Technical Support Document (TSD)

for the Cross-State Air Pollution Rule for the 2008 Ozone NAAQS

Docket ID No. EPA-HQ-OAR-2015-0500

EGU NO_X Mitigation Strategies Proposed Rule TSD

U.S. Environmental Protection Agency

Office of Air and Radiation

Abstract:

This Technical Support Document (TSD) discusses costs and emission reduction potential for common electric generating unit (EGU) NO_x emission control systems. Specifically, this TSD explores three topics: (1) the appropriate representative cost resulting from "widespread" implementation of a particular NO_x emission control technology; (2) the NO_x emission rates commonly achievable by "fully operating" emission control equipment; and, (3) the time required to install and/or restore an emission control system to full operation. These estimates form the basis for modeling costs and emission reductions within IPM v 5.14 and 5.15.

Introduction:

Evaluation of power sector NO_x emissions data within the CSAPR region identified units emitting NO_x at higher rates than previously demonstrated after commissioning post combustion controls. The agency acknowledges an EGU owner retains latitude regarding operational decisions for compliance with CSAPR, which include: operating existing NO_x control equipment, installing new or upgrading NO_x controls, purchasing allowances, or shifting generation. As described in the preamble, the compliance timeline for implementing the updated CSAPR led the agency to focus on the following compliance options:

- Returning to full operation existing SCRs operating at fractional design capability.
- Restarting inactive SCRs and returning to full operation.
- Restarting inactive SNCRs and returning to full operation.
- Replacing outdated combustion controls (LNB/OFA) with newer advanced technology.
- Changing dispatch from high to low-emitting units.

Preliminarily, EPA sought to understand each unit's cost and emission reduction potential for these compliance options. The agency used the capital expenses, fixed and variable operation and maintenance costs for installing and fully operating emission controls researched by a nationally recognized architect / engineering firm (A/E firm)[1] familiar with the EGU sector.[2] Finally, EPA used the Integrated Planning Model (IPM) to analyze power sector response while accounting for electricity market dynamics such as generation shifting.

Results and Discussion: Emission and Cost Estimates for Full Operation of SCR and SNCR

SCR and SNCR are post-combustion controls that reduce NO_x emissions through reacting this pollutant with either ammonia or urea either in presence or absence of a catalyst. The SCR technology utilizes a catalyst and produces high conversion of NO_x while SNCR technology forgoes catalyst but with greatly reduced efficiency. Fully operating an emission control device includes maintenance costs, labor, auxiliary power, capital recovery, catalyst (if utilized), and reagent cost; the chemical reagent (typically ammonia or urea) costs become a significant portion of costs for operating these controls.

Minimum Cost: Returning Partially Operating SCRs and SNCRs to Full Operation

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[1] Sargent & Lundy

[2] See: http://www.epa.gov/airmarkets/documents/ipm/Chapter_5.pdf

Since units that are partially running their SCR or SNCR system have already incurred the fixed operating costs (which are associated with having the controls functioning at any level), the remaining cost to achieve full design capability is the cost of additional reagent. Changing NO_x removal rates following commencement of operations does not affect fixed operation and maintenance (FOM) costs; likewise, the variable operation and maintenance (VOM) components of catalyst replacement and auxiliary power are indifferent to reagent consumption or NO_x removal. In short, for SCRs and SNCRs, the marginal cost to increase from partial operation to full operation reflects the cost of additional reagent.

In an SCR, the chemical reaction consumes approximately 0.57 tons of ammonia or 1 ton of urea for every ton of NO_x removed. During development of CAIR and CSAPR, the agency identified a marginal cost threshold of $500 per ton of NO_x removed (1999$) with reagent costing $190 per ton of ammonia, which equated to $108 / ton of NO_x removed for the reagent procurement portion of operations.[3] The remaining balance reflected other operating and capital recovery costs. Over the years, these commodity prices changed, affecting the operational cost in relation to reagent procurement. To understand the relationship between reagent price and its associated cost regarding NO_x reduction, see Appendix A: Table 1; "Anhydrous Ammonia and Urea Costs and their Associated Cost per NO_x ton Removed." Today, based on pure chemistry and theoretically achieving 100 percent reagent consumption towards NO_x reduction, the reagent portion of operations costs $503 per ton NO_x removed. This represents a reasonable estimate of the cost for operating these post combustion controls based on current market ammonia prices. For purposes of the IPM modeling, the agency assumes that $500 per ton of NO_x removed is a broadly available cost point for units that currently are partially-operating SCRs and SNCRs to fully operate their NO_x controls, which in fact, represents procuring additional reagent.

Cost Estimates for Returning an Inactive SCR to Full Operation

For a unit with an idled, bypassed, or mothballed SCR, all FOM and VOM costs such as auxiliary fan power, catalyst costs, and additional administrative costs (labor) are realized upon resuming operation through full potential capability. Some of these expenses, as modeled by the Sargent & Lundy cost tool, vary depending on factors such as unit size, NO_x generated from the combustion process, and reagent utilized. The EPA performed multiple assessments with this tool's parameters to investigate sensitivity relating to cost per ton of NO_x removed. Additionally, the agency conservatively modeled costs with urea reagent, the higher costing raw material for NO_x mitigation.

Assessed on a per ton basis, the FOM and VOM costs assumed in IPM modeling are generally independent of unit size; however, cost estimates are sensitive to unit uncontrolled[4] NO_x rate. For a wide range of potential NO_x rates anticipated, a bounding analysis was performed to identify reasonable high and low costs. For a hypothetical unit with a high uncontrolled NO_x rate (e.g., 0.7 lb NO_x / MMBtu and 80 percent removal efficiency), VOM and FOM costs were around $700/ton of NO_x removed. Conversely, a unit with a low uncontrolled NO_x rate (e.g., 0.2 lb NO_x / MMBtu and 60 percent removal) experienced a higher cost range revealing VOM and FOM costs about $1,650/ton of NO_x removed. Next, the analysis applied these equations to all coal-fired units equipped with SCRs in 2014 with collected emissions data. For the SCR input NO_x rate, each unit's maximum monthly emission rate was examined from the period 2002-2014 (inclusively) for the purpose of identifying the unit's maximum emission rate prior to the control's installation or alternatively during time-periods when the control was not operating.

[3] EPA Memorandum to Docket; "Analysis of the Marginal Cost of SO2 and NOx Reductions", Jan 28, 2004

[4] For these hypothetical cases, the "uncontrolled" NO_x rate includes the effects of existing combustion controls present (i.e., low NO_x burners).

The long time frame allowed examination prior to the onset of annual NO_x trading programs (e.g., CAIR and CSAPR) with units expected to be operating their SCRs year-round. The analysis made the following assumptions: a NO_x removal efficiency of 87.6 percent,[5] a capacity factor of 85 percent, and combustion of bituminous coal with a heat rate reflecting the median annual heat rate over the time-period. This assessment found 223 of the 249 units (about 90 percent) demonstrated VOM plus FOM costs lower than $1,300/ton of NO_x removed. The units with higher costs exhibited low uncontrolled NO_x rates suggesting the SCR operated year-round.

Examining the results, the EPA concludes that a cost of $1,300/ton of NO_x removed would be sufficient for owners with installed SCRs to resume and fully operate their controls.

<u>NO_x Emission Rate Estimates for Full SCR Operation</u>

The agency examined the ozone-season average NO_x rates for 272 coal-fired units with an installed SCR over the time-period 2003-2014, then identified each unit's lowest, second lowest, and third-lowest ozone-season average NO_x rate. The EPA selected 0.075 lbs NO_x/MMBtu as a reasonable, representation for full operational capability of an SCR noting that over half of the 272 EGUs examined in this case study achieved this rate over an entire ozone season. This average rate represents the second-lowest ozone-season NO_x rate over the time period investigated; the median value was 0.065 lbs NO_x/MMBtu (see Figure 1, top panel). The selection of the second-lowest ozone-season rate avoids a possible issue associated with the best level of performance in an ozone season; namely, accounting for the non-repeatable performance related with commissioning, or "breaking in," a newly constructed SCR. For the next step, the agency examined each ozone-season over the time period and identified the lowest monthly average NO_x emission rates. The second-lowest historical monthly NO_x rate analyzed illustrated 218 of 262 units displayed NO_x rates below 0.08 lb/MMBtu (see Figure 1, bottom panel) and 208 units (or 79%) achieved monthly emission rates below 0.075 lbs NO_x/MMBtu. Based on these monthly demonstrated emission rates, the agency concludes a 0.075 lb NO_x / MMBtu average rate is widely achievable by the EGU fleet.

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[5] A NO_x removal efficiency of 87.6 percent is based on the median ratio of the month with the highest NOx rate to the second best ozone season value for the time-period 2003-2014. The agency selected the median value to ensure exclusion of outliers.

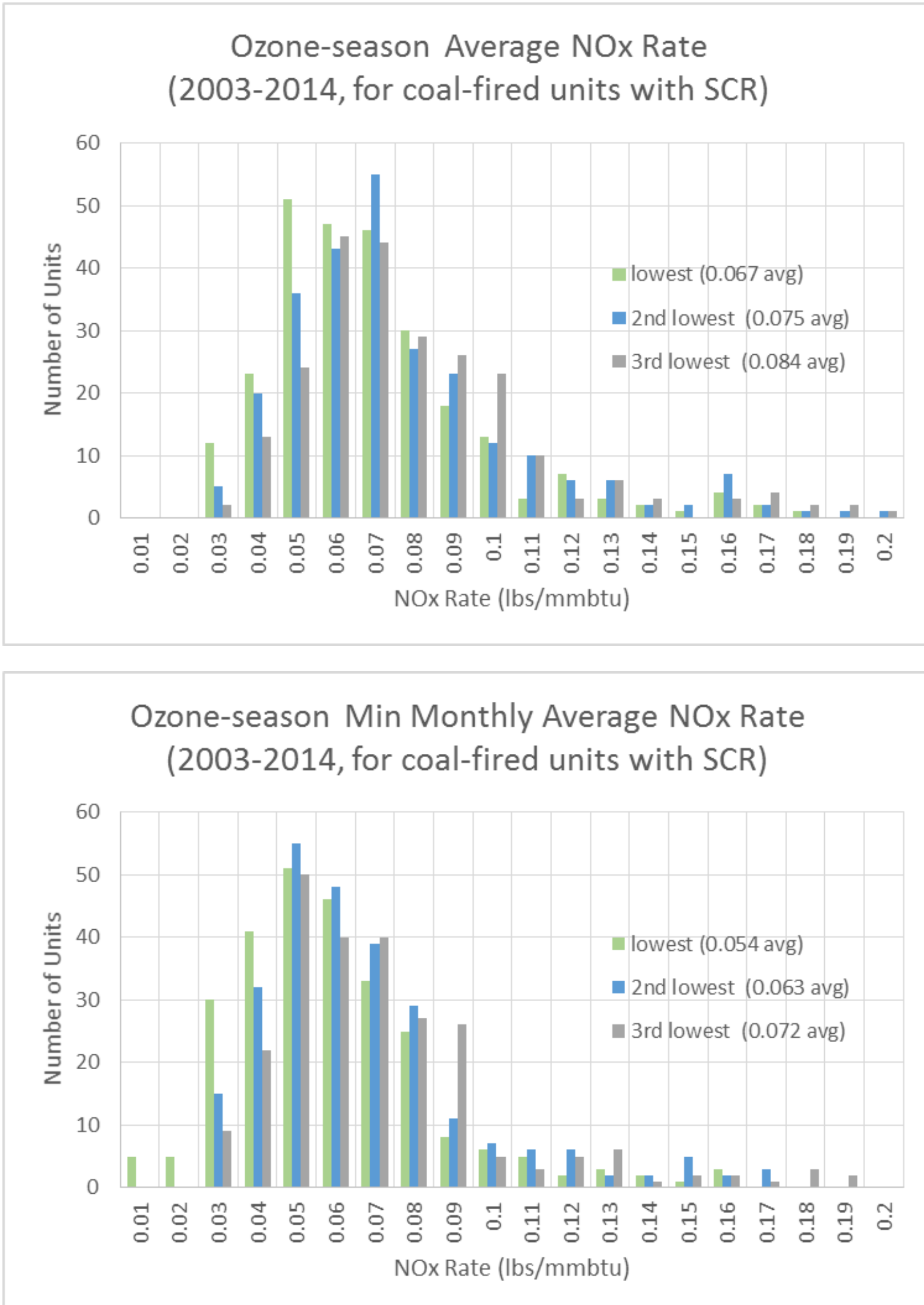

Figure 1. "Frequency" distribution plots for 272 coal-fired units with an SCR showing their NO_x emission rates (lbs/MMBtu) during ozone seasons from 2003-2014. For each unit, the best, second best, and third best ozone-season average NO_x rate (top panel) and minimum monthly average NO_x rate (bottom panel) are illustrated.

<u>Cost Estimates for Returning an Inactive SNCR to Full Operation</u>

SNCR removes NO_x but with significantly lower removal rates than an SCR system. Conducting the NO_x reaction without catalyst typically requires three to four times the amount of reagent per percent NO_x removed. Furthermore, an SNCR system is incapable of achieving the low emission rates of 0.07 lb NO_x

/MMBtu which an SCR achieves. That said, SNCR can serve as a cost-effective strategy for some owners with particularly low capacity factors or short time horizons. The agency conservatively sets SNCR reduction potential at 25 percent, noting some installations achieved superior results. For the SNCR analysis, as with the SCR analysis, the agency used the Sargent & Lundy cost tool to perform a bounding analysis for examining operating expenses associated with returning a "generic" unit to full operation. For units with an idled SNCR returning to full operation, the owner incurs the full suite of VOM and FOM costs, however these costs are relatively insensitive to unit size. On the other hand, reagent consumption represented the largest portion of the VOM component. A step change in costs occurs at an uncontrolled NO_x rate below 0.30 lb / MMBtu which results in significantly higher costs per ton removed. For the bounding analysis, the agency examined two cases[6]: first, a unit with a high NO_x rate 0.70 lb / MMBtu; secondly, a unit with a low NO_x rate 0.20 lb /MMBtu – both with 25 percent removal efficiency. For the high rate case, VOM and FOM costs approximated $1950/ton NO_x with about $1,600/ton associated with urea cost. For the low rate case, VOM and FOM costs approached $3,400/ton NO_x with nearly $2,700/ton associated with urea reagent cost.

Cost Estimates for Installing Low NOx Burners and / or Over Fire Air

Combustion control technology has existed for many decades with improvements occurring over the years. Today's combustion controls are superior to those controls installed two decades ago. While many units contain some form of this technology, some units can reduce NO_x creation in the furnace by modernizing their combustion controls without having to install SCR or SNCR. Modern combustion control technologies routinely achieve rates from 0.20 – 0.25 lb NO_x / MMBtu and, depending on unit type, can achieve rates well below 0.20 lb NO_x / MMBtu. Installation or upgrade of low NO_x burners can be a highly cost-effective strategy to substantially reduce NO_x emissions. Agency staff checked the National Electric Energy Data System, or NEEDs, to verify installed vintage, and then developed an upgrade path based on the options available within IPM for estimating cost. Below, Table 1 "Combustion Control Upgrade Path for Vintage Systems" lists the upgrade paths available with cost estimating utilizing Chapter 5, Table 5-4 "Cost (2011$) of NO_x Combustion Controls for Coal Boilers (300 MW Size)" from IPM documentation.[7]

The agency reasonably assumes for these units:

- Modern Low NOx burner technology, or LNB, replaces old existing burners;
- Over Fire Air, or OFA, is preserved, if it exists;
- Tangential fired units[8] not currently at LNC3 level receive LNC1 or LNC2 depending on their current configuration.

Table 1: Combustion Control Upgrade Path for Vintage Systems

Current Combustion Controls (NEEDS 5.14)	Retrofit / Install Projection	Final Configuration
- None -	LNB + OFA	LNB + OFA
OFA	LNB	LNB + OFA

[6] For both cases, we examined a 500 MW unit with a heat rate of 10,000 Btu/kWh operated at an 85% annual capacity factor while burning bituminous coal.

[7] http://www.epa.gov/airmarkets/documents/ipm/Chapter_5.pdf

[8] Definitions of Low NO_x controls available for Tangentially-fired units include: Low NO_x Coal-and-Air Nozzles with Close-Coupled Overfire Air (LNC1), Low NO_x Coal-and-Air Nozzles with Separated Overfire Air (LNC2), Low NO_x Coal-and-Air Nozzles with Close-Coupled and Separated Overfire Air (LNC3).

LNB	LNB + OFA	LNB + OFA
LNB + OFA	LNB	LNB + OFA
LNC1	LNC2	LNC3
LNC2	LNC1	LNC3
BF, LA, CO,	LNB + OFA	LNB + OFA

With the wide range of LNB configurations available and furnace types present within the fleet, the agency decided to provide a range of estimated compliance costs based on an illustrative unit used in the previous section.[9] For this unit, the agency calculated the costs for each combustion control path listed above and determined that costs ranged from $430 to $1200 per ton NO_x removed. ($2011)

Retrofitting with SCR and Related Costs

The agency also examined the cost for retrofitting a unit with SCR technology, which typically attains extremely low controlled NO_x rates of 0.07 lb NO_x / MMBtu, or less, but with a greater expense. For owners desiring to drive NO_x emissions to their lowest potential, SCR retrofit becomes a prime choice for coal-fired units. The tool developed by Sargent & Lundy illustrates the point; a unit with an uncontrolled rate of 0.35 lb NO_x / MMBtu, retrofitted with an SCR to lower emissions to 0.07 lb NO_x / MMBtu, results in a compliance cost of $5000 / ton of NO_x removed. Installation of SCR involves substantial expenditure of capital. Consequently, SCR installation is most often seen for units which generate substantial electricity and have high capacity factors. Because of the substantial capital cost of an SCR, for a unit with low utilization, owners may adopt SNCR as a more appropriate choice for NO_x control, thereby reducing the "cost per ton" of NO_x reduction.

Retrofitting with SNCR and Related Costs

The agency examined SNCR retrofit technology costs with the Sargent & Lundy tool, and conservatively set the NO_x emission reduction rates at 25 percent. This technology gives owners a low capital cost option for reducing NO_x emissions for units with anticipated short lives or low utilization, albeit at a higher cost per ton of NO_x removed, reflecting this technology's lower removal efficiency. For the unit examined above, but with a 40 percent capacity factor, the cost is $6500 / ton of NO_x removed. Capital costs reflecting this unit represent $46 / kW (unlike the SCR above which represented $292 / kW). In short, the lower removal efficiency consumes greater amounts of reagent which escalates the VOM cost component.

[9] assumed 500 MW unit, heat rate of 10,000 Btu/kWh, 85% annual capacity factor, bituminous coal, 0.50 lb NO_x / MMBtu initial rate with 41 percent reduction after upgrades

Shifting Generation to Lower Emitting Units

Shifting generation to lower NO_x-emitting EGUs, similar to operating existing post-combustion controls, uses investments that have already been made, can be done quickly, and can significantly reduce EGU NO_x emissions.

Since CSAPR was promulgated, electricity generation has trended toward lower NO_x-emitting generation due to market conditions (e.g., low natural gas prices) and state and federal environmental policies. For example, new NGCC facilities, which represented 45% of new 2014 capacity, can achieve NO_x emission rates of 0.0095 lb/MMBtu, compared to existing coal steam facilities, which emitted at an average rate across the 23 states included in this proposal of 0.18 lbs/MMBtu of NO_x in 2014. This substantial difference in NO_x emission performance between existing coal steam and new NGCC generation is due both to higher nitrogen content in coal compared to natural gas, as well as to the substantially lower generating efficiency of steam combustion technology compared to combined cycle combustion technology. Shifting generation to lower NO_x-emitting EGUs would be a cost-effective, timely, and readily available approach for EGUs to reduce NO_x emissions and the EPA included this NO_x mitigation strategy in quantifying EGU NO_x obligations for this proposal.

Shifting generation to lower NO_x-emitting EGUs occurs in response to economic factors. As the cost of emitting NO_x increases, combined with all other costs of generation, it becomes increasingly cost-effective for units with low NO_x rates to increase generation, while units with higher NO_x rates to reduce generation. Because the cost of generation is unit-specific, as the cost of emitting NO_x increases with increasing cost thresholds, this generation shifting occurs incrementally. Consequently, there is more generation shifting at higher cost NO_x thresholds. This generation shifting occurs on a continuum in response to costs. Because we have identified discrete cost thresholds resulting from the full implementation of particular types of emission controls, it is reasonable to simultaneously quantify the reduction potential from generation shifting strategy at each cost level. Including these reductions is important, ensuring that other cost-effective reductions (e.g., fully operating controls) can be expected to occur.

The EPA limited shifting generation to units with lower NO_x emission rates within the same state due to the near-term 2017 implementation timing for this proposed rule.

Feasibility Assessment: Compliance Time for Each Option

The agency assessed the time needed for implementation of each option to assess the feasibility of achieving reductions during the 2017 ozone-season.

For SCRs and SNCRs currently operating at partial design capability, these functioning systems require increasing reagent flow rate and ensuring sufficient chemical reagent exists to sustain higher reagent flow operations. Considering that system design likely already supports higher throughput, increasing control operation requires procurement of additional reagent. Stocking-up additional reagent for sustaining increased operation may require one to two weeks.

For inactive SCRs and SNCRs, restoring functionality may require three months. As mentioned previously, power plant management needs to inform operations and maintenance of upcoming changes. Personnel need to retrain and become familiarized with emission controls operating procedures for their plant site. Reagent needs to be ordered and stock-piled. Maintenance needs to bring the system out of protective lay-up, perform inspections, and correct deficiencies (if present). Operations will test run, and re-tune the system before compliance season. The EGU sector is very familiar with restarting SNCR and SCR systems since the original NO_x SIP Call program allowed these systems to shut-down during non-ozone season. Typically, utilities restarted these systems the following season on time and without incident.

Since Low NO_x burner and / or overfire air is a mature technology requiring a short time to complete installation, the Agency concludes that sufficient time exists for EGU owners to select this option for compliance. Construction time requirements for installing combustion controls were examined by the EPA during CSAPR development and are reported in the TSD for prior CSAPR rulemaking entitled; "Installation Timing for Low NO_x Burners (LNB)", Docket ID No. EPA-HQ-OAR-2009-0491-0051.[10] The estimates and conclusions of that assessment are included here.

Retrofitting with SCR and SNCR are not being considered for this rule as a compliance option. The time requirements for an SCR retrofit exceed 18 months from contract award through commissioning. SNCR is similar to ACI and DSI installations and requires 12 months from contract award through commissioning. For both technologies, conceptual design, permitting, financing, and bid review require additional time. Detailed analysis can be found in: "Final Report: Engineering and Economic Factors Affecting the Installation of Control Technologies for Multipollutant Strategies", EPA-600/R-02/073, Oct 2002.[11] The estimates and conclusions of that assessment are included here.

[10] http://www.epa.gov/airmarkets/airtransport/CSAPR/pdfs/TSD_Installation_timing_for_LNBs_07-6-10.pdf
[11] http://nepis.epa.gov/Adobe/PDF/P1001G0O.pdf

Appendix A: Ammonia / Urea Costs and their Associated Cost per NO_x ton Removed

Minimum Cost to Operate

Anhydrous NH_3 & Urea costs ($/ton) [from USDA]

year	NH_3 (anh)	Cost / ton NO_x	Urea cost	Cost / ton NO_x
1999	$ 190	$ 108	$ 165	$ 165
2000	$ 209	$ 118	$ 194	$ 194
2001	$ 385	$ 218	$ 277	$ 277
2002	$ 228	$ 129	$ 179	$ 179
2003	$ 374	$ 212	$ 258	$ 258
2004	$ 366	$ 207	$ 264	$ 264
2005	$ 394	$ 223	$ 319	$ 319
2006	$ 489	$ 277	$ 345	$ 345
2007	$ 500	$ 283	$ 445	$ 445
2008	$ 731	$ 414	$ 537	$ 537
2009	$ 640	$ 363	$ 450	$ 450
2010	$ 474	$ 269	$ 421	$ 421
2011	$ 744	$ 422	$ 501	$ 501
2012	$ 812	$ 460	$ 547	$ 547
2013	$ 877	$ 497	$ 574	$ 574
2014	$ 888	$ 503	$ 550	$ 550

USDA

http://www.neo.ne.gov/statshtml/181.htm