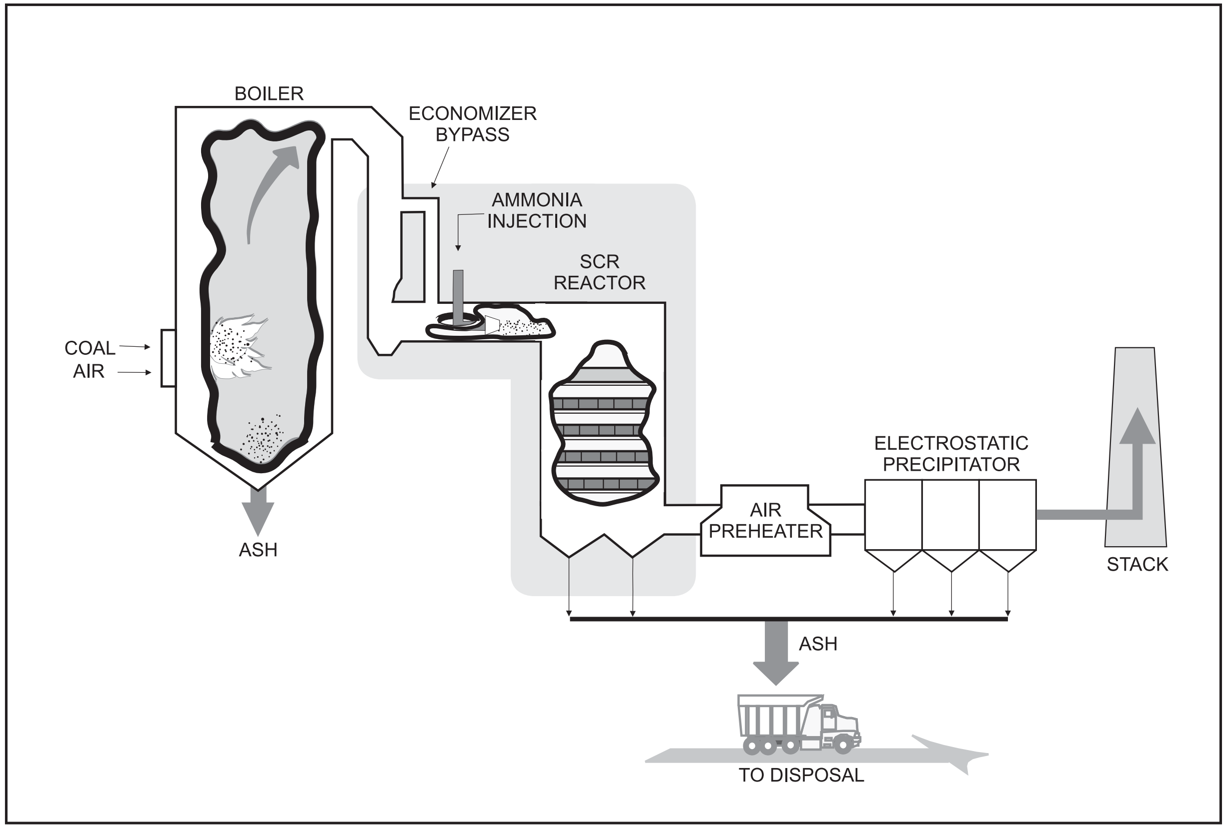
Demonstration of Selective Catalytic Reduction Technology for the Control of NO_x Emissions from High-Sulfur, Coal-Fired Boilers



Project completed

Participant

Southern Company Services, Inc.

Additional Team Members

Electric Power Research Institute—cofunder

Ontario Hydro—cofunder

Gulf Power Company—host

Location

Pensacola, Escambia County, FL (Gulf Power Company's Plant Crist, Unit No. 5)

Technology

Selective catalytic reduction (SCR)

Plant Capacity/Production

8.7-MWe equivalent (three 2.5-MWe and six 0.2-MWe equivalent SCR reactor plants)

Coal

Illinois bituminous, 2.7% sulfur

Project Funding

Total	$23,229,729	100%
DOE	9,406,673	40
Participant	13,823,056	60

Project Objective

To evaluate the performance of commercially available SCR catalysts when applied to operating conditions found in U.S. pulverized coal-fired utility boilers using high-sulfur U.S. coal under various operating conditions, while achieving as much as 80% NO_x removal.

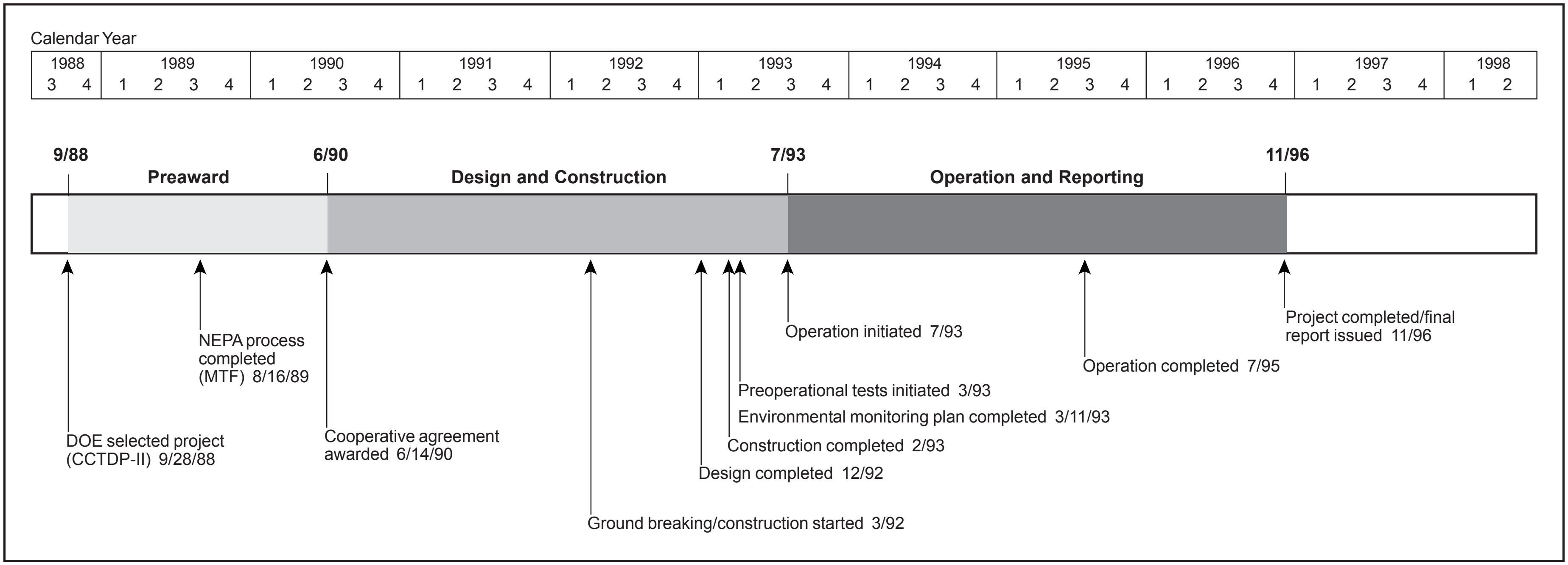
Technology/Project Description

The SCR technology consists of injecting ammonia into boiler flue gas and passing it through a catalyst bed where the NO_x and ammonia react to form nitrogen and water vapor.

In this demonstration project, the SCR facility consisted of three 2.5-MWe equivalent SCR reactors, supplied by separate 5,000-scfm flue gas slipstreams, and six 0.20-MWe equivalent SCR reactors. These reactors were calculated to be large enough to produce design data that will allow the SCR process to be scaled up to commercial size. Catalyst suppliers (two U.S., two European, and two Japanese) provided eight catalysts with various shapes and chemical compositions for evaluation of process chemistry and economics of operation during the demonstration.

The project demonstrated, at high- and low-dust loadings of flue gas, the applicability of SCR technology to provide a cost-effective means of reducing NO_x emissions from power plants burning high-sulfur U.S. coal.

The demonstration plant, which was located at Gulf Power Company's Plant Crist near Pensacola, Florida, used flue gas from the burning of 2.7% sulfur coal.



Results Summary

Environmental

- NO_x reductions of over 80 percent were achieved at an ammonia slip well under the 5 ppm deemed acceptable for commercial operation.
- For most catalysts, flow rates could be increased to 150 percent of design without exceeding the ammonia slip design level of 5 ppm at 80 percent NO_x reduction.
- While catalyst performance increased above 700 °F, the benefit did not outweigh the heat rate penalties.
- Ammonia slip, a sign of catalyst deactivation, went from less than 1 ppm to approximately 3 ppm over the nearly 12,000 hours of operation, thus demonstrating that deactivation in coal-fired units was in line with worldwide experience.
- Long-term testing showed that SO_2 oxidation was within or below the design limits necessary to protect downstream equipment.

Operational

- Fouling of catalysts was controlled by adequate soot-blowing procedures.
- Long-term testing showed that catalyst erosion was not a problem once sootblowing procedures were adopted.
- Air preheater performance was degraded because of ammonia slip and subsequent by-product formation; however, solutions were identified.
- The SCR process did not significantly affect the results of Toxicity Characteristic Leaching Procedure (TCLP) analysis of the fly ash.

Economic

- Levelized costs on a 30-year basis for a 250-MWe unit, with a SCR inlet NO_x concentration of 0.35 lb/10^6 Btu, were 2.39, 2.57, and 2.79 mills/kWh (constant 1996$) for 40, 60, and 80 percent removal efficiency, respectively, which equates to 3,502; 2,500; and 2,036 $/ton (constant 1996$), respectively.

Project Summary

The demonstration tests were designed to address several uncertainties, including potential catalyst deactivation due to poisoning by trace metals species in U.S. coals, performance of the technology and its effects on the balance-of-plant equipment in the presence of high amounts of SO_2 and SO_3, and performance of the SCR catalyst under typical U.S. high-sulfur coal-fired utility operating conditions. Catalyst suppliers were required to design the catalyst baskets to match predetermined reactor dimensions, provide a maximum of four catalyst layers, and meet the conditions shown in Exhibit 3-27.

The catalysts tested are listed in Exhibit 3-28. Catalyst suppliers were given great latitude in providing the amount of catalyst for this demonstration.

Environmental Performance

Ammonia slip, the controlling factor in the long-term operation of commercial SCR, was usually <5 ppm because of plant and operational considerations. Ammonia slip was dependent on catalyst exposure time, flow rate, temperature, NH_3/NO_x distribution, and NH_3/NO_x ratio (NO_x reduction). Changes in NH_3/NO_x ratio and consequently NO_x reduction generally produced the most significant changes in ammonia slip. The ammonia slip at 60% NO_x reduction was at or near the detection limit of 1 ppm. As NO_x reduction was increased above 80%, ammonia slip also increased and remained at reasonable levels up to NO_x reductions of 90%. Over 90%, the ammonia slip levels increased dramatically.

The flow rate and temperature effects on NO_x reduction were also measured. In general, flows could be increased to 150% of design without the ammonia slip exceeding 5 ppm, at 80% NO_x reduction and at the design temperature. With respect to temperature, most catalysts exhibited fairly significant improvements in overall performance as temperatures increased from 620 °F to 700 °F, but relatively little improvement as temperature increased from 700 °F to 750 °F. The conclusion was that the benefits of high-temperature operation probably do not outweigh the heat rate penalties involved in operating SCR at the higher temperatures.

Catalyst deactivation was observed by an increase in ammonia slip over time, assuming the NO_x reduction efficiency was held constant. Over the 12,000 hours of the demonstration tests, the ammonia slip did increase from less than 1 ppm to approximately 3 ppm. These results demonstrated the maturity of catalyst design and that deactivation was in line with prior worldwide experience.

Experience has shown that the catalytic active species that result in NO_x reduction often contributed to SO_2 oxidation (*i.e.*, SO_3 formation), which can be detrimental to downstream equipment. In general, NO_x reduction can be increased as the tolerance for SO_3 is also increased. The upper bound for SO_2 oxidation for the demonstration catalyst was set at 0.75% at baseline conditions. The average SO_2 oxidation rate for each of the catalysts is shown in Exhibit 3-29. These data reflect baseline conditions over the life of the demonstration. All of the catalysts were within design limits, with most exhibiting oxidation rates below the design limit.

Other factors affecting SO_2 oxidations were flow rate and temperature. Most of the catalysts exhibited fairly constant SO_2 oxidation with respect to flow rate (*i.e.*, space velocity). In theory, SO_2 oxidation should be inversely proportional to flow rate. Theoretically, the relationship between SO_2 oxidation and temperature should be exponential as temperature increases; however, measurements showed the relationship to be linear with little difference in SO_2 oxidation between 620 ºF and 700 ºF. On the other hand, between 700 °F and 750 °F, the SO_2 oxidation increased more significantly.

Other findings from the demonstration deal with pressure drop, fouling, erosion, air preheater performance, ammo-

Exhibit 3-27

Reactor Baseline Conditions

Parameter	Minimum	Baseline	Maximum
Temperature (ºF)	620	700	750
NH_3/NO_x molar ratio	0.6	0.8	1.0
Space velocity (% design flow)	60	100	150
Flow rate			
Large reactor (scfm)	3,000	5,000	7,500
Small reactor (scfm)	240	400	600

Exhibit 3-28

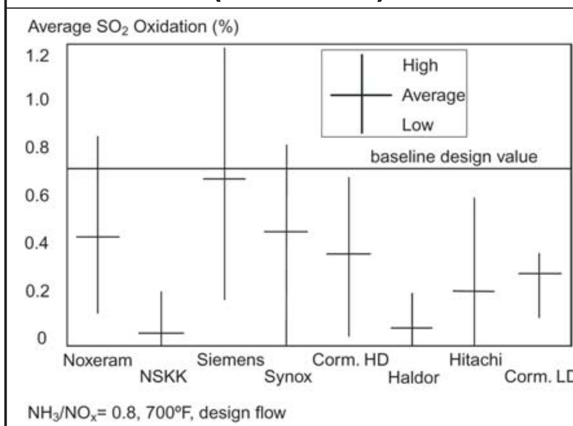
Catalysts Tested

Catalyst	Reactor Size*	Catalyst Configuration
Nippon/Shokubai	Large	Honeycomb
Siemens AG	Large	Plate
W.R. Grace/Noxeram	Large	Honeycomb
W.R. Grace/Synox	Small	Honeycomb
Haldor Topsoe	Small	Plate
Hitachi/Zosen	Small	Plate
Cormetech/High dust	Small	Honeycomb
Cormetech/Low dust	Small	Honeycomb

* Large = 2.5 MWe; 5,000 scfm   Small = 0.2 MWe; 400 scfm

Exhibit 3-29

Average SO_2 Oxidation Rate (Baseline)



nia volatilization, and TCLP analysis. Overall reactor pressure drop was a function of the catalyst geometry and volume, but tests were inconclusive in determining which parameter was controlling. The fouling characteristics of the catalyst were important to long-term operation. During the demonstration, measurements showed a relatively level pressure drop over time, indicating that sootblowing procedures were effective. The plate-type configuration had somewhat less fouling potential than did the honeycomb configuration, but both were acceptable. Catalyst erosion was not considered to be a significant problem because most of the erosion was attributed to aggressive sootblowing. With regard to air preheater performance, the demonstration showed that the SCR process exacerbated performance degradation of the air preheaters, mainly due to ammonia slip and subsequent by-product formation. Regenerator-type air heaters outperformed recuperators in SCR applications in terms of both thermal performance and fouling. The ammonia volatilized from the SCR fly ash when a significant amount of water was absorbed by the ash. This was caused by formation of a moist layer on the ash with a pH high enough to convert ammonia compounds in the ash to gas-phase ammonia. TCLP analyses were performed on fly ash samples. The SCR process did not significantly affect the toxics leachability of the fly ash.

Exhibit 3-30
SCR Design Criteria for Economic Evaluation

Parameter	Specification
Type of SCR	Hot side
Number of reactors	One
Reactor configuration	3 catalyst support layers
Initial catalyst load	2 of 3 layers loaded
Range of operation	35–100% boiler load
NO_x inlet concentration	0.35 lb/10^6 Btu
Design NO_x reduction	60%
Design ammonia slip	5 ppm
Catalyst life	16,000 hr
Ammonia cost	$250/ton
SCR catalyst cost	$400/$ft^3$

Economic Performance

An economic evaluation was performed for full-scale applications of SCR technology to a new 250-MWe pulverized coal-fired plant located in a rural area with minimal space limitations. The fuel considered was high-sulfur Illinois No. 6 coal. Other key base case design criteria are shown in Exhibit 3-30.

The economic analysis of capital, operating and maintenance (O&M), and levelized cost for various unit sizes for an SCR system are shown in Exhibit 3-31. Results of the economic analysis of capital, O&M, and levelized cost for various NO_x removal efficiencies for a 250-MWe unit are shown in Exhibit 3-32. For retrofit applications, the estimated capital costs were $59–112/kW, depending on the size of the installation and the difficulty and scope of the retrofit. The levelized costs for the retrofit applications were $1,850–5,100/ton (1996$).

Exhibit 3-31
SCR Economics by Unit Size

	125 MWe	250 MWe	700 MWe
Capital cost ($/kW)	61	54	45
Operating cost ($/yr)	580,000	1,045,000	2,667,000
Constant 1996$ levelized cost			
Mills/kWh	2.89	2.57	2.22
$/ton NO_x removed	2,811	2,500	2,165

Note: 30 year life; 60% NO_x removal

Exhibit 3-32
SCR Economics by NO_x Removal

	40%	60%	80%
Capital cost ($/kW)	52	54	57
Operating costs ($/yr)	926,000	1,045,000	1,181,000
Constant 1996$ levelized cost			
mills/kWh	2.39	2.57	2.79
$/ton NO_x removed	3,502	2,500	2,036

Note: 250MWe; 0.35 lb/10^6 Btu of inlet NO_x

Commercial Applications

As a result of this demonstration, SCR technology has been shown to be applicable to existing and new utility generating capacity for removal of NO_x from the flue gas of virtually any size boiler. There are over 1,000 coal-fired utility boilers in active commercial service in the United States; these boilers represent a total generating capacity of approximately 300,000 MWe.

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References

"Demonstration of SCR Technology for the Control of NO_x Emissions from High-Sulfur Coal-Fired Utility Boilers." Fifth Annual Clean Coal Technology Conference: Technical Papers. Maxwell, J. D., *et al.* January 1997.

Demonstration of SCR Technology for the Control of NO_x Emissions from High-Sulfur, Coal-Fired Utility Boilers: Final Report. Vol. 1. Southern Company Services, Inc. October 1996. (Available from NTIS, Vol. 1 as DE97050873, Vol. 2: Appendixes A–N as DE97050874, and Vol. 3: Appendixes O–T as DE97050875.)

U.S. Department of Energy. *Demonstration of Selective Catalytic Reduction for the Control of NOx Emissions from High-Sulfur, Coal-Fired Utility Boilers— Project Performance Summary*. November 2002.