

## Enhancing the Use of Coals by Gas Reburning and Sorbent Injection

**Project completed**

### Participant

Energy and Environmental Research Corporation

### Additional Team Members

Gas Research Institute—cofunder

State of Illinois, Department of Commerce & Community Affairs—cofunder

Illinois Power Company—host

City Water, Light and Power—host

### Locations

Hennepin, Putnam County, IL (Illinois Power Company's Hennepin Plant, Unit No. 1)

Springfield, Sangamon County, IL (City Water, Light and Power's Lakeside Station, Unit No. 7)

### Technology

Energy and Environmental Research Corporation's gas reburning and sorbent injection (GR-SI) process

### Plant Capacity/Production

Hennepin: tangentially fired 80 MWe (gross), 71 MWe (net)

Lakeside: cyclone-fired 40 MWe (gross), 33 MWe (net)

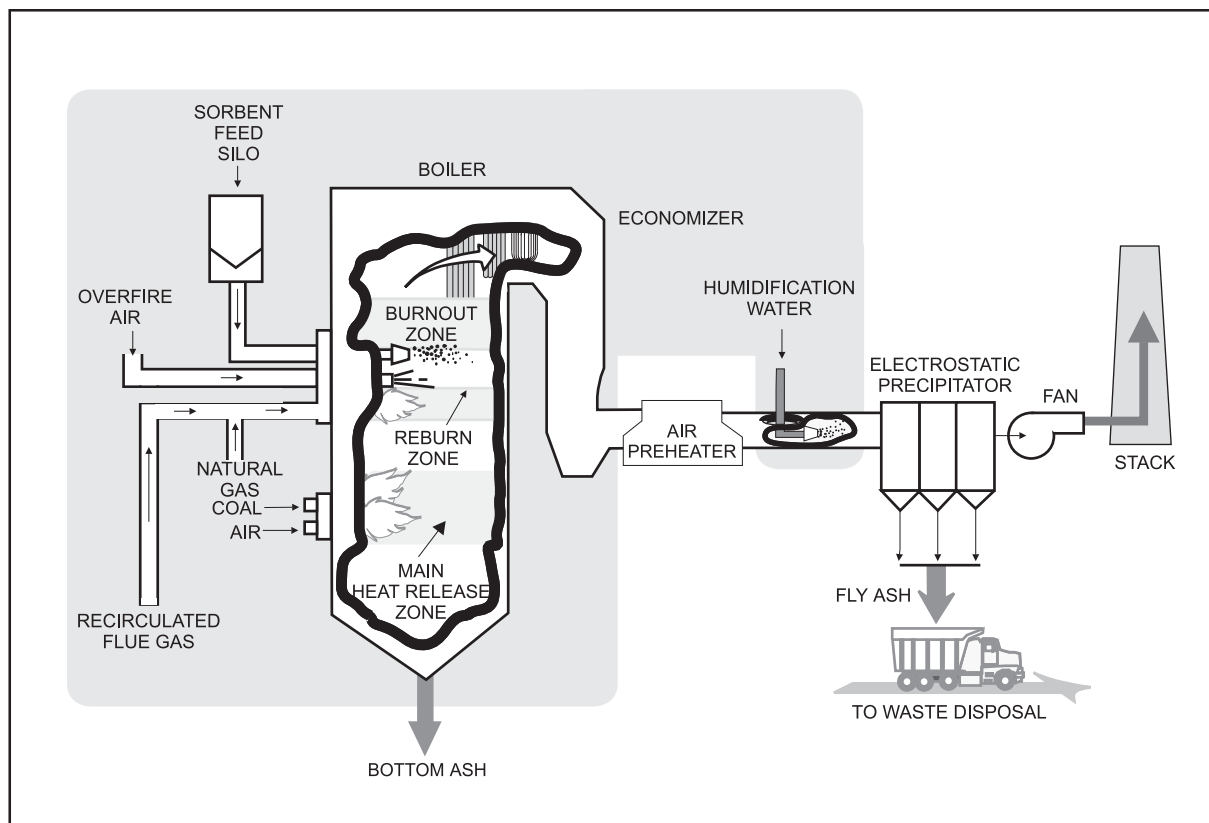
### Coal

Illinois bituminous, 3.0% sulfur

### Project Funding

Total	\$37,588,955	100%
DOE	18,747,816	50
Participant	18,841,139	50

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### Project Objective

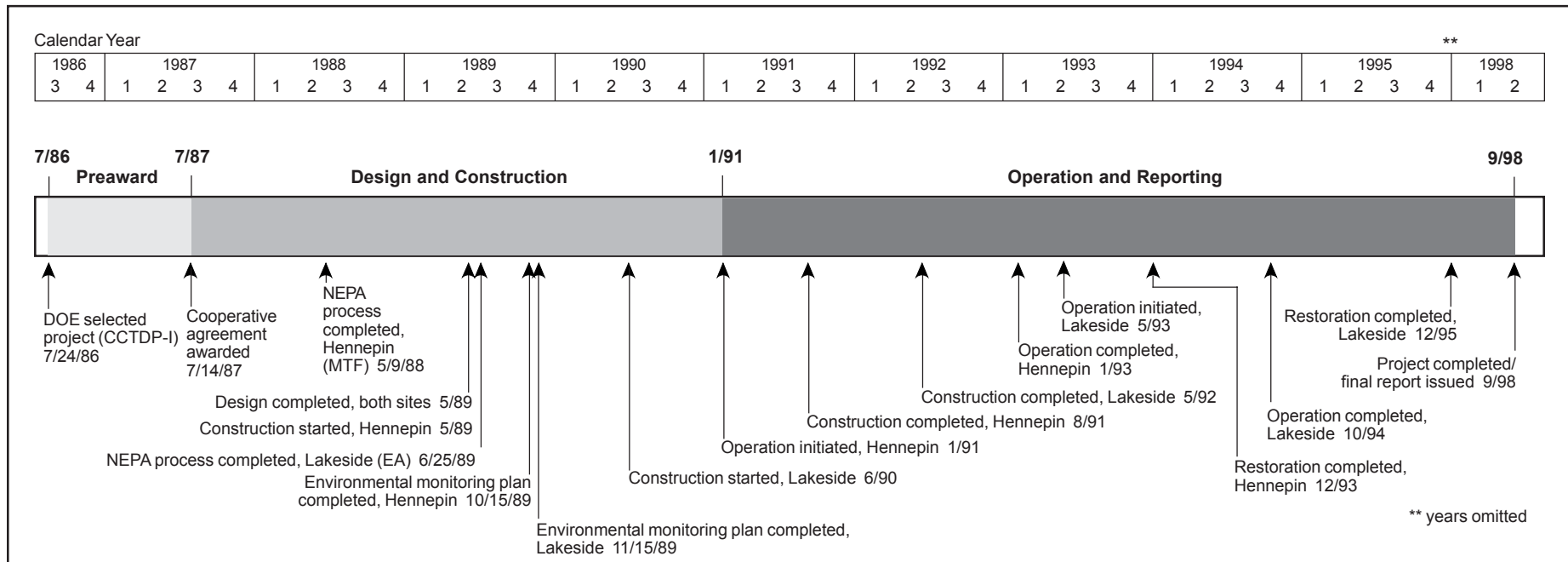
To demonstrate 60%  $\text{NO}_x$  reduction with gas reburning and at least 50%  $\text{SO}_2$  removal with sorbent injection on two different boiler configurations—tangentially fired and cyclone-fired—while burning high-sulfur midwestern coal.

### Technology/Project Description

In this process, 80–85% of the fuel as coal is supplied to the main combustion zone. The remaining 15–20% of the fuel, provided as natural gas, bypasses the main combustion zone and is injected above the main burners to form a reducing (reburning) zone in which  $\text{NO}_x$  is converted to molecular nitrogen ( $\text{N}_2$ ). A calcium compound (sorbent) is injected in the form of dry, fine particulates above the reburning zone in the boiler. Hydrated lime ( $\text{Ca}(\text{OH})_2$ ) serves as the baseline sorbent.

This project demonstrated the GR-SI process on two separate boilers representing two different firing configurations—a tangentially fired, 80-MWe (gross) boiler at Illinois Power Company's Hennepin Plant in Hennepin, Illinois, and a cyclone-fired, 40-MWe (gross) boiler at City Water, Light and Power's Lakeside Station in Springfield, Illinois. Illinois bituminous coal containing 3% sulfur was the test coal for both Hennepin and Lakeside.

A comprehensive test program was conducted at each of the two sites, operating the equipment over a wide range of boiler conditions. Over 1,500 hours of operation were achieved, enabling a substantial amount of data to be obtained. Intensive measurements were taken to quantify the reductions in  $\text{NO}_x$  and  $\text{SO}_2$  emissions, the impact on boiler equipment and operability, and all factors influencing costs.



## Results Summary

### Environmental

- On the tangentially fired boiler, GR-SI NO<sub>x</sub> reductions of up to 75% were achieved, and an average 67% reduction was realized at an average gas heat input of 18%.
- GR-SI SO<sub>2</sub> removal efficiency on the tangentially fired boiler averaged 53% with hydrated lime at a calcium-to-sulfur (Ca/S) molar ratio of 1.75 (corresponding to a sorbent utilization of 24%).
- On the cyclone-fired boiler, GR-SI NO<sub>x</sub> reductions of up to 74% were achieved, and an average 66% reduction was realized at an average gas heat input of 22%.
- GR-SI SO<sub>2</sub> removal efficiency on the cyclone-fired boiler averaged 58% with hydrated lime at a Ca/S molar ratio of 1.8 (corresponding to a sorbent utilization of 24%).
- Particulate emissions were not a problem on either unit undergoing demonstration, but humidification had to be introduced at Hennepin to enhance electrostatic precipitator (ESP) performance.

- Three advanced sorbents tested achieved higher SO<sub>2</sub> capture efficiencies than the baseline Linwood hydrated lime. PromiSORB™ A achieved 53% SO<sub>2</sub> capture efficiency and 31% utilization without gas reburning (GR) at a Ca/S molar ratio of 1.75. Under the same conditions, PromiSORB™ B achieved 66% SO<sub>2</sub> reduction and 38% utilization, and high-surface-area hydrated lime achieved 60% SO<sub>2</sub> reduction and 34% utilization.

### Operational

- Boiler efficiency decreased by approximately 1% as a result of increased moisture formed in combustion from natural gas use.
- There was no change in boiler tube wastage, tube metallurgy, or projected boiler life.

### Economic

- Capital cost for GR was approximately \$15/kW plus the gas pipeline cost, if not in place (1996\$).
- Operating costs for GR were related to the gas/coal cost differential and the value of SO<sub>2</sub> emission allowances (because GR replaces some coal with gas, it also reduces SO<sub>2</sub> emissions).

- Capital cost for sorbent injection (SI) was approximately \$50/kW.
- Operating costs for SI were dominated by the cost of sorbent and sorbent/ash disposal costs. SI was estimated to be competitive at \$300/ton of SO<sub>2</sub> removed.

## Project Summary

The GR-SI project demonstrated the success of gas reburning and sorbent injection technologies in reducing  $\text{NO}_x$  and  $\text{SO}_2$  emissions. The process design conducted early in the project combined with the vast amount of data collected during the testing created a database enabling effective design for any site-specific utility or industrial application.

### Environmental Performance (Hennepin)

Following optimization testing throughout 1991, the GR-SI long-term demonstration tests spanned 1992. The unit was operated at constant loads and with the system under dispatch load following. With the system under dispatch, the load fluctuated over a wide range from 40 MWe to a maximum load of 75 MWe. Over the long-term demonstration period, the average gross power output was 62 MWe.

For long-term demonstration testing, the average  $\text{NO}_x$  reduction was approximately 67%. The average  $\text{SO}_2$  removal efficiency was over 53% at a Ca/S molar ratio of 1.75. (Linwood hydrated lime was used throughout these tests except for a few days when Marblehead lime was used.)  $\text{CO}$  emissions were below 50 ppm in most cases, but were higher during operation at low load.

A significant reduction in  $\text{CO}_2$  was also realized. This was due to partial replacement of coal with natural gas having a lower carbon-to-hydrogen ratio. This cofiring with 18% natural gas resulted in a theoretical  $\text{CO}_2$  emissions reduction of nearly 8% from the coal-fired baseline level. With flue gas humidification, ESP collection efficiencies greater than 99.8% and particulate emissions less than 0.025 lb/10<sup>6</sup> Btu were measured, even with an increase in inlet particulate loading resulting from sorbent injection. These levels compared favorably to baseline emissions of 0.035 lb/10<sup>6</sup> Btu and a collection efficiency greater than 99.5%.

Following completion of the long-term tests, three specially prepared sorbents were tested. Two were manufactured by the participant and contained proprietary additives to increase their reactivity toward  $\text{SO}_2$ , and were referred to as PromiSORB™ A and B. The Illinois Geological Survey developed the other sorbent—high-

surface-area hydrated lime—in which alcohol is used to form a material that gives rise to a much higher surface area than that of conventionally hydrated limes.

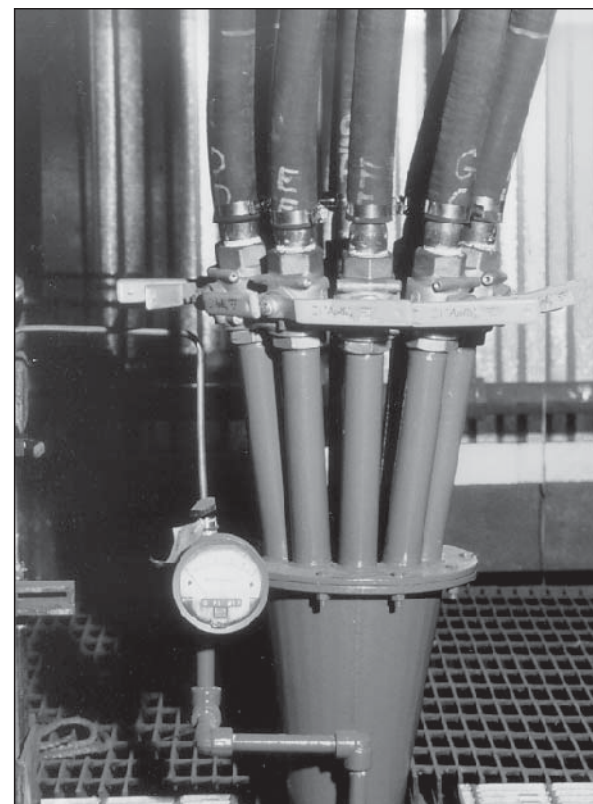
The  $\text{SO}_2$  capture without GR, at a nominal 1.75 Ca/S molar ratio, was 53% for PromiSORB™ A, 66% for PromiSORB™ B, 60% for high-surface-area hydrated lime, and 42% for Linwood lime. At a 2.6 Ca/S molar ratio, the PromiSORB™ B yielded 81%  $\text{SO}_2$  removal efficiency.

### Environmental Performance (Lakeside)

Parametric tests were conducted in three series: GR parametric tests, SI parametric tests, and GR-SI optimization tests. A total of 100 GR parametric tests were conducted at boiler loads of 33, 25, and 20 MWe. Gas heat input varied between 5% and 26%. The GR parametric tests achieved a  $\text{NO}_x$  reduction of approximately 60% at a gas heat input of 22–23%. Additional flow modeling and computer modeling studies indicated that smaller reburning fuel jet nozzles could increase reburning fuel mixing and thus improve the  $\text{NO}_x$  reduction performance.

A total of 25 SI parametric tests were conducted to isolate the effects of sorbent on boiler performance and operability. Results showed that  $\text{SO}_2$  reduction levels varied with load because of the effect of temperature on the sulfation reaction. At a Ca/S molar ratio of 2.0, a 44%  $\text{SO}_2$  reduction was achieved at full load (33 MWe); a 38%  $\text{SO}_2$  reduction was achieved at mid load (25 MWe); and a 32%  $\text{SO}_2$  reduction was achieved at low load (20 MWe).

In the GR-SI optimization tests, the two technologies were integrated. Modifications were made to the reburning fuel injection nozzles based on the results of the initial GR parametric tests and flow modeling studies. The total cross-sectional area of the reburning jets was decreased by 32% to increase the reburning jet's penetration characteristics. The decrease in nozzle diameter increased  $\text{NO}_x$  reduction by an additional 3–5% compared with the initial parametric tests. With GR-SI, total  $\text{SO}_2$  reductions resulted from partial replacement of coal with natural gas and sorbent injection. At a gas heat input of 22% and Ca/S molar ratio of 1.8, average  $\text{NO}_x$  reduction during the long-term testing of GR-SI was 66% and the average  $\text{SO}_2$  reduction was 58%.



The flexible lime-sorbent distribution lines lead from the sorbent splitter to the top of the cyclone-fired boiler at Lakeside Station.

### Operational Performance (Hennepin/Lakeside)

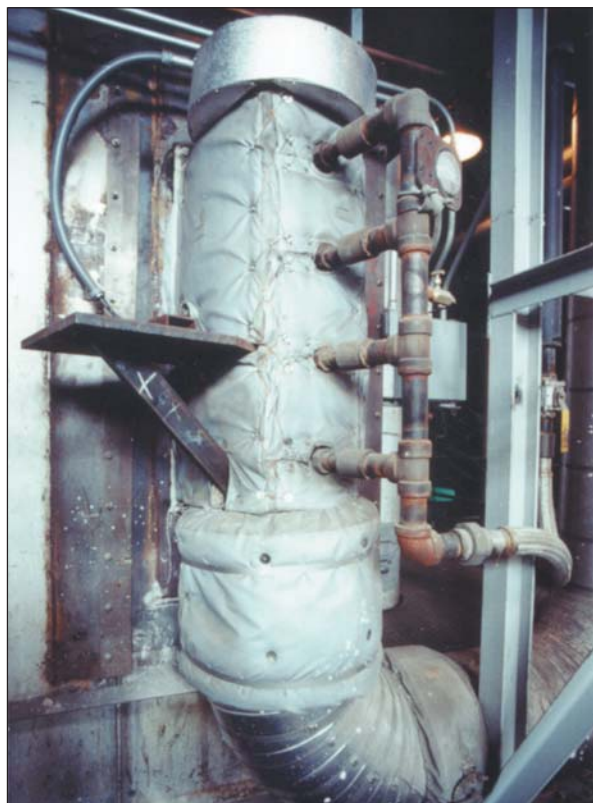
Sorbent injection increased the frequency of sootblower operation but did not adversely affect boiler efficiency or equipment performance. Gas reburning decreased boiler efficiency by approximately 1.0% because of the increase in moisture formed with combustion of natural gas. Examination of the boiler before and after testing showed no measurable change in tube wear or metallurgy. Essentially, the scheduled life of the boiler was not compromised.

The ESPs adequately accommodated the changes in ash loading and resistivity with the presence of sorbent in the ash. No adverse conditions were found to exist. But as

mentioned, humidification was added at Hennepin to achieve acceptable ESP performance with GR-SI.

### **Economic Performance (Hennepin/Lakeside)**

Capital and operating costs depend largely on site-specific factors, such as gas availability at the site, coal/gas cost differential, SO<sub>2</sub> removal requirements, and value of SO<sub>2</sub> allowances. It was estimated that for most installations, a 15% gas heat input will achieve a 60% NO<sub>x</sub> reduction. The capital cost for such a GR installation was estimated at \$15/kW for 100-MWe and larger plants plus the cost of the gas pipeline (if required) (1996\$). Operating costs were almost entirely related to the differential cost of the gas over the coal as reduced by the value of SO<sub>2</sub> emission allowances.



The natural gas injector was installed on the corner of Hennepin Station's tangentially fired boiler.

The capital cost estimate for SI was \$50/kW. Operating costs for SI were dominated by the cost of the sorbent and sorbent/ash disposal costs. SI was projected to be cost competitive at \$300/ton of SO<sub>2</sub> removed.

### **Commercial Applications**

The GR-SI process is a unique combination of two separate technologies. The commercial applications for these technologies, both separately and combined, extend to both utility companies and industry in the United States and abroad. In the United States alone, these two technologies can be applied to more than 900 pre-NSPS utility boilers. The technologies also can be applied to new utility boilers. With NO<sub>x</sub> and SO<sub>2</sub> removal exceeding 60% and 50%, respectively, 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.

Illinois Power has retained the gas-reburning system and City Water, Light & Power has retained the full technology for commercial use. The project was one of two receiving the Air and Waste Management Association's 1997 J. Deane Sensenbaugh Award.

### **Contacts**

Blair A. Folsom, Senior V.P., (949) 859-8851, ext. 140  
General Electric Energy and Environmental Research Corporation  
18 Mason  
Irvine, CA 92618  
blair.folsom@ps.ge.com  
(949) 859-3194 (fax)

Victor K. Der, DOE/HQ, (301) 903-2700  
victor.der@hq.doe.gov

Jerry L. Hebb, NETL, (412) 386-6079  
hebb@netl.doe.gov

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