_O)] / Q_T$.
(1) E = the emission limit for combination in lb/ million BTU.
(2) E_C = emission limit for coal only as determined by Paragraph (a) or (b) of this Regulation in lb/million BTU.
(3) E_O = emission limit for oil or gas determined by Paragraph (a) or (b) of this Regulation in lb/million BTU.
(4) Q_C = the actual coal heat input to the combination in BTU/hr.
(5) Q_O = the actual oil and gas heat input to the combination in BTU/ hr.
(6) $Q_T = Q_C + Q_O$ and is the total heat input to the combination in BTU/hr.[14,15]