NESCAUM's Status Report on NOx: Post-RACT Control Technologies and Cost Effectiveness

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ABSTRACT

The Northeast States for Coordinated Air Use Management (NESCAUM) has published two reports (1992, 1995) on electric utility NOx controls. A third report is scheduled for release by summer 1998. This third report provides a review of the state-of-the-art in NOx control technologies. It has special emphasis on field experience with those technologies that are likely to be used by electric utility boilers to comply with Phases II and III of the September 1994 Ozone Transport Commission's (OTC's) Memorandum of Understanding (MOU). OTC's MOU requires up to 75% NOx reduction from 1990 emission rates by the year 2003. For coal-fired boilers in particular, the technologies that are expected to play a crucial role in reducing NOx for Phase III compliance include Selective Catalytic Reduction (SCR), Selective Non-Catalytic Reduction (SNCR) and Reburning. The principal motivation of this effort is to document the most recent experience that has been gained over the last few years at facilities that have utilized these technologies for the purpose of 1995 Reasonably Available Control Technology (RACT) and other Federal and State NOx control requirements. A key feature of this report is case studies of experience at facilities that are commercially operating the technologies of interest. The case studies were prepared in cooperation with facility operators. An up-to-date assessment of cost (capital and operating) and cost effectiveness was prepared utilizing information from the case studies as well as publicly available information.

This paper highlights the findings of the NESCAUM report specifically as they relate to experience with SCR and SNCR technologies, cost effectiveness, and lessons learned in applying the technologies to utility power plants.

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Case Studies

A unique feature of this effort was the case studies of electric utility boilers that are commercially operating technologies that are likely to play a significant role in Phase II and Phase III NOx reductions in the Ozone Transport Region (OTR). These case studies are identified in Table 1. A summary of experience with these technologies is listed in Table 2 while pertinent experience on coal-fired facilities is summarized in Table 3. Although each application had its challenges, all of the projects were completed on time. Every SCR system meets its expected level of NOx reduction and ammonia slip performance. Every SNCR system that uses wall injectors (all but two of the commercial SNCR systems) provides the intended performance with high reliability. The two most difficult SNCR applications, which use multi-nozzle, in-furnace lances, are operating close to the intended performance level. The experience summarized in Table 3 suggests a very high reliability - only 6 forced outages in over 40 boiler-years of experience. None of these outages were a result of process failure. In fact, the cause of three outages on an SNCR system was corrected permanently with improved maintenance practices. The cause of the remaining three outages (on an SCR system) was a result of expansion joint failures that will be addressed fully over time as the original duct expansion joints are replaced with more durable ones. In summary, SCR and SNCR have provided reliable NOx reductions to the operators of these units with a minimum of concerns.

Cost Effectiveness

The costs of the various NOx control technologies were evaluated on a Constant Dollar basis using a project lifetime of 15 years and real cost of capital rate of 6.55% (nominal rate of 9.75% with inflation at 3%). The results of these calculations are shown in Tables 4, 5, and 6. The average age of boilers in the OTR is just over 30 years. *Note that some other studies have used an average project lifetime of 20 years to evaluate the costs of NOx control, which was appropriate for those studies. However, the unusually high age of boilers in the OTR makes a shorter lifetime more appropriate for this study.* Cost information was based upon publicly available information and information gathered in the program case studies. The case study information provided useful information on operating costs for these technologies that does not appear to have been available in the public literature. As a result, it is believed that the cost information in this report is likely to be more up-to-date and reliable than any previous evaluations.

For nearly all coal-fired boiler types NOx reduction is possible for less than $1,500/ton (based on annual controls). Because of the very low capacity factors of the oil and gas units in the OTR, NOx reduction from these units beyond what is achievable with primary controls is generally much more expensive than for coal units. The OTC's MOU provides for substantial flexibility in how compliance may be achieved, such as emissions trading and averaging. Because many facilities can reduce NOx for well below $1,000/ton, it is expected that the actual cost of controls for the region will average well below $1,500/ton for even high levels of reduction (85% reduction). For seasonal controls, the $/ton value will be higher; however, the total cost to the utility industry will be less as indicated by the lower $/MWhr figure.

Combination of technologies was shown to be very beneficial in reducing NOx control costs. One example is combination of gas reburning with SNCR shown on Table 7. Even with a relatively high incremental price of gas of $1.50/MMBTU over the price of coal, the combination of these technologies can reduce total NOx reduction costs substantially. Ongoing work to integrate these technologies further to get even more synergistic effects will result in even more significant improvements in the cost of NOx reduction.

Table 1. Case Studies

	SNCR Case Studies
SNCR-1:	New England Power Salem Harbor #s 1, 2 & 3, (Salem, MA)
SNCR-2:	Montaup Electric, Somerset Boiler #8, (Somerset, MA)
SNCR-3:	Atlantic Electric, B.L. England #s 1, 2 & 3, (Beesley's Point, NJ)
SNCR-4:	Public Service of New Hampshire, Merrimack #1, (Bow, NH)
SNCR-5:	GPU Generation Company, Seward #15, (Seward, PA)
SNCR-6:	PSE&G, Mercer #1 and #2, (Trenton, NJ)
	SCR Case Studies
SCR-1:	Public Service of New Hampshire, Merrimack #2 (Bow, NH)
SCR-2:	Orlando Utilities, Stanton Energy Center (Orlando, FL)
SCR-3:	Southern Energy, Inc., Birchwood #2 (Sealston, VA)
SCR-4:	U.S. Generating Company, Indiantown (Indiantown, FL), Logan (Swedesboro, NJ), Carney’s Point (Carney's Point, NJ)
SCR-5:	PSE&G SCR and SNCR/SCR Demonstration (Trenton, NJ)
SCR-6:	Southern California Edison (various units in the Los Angeles area)
	Reburning Technology Case Studies
RB-1:	NYSE&G Greenidge #4 (Dresden, NY)
RB-2:	Eastman Kodak, Kodak Park Boilers #15 and #43 (Rochester, NY)

Table 2 Summary of Case Study Results						
Boiler Type	Technology[1]	# boilers		performance achieved?[2]	Tot. months in service [3]	# forced outage incidents
Gas	LNB	5		yes	na	0
	SNCR	18		yes	na	0
	SCR	9		yes	na	0
Oil	SNCR	1		yes	30	0
Coal, Grp 1	SNCR	4		yes	158	3 [4]
	SNCR	1		yes [5]	30	0 [5]
	SCR	5		yes	142	0
	gas reburn	1		yes	12	0
Coal, Grp 2	SNCR	3		yes	72	0
	SNCR, NH_3	1		no [6]	30	0
	SCR	1		yes	30	3 [7]
	SCR, demo	1		yes	5 [8]	0
	hybrid demo	1		yes	2	0
	gas reburn	1		yes	22	0
Totals		**Gas/Oil 33**	**Coal 19**		**533**	**6**

Notes:

1 - SNCR is urea-SNCR, except where noted as ammonia-SNCR (NH_3)

2 - Yes for performance achieved means that design NOx reduction, ammonia slip, CO emissions, etc. have all been met and catalyst activity has - thus far - met expectations

3 - Months in service as of Nov/Dec 1997. Gas-fired unit data not available. Most of the units have been in operation since 1994. No operating problems were reported with the gas-fired units.

4 - Forced outage incidents were in initial months of operation. Improved O&M practices - more frequent inspection of urea injectors - have corrected problem

5 - System meets design reduction and ammonia slip; however, unexpected high air preheater deposit formation rates cause system to be operated at lower level of reduction. Since modified operation, no forced outages have occurred

6 - At design reduction, ammonia slip is high and causes rapid air heater deposit formation. System is operated at lower reduction levels

7 - Forced outages resulted from failure of auxiliary mechanical equipment (expansion joints). Operator will replace/upgrade all expansion joints over time, reducing these failures. SCR catalyst and controls operate as intended.

8 - Catalyst is still in duct after over 30 months of operation and continues to be tested. Catalyst has met or exceeded expected activity levels over this time.

Table 3. Summary of Commercial Coal Experience by Technology from Case Study Participants			
Technology	# of boilers	Total Boiler-Months in Service (Nov '97)	Total Forced Outage Incidents
SNCR (urea & NH_3)	9	290	3
SCR	7	177	3
Gas Reburn	2	34	0
Total	18	501	6

Table 4. Summary of Approximate NOx Control Costs - SCR									
Technology	**Reduction**			**Cap. Cost**	**Capacity Factor**	**Annual Control**		**Seasonal Control**	
	From: lb/MMBTU	**To: lb/MMBTU**	**% Red'n**	**$/KW**	**%**	**$/ton**	**$/MWhr**	**$/ton**	**$/MWhr**
SCR Coal-Grp 1	0.45	0.15	67%	50-70	50-80	825-1,525	1.25-2.30	1,750-3,430	1.10-2.15
SCR Coal-Grp 1	0.45	0.07	85%	70-90	50-80	900-1,550	1.65-2.80	1,890-3,350	1.50-2.65
SCR Coal-Grp 2	1.50	0.35	75%	50-70	50-80	390-560	2.23-3.20	760-1,165	1.80-2.80
SCR Coal-Grp 2	1.50	0.15	90%	70-90	50-80	400-570	2.70-3.85	790-1,200	2.20-3.40
SCR Gas	*0.20*	*0.03*	*85%*	*~35*	*50-80**	*1,200-1,500*	*1.00-1.40*	*2,500-3,800*	*0.90-1.30*
SCR Gas	0.20	0.03	85%	~35	10-20	2,950-5,450	2.50-4.64	6,700-12,750	2.37-4.51

***Only 8 of the 123 oil/gas fired units in the OTR have CF of 50% or more**

Notes on Table 4:

For example, a Group 1 boiler that annually controls from 0.45 to 0.15 lb/MMBTU will cost in the range of $50-70/KW in capital and reduce NOx in the range of $825-$1525/ton and $1.25-$2.30/MWhr, depending upon capacity factor. Greater reduction (85%) can be achieved at a higher cost of about $70-90/KW in capital, $900-$1550/ton and about $1.65-$2.80/MWhr.

Group 2 results are based on a unit with fly ash reinjection and arsenic-resistant catalyst with a lifetime of 14,000 hours. For Group 2 units that do not reinject fly ash, costs should be lower. For Group 1 boilers, the catalyst lifetime was assumed to be 24,000 hours.

The ranges shown for SCR costs include the effect of capacity factor variations from 50% to 80% and the range of capital costs shown, regardless of MW.

Capital cost of Group 2 boilers equipped with SCR is expected to be somewhat higher than that of similar MW Group 1 boilers. This difference was generally found to be within the ranges shown.

For SCR on Gas and Gas/Oil facilities, it is assumed that the catalyst lifetime varies from a low of 32,000 hours to as much as 48,000 hours to address the uncertainties associated with oil operation.

The seasonal cost analysis values are based upon a 5-month ozone season and no operation at all outside of the ozone season.

The results shown in this table should be regarded as typical values, and representative of the majority of facilities - most having similar properties and circumstances as those included in the analysis. In practice, each facility should be evaluated individually.

The capacity-weighted average capacity factor of oil and gas fired units in the OTR is 12.5%

The capacity-weighted average capacity factor of coal fired units in the OTR is about ~65%

Table 5. Summary of Approximate NOx Control Costs - SNCR								
Technolog	**Reduction**		**Capital**	**Chemical**	**Annual Control**		**Seasonal Control**	
	From:	**To:**	**$/KW**	**Utilization**	**$/ton**	**$/MWhr**	**$/ton**	**$/MWhr**
SNCR	0.45	0.27	15	35-60	860-	0.78-1.05	1,370-	0.51-0.63
SNCR	1.00	0.60	15	35-60	620-920	1.24-1.84	845-	0.71-0.95
SNCR	1.50	0.90	15	35-60	550-850	1.66-2.55	705-	0.88-1.25

Notes on Table 5:

For example, an SNCR system on a Group 1 boiler might provide 40% reduction from 0.45 to 0.27 lb/MMBTU at a cost of $15/KW in capital, $860-$1160/ton NOx, and $0.78-1.05/MWhr.

Since all but one commercial utility SNCR system are urea-based, the SNCR analysis is based upon using urea as the reagent. Furthermore, SNCR is extremely process dependent; therefore, 40% reduction was considered because it is in the range of reduction that is typically possible with this technology. Chemical utilization was assumed to be in the range of 35% to 60%, which is typical for about 40% reduction with this technology. In some cases reduction may be higher or lower. It was assumed that capacity factor equals 65% (SNCR economics have a relatively low sensitivity to capacity factor). For lower reduction, utilization will often be higher, resulting in lower cost.

The seasonal cost analysis values are based upon a 5-month ozone season and no operation at all outside of the ozone season.

The results shown in this table should be regarded as typical values, and representative of facilities that have similar properties and circumstances as those included in the analysis. Each facility owner should evaluate their facility individually.

Table 6. Summary of Approximate NOx Control Costs- Reburn							
Technology	**Reduction**			**Annual Control**		**Seasonal Control**	
	From:	To:	% Red'n	$/ton	$/MWhr	$/ton	$/MWhr
Gas Reburn	1.00	0.60	40%				
Gas Reburn	1.00	0.40	60%				
Gas Reburn	0.45	0.27	40%				
Gas Reburn	0.45	0.18	60%				
Coal Reburn **	1.00	0.50	50%	315-485	0.78-1.20	710-1,115	0.75-1.15
Coal Reburn **	1.50	0.75	50%	210-320	0.78-1.20	475-745	0.75-1.15

* *reburn fuel premium: cost of natural gas minus cost of coal*
** *see last note about coal reburn*

Notes on Table 6:

Gas reburning economics are extremely sensitive to the incremental cost of natural gas over coal. Gas reburning economics, like SNCR, are less sensitive to variations in capacity factor than other technologies, and a capacity factor of 0.65 is assumed. Also, the costs shown are based upon a compilation of data from commercial installations and long term demonstrations. The fuel flows at 60% reduction could vary such that cost might increase by as much as 20% or be reduced by up to 10%. For 40% NOx reduction, the costs may vary by about ± 10% from those shown.

The seasonal cost analysis values are based upon a 5-month ozone season and no operation at all outside of the ozone season.

The results shown in this table should be regarded as typical values, and representative of facilities that have similar properties and circumstances as those included in the analysis. Each facility owner should evaluate their facilities individually.

The coal reburn example is based on a 500 MW plant and capital cost of $45/KW (based on DOE estimate of capital cost). However, there is very little experience with this technology. Two demonstration systems <~100MW cost well in excess of $100/KW in capital cost. Hence, the cost values for coal reburn are very uncertain.

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Table 7: Combination of urea SNCR and Gas Reburn

	urea SNCR: 1.0 to 0.40	Gas Reburn: 1.0 to 0.40	Gas Reburn: 1.0 to 0.60 + urea SNCR: 0.60 to 0.36
Reburn Annual Costs		$3.84 million	$1.51 million
SNCR Annual Costs	$3.90 million		$1.15 million
Total Annual Costs	$3.90 million	$3.84 million	$2.66 million
	urea SNCR: 1.5 to 0.60	**Gas Reburn: 1.5 to 0.60**	**Gas Reburn: 1.5 to 0.90 + urea SNCR: 0.90 to 0.54**
Reburn Annual Costs		3.84 million	$1.51 million
SNCR Annual Costs	$5.62 million		$1.61million
Total Annual Costs	$5.62 million	3.84 million	$3.12 million

Both SNCR and gas reburning are highly process specific, and each facility should be evaluated individually. This data should be considered indicative of possible scenarios. The analysis assumes 45% urea chemical utilization for 40% reduction and 25% urea chemical utilization for 60% reduction. In any particular SNCR application, these numbers could be significantly different; but, the same trends should exist. Also, it should be kept in mind that for the majority of utility boilers 60% NOx reduction is not practical with SNCR alone. A compilation of data from commercial installations and long term demonstrations was used to estimate reburn fuel heat input, and it was assumed that the cost of gas is $1.50/MMBTU greater than that of coal.