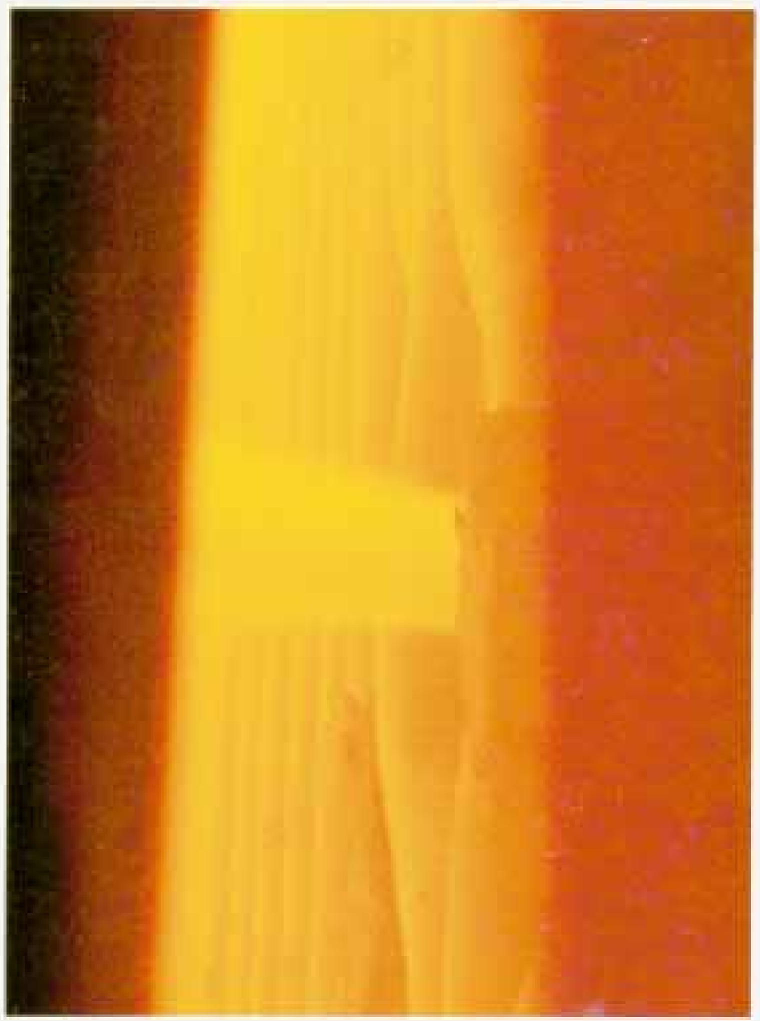
TOPICAL REPORT NUMBER 3

SEPTEMBER 1993

CLEAN COAL TECHNOLOGY



Reduction of NO_x and SO_2 Using Gas Reburning, Sorbent Injection and Integrated Technologies

TOPICAL REPORT NUMBER 3 SEPTEMBER 1993

REVISION NO. 1

Reduction of NO_X and SO_2 Using Gas Reburning, Sorbent Injection, and Integrated Technologies

A report on two projects conducted jointly under cooperative agreements between:

The U.S. Department of Energy
and
Energy and Environmental Research Corporation

CLEAN COAL

TECHNOLOGY

Reduction of NO_X and SO_2 Using Gas Reburning, Sorbent Injection, and Integrated Technologies

Cover photo: Sorbent injection through boiler wall at Hennepin Unit No. 1.

Introduction and Executive Summary

Coal is America's most abundant fossil fuel. Its combustion creates the steam that produces most of this country's electricity. The burning of coal, however, liberates two types of gases that have been linked to the formation of acid rain: nitrogen oxides (NO_X) and sulfur dioxide (SO_2). With the passage of each successive piece of clean air legislation over the past two decades, the electric utility industry has been made increasingly aware that it would eventually have to reduce both types of emissions from existing and new plants, to environmentally acceptable levels.

With increasing pressures to change operations on one hand and aging plants with limited lives and physical space on the other, the power industry, in conjunction with the Department of Energy (DOE), has been exploring and cooperatively developing retrofit emission-control technologies able to resolve this dilemma. After more than 15 years of experimentation and laboratory testing, these and other new technologies have come of age and are now ready for commercial-scale application.

The Clean Coal Technology Demonstration Program (also referred to as the CCT Program), is a unique government/industry cost-shared effort to develop these advanced coal-based technologies. The CCT Program provides numerous options for addressing a wide range of energy and environmental issues, including acid rain, global climate change, improved energy efficiency, energy security, and environmental quality. It is intended to demonstrate a new generation of innovative coal utilization processes in a series of full-scale, "showcase" facilities built throughout the United States. This program will take the most promising of the advanced coal-based technologies and move them into the marketplace by demonstrating their commercial viability. These demonstrations are at a scale large enough to provide the necessary data—design, construction, and operation—to enable the private sector to evaluate the commercial potential of each and to confidently predict each technology's commercial readiness. The importance of successfully demonstrating these technologies has increased significantly since the passage of the 1990 Clean Air Act Amendments and the soon-to-follow regulations for the control of nitrogen oxides.

Gas Reburning, Sorbent Injection and Integrated Technologies — the subject of this Topical Report — are one such set of promising innovative developments. In addition to discussing the technologies involved, this report will describe two specific projects, results to date, and the commercial promise of these processes.

The objectives of Gas Rebuming and Sorbent Injection were to have a 60% reduction in NO_X emissions and a 50% reduction in SO_2 emissions. These objectives have been achieved at the tangentially-fired boiler at the Hennepin site of Illinois Power and at the cyclone-fired boiler operated by City Water, Light and Power in Springfield, Illinois.

The other project, Gas Reburning and Low-NO_X Burners, had the goal of a 70% NO_X reduction from the wall-fired boiler operated by Public Service of Colorado at Denver. In early preliminary testing, this goal was also achieved. Energy and Environmental Research (EER) is now ready to design and install Gas Reburning and Sorbent Injection systems, and Gas Reburning-Low NO_X Burner systems for any utility or industrial application. These technologies are offered with performance and emission control guarantees.

Reduction of NO_X and SO_2 Using Gas Reburning, Sorbent Injection, and Integrated Technologies

Project Participants

Gas Reburning and Sorbent Injection:
Energy and Environmental Research Corp.
U.S. Department of Energy
Gas Research Institute
Illinois Department of Energy and Natural Resources
Illinois Power Company
City Water, Light and Power of Springfield (IL)

Gas Reburning and Low-NO_X Burners:
Energy and Environmental Research Corp.
U.S. Department of Energy
Gas Research Institute
Public Service Company of Colorado
Colorado Interstate Gas Company
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Gas reburning is an extremely flexible technology, adaptable to a variety of electric utility retrofit situations. Used either by itself, or in combination with other emission-control technologies, it can help to significantly reduce NO_X, SO_2 and CO_2 emissions.

The further development of gas reburning and its integration with other emission-control technologies is currently being assisted through two Clean Coal Technology demonstration projects. As subsequently detailed in this topical report, the two demonstration projects include: (1) a two-plant project where gas reburning is combined with sorbent injection and applied to a tangentially-fired boiler and a cyclone-fired boiler, both burning high-sulfur Illinois coal (Hennepin and Lakeside, respectively); and (2) a western, low-sulfur coal-burning plant with a wall-fired boiler, where gas reburning and low-NO_X burners are combined to reduce NO_X emissions (Cherokee). These three boiler types (tangential, cyclone, and wall-fired) represent 97% of the pre-NSPS boiler population. Each of the three demonstration facilities has its own set of retrofit conditions and emission problems, yet each is a logical candidate for demonstrating gas reburning technology.

Definitions of Technology

Gas Reburning

Gas Reburning (GR) is primarily a NO_X control technology. A small amount of natural gas (15 to 20% of the total energy input) is injected in place of coal into the boiler above the normal combustion zone. This creates an oxygen-deficient (fuel-rich) zone where the hydrocarbon radicals from the gas react with the nitrogen oxides from the coal combustion. This reaction forms molecular nitrogen, the same kind of nitrogen that exists naturally in the atmosphere. Additional air is injected above the reburn zone, finishing the combustion at a lower temperature and preventing NO_X from forming. Used by itself, gas reburning has been shown to routinely reduce NO_X emissions by more than 60%.

Illinois Power's Hennepin Unit No. 1 is the demonstration site for the GR-SI process on a tangentially-fired pulverized coal unit.

Sorbent Injection

Sorbent Injection (SI) technology is used to decrease SO_2 in emissions from coal-fired boilers. A sulfur-absorbing agent, usually lime or hydrated lime, is blown into the flue gases. SO_2 removal is enhanced by the injection pattern of the sorbent and by using chemical additives. The resulting reactions produce dry non-toxic particles which are collected down-stream in either the electrostatic precipitator after flue gas conditioning or the baghouse. SI in combination with GR technology has achieved SO_2 removal in the 50-60% range.

Low-NO_X Burners

Low-NO_X Burners (LNBs) are coal-fired burners specifically designed to reduce the formation of nitrogen oxides through the careful control of the coal/air mixture during combustion. By causing a more gradual mixing of the fuel and air, the combustion flame temperature is lowered, resulting in a NO_X reduction of 30 to 50%, and up to a 70-75% reduction of NO_X when used in combination with GR.

Overview Of Two Demonstration Projects At Three Sites

There are two demonstration projects discussed in this report, each involving the use of gas reburning in conjunction with a second type of emission control technology. The performing organization in both projects is Energy and Environmental Research Corporation (EER) of Irvine, California, with its Engineering Services Group located at Orrville, Ohio.

The Hennepin/Lakeside Project

The Hennepin/Lakeside Project was intended to demonstrate the combined use of gas reburning and sorbent injection to achieve approximately 60% NO_X reduction and 50% SO_2 capture on each of two different boiler configurations (tangential and cyclone). Both of these boilers are burning high-sulfur coal.

CCT	Site	Firing	Control Technologies
I	Hennepin	Tangential	GR, GR-SI, SI
I	Lakeside	Cyclone	GR, GR-SI, SI
III	Cherokee	Wall	LNB, GR-LNB

City Water, Light and Power Company's Lakeside Unit 7 is the demonstration site for GR-SI technology on a cyclone-fired boiler.

Gas reburning and sorbent injection can be conducted independently or in combination.

The total project cost of approximately $37.5 million is shared 50/50 between DOE and the project participants, which include: Energy and Environmental Research Corporation (EER), the Gas Research Institute (GRI), the State of Illinois, Department of Energy and Natural Resources, and the two host utilities, Illinois Power Company and City Water, Light and Power of Springfield, Illinois.

The Hennepin/Lakeside Project was selected by DOE in 1986 and was awarded a cooperative agreement in 1987. Construction was initiated at Hennepin in May 1989 and was completed in August 1990 followed by startup testing. At Lakeside, construction was initiated in June 1990 and was completed in May 1993. Operation at Hennepin was begun in December of 1990 and at Lakeside in May of 1993. A final report is scheduled for publication in November of 1994.

The Cherokee Station Project

The Cherokee Station Project, located in Denver, Colorado, focuses on NO_X reduction only, since ground-level ozone is a major concern in the Denver area and because the station's wall-fired boiler is burning compliance coal. Both gas reburning and low-NO_X burners are used to reduce NO_X emissions by approximately 70%. The total project cost of about $16.2 million is divided 50/50 between DOE and the remaining project co-funders: the Public Service Company of Colorado (the host utility), the Gas Research Institute, Colorado Interstate Gas Company, the Electric Power Research Institute, and EER. The demonstration is located at the 172 MWe Cherokee Station, Unit No. 3.

The Cherokee Station project was selected by DOE in December of 1989. Design work began in 1990 and construction was completed in April of 1992. Project completion and the final report are scheduled for December 1994.

Gas Reburning

The need to reduce NO_X emissions from coal-fired boilers has gained increased attention in recent years as more is learned about the environmental impact of nitrogen oxides in the formation of acid rain, smog, visibility impairment and climatic warming. While about half of all NO_X pollution comes from automobiles and other types of vehicles, coal-burning boilers contribute about 25% of the total NO_X emitted nationwide. Thus, there is a significant need to develop more emission-control technologies for reducing NO_X from power plants. Gas reburning is one such technology that has been shown to reduce nitrogen oxides by 60% or more in a typical coal-fired boiler.

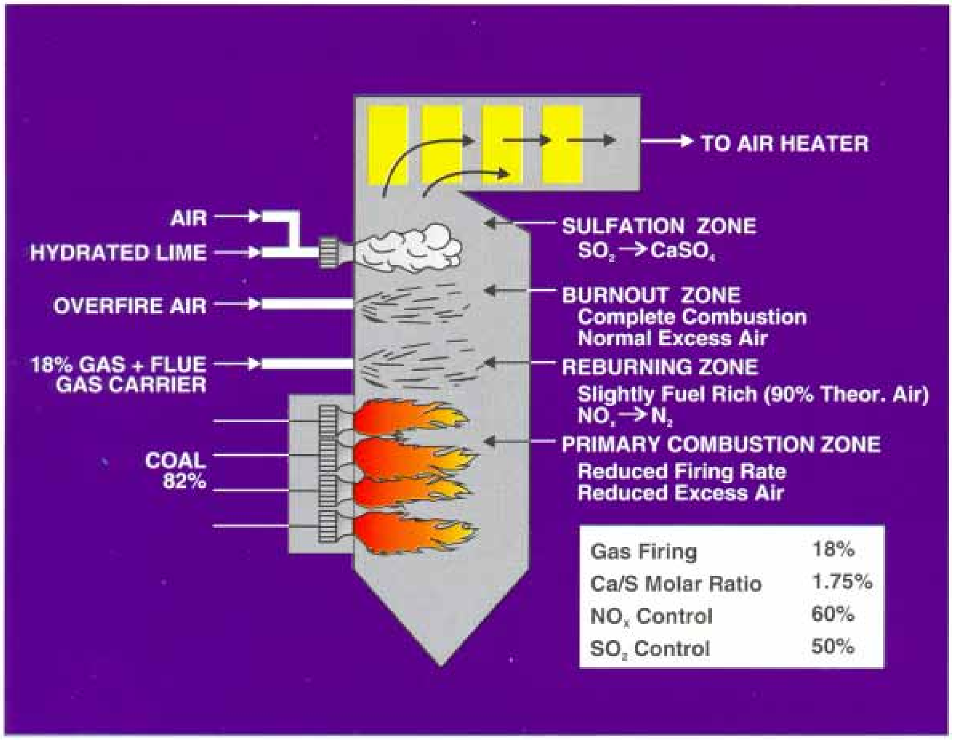
Gas reburning is applicable to all types of coal-fired boilers. Even though other methods exist to reduce NO_X emissions from boilers, gas reburning is one of the most cost-effective reduction methodologies.

Full Scale Gas Reburning Tests

Utility	Unit	Gross Capacity (MWe)	Firing Configuration
Illinois Power	Hennepin 1	80	Tangential
P.S. Colorado	Cherokee 3	172	Wall
City Water, Light & Power	Lakeside 7	40	Cyclone
Ohio Edison*	Niles	108	Cyclone

**This demonstration is not part of the CCT Program.*

Public Service of Colorado's Cherokee Station Unit No. 3 is the test site for the GR/Low-NO_X Burner technology demonstration. It burns low-sulfur western coal. The city of Denver, Colorado is in the background.



Typical GR-SI injector specifications.

Natural Gas Reburning Controls Emissions

In the 1970s burning natural gas in a utility boiler was limited. Gas supplies appeared to be diminishing rapidly, and the government passed laws restricting the use of gas in utility boilers. But today, the position on natural gas use has changed. As federal price controls were removed from gas, new supplies became available, and a gas surplus developed. Concerns over acid rain prompted new attention to gas, which burns cleanly and emits virtually no SO_2.

NO_X emissions from a gas reburning system are expected to be about 60% less than those from a unit fired solely with coal.

The capital cost of retrofitting a natural gas reburn system on a 500-megawatt boiler is estimated to be around $30 per kilowatt.

This approximate capital cost must be adjusted depending on the boiler configuration and design requirements.

An industry study examined the feasibility of using up to 20% natural gas at the 50 largest SO_2 emitting power plants in the United States. It found that gas supplies are available and that nearly 86% of the plants could be hooked into gas pipelines at a cost of less than $8 million per plant.

Process Benefits

While being able to significantly reduce nitrogen oxide emissions from coal-fired powerplant boilers, gas reburning has the following additional benefits:

Flexibility—
Gas reburning is applicable to all types of coal-buming boilers: tangentially-fired, cyclone-fired, wall-fired, wet bottom, etc. As detailed in the demonstration project descriptions, gas reburning is a technology that can be made to work with, and positively complement, other types of emission-control processes, such as sorbent injection and low-NO_X burners;

Ease of Retrofit—
Gas reburning requires a minimum amount of new capital equipment to make it work on an existing coal-fired boiler. Since there is very little additional space required, gas reburning can be retrofitted into plants on even the most physically restricted sites:

Particulate Reduction—
Since natural gas contains no ash, particulate loading is reduced in direct proportion to the amount of coal displaced;

SO_2 Reduction—
In similar fashion, since natural gas contains no sulfur, SO_2 emissions are reduced in direct proportion to the amount of coal displacement; and

CO_2 Reduction—
Since the ratio of hydrogen to carbon is greater for natural gas than for coal, gas reburning reduces carbon dioxide (CO_2) emissions by about 6-9% at nominally 15-20% of fuel substituted by natural gas (CO_2 is not normally considered a pollutant, but it has been identified as a "greenhouse gas" contributing to climate change).

Reduced Firing Rate

The firing rate of the coal burner is reduced by simply cutting back on the amount of coal supplied to the burner. Their operation at less than maximum capability is known as burner "turndown." Burner turndown has several benefits by itself. Because there is less coal processed through the plant pulverizers, there is less fly ash produced, resulting in a reduced load on the precipitator. Also, since the combustion intensity in the lower furnace regions is reduced in proportion to the burner turndown, there is a direct beneficial effect on NO_X emissions, and a further reduction in ash deposition potential.

Flue Gas Recirculation

For gas reburning to be most effective, the natural gas must be injected into the furnace and mixed rapidly with the coal's combustion products. In smaller boilers, adequate mixing can normally be achieved by simply injecting the natural gas at a high velocity. However, in larger furnaces it is difficult to obtain adequate mixing through simple injection, since the amount of gas supplied is quite small, compared to the total mass flow passing through the furnace. In these instances, penetration of the injected gas can be improved by adding flue gas as a carrier with minimal oxygen content to maintain the fuel-rich zone.

Demonstration Summary and Status Update
Enhancing the Use of Coals by Gas Reburning and Sorbent Injection

Project Status Update

The GR-SI process has achieved 60% NO_X reduction and 50% SO_2 reduction goals on different boiler configurations at power plants burning high-sulfur midwestern coal —a tangentially fired nominally 80-MWe boiler at Illinois Powers Hennepin Plant in Hennepin, IL, and a cyclone-fired nominally 40-MWe boiler at City Water, Light, and Power's Lakeside Station in Springfield, IL. The Hennepin project has been completed.

Plant Capacity/Production

Hennepin: tangentially-fired 80 MWe (nominal)
Lakeside: cyclone-fired 40 MWe (nominal)

Project Status/Accomplishments

Permitting and engineering design efforts were originally completed for three project sites. In 1990, plans to use the third site (Bartonville, IL) were suspended.

Construction and operations are complete at the tangentially-fired boiler at Hennepin. A matrix of 32 gas reburn tests were completed, achieving NO_X reduction rates of 60-65%. In one short-term test, a 77% reduction in NO_X was achieved. Evaluation of 20 over-fired air tests indicated substantial NO_X reduction was achieved at low loads with lesser reductions as load increased. Combined operational testing of gas reburning and sorbent injection began in August 1991 with SO_2 reduction in the range of 50-55%. Long-term load following testing, initiated in January 1992, has exceeded project goals of 60% NO_X and 50% SO_2 reductions. Operations at Hennepin were completed January 15, 1993.

At Lakeside, construction and equipment checkout were completed in May 1993, at which time start-up activities were initiated.

Project Funding

Total project cost	$ 37,588,955	100%
DOE	18,747,816	50%
Participants	18,841,139	50%

Participants

Energy and Environmental Research Corporation; Gas Research Institute; Illinois Department of Energy and Natural Resources; Illinois Power Company; City Water, Light and Power of Springfield, Illinois.

Project Objective

To demonstrate gas reburning to attain 60% NO_X reduction along with sorbent injection to reduce 50% of the SO_2 on two different boiler configurations: tangentially-fired and cyclone-fired.

Commercial Application

Gas reburning and sorbent injection is the unique combination of two technologies. The commercial application for these technologies, both separately and combined, extends to both utility companies and industry in the United States and abroad. In the United States alone, these two technologies can be applied to over 900 pre-NSPS utility boilers; additionally the technologies can be applied to new utility boilers. With 60% NO_X removal and 50% SO_2 removal, these technologies have the potential to extend the life of a boiler or power plant and also provide a way to use higher sulfur coals without exceeding emission limits for NO_X and SO_2.

Milestone	Completion
Phase I–Design and Permitting	5-89
Phase II–Construction, Start-up, and Shakedown	
Hennepin	8-91
Lakeside	5-93
Phase III–Operation, Data Collection, Reporting and Disposition	
Hennepin	12-93
Lakeside	8-94
Project Complete	12-94

Boiler Distribution in U.S.

	%
Wall-Fired	46
Tangentially-Fired	40
Cyclone-Fired	11
Other	3
Total	100

Flue gas is a convenient natural gas carrier, since it contains only about three percent oxygen and is readily available from the combustion process. Normally recirculation of about three percent of this gas is sufficient. In the case of a gas reburning application, a typical flue gas recirculation system includes a low-volume high-pressure fan, a cyclone dust collector, and ducting to the injectors. Since flue gas recirculation is commonly used in many commercial coal-fired boilers to control steam temperatures, its technology is proven. For application in gas reburning, however, the flow rate of these systems must be lowered and the pressure increased.

Correct location, size, and shape of the gas injectors are important to the success of the gas reburning process. These parameters vary with each application and are therefore determined by site-specific design and process modeling.

Overfire Air System

The overfire air system supplies the remaining air required to complete combustion. The total air supplied to a boiler with gas reburning is about the same as that supplied for normal operation. The only difference is due to the slightly different combustion air requirements for natural gas compared to coal.

The location, size, and shape of the overfire air ports are important design parameters. For instance, the air must be injected far enough downstream from the gas injectors to provide adequate residence time for the NO_X reduction reactions to occur. At the same time, however, they must be close enough to assure complete combustion within the furnace chamber. It is possible, by varying the design of the gas injectors and overfire air ports, to minimize NO_X emissions without significant reduction of boiler thermal performance or combustion efficiency.

Retrofitting with gas reburning can therefore provide an opportunity to improve the operation of an existing power plant.

Boiler Control and Safety Systems

Some modifications are required to the boiler control system in order to implement gas reburning. These usually involve changing the fuel and air controls to include the gas and overfire air streams. Additional controls are required where flue gas recirculation is utilized. The overall operation of the boiler, including the control of steam flow, excess air, steam pressure and temperature are not affected provided that adequate excess air control capability exists on the boiler.

As with these demonstrations it is necessary to design a Safety System according to NFPA guidelines to ensure that no added risks to boiler operation are introduced by the installation of the gas reburning system. Each site must be examined individually due to the presence (or absence) of an existing flame safety system. The presence of a main fuel flame in the boiler and boiler load greater than minimum safe values for reburning must exist.

Boiler Adaptation

Even though each firing configuration has similar flow pattern characteristics, existing plants have all been engineered to achieve specific steam conditions and flow rates, and to bum specific types of coal. No two retrofit situations can therefore be expected to be the same. Generally, however, installing a gas reburning system within a given type of boiler will require the following types of changes.

Coal burners must be "turned down" by about 20% when retrofitting with gas reburning. Although most types of boiler firing configurations can accommodate this level of turndown, the effects on the furnace flow patterns differ. In wall- and cyclone-fired boilers, turndown can be achieved by removing some burners or cyclones from service, or by turning them down uniformly. The general flow patterns in the furnaces remain virtually unchanged. With a tangentially-fired boiler, however, turning down the burners can also change the overall swirl in the furnace. This, coupled with changes in burner tilt to maintain steam temperature, can cause changes in the furnace's overall flow patterns. When low-NO_X burners are used with gas reburning in wall-fired units, burner velocities, swirl, and flame volume are altered.

Upper furnace conditions are substantially different for wall-, tangentially-, and cyclone-fired boilers. This means a different approach must be taken to retrofit each type. Both numerical and physical flow models have been developed to determine the optimal injection location. These models address both furnace flow patterns and thermal conditions.

Integration Of Gas Reburning With Other Technologies

One overriding advantage of gas reburning technology is its compatibility with other emission-control technologies, enabling it to be integrated into other advanced systems. This capability significantly expands its potential role for combination with a wide range of other applications. Examples include using it in combination with the following technologies:

SO_2 Control Technologies — Furnace Sorbent Injection, Duct Sorbent Injection, Wet Scrubbers, Dry Scrubbers, and Coal Switching;

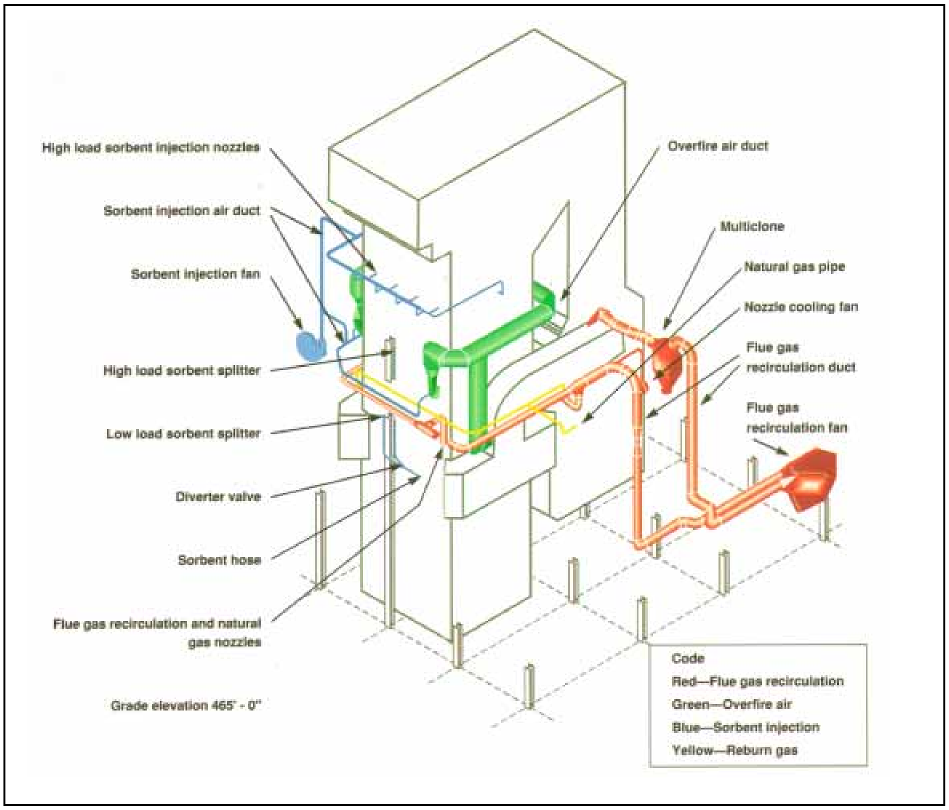
NO_X Control Technologies — Low-NO_X Burners, Selective Non-Catalytic Reduction (ammonia or urea injection), and Selective Catalytic Reduction; and

Particulate Control Technologies — Electrostatic Precipitators and Fabric Filters (Baghouse).

Gas reburning has been integrated with two other emission-control technologies (Furnace Sorbent Injection and Low-NO_X Burners) in two demonstration projects involving all three types of boiler firing configurations. The two types of integrated emission-control systems may prove to be popular, due to their universal benefits *vis-a-vis* the specific requirements of the 1990 Clean Air Act Amendments.

One other type of combined system, Gas Reburning/Low Sulfur Coal Switching, also seems to be an attractive means of controlling both NO_X and SO_2. However, switching to low-sulfur coal changes a number of combustion dynamics and design parameters.

GR/S1 equipment schematic, Hennepin Unit No. 1.



Gas Reburning Process Factors

- Slightly Fuel-Rich (90% theoretical air)
- Reactant Gas Phase Residence Time (0.3 - 0.5 seconds)
- Furnace Temperature (1600-2200 °F)

History of Development

The development of gas reburning technology has been underway in various laboratories for some time. Researchers in the 1970s included the John Zink Company and Shell Development Company in the U.S. Subsequent work was also done by Mitsubishi of Japan, including commercial scale tests where NO_X reductions greater than 50% were achieved when oil was used as the reburning fuel. The California-based firm of Energy and Environmental Research Corporation (EER) became interested in the potential of gas reburning and, with support from EPA and GRI, began extensive bench and pilot-scale testing in 1981 to characterize the fundamental process variables. Tests conducted on a 10 million Btu/hr (1 MWe) pilot plant convinced EER that natural gas is the best fuel for reburning. These tests also provided valuable scale-up information needed for the development of commercial applications under industrial conditions.

Sorbent injection has been undergoing development since the mid 1970s with funding from EPA, DOE, EPRI and several commercial firms. Most of the work has focused on identifying the process parameters which optimize sulfur capture. Work has also been done on determining the impacts of the sorbent injection process on the overall performance of boilers, and on finding methods to reduce these impacts. This work included laboratory scale reactivity tests; bench scale process design development tests that focused on time/temperature history and sorbent reactivity effects; large pilot-scale testing that focused on impacts of firing system design; and combustion model development programs. A number of field evaluations have been completed and additional efforts are in progress. EER has participated both directly and indirectly in most of this development work.

In the last 10 years, a number of test programs for sorbent injection have been carried out on boilers ranging from 15 to 600 MW, using a variety of coals. The Clean Coal Technology Program has several of these sorbent injection projects. These projects, however, all focused on optimizing sorbent injection by itself. None involved gas reburning.

Demonstration Beginnings

The next logical step toward commercialization of gas reburning and integrated technologies is to apply the existing knowledge and experience gained at the bench and pilot-plant level to a commercial operating plant. The technology needs to be demonstrated as being technically sound and economically competitive. DOE's Clean Coal Technology Demonstration Program is providing the means to accomplish that end.

EER's Gas Reburning-Sorbent Injection (GR-SI) proposal was chosen for funding in DOE CCT-1. Initially intended to be installed at three different sites with three different boiler configurations, this project was subsequently cut back to only two host sites in Illinois. The May 1989, CCT-III solicitation resulted in funding of EER's second gas reburning demonstration project: an integrated GR/Low-NO_X Burner project on a wall-fired boiler at the Cherokee Station of Public Service of Colorado near Denver, Colorado.

Work on these two projects is well underway. When completed, they will provide a comprehensive data base for use in the development of additional applications to other commercial plants. These two projects will also provide the much needed validation of the processes involved and the design methodologies employed. They will demonstrate to the utility industry that viable technologies do exist to reduce NO_X and SO_2 emissions to the levels required by the Clean Air Act Amendments of 1990, without having undue economic or operational impacts.

Legislative & Marketplace Incentives

Gas reburning can be applied commercially to meet specific NO_X control requirements in a cost-effective manner. Gas reburning also controls SO_2 by displacing part of the coal which contains sulfur. In addition, sorbent injection, integrated with gas reburning, provides enhanced SO_2 control. Therefore, both SO_2 and NO_X control regulations are important to the deployment of gas reburning and integrated technologies.

Titles I and IV of the 1990 revisions to the Clean Air Act are intended to mitigate NO_X in ozone non-attainment areas and acid rain, respectively. They include NO_X and SO_2 control provisions which could be met by gas reburning and integrated technologies.

Title IV – Acid Rain Mitigation

Title IV is intended to reduce both NO_X and SO_2 so as to mitigate acid rain. The top 100 SO_2 sources are required to moderate SO_2 emissions and implement NO_X controls in Phase I (starting in January 1995). In Phase II (starting in January, 2000) all sources are required to have both NO_X and more stringent SO_2 controls.

Title IV controls SO_2 via a system of emission allowances. Each allowance authorizes the bearer to emit one ton of SO_2. The EPA will distribute the allowances based on the plant's total annual heat input in the mid 1980s multiplied by an emission factor (2.5lb./

Demonstration Study and Status Update

Evaluation of Gas Reburning and Low-NO_X Burners on a Wall-Fired Boiler

Plant Capacity/Production

Public Service of Colorado Cherokee Station, Unit No. 3 — 172 MWe

Project Status/Accomplishments

Phase 1, Design and Permitting, began on October 13, 1990 and was essentially completed in September of 1991. Work completed in Phase I included permitting activities, engineering design, drawings and process specifications and ordering of long lead time items.

Phase 11, Construction and Startup, began on June 13, 1991 with demolition and the removal of an abandoned electrostatic precipitator. The construction phase of the project proceeded through the remainder of 1991 and was concluded on April 24, 1992. Startup was completed with only minor problems on June 30,1992.

Phase III of the project began after maintenance work was performed on Unit #3's pulverizers during the summer of 1992. Phase III work completed to date includes complete checkout of the Continuous Emissions Monitoring System (CEMS) and the Boiler Performance Monitoring System (BPMS), a baseline test with the Low NO_X Burners and parametric optimization tests. The optimization testing was completed in April 1993. Results of the optimization tests indicate that NO_X reduction of 70% from baseline values were achieved at full load. Long Term Testing has started and is planned to continue for a twelve month period. In preliminary startup tests a 70% NO_X reduction was achieved.

Project Funding

Total project cost	$16,194,172	100%
U.S. DOE:	8,097,085	50%
Other Participants:	8,097,087	50%

Participants

Energy and Environmental Research Corporation, Public Service Company of Colorado, Gas Research Institute, Colorado Interstate Gas Company, Electric Power Research Institute, U.S. Department of Energy.

Project Objective

To attain a 70% decrease in the emissions of NO_X from an existing wall-fired utility boiler firing low-sulfur coal using both gas reburning and low-NO_X burners.

Commercial Application

Gas reburning in combination with low-NO_X burners is applicable to wall-fired boilers. The technology can be used in new and pre-NSPS wall-fired boilers. Specific features of this technology that increase its potential for commercialization are as follows:

- Can be retrofitted readily to existing plants
- Reduces emissions by more than 70%
- Has the potential to improve boiler operability
- Has the potential to reduce the cost of electricity
- Consists of commercially available components
- Requires minimal space

Milestone	Completion
Phase I—Design and Permitting	9-91
Phase II—Construction, Start-up, and Shakedown	6-92
Phase III—Operation, Data Collection, Reporting and Disposition	9-94
Project Complete	12-94

10^6 Btu for Phase I and 1.2 lb/10^6 Btu Phase II). New plants receive no allowances.

The SO_2 emission allowances may be sold or bought. Decisions will be made to install so 2 controls or to buy allowances based on the commodity costs of SO_2 allowances ($/ton of SO_2 emitted)

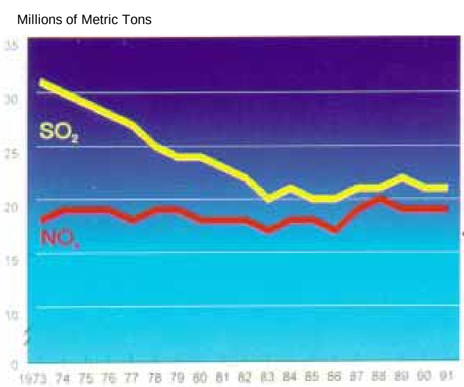
The SO_2 control provided by gas reburning and integrated technologies will free additional allowances which may be sold at current market values.

Title IV requires existing units to be retrofitted to reduce NO_X emissions to preliminary emission limits of 0.45 and 0.50 lb/10^6 Btu for tangentially- and wall-fired units, respectively. Gas reburning demonstrations have satisfied these NO_X limits readily on a routine basis. Environmental Protection Agency will define limits for cyclones, wet bottom furnaces and cell burner furnaces by 1997. Compliance may be achieved by meeting these limits on an annual average basis by any means, or by applying "Low NO_X Burner Technology." This term will be specifically defined by EPA in late 1993 and is expected to include conventional low NO_X burners and possibly overfire air ports which are an integral part of gas reburning.

Title I — Ozone Non-Attainment Area NO_X Mitigation

Atmospheric ozone is produced in part by reactions involving NO_X. Title I requires NO_X emissions to be reduced so as to bring areas with high ozone into compliance with ambient air quality standards. The EPA has defined the specific areas of the country with ambient ozone concentrations exceeding the standards as ozone non-attainment areas.

In some cases, NO_X sources outside of non-attainment areas may be transported into the areas by prevailing winds, thus contributing to the high ozone levels in the area. In such cases, the contributing areas and non-attainment areas may be combined into Transport Regions. All sources within the Transport Regions are then subject to NO_X control. There is potential for most of the United States east of the Mississippi River to be included in such Transport Regions.



SO_2 and NO_X emissions in the United States, showing that NO_X emissions have generally held constant from 1973 to 1991 at 18-20 million tons per year. Sources: DOE/FE0193P and EPA-450-R-92-001

For plants within ozone non-attainment areas or transport regions, compliance with the Title IV NO_X requirements may be a moot point. The additional NO_X reductions required by Title I will necessitate more effective controls than the Low NO_X Burner Technology of Title IV.

Gas reburning and integrated technologies are excellent candidates for meeting these combined Title I and Title IV requirements. Gas reburning alone can achieve over 60% NO_X control. In addition, if less NO_X control is required initially (for Title IV compliance), less gas can be cofired, further reducing cost. If more NO_X control is required, the gas reburning system can be upgraded with Low NO_X Burners or to Advanced Gas Reburning.

Commercialization

EER is now ready to design gas reburning and sorbent injection systems for virtually any utility boiler application. Accordingly, EER is now offering these technologies commercially with performance and emission control guarantees.

The potential commercial applications of the emissions-control technologies involved in both demonstration projects, while similar, are nevertheless different enough to discuss separately.

GR-SI
(Hennepin & Lakeside Projects)

The commercial market potential for gas reburning and sorbent injection, either separately or combined, includes both utility and industrial applications in the U.S. and abroad. In combination, these two technologies can be retrofitted to over 900 pre-NSPS utility boilers in the U.S. alone. They can also be applied to new boilers. Their use could enable the use of higher sulfur coals without exceeding emission limits of NO_X and SO_2.

Economic Considerations

Since gas reburning and integrated technologies can meet or exceed the NO_X control requirements of both Title I or Title IV of the 1990 Amendments to the Clean Air Act, economic considerations are a key issue affecting technology development. Application of gas reburning and integrated technologies requires modifications to existing power plant equipment. As a result its capital costs and operating costs depend on site-specific factors. Some factors affecting the cost of these gas reburning technologies are:

- gas availability at site
- coal-gas cost differential
- sulfur dioxide removal requirements
- value of SO_2 allowances

The emission control costs for gas reburning and integrated technologies as applied to a nominal 500 MWe power station with a capacity factor of 65%, a SO_2 emission level of 6.0 lb/10^6 Btu and a \$1.00/10^6 Btu coal to gas cost differential are shown below in the table.

The operating cost of gas reburning is dominated by the differential cost between coal and gas. For the subject sites of this report, the gas-coal cost differential ranges from \$1.00 to \$1.50/10^6 Btu, corresponding to 90-95% of the total operating cost. For gas reburning-sorbent injection, the cost of the sorbent influences costs particularly for high sulfur coals requiring substantial amounts of sorbent. Typical capital and operating costs for gas reburning technologies is shown in the figure below as a function of the coal to gas cost differential.

The capital cost component corresponds to 0.7 to 2.0 mills/kwhr for the various systems, independent of the coal-gas cost differential. The operating cost increases linearly with the coal to gas cost differential.

Capital and operating costs presented here are application specific; consequently the data presented here serve to indicate economic trends.

Nominal Performance and Costs of Gas Reburning and Integrated Technologies

	Emission Control (%)		Cost Factors		
	NO_x	SO_2	Capital (\$/kw)	Capital + Operating (mills/kwh)	Pollutant Removal (\$/ton)
Gas Reburning (GR)	60	18	30	2.8	254
Gas Reburning - Sorbent Injection (GR-SI)	60	50	90	8.0	388
Gas Reburning - Low-NO_x Burners (GR-LNB)	70	18	50	3.3	270

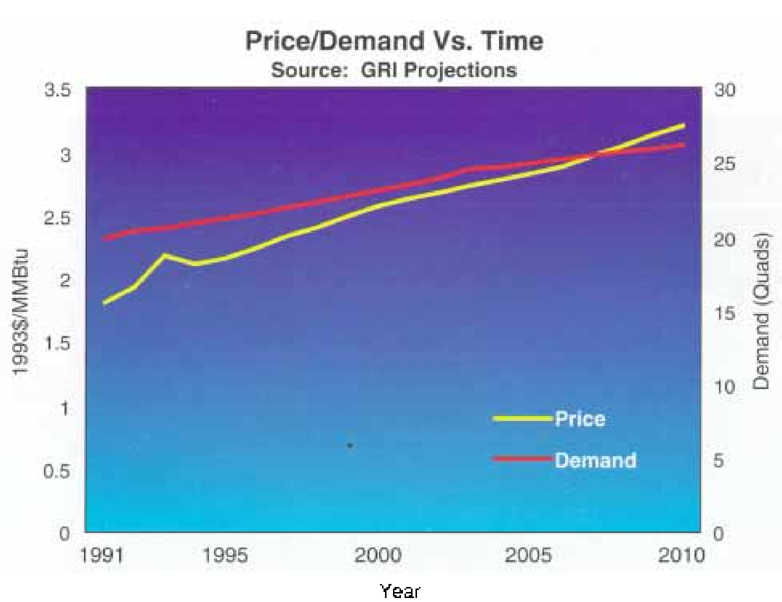
Based on \$1/10^6 Btu coal to gas differential

GR-Low-NO_X Burners (Cherokee Station)

Gas reburning in combination with low-NO_X burners is applicable to wall-fired utility boilers, both pre-NSPS and new. The addition of the low NO_X burner enhances the commercialization potential of this combined technology.

Gas Pricing and Availability

Current forecasts show excellent gas reserves and stable prices compared to previous projections. Gas is now increasingly a market commodity not so different from coal. Gas users can negotiate directly with producers and transporters under a variety of contractual arrangements and options ranging from spot pricing to long-term/ price-certain contracts for natural gas supply.



EER's Marketing Plans

EER has been closely involved in the commercial development of both sorbent injection technology (since the mid-1970s) and gas reburning systems (since 1981). It is also a pioneer in the integration of these two technologies, and is the first organization to combine gas reburning with low-NO_X burners. This long and accomplished track record in the development of NO_X and SO_2 control systems, coupled with the sponsorship and involvement in the three integrated GR demonstration projects featured in this report, gives EER the necessary experience and the technical know-how to market these technologies.

According to recent reports, the marketplace demand for such easily retrofitted, integrated emission control systems is quite large, ranging from 25% to 80% of the coal-fired utility boilers in the U.S., depending primarily on the gas-coal cost differential.

The most likely candidates for gas reburn/sorbent injection retrofits would be utility boilers with the following characteristics:

- Currently burning medium- to high-sulfur coal,
- Have at least 10 but less than 20 years of remaining useful life,
- Restricted or cramped sites, and
- Ready access to a natural gas supply.

Commercialization of this technology will largely depend upon the technical expertise and demonstration experience gained from this program. This information will permit the analysis and design of customized gas reburning and integrated technology retrofit systems to suit the specific needs of all potential customers — a capability absolutely critical to the successful implementation of these technologies.

Hennepin: Demonstrating The Potential Of GR-SI On Tangentially-Fired Boilers

The GR-SI testing and demonstration program recently completed at Illinois Power's Hennepin Generating Station, Unit #1 is one-half of a larger project intended to show the ability of EER's integrated gas reburning and sorbent injection process to reduce NO_X emissions by 60% and SO_2 by 50%.

Testing Program

The objectives of the test program were: (1) to optimize the operation of the GR-SI system, (2) to show that the performance goals have been achieved, (3) to quantify the costs and operational impacts of the GR-SI process, (4) to build a data base for use in subsequent GR-SI applications, and (5) to provide sufficient operating hours to determine the long-term effects of GR-SI operation.

Testing began with baseline operation (without GR-SI) for 50 days to gather baseline NO_X and SO_2 emission data. Gas reburning was then optimized, followed by the optimization of the sorbent injection process. A 12-month, long-term demonstration of GR-SI using the baseline coal as primary fuel was concluded in October 1992.

In addition to emission data, operation and maintenance costs for the GR-SI system were monitored, along with all maintenance costs associated with boiler operation. Data were also collected for optimization of the percentage of gas heat input, zone stoichiometries, gas injection velocity, sorbent mass flow rate, sorbent injection velocity and configuration, and boiler operation parameters.

To be able to monitor the emissions and performance data, a Boiler Performance Monitoring System (BPMS) was developed and installed at Hennepin. This automated, real-time system enables EER to continuous monitor emissions, heat absorption trends, stoichiometric calculations, and boiler performance. It also provides immediate information on fuel mass flow rates, steam rates, temperatures, and pressures. Manual sampling was done of particulate flow at the ESP inlet and outlet to determine the effect of sorbent injection on ESP performance. N_2O was measured at the stack breeching. To be able to characterize the furnace flow field, in-furnace temperatures were measured, both before and after installation of the GR-SI system.

Extensive testing of boiler tube thickness was conducted before, during, and after the program to determine the effects of GR-SI on tube wear. Tests on promoted sorbents were also run at the end of the program.

Hennepin Operating Hours

	Hours
Baseline	860
Gas Reburning (GR)	397
Sorbent Injection (SI)	115
GR-SI	757
Total	2,129

Main process gas supply.

Pretest Modifications

To retrofit the Hennepin plant with a GR-SI test system, modifications for SI were required in four areas: the sorbent receiving and storage area, boiler piping, ash disposal, and the electrostatic precipitator. For GR, natural gas injection nozzles were installed at the four comers of the boiler, directly above the primary combustion zone. To improve the penetration of natural gas mixing in the furnace, an 18-inch-diameter duct was installed to recycle flue gas from the duct between the economizer and air heater. The flue gas was then directed through a particulate removal device, a recirculation fan and delivered to the gas reburning nozzles for injection with the natural gas.

Overfire air ducts were also installed at each comer of the boiler, directly above the reburning zone. These air ducts also serve as ports for the lower level sorbent injectors. A second sorbent injection elevation with a six nozzle configuration was installed in the upper furnace.

Site-specific auxiliary systems associated with ash collection from sorbent injection include a flue gas humidification system between the air heater and ESP, and a CO_2 injection system to control pH of the spent sorbent before being discharged to the ash pond.

Hennepin Short-Term HCI-HF Data

Natural gas: 19% of the total heat input

Calcium/sulfur molar ratio: 1.66

	% Reduction	Final lb/10^6 Btu
HCI	63-86	(9.3 - 25) X 10^{-3}
HF	95-99.7	(1.6 - 19) X 10^{-5}

GR-SI Demonstration Data

At this stage of project evaluation, test results are available from the Hennepin tangentially-fired boiler GR-SI demonstration. The following findings are conclusive:

- Gas reburning performance is unaffected by injection of the regular hydrated lime.
- SO_2 emissions reduction of up to 57% has been achieved during short-term testing by injecting hydrated lime with a Ca/S molar ratio of 2 through the upper injection configuration at full load. Eighteen percent of the SO_2 reduction is attributable to the replacement of coal with sulfur-free natural gas. The remaining 39% reduction is due to the effectiveness of the fine hydrated lime that is injected into the top of the boiler. Long-term testing has also shown that the 50% SO_2 reduction goal can be obtained at a molar Ca/S ratio of 1.75; and
- So far, there have been no observed adverse effects to boiler performance: ash deposition and fireside corrosion have not increased, and neither has boiler-wall deposition.

Other encouraging results include: successful start-ups of the retrofitted plant and long-term operation of the GR-SI system; and close correlation between the pilot-scale and predicted results.

Achievement of 60% and 50% reductions in NO_X and SO_2 is a commercial reality. Routine day-to-day operation of the Hennepin GR-SI system by plant personnel resulted in NO_X/SO_2 emissions reduction of 67% and 53%, respectively. Hydrogen chloride (HCl) and hydrogen fluoride (HF) combustion products were also removed.

ESP Performance

Emissions of particulate matter during

Gas Reburning Demonstration Data

A substantial body of data has been obtained from the Hennepin Gas Reburning installation after operation for 1,150 hours (including GR and GR-SI operating hours). This includes parametric optimization tests as well as long term data. The operations at Hennepin were completed in January 1993. Illinois Power intends to retain the gas reburning system for future NO_X control.

The parametric tests evaluated the effects of Gas Reburning process variables over the boiler operating range. Once during parametric testing under optimum conditions, NO_X emissions were reduced by as much as 77% from the baseline coal fired level. These data were analyzed to select conditions which produced the best balance of performance for commercial operation. NO_X emission data were obtained under these conditions as a function of the gas firing rate in parametric and long-term tests (under comparable conditions). Baseline uncontrolled emissions firing 100% coal (no gas) were 0.75 lb/10^6 Btu before installation of the Gas Reburning system. Gas Reburning with the design amount of gas firing (118%) reduced NO_X emissions by 60% to 70% down to 0.23 to 0.30 lb/10^6 Btu. The gas injection rate can be used as an adjustable parameter to control NO_X emissions to meet a range of requirements. Even with only 10% gas firing, NO_X emissions are reduced by 55% to 0.34 lb/10^6 Btu. The cost effectiveness of gas is high.

Following the parametric tests, long-term tests were conducted under normal commercial service conditions. This was a particularly severe test since the unit is cycled daily. NO_X emissions were measured as a function of time (no tests in May or June 1992). NO_X emissions were reduced by an average of 67.3% to 0.245 lb/10^6 Btu.

The effect of Gas Reburning on durability of the unit was also evaluated during the long-term test. Since the Reburning zone operates under oxygen deficient conditions, there was concern that tube wastage might be accelerated in this area due to the presence of reduced sulfur species or fluctuating oxidizing and reducing conditions. Accordingly, extensive durability evaluations were conducted throughout the test program including both baseline and GR-SI operating periods. The measurements included direct inspection, ultrasonic tube thickness measurements and destructive testing of tube sections. The results of these tests have confirmed no measurable increase in tube wastage rates occurred due to Gas Reburning or Sorbent Injection. Gas Reburning is a demonstrated process and is ready now for commercial use.

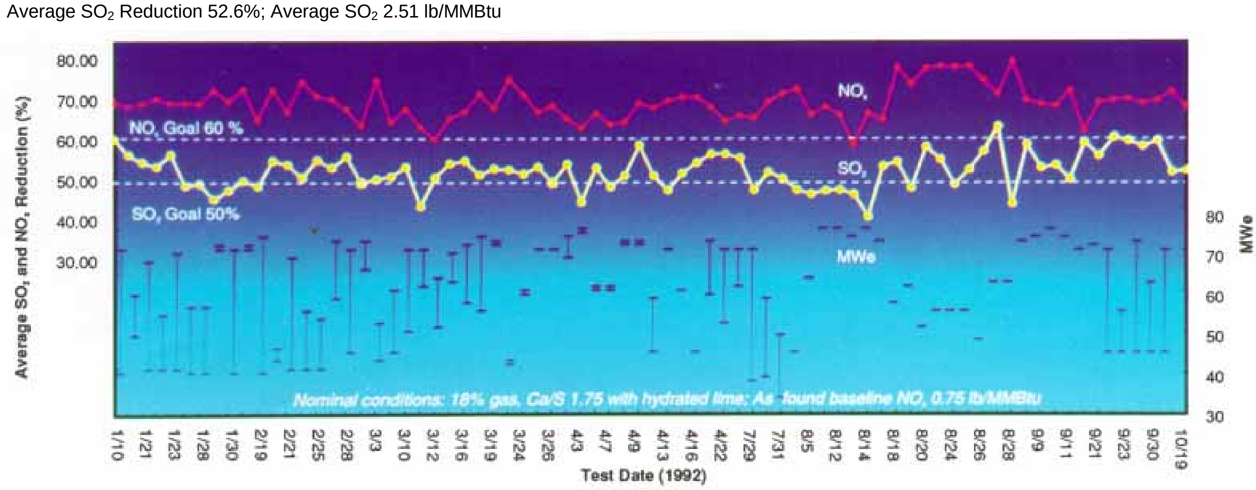
Average Hennepin Long-Term GR-SI Data

Natural gas: 18% of the total heat input
Calcium/sulfur molar ratio: 1.75

	% Reduction	Final lb/10^6 Btu
SO_2	52.6	2.51
NO_X	67.3	0.245

Long-Term GR-S1 Performance at Hennepin

Average NO_X Reduction 67.3%; Average NO_X 0.245 lb/MMBtu
Average SO_2 Reduction 52.6%; Average SO_2 2.51 lb/MMBtu



Advanced Gas Reburning

Advanced Gas Reburning is a synergistic combination of Gas Reburning and Selective Non-Catalytic Reduction (SNCR). In this case, Gas Reburning uses only 10% of the boiler fuel as natural gas and SNCR uses urea, ammonia or other proprietary nitrogen compounds. NO_X reductions achieved in pilot plant testing were 82% to 83% based on a nitrogen agent to NO_X molar ratio of 1.5:1.

A Comparison of Gas Reburning (GR) and Its Advanced Technology

Process	Status	Gas	Urea	NO_X Reduction
GR	Com.	18%	-	60-75%
Advanced GR	Pilot	10%	Yes	82-83%

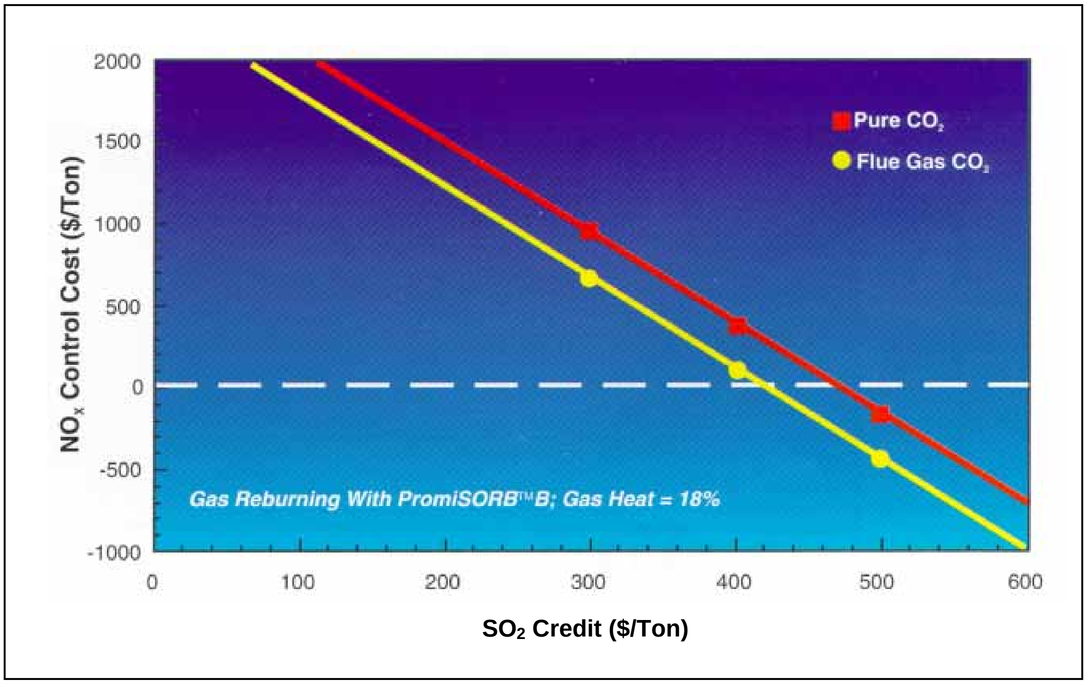
GR-SI operation with flue gas humidification have been limited to essentially the levels of baseline operation without humidification. Full load (70 MWe) baseline particulate emissions ranged from 0.018 to 0.035 lb/10^6 Btu, corresponding to ESP collection efficiencies of 99.6 to 99.8%. These results compared to full load GR-SI particulate emissions of 0.015 to 0.025 lb/ 106 Btu, corresponding to ESP collection efficiencies of 99.8 to 99.9%. The particulate emissions decreased with decreasing ESP flue gas temperature due to flue gas cooling by humidification.

Boiler Efficiency and Heat Transfer

The boiler efficiency decreased slightly (less than 2%) during GR and GR-SI operations, compared to the baseline operation.

GR and GR-SI also impacted the heat transfer profile. GR results in increased heat absorption in the secondary and reheat superheaters, a decrease in the furnace heat absorption, and no change in the heat absorption by the primary superheater or economizer. GR-SI results in reduced heat absorption in the furnace, secondary and reheat superheaters, and an increase in the primary superheater and economizer heat absorption.

Effect of SO_2 credit on NO_X control cost (with spent sorbent-ash sluice neutralization)



Boiler Tubes

Ultrasonic tube thickness measurements were taken at approximately 4,000 points in the boiler during each of the three tests: 1988 (prior to GR-SI retrofit), 1990 (prior to GR-SI operation), and 1992 (after GR-SI operation). The results indicate that wall thicknesses measured in 1992 were, in many cases, larger than 1988 and 1990 measurements. In some cases the wall thickness reductions between 1990 and 1992 were preceded by an apparent increase from 1988 to 1990. In only a few sections, was there a consistent reduction in wall thickness from 1988 to 1992. In those areas, the tube wall life would still be expected to last beyond the year 2023, the expected life of the unit. Several areas showed that significant tube wall wear had already occurred at the time of the earliest measurements (1988).

Chimney Inspection

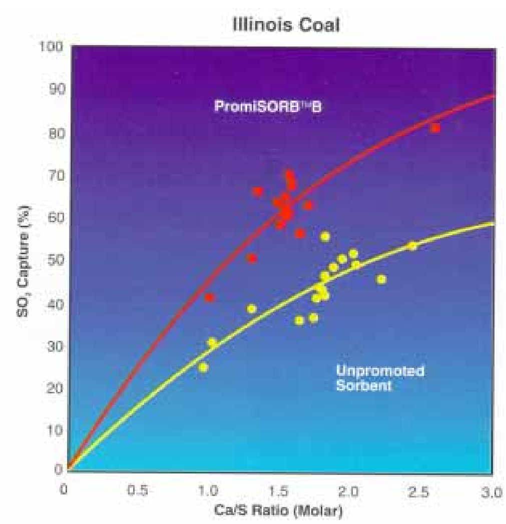
The chimney was inspected before and after GR-SI testing, in April 1990 and October 1992. Internal and external examinations of the chimney were conducted for changes in wear rate and deposition of particulate matter. The inspections showed no increase in the internal wear (mortar) but increased deposition of particulate matter throughout the chimney. Illinois Power has indicated that this is not of concern.

Promoted Sorbents

In addition to the regular hydrated lime (HL), three sorbents promoted with proprietary additives were also tested at Hennepin.

Promoted sorbents have better performance and lower SO_2 control costs than the hydrated lime. PromiSORB™ A also contributes some NO_X reduction. PromiSORB™ B provides significant improvement in the cost of SO_2 emission control. PromiSORB™ is a commercial product offered by a joint venture between EER Corporation and Petroleos de Venezuela. Similarly, higher surface area hydrated lime (HSAHL), as developed by the State of Illinois Geological Survey, has better performance and lower costs.

PROMISO$_X$™ PROCESS



Sorbents Tested at Hennepin

	Hydrated Lime (HL)	High Surface Area HSAHL	PromiSORB™ A	PromiSORB™ B
$/ton sorbent delivered	74	89	89	93
Ca/S Molar Ratio	1.75	1.71	1.75	1.75
Ca utilization, %	24	35	33	39
Sorbent cost, $/ton SO_2 removed*	380	310	330	290

*Actual **costs will depend on site specific factors**

Lakeside: GR-SI Demonstration On A Cyclone-Fired Boiler

This City Water, Light, and Power generating unit (Lakeside Station) in Springfield, Illinois, is the second half of a two-site project to demonstrate the ability of EER's integrated GR-SI retrofit process to reduce NO_X and SO_2 emissions. The Lakeside Unit #7 is a cyclone-fired, 40 MWe boiler that bums high-sulfur Illinois coal.

Project Status

The retrofitting at Lakeside was begun in mid-1990, and was completed in early 1993. Start-up and baseline operation of the GR-SI began in the May of 1993. All demonstration operation and testing is scheduled for completion in August of 1994. The date of the final report on this project is scheduled for November of 1994.

Natural gas injectors being installed at Lakeside. Flanged piping is for connecting recirculated flue gas lines.

Testing Program

This specific testing program has the same five objectives as the overall GR-SI demonstration program: (1) to optimize the operation of the GR-SI system, (2) to demonstrate that the performance goals can be achieved, (3) to quantify the costs and operational impacts of the GR-SI process, (4) to establish a data base for use in future GR-SI applications, and (5) to provide sufficient operating hours to determine the long-term effects of GR-SI operation.

Testing began with baseline operation (without GR-SI) in order to gather baseline NO_X and SO_2 emission data. Once this baseline testing was completed, the gas reburn portion of the process was optimized. This was followed by the optimization of the sorbent injection system in the presence of ideal GR conditions.

A 12-month demonstration of GR-SI is underway using baseline coal. During this operational demonstration, continuous monitoring of NO_X and SO_2 emissions is being conducted. In addition, all operating and boiler/system maintenance data is being recorded.

As at Hennepin, the impact of GR-SI on boiler tube thickness will be extensively tested before, during, and after the test program to determine if there is any wall erosion or tube deterioration. Additional tests, including alternate sorbents, will also be carried out within the program. Upon completion of this demonstration testing, a final report will be published. All test results will be reported to DOE, GRI, and the Illinois Department of Energy and Natural Resources, the three major co-funders of the project.

Pretest Modifications

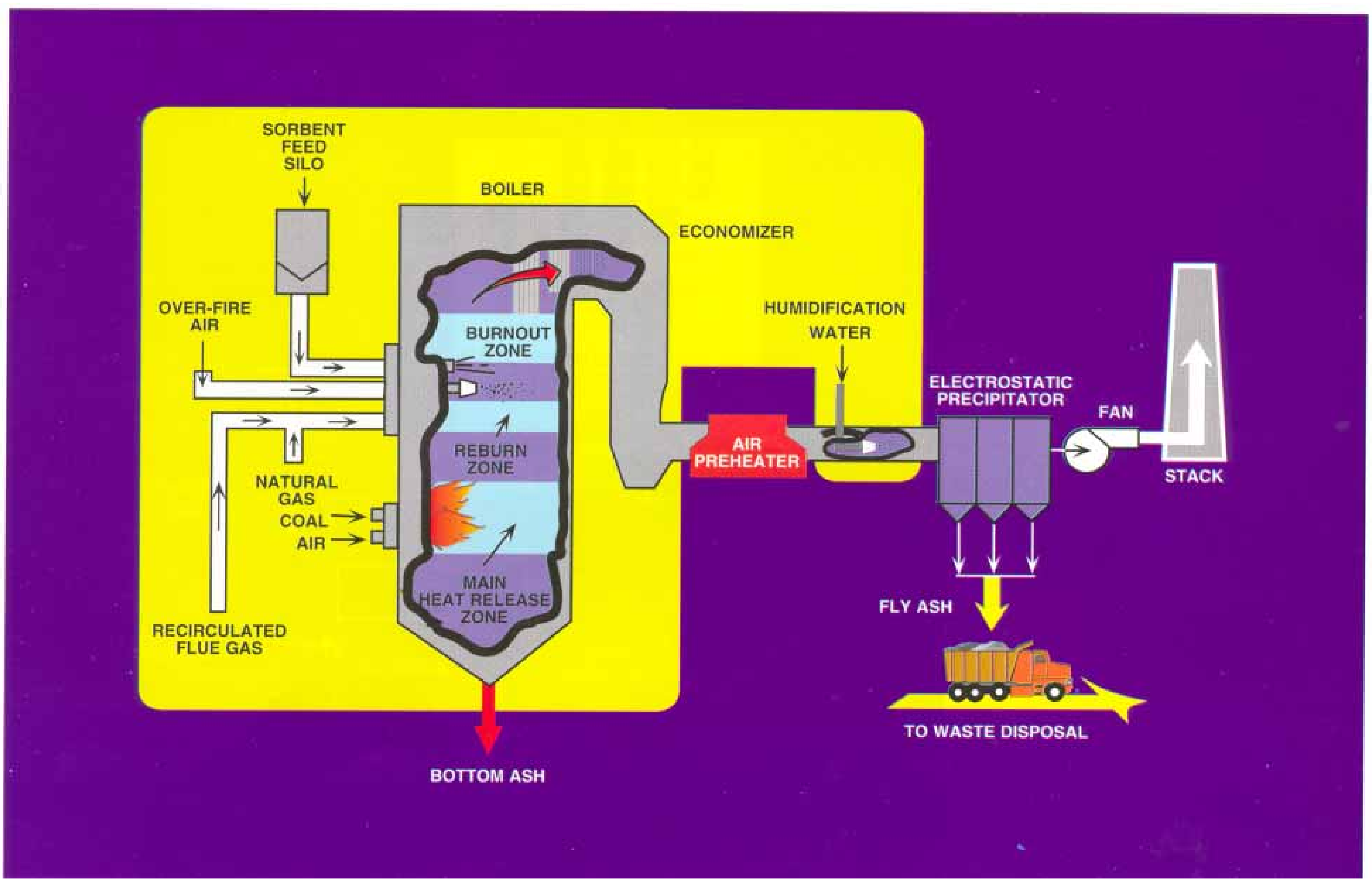
The following physical modifications were required to retrofit the Lakeside #7 boiler and related equipment with the GR-SI emission reduction system. The principal boiler changes included the through-the-wall installation of an array of natural gas/flue gas recirculation nozzles, an overfire air duct and nozzles, sorbent injection nozzles, and test ports. To improve the penetration of the natural gas into the furnace, a flue gas recirculation fan was installed, with appropriate ductwork, to provide flue gas as a transport medium. The sorbent is delivered to the various sorbent injection nozzles through a pneumatically-operated system of flexible hoses from the newly constructed sorbent storage facility. To enhance the penetration of the sorbent into the boiler, a 125 HP sorbent injection fan was installed to pull air from the boiler room for delivery to the sorbent injection nozzles.

Related construction activities included: the construction of a cylindrical sorbent storage silo, able to hold a five-day supply (325 tons) of hydrated lime, and all related sorbent handling equipment and unloading facilities; a dry ash handling facility for short-term storage of the GR-SI ash by-product before shipment to a landfill; and the installation of a natural gas supply line to the plant, including a pressure-reducing station and meter.

Test Results

GR-SI operation of the Lakeside unit has just begun. The initial GR tests show that the 60% NO_X reduction goal has been achieved. Initial SI tests similarly indicate that the 50% SO_2 reduction goal for GR-SI operation will be achieved.

GR-SI-process flow diagram.



Cherokee: Demonstrating GR & Low-NO_X Burners On A Wall-Fired Boiler

This project is intended to demonstrate the ability of an integrated gas reburning, low-NO_X burner process to significantly reduce NO_X emissions. It has been installed on the Public Service Company of Colorado's Cherokee Station, Unit #3, which is a 172 MWe, low-sulfur coal-burning, wall-fired boiler.

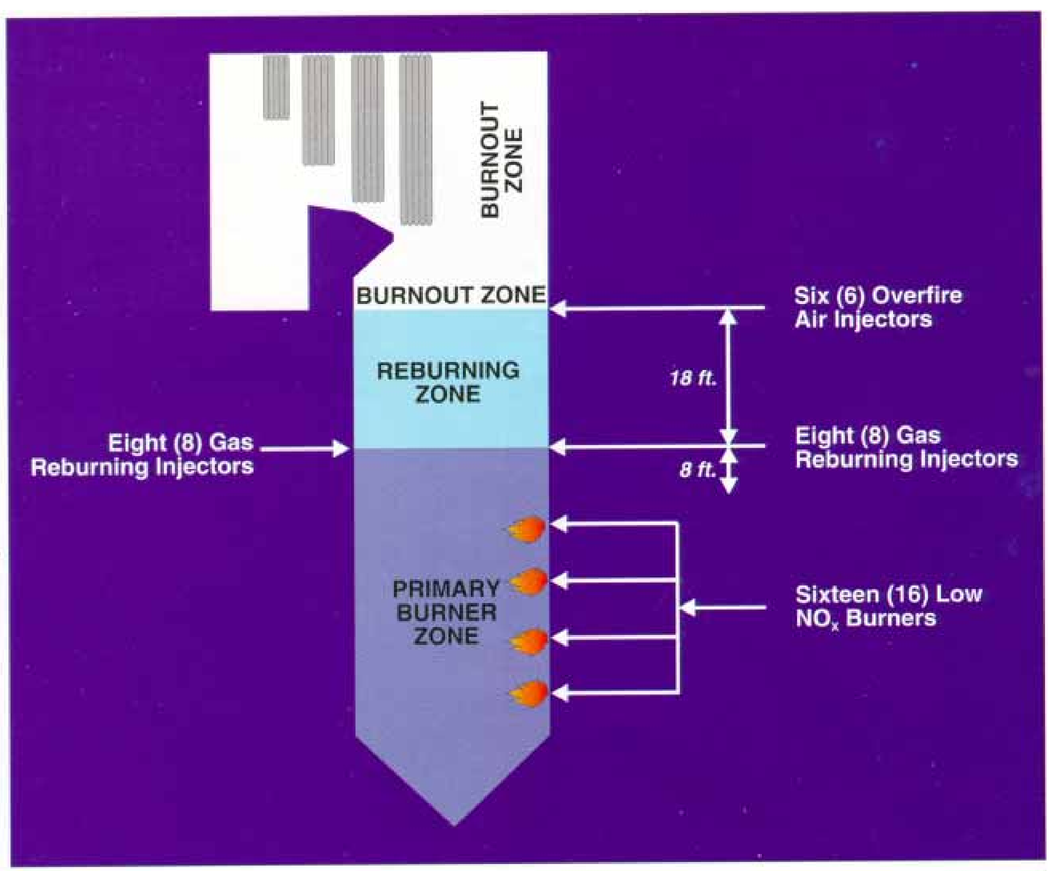
Developed by EER, this process uses natural gas as a reburn fuel (up to 20% of total fuel input). The gas is fired above the main coal combustion zone in the boiler, creating a slightly fuel-rich zone. NO_X moving upward from the lower region of the furnace is "reburned" in this zone and converted to atmospheric nitrogen.

Low-NO_X burners installed in the coal combustion zone retard the production of NO_X by staging the burning process to carefully control the coal/air mixture. When LNBs are used synergistically with GR, a projected 70% reduction in NO_X emissions is attainable.

Project Status

This project was awarded in October of 1990. Design of the Cherokee retrofit began immediately, including the design, arrangement, and sizing of the system's components; placement of component orders; and the selection of contractors. The design process was completed in mid-1991.

Construction began immediately afterward and was completed in April of 1992. Baseline operation of the GR system was delayed while the plant rebuilt its coal pulverizers. Optimization testing began in November 1992. The long-term operation phase began in April 1993. Initial test results have achieved the project goal of a 70% reduction in NO_X emissions at a controlled excess air level.



GR-LNB System Schematic at Cherokee

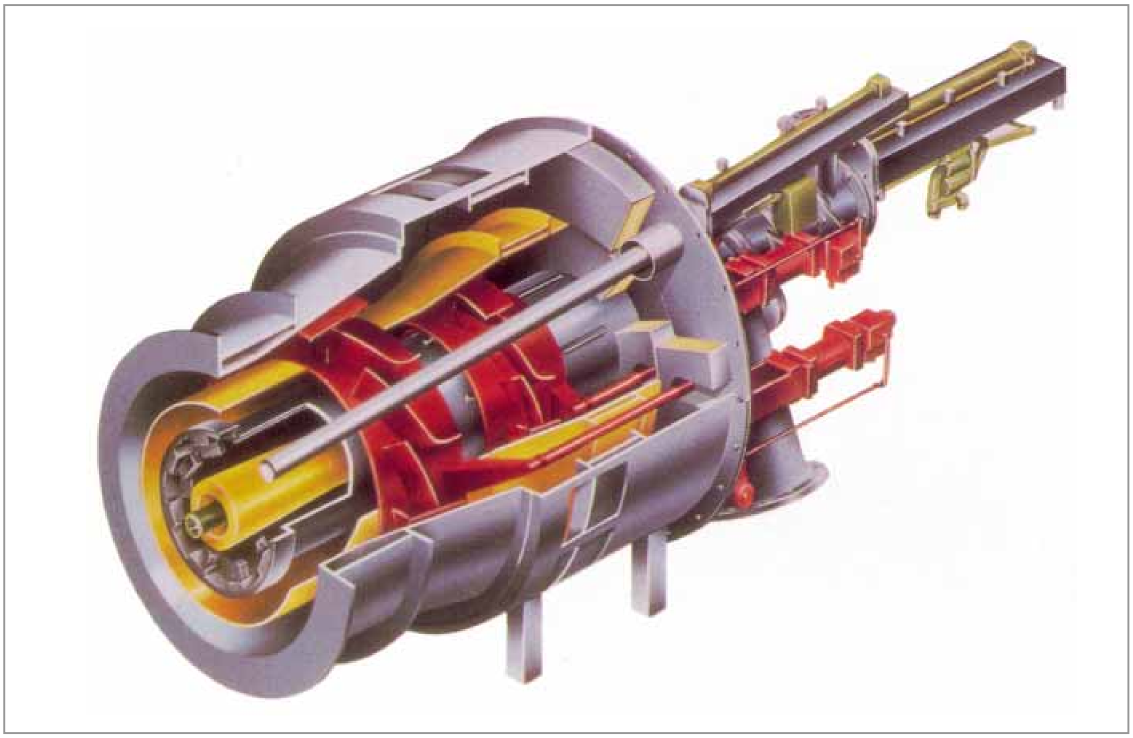


Diagram of a low-NO_X burner.
(EER's FlamemastEER™ Type 4AFW Low NO_X Burner is shown)

Testing Program

The objectives of the GR-LNB testing program are: (1) to optimize the operation of the GR-LNB process, (2) to demonstrate that the performance goal (>70% NO_X reduction) is achievable, (3) to quantify the costs and operational impacts of the GR-LNB process, and (4) to build a data base and the know-how for use in subsequent GR-LNB applications.

Pretest Modifications

The major LNB retrofit item was the replacement of the 16 front-wall burners with Foster Wheeler Internal Fuel Staging low-NO_X burners. The remaining portions of the fuel system required only minor modifications.

Placing a GR system on this boiler involved the installation of three subsystems: (1) the natural gas metering and distribution system; (2) the flue gas reinjection system; and (3) the overfire air system. The first of these subsystems delivers natural gas to the upper furnace reburning area. The flue gas reinjection subsystem helps ensure good natural gas penetration into and dispersion throughout the furnace. The overfire air subsystem is above the natural gas injection zone and assists in achieving complete combustion.

Initial construction work involved the removal of an obsolete electrostatic precipitator to make room for the overfire air and flue gas reinjection fans, motors, ductwork, and supporting structures. Next, natural gas injectors and overfire air nozzles were installed in the furnace walls. Since portions of the furnace wall tubing had to be removed, the boiler was shut down for about two months. During this outage, most of the work on the natural gas subsystem was completed, and much of the overfire air and flue gas recirculation system work, at and adjacent to the boiler, was also completed. Simultaneous with this mechanical work was the installation of all electrical, instrumentation, and system controls.

Cherokee gas reburning low-NO_X burner model.

Similar to the other GR demonstration systems installed, the Cherokee unit's overfire air is taken from the boiler, downstream from the air heater. It is then routed around the boiler to an overfire air fan, boosted in pressure, and routed back to the boiler. The flue gas reinjection subsystem takes flue gas leaving the air heater, routes it to a multiclone and recirculation fan, boosts its pressure, and then routes it back to the boil

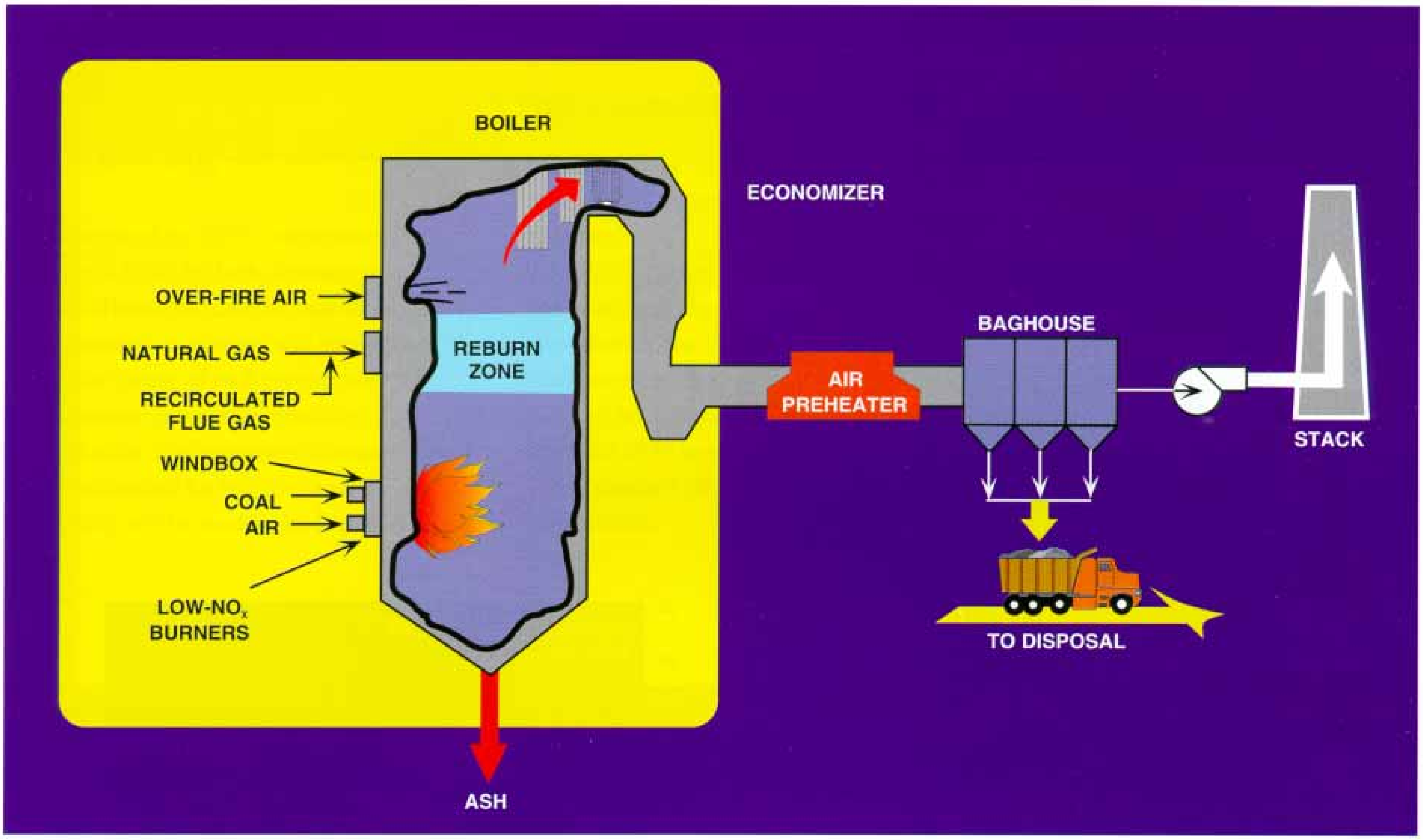
Test Results

Extensive parametric tests of gas reburning have been completed at Cherokee. NO_X emissions can be shown as a function of stoichiometry. For the baseline and low NO_X burner tests, which involve a single combustion zone, the overall stoichiometry is employed. For GR, the stoichiometry refers to the Gas Reburning Zone. The minimum NO_X emission with GR-LNB measured to date was 0.20 lb/10^6 Btu. This was found at a Reburning Zone stoichiometry of 88% of theoretical air and a gas firing rate of 20%. This NO_X level corresponds to a reduction of 72% from the baseline level and 60% from the low NO_X burner level. The one-year long-term test is currently in progress.

In general, the NO_X emission is reduced with increasing gas feed up to about the 20% input level.

For baseline, LNB, and GR-LNB, the NO_X emission increases with increasing load. The increase in NO_X with increasing load is more moderate with GR-LNB than that with baseline or LNB.

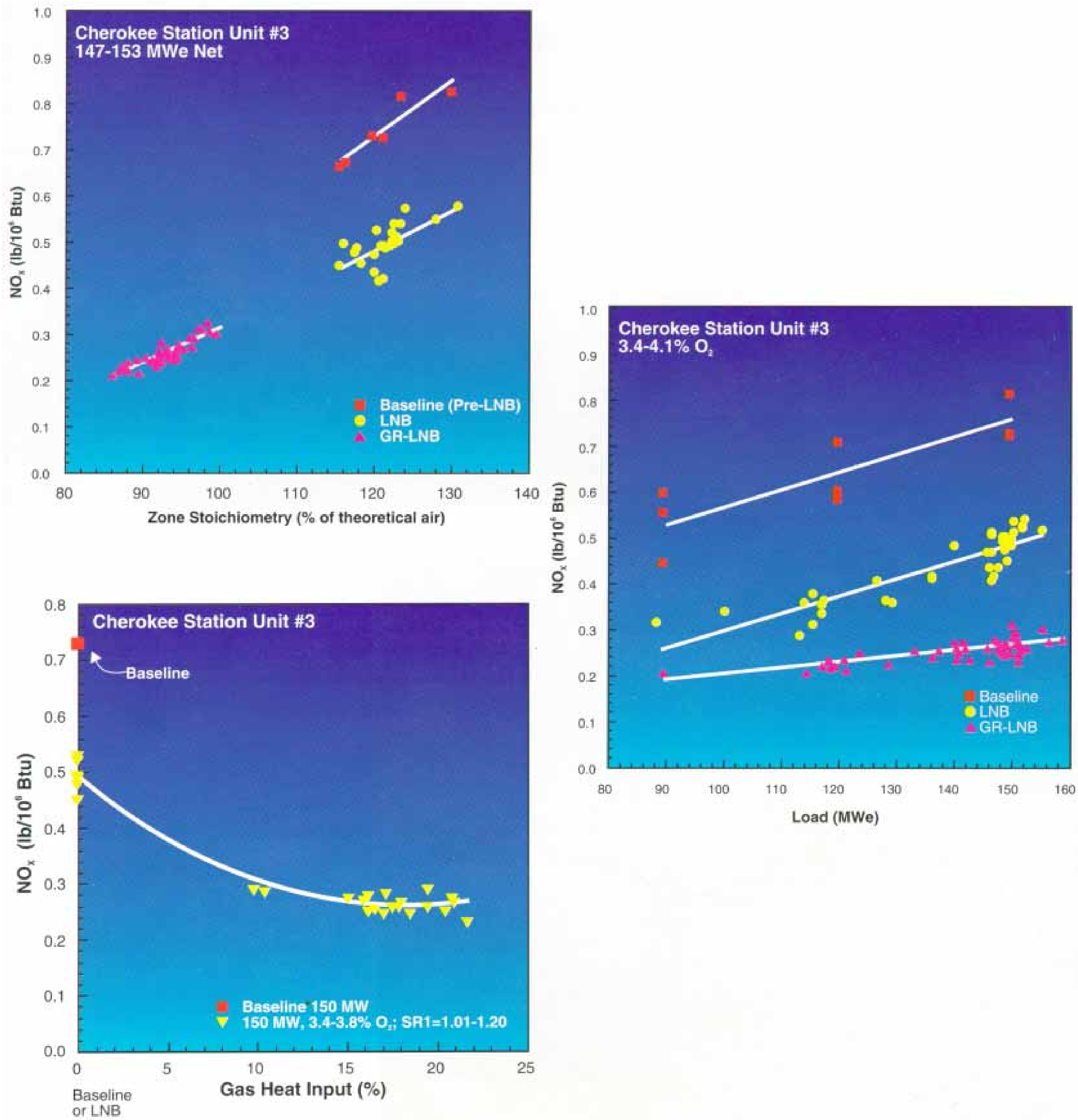
Long-term demonstration of the Cherokee Unit's GR-LNB system has just begun. The initial demonstration results obtained at constant or varied loads in the first three months agreed with parametric test results.



Flow diagram, gas reburning and low-NO_X burners on a wall-fired boiler.

The mounting shroud for the low-NO_X burner is being checked during installation in the boiler wall at Cherokee Unit No. 3.

NO_X Data from Cherokee Unit 3

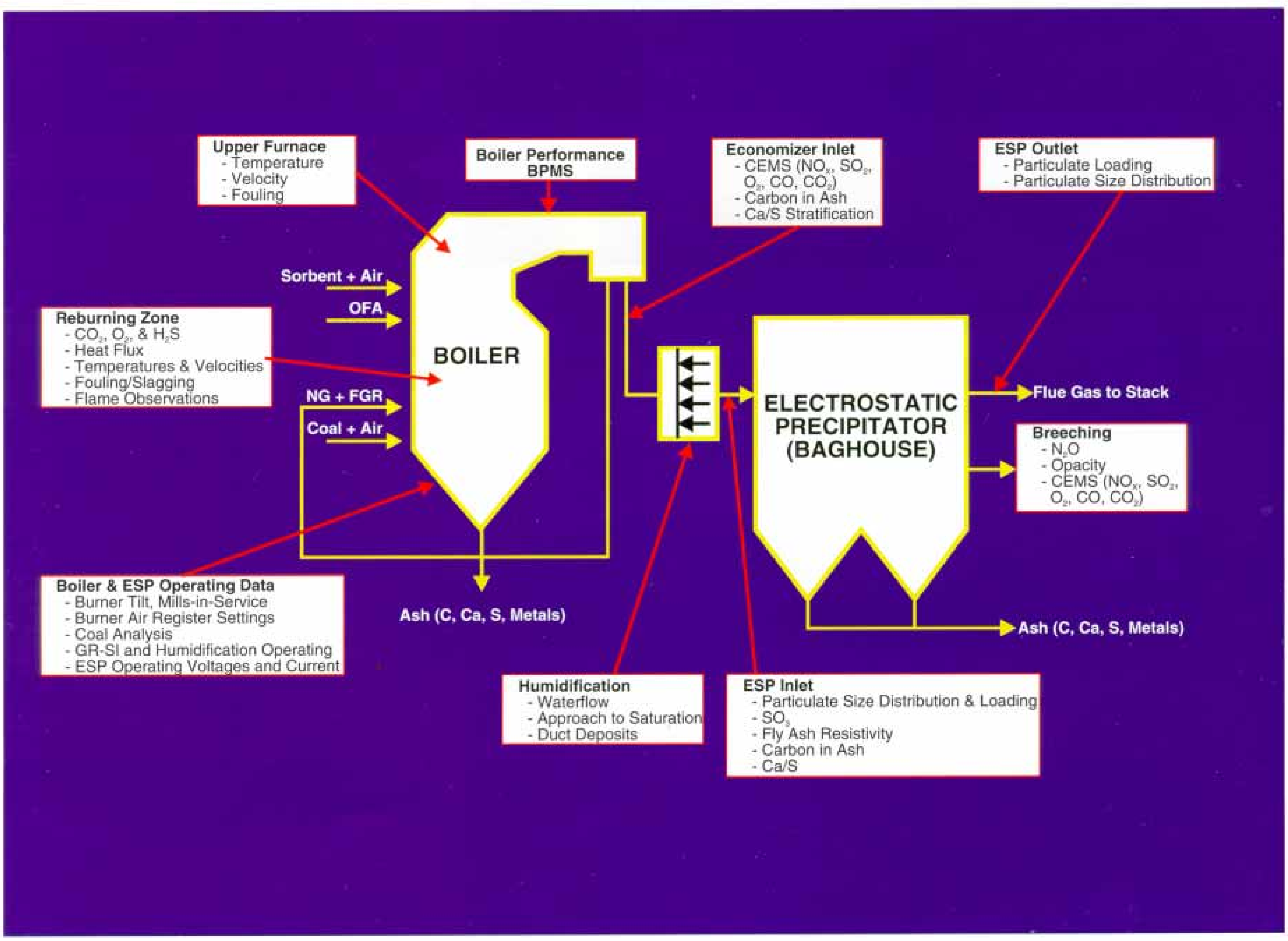


Environmental Monitoring

As required by EER's cooperative agreements with DOE for both demonstration projects (Hennepin/Lakeside and Cherokee), environmental monitoring will be conducted during the course of each project at all three sites to ensure process acceptability. As detailed in the Environmental Monitoring Plan (EMP) submitted for both projects, this monitoring will be used to develop a data base for the assessment of the environmental performances of the technologies used (i.e., gas reburning, sorbent injection, LNBs, and their respective integrated applications). It will also be used for the replication of any of these technologies, independent of specific site characteristics.

Specific monitoring described in both EMPs includes: air, wastewater, solid waste, groundwater, and health and safety conditions. Also described is all additional monitoring required for specific state and local regulations. All EMP testing and measurements utilize standard EPA methods and procedures as applicable.

Environmental monitoring flow chart



Shaped boiler tubes, part of the over-fire air and gas reburn system, were welded into the boiler wall at Cherokee Station.

Air Monitoring

The air monitoring plans for both demonstration projects include specifications for point-source emissions, fugitive dust emissions, and ambient air concentrations. Both demonstrations closely monitor flue gas NO_X, SO_2, CO, CO_2, and O_2 continuously. Measurements of particulate loading and particle size are also included. Samples are being collected at both the inlet and outlet sides of the precipitators or baghouse.

Compliance monitoring of point-source emissions is conducted for SO_2, opacity, and particulate loading. Supplemental monitoring is also being done for particulates (including particle size distribution), SO_2, NO_X, and CO. Substances monitored are regulated by the various state air permitting requirements, or are criteria pollutants under the National Ambient Air Quality Standards. CO_2 and O_2 are also monitored to help in the data interpretation of SO_2, NO_X, and CO levels.

The hazardous air pollutants, hydrochloric acid (HCl) and hydrofluoric acid (HF), in flue gas have been monitored for the GR-SI demonstration project, in which HCl and HF are theoretically expected to be captured by the sorbent used. This expectation has been verified at Hennepin and will be tested at Lakeside as well.

Wastewater Monitoring

On two of the demonstration sites, large quantities of sorbent chemicals are being injected into the boilers. The test program is performing more sampling and analyses of wastewater to ensure adequate data for future applications. This compliance with supplemental monitoring requirements will primarily be concerned with the measurement of calcium-sulfur compounds, and pH levels in the groundwater.

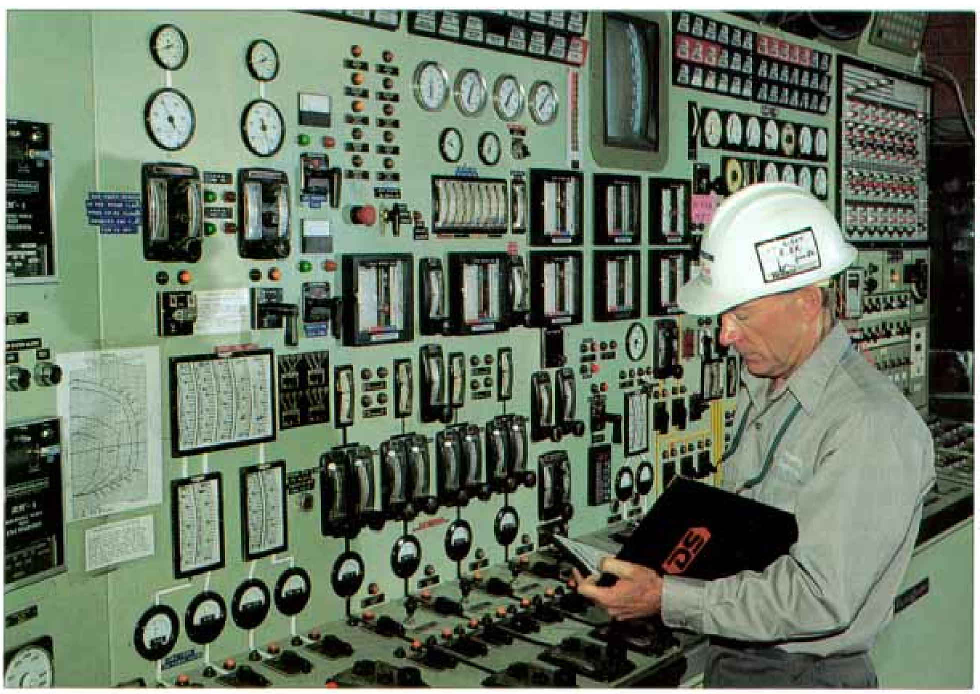
Solid Waste & Groundwater Monitoring

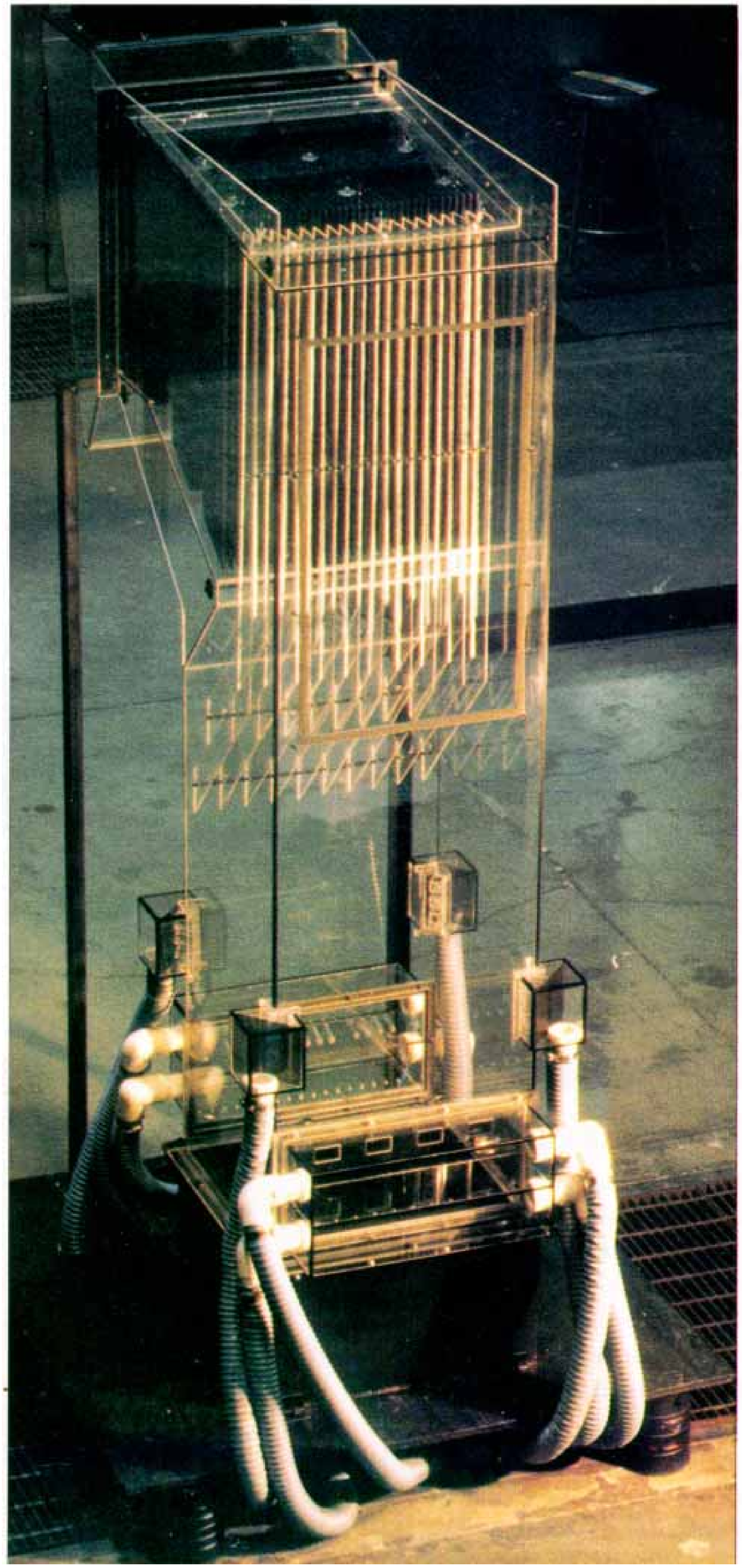
The EMP for the Hennepin and Lakeside project addresses the increased volume of ash generated, and the changed chemical and physical characteristics of this ash as a result of the sorbent used. It also discusses the need for ongoing groundwater monitoring in the vicinity of the two ash disposal sites after completion of the operational phases of these projects.

Health & Safety Monitoring

Each of the utility companies involved has a health and safety program in place which ensures safe working conditions at their individual plants. Each has extensive training programs in safety procedures, hazardous conditions, and identification of all hazardous materials their workers normally encounter. EER also determines total suspended particulate concentrations and noise levels in work areas according to the environmental monitoring plan.

GR-LNB Operations Control Center





Isothermal flow model of the Hennepin tangentially-fired boiler. Test results were used to locate gas, overfire air and sorbent injection ports.

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To Receive Additional Information

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