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NO_x CONTROL ON COMBINED CYCLE TURBINES
Issues Regarding the Use of Selective Catalytic Reduction in Attainment Areas for Dry Low NOx Natural Gas Combined Cycle Turbines

Introduction

This paper is a review of issues brought to EPA's attention as a result of several recent controversies involving state permitting agencies, utilities, and turbine manufacturers over appropriate best available control technology (BACT) controls for NO_x at natural gas combined cycle turbines for electric power generation. It is intended as background to a guidance issued by John Seitz, Director of the Office of Air Quality Planning and Standards entitled, "Consideration of Collateral Environmental Impacts Associated with the Use of SCR at Dry Low NO_x Combined Cycle Natural Gas Turbines", dated _____. That guidance discusses issues that related to collateral environmental impacts associated with the use of of Selective Catalytic Reduction (SCR) that are appropriate to consider as part of a BACT determination at combine cycle natural gas dry low NO_x turbines. This paper provides additional technical information on those collateral impacts. It also provides more general background information related to the structure and functioning of the electric utility industry and on dry low NO_x as a pollution prevention technology.

SCR is often considered BACT for limiting NO_x emissions on natural gas combined cycle turbines in ozone attainment areas. Some have argued, however, that dry low NO_x (DLN) turbines should not need to apply SCR in attainment areas. Even though SCR, when used with dry low NO_x turbines would limit NO_x emissions to below the level of a dry low NO_x turbine alone, they argue that it may be environmentally preferable to operate these turbines without SCR. The cost of SCR, they argue, may mean that, if these turbines must use SCR, more electricity will be produced by dirtier plants and therefore total NO_x emissions would increase, not decrease. Further some have argued that the ammonia that is required for SCR to operate has its own set of environmental problems that outweigh any benefit of the small increment of NO_x reduction that is achieved by putting SCR on dry low NO_x turbines. Also, the dry low NO_x turbine is a pollution prevention technology that limits NO_x, formation unlike SCR which is designed to control NO_x that has been formed. Preventing pollution rather than controlling it is the Agency's and the Federal government's stated preference.

Pollution control technologies and NO_x control technologies specifically are evolving rapidly. New technologies that may eventually replace SCR are already becoming available and a new generation of combined cycle turbines is being designed. Each will have its own set of issues that may make them more or less suitable for a given plant and location when they are used in an ozone attainment area. A site specific BACT analysis is meant to allow the permit applicants and permitting

authorities an opportunity to review those issues. This paper reviews the issues that have been raised concerning SCR and dry low NO_x turbines.

Background on NO_x Control

Combined cycle natural gas turbines that are widely available today produce less NO_x than other types of fossil fuel electricity generating plants. GE will conditionally guarantee that its DLN turbines will emit no more than 9 parts per million (ppm) of NO_x. Other manufacturers' turbines typically emit up to 25 ppm NO_x and are usually permitted at between 2.5 ppm and 4.5 ppm with SCR. A GE DLN turbine with SCR will also emit NO_x in the 2.5 ppm to 4.5 ppm range. Exhibit 1 compares these emission concentrations to emission rates in units of tons of NO_X per year for typical 200 MW power plants operating at 100% load for 80% of the year. Exhibit 1 also compares the emission concentrations and emission rates of combined cycle natural gas plants to those for coal fired power plants of the same generating capacity that are uncontrolled and those that comply with the 1998 SIP call's levels of NO_x control.

Exhibit 1
NO_x Emissions
Representative 200MW Coal and Natural Gas Combined Cycle Power Plants

Plant Type/ NO_x Emissions	*Approximate NO_x Concentration (ppm)*	*Approximate Tons of NO_x Emitted per Year*
Existing Coal Plant	240	3000
Coal Plant with SIP Call Level of Control	90	1100
F Class Natural Gas Combined Cycle Plant without SCR	25	420
F Class Natural Gas Combined Cycle Dry Low NO_x, without SCR	9	150
F Class Natural Gas Combined Cycle with SCR	3.5	60

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SCR is a widely used technology for controlling NO_x emissions from a wide variety of stationary combustion sources. SCR selectively reduces NO_x emissions by injecting ammonia into the exhaust gas upstream of a catalyst where the NO_x reacts with the ammonia and oxygen to form N_2 and water. SCR is most effective within a certain temperature range and higher or lower temperatures and other operating conditions can cause some of the NO_x and ammonia to pass through the catalyst without reacting. Catalysts degrade eventually and that also can cause ammonia to pass through the catalyst unreacted.

The ammonia that is emitted is called the ammonia slip. Plant operators can minimize the ammonia slip by replacing catalyst as it degrades. Some states specify a limit for the ammonia slip, usually between 5 ppm and 10 ppm, in permits for combined cycle natural gas turbines. Plants operate well below the limit for most of time they are operating so as not to exceed the permitted limit.

NO_x control technology is evolving. For example, ABB Alstom Power recently announced the availability of SCONOX , a NO_x control technology that does not depend on ammonia. This technology is currently considerably more expensive than SCR and it has not yet been used on large combined cycle natural gas turbines.

The Legal Background: BACT in the Clean Air Act

Best available control technology, or BACT, is required for new or modified major sources in order to prevent significant deterioration of air quality in attainment areas.[1] The Clean Air Act allows permitting authorities to weigh environmental, energy and economic concerns against the proven environmental benefits of technologies such as SCR in making BACT determinations in order to determine whether a less effective technology for NO_x control is warranted in specific cases. See In re Kawaihae Cogeneration Project, 7 E.A.D. 107 at 115-119 (EAB 1997).

The Clean Air Act defines "best available control technology," or BACT, as

> [A]n emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this chapter emitted from or which results from any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy,

[1]In non- attainment areas new and modified sources have to meet a different standard, Lowest Achievable Emissions Rate, or LAER, which is not discussed in this paper.

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environmental, and economic impacts and other costs, determines is achievable for such facility. 42 U.S.C. § 7479(3).

Taking these "collateral" impacts into account, the permitting authority may reject the most effective control technology as BACT, but only in limited circumstances. In re Columbia Gulf Transmission Co., 2 E.A.D. 824, 827 (Adm'r 1989)("[T]he collateral impacts clause operates primarily as a safety valve whenever unusual circumstances specific to the facility make it appropriate to use less than the most effective technology."); In re World Color Press, Inc., 3 E.A.D. 474, 478 (Adm'r 1990) ("[T]he collateral impacts clause focuses upon specific local impacts which constrain a particular source from using the most effective control technology."). More specifically, with respect to the consideration of collateral environmental impacts, the Environmental Appeals Board has explained that the definition of BACT has been interpreted to mean that "if application of a control system results directly in the release (or removal) of pollutants that are not currently regulated under the Act, the net environmental impact of such emissions is eligible for consideration in making the BACT determination." Kawaihae, 7 E.A.D. at 116, citing In re North County Resource Recovery Associates, 2 E.A.D. 229, 230 (Adm'r 1986).

A decision by a permitting authority to reject the most effective control technology, due to environmental concerns, must be based on sound evidence that the environmental concerns associated with the use of this technology outweigh the benefits. Thus for, example, in Kawaihae, the EAB rejected a claim "that purely hypothetical catastrophic failure of the SCR ammonia system...warrants further consideration as a 'collateral environmental impact' in [the State's] BACT analysis." 7 E.A.D. at 117. The State had considered the risks associated with the use of ammonia and found them to be minimal. The EAB, also found that the source must use the most effective technology unless it is demonstrated to the permitting authority's satisfaction that unique circumstances specific to the facility would make the use of that technology inappropriate. Similarly, the New Source Review Workshop Manual (Draft 1990) makes clear that if a control technology has been applied to similar facilities elsewhere, it may still be rejected as BACT if the permit applicant can show that unusual circumstances at the proposed facility create greater problems than experienced elsewhere.[2] In the same way, if the permit applicant can convincingly show evidence that the environmental impacts associated with a control technology outweigh the benefits, that can be taken into account in the BACT determination. Thus, a permitting authority could appropriately conclude that BACT in a specific case was DLN turbines without additional controls for a combined cycle gas turbine if a case-by-case assessment of the environmental, energy, and economic impacts demonstrates that the collateral environmental impacts associated with a control technology such as SCR outweighed the benefits of additional NOx reduction.

[2] U.S. EPA, NSR Draft Manual at B.47.

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Pollution Prevention and DLN Turbines

The Pollution Prevention Act of 1990 made pollution prevention a national policy goal.[3] The 1990 Act asserts that reducing pollution is fundamentally different from and preferable to controlling emissions. This policy is affirmed in the Administrator*s Policy Statement on Pollution Prevention, which states that "pollution should be prevented or reduced at the source whenever feasible" and cites the importance of encouraging the private sector to commit resources to pollution prevention.[4] In the long run, encouraging continued investment in the development of pollution prevention technology may have a very important environmental benefit.

DLN turbines are the result of the type of private industry investment that the Agency seeks to encourage. The DLN turbines were developed by GE in cooperation with the U.S. Department of Energy (DOE) with the specific goal of achieving acceptably low emissions without the use of post-combustion controls. The goals of the DOE program were to develop a turbine with less than 10 ppm of NO_X emissions. Protection of public health and the environment is of paramount concern, but the potential future public health and environmental benefits of encouraging the development of cleaner technology, such as the DLN turbines, merits attention.

Background on Displacement and Effects on NO_x Emissions

Because DLN combined cycle electric generating plants emit only very small amounts of NO_x, and because of the market in which they operate, the effect of requiring SCR or other add-on NO_x controls on these turbines may be to increase rather than decrease NO_x emissions. Although this may seem counter-intuitive, it makes sense when considered in the context of the market in which electricity is generated today. To fully understand the impact of requiring controls on a unit or plant it is important to look at that unit or plant not just individually, but to look at the unit or plant as part of a larger system because it is operated, as part of a system.

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[3] 44 U.S.C.§§13101(a) (4).

[4] Carol M. Browner, *New Directions for Environmental Protection,* US EPA, June 15, 1993.

Until recently, the electricity generation market was regulated. Prices were set by government bodies rather than in the a competitive market. Those prices generally allowed power producers to pass the costs of generating electricity on to consumers. Over the past few years, however, market regulation of electricity generation has been lifted in a number of places and there is a trend toward a competitive market for electricity. In a competitive market, electric power generators can no longer pass on all of their costs to their customers because higher prices mean fewer sales. They have an incentive to keep their generating costs to a minimum. Under market regulation, new plants were built mainly to meet new demand. In a competitive market, the incentive to produce electricity more cheaply means that generators build new plants in part to meet increased demand, but also in part, because new natural gas combined cycle plants produce electricity more cheaply than many older steam generating units.

As with other competitive industries, changes in capital and operating costs associated with requirements for pollution control devices can have an affect on decisions about whether new plants will be built in the electricity generating industry. But to a much greater extent than other industries, electricity generating industry is able to respond quickly and effectively to very small changes in the cost of electricity production by adjusting the order in which individual plants are dispatched to the grid. Electric power is dispatched generally in order of the least expensive power first. Thus those plants that produce power at the lowest costs are operated most often. Plants that produce more expensive power are operated only in periods of peak demand.

New natural gas combined cycle units are dispatched before plants that are more expensive to operate. Adding SCR to a natural gas combined cycle turbine increases its capital costs and operating costs. The increases are modest and therefore have a modest effect on the number of units built. An increase in operating costs also is reflected in a lower dispatch order so that even very small increases mean that the generating unit is run less often and the difference is made up by another unit that is less expensive to operate. Often these less expensive plants emit more NOx and than natural gas combined cycle generation with or without SCR.

The implications of requiring SCR on combined cycle turbines can be analyzed with the Integrated Planning Model (IPM)[5]. EPA's Office of Air and Radiation published a report in March of

[5]The Integrated Planning Model predicts the actions of power plant operators over time in response to alternative levels of air pollution controls. It was developed by ICF Resources as a commercial capacity planning tool and for policy applications over wide geographic areas or for the entire country. EPA has used this model extensively to analyze the emissions reductions and costs for the electric power industry under a variety of policy options.

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1999, that used the IPM to examine emissions of NO_x, SO_2, CO_2, and mercury from the electric power industry under a set of hypothetical pollution control scenarios.[6] In the course of that effort, an analysis was made comparing the total NO_x emissions across the country with and without a requirement that SCR be used on combined cycle gas turbines.[7] The results of the analysis for the year 2010 are shown below in Exhibit 2.

Exhibit 2
2010 Annual National Capacity, Generation and NO_x Emissions With and Without SCR on Combined Cycle Natural Gas Units.[8]

	SCR Required	*SCR Not Required*
Total CC capacity (MW)	112,161	115,224
Total coal, oil and gas steam capacity (MW)	473,397	470,486
Total CC generation (GWh)	622,008	634,475
Total coal, oil and gas steam generation (GWh)	2,251,443	2,238,869
Total NO_x emissions	4,147,240	4,132,113

The analysis forecasted slightly lower NO_x emissions nationally from all utility sources when SCR is not required for new combined cycle gas turbines. When SCR is required, less combined cycle capacity is constructed and less existing combined cycle capacity is used for generation. Thus, more

[6]EPA.1999. *Analysis of Emissions Reduction Options for the Electric Power Industry*, Office of Air and Radiation, Washington, DC, March 1999. Available at the web site: *www.epa.gov/capi*.

[7]The results of that analysis, presented here, were not included in the published report.

[8]Among the assumptions used for this analysis is that sources will have complied with federal regulations that had been promulgated at the time the report was published including phase two of the acid rain program and the NO_x SIP call. For a full discussion of the assumptions used in the study see the study or *www.epa.gov/capi*.

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power is generated by higher emitting sources and total NO_x emissions are higher when combined cycle gas plants are required to use SCR.

The results of the analysis presented in Exhibit 2 show a modest increase in NO_x emissions as a consequence of requiring SCR on combined cycle turbines. These results suggest that a policy that requires these relatively low NO_x emitting sources to apply SCR does not necessarily reduce national NO_x emissions. Rather it may reduce the amount of combined cycle capacity and generation in favor of other less clean existing generation which could, on a national basis increase, or at least not decrease, NO_x emissions. Generally, natural gas combined cycle generation also produces lower levels of other pollutants than the generation it displaces, including lower SO_2, mercury and CO_2 emissions. So a policy that reduces the use of this lower emitting generation could have a negative impact on air quality nationally from that perspective as well.

The results discussed consider national emission levels. Regionally the results vary somewhat so that in some locations requiring SCR on combined cycle units may reduce NO_x emissions although on balance they do not.

Furthermore, the relationship between NOx emissions and ozone formation is not linear. Smaller sources of NO_x emissions are more efficient at producing ozone than are large sources of NO_x. The difference in emissions is larger than the difference in ozone formation.[9] So the analysis presented here may overstate the air quality benefit of not requiring SCR on combined cycle turbines.

It is useful to keep these issues in mind when considering the more site specific environmental considerations, discussed below, that may affect a BACT determination.

Site Specific Tradeoffs of NO_X and Ammonia Emissions

This section is a discussion of collateral environmental impacts that are appropriate to consider concerning the use of SCR for DLN combined cycle turbines in making a case-by-case BACT determination, if they brought to the permitting authority by the applicant. In the case of DLN turbines with and without SCR, the change in NO_X emissions (approximately 5.5 ppm of NO_X) is small in comparison to NO_X emissions from other types of combustion power plants, and therefore, it is important to compare the impacts from this increment of NO_X emissions to the small amount of

[9]Ryerson, T.B., M.P. Buhr, and F.C. Fehsenfeld (1998). Journal of Geophysical Research, D. Atmospheres, 103(17):22569. September 20, 1998.

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ammonia slip emissions that result from the use of SCR (often less than 5 to 10 ppm of ammonia).

The tradeoffs between NO_X and ammonia emissions are not simple. Both NO_X and ammonia are acutely toxic; both contribute to fine particle formation, acidifying deposition, eutrophication, and enrichment of terrestrial soils; and both may be converted to nitrous oxide (N_2O), a powerful greenhouse gas. In addition, NO_X (as NO_2) is a chronic toxin and an essential precursor for the formation of tropospheric ozone. The contribution of NO_X or ammonia emissions from a single facility to any of these environmental problems is primarily determined by existing levels of NO_X and ammonia in the area of a source and the availability of other pollutants in the atmosphere that react with and transform the emitted oxidized or reduced nitrogen.

With respect to comparing the incremental impact of a new source to the overall inventory of NO_X or ammonia emissions, it is important to realize that the emissions inventories of both pollutants are not of equal quality. While NO_X emissions and ambient concentrations are measured routinely, there is little data available on ambient ammonia concentrations and the emission inventories for ammonia are highly uncertain. Agricultural operations are the largest source of ammonia emissions nationwide, however urban areas may have significant ammonia emissions from industrial sources, as well as from catalyst equipped automobiles.[10]

Each of the potential environmental problems associated with NO_X and ammonia emissions is discussed qualitatively below.

Tropospheric Ozone

NO_X is an essential precursor to the formation of ozone, which is formed through a series of reactions of NO_X and volatile organic compounds (VOCs) in the presence of sunlight. More specifically, ozone is formed through the photolysis of NO_2 to NO. Instead of playing a direct role in the formation of ozone, the presence of VOCs affect the efficiency with which NO_X forms ozone. VOCs are oxidized in a chain of reactions that recycles NO to NO_2 so that it can be photolyzed again. The efficiency of this system of reactions (i.e., the number of ozone molecules produced per molecule of NO_2) is largely a function of the amount and composition of the VOCs that are present and the availability of sunlight. This photochemical recycling continues until the NO_X is converted to nitric acid

[10]Fraser and Cass (1998) demonstrated that catalyst-equipped automobiles in the South Coast Air Basin surrounding Los Angeles emit between 24 and 29 tons of ammonia per day, which is 11-18% of the total ammonia emissions and equivalent to the emissions from all of the livestock operations in the Basin. Environmental Science and Technology, 32(8):1053-1057.

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(HNO_3) or an organic nitrate, such as peroxyacetylnitrate (PAN).

While nitric acid readily deposits on surfaces or dissolves in cloud or fog water droplets, PAN is relatively inert and can be transported long distances before thermally decomposing to recreate NO_2. Thus, PAN acts as a "reservoir species" that allows the nitrogen to be transported over 100's of kilometers, projecting the impact of emissions regionally, far beyond the immediate source area.

The impact of NO_X emissions on ozone concentrations are functions of the levels of NO_X, VOCs, and sunlight that are available, and the impacts may be different on the local scale than on the regional scale. As noted above, the efficiency of ozone formation in small NO_X plumes is greater than that in large NO_X plumes, such that a small emission source may produce the same peak concentration that results from a larger emission source. Thus, the nonlinearity of photochemistry can require large NO_X emission decreases to achieve small improvements in ozone air quality. In ozone nonattainment areas and attainment areas that are immediately upwind of nonattainment or Class I areas, the impact of NO_X emissions on regional ozone concentrations should be an important consideration in any permitting decision.

Fine Particles

Both NO_X and ammonia emissions contribute to the formation of fine particles. As the primary chemical base in the atmosphere, the primary fate of ammonia is the neutralization of acids either in the gas, liquid, or particle phase. Ammonia reacts preferentially with acid sulfate aerosols, which are formed from the oxidation of SO_2 emissions. The acid sulfate aerosols, which may contain sulfuric acid or ammonium bisulfate, react with ammonia to form ammonium sulfate particles, $(NH_4)_2SO_4$. This reaction increases the mass of the sulfate particles and increases the rate of formation of particles by increasing the rate of SO_2 oxidation.[11] Ammonium sulfate is the dominant form of ammonium aerosols and a primary constituent of fine particle concentrations in many parts of the U.S., particularly in the East.

Ammonia also reacts with nitric acid, derived from NO_X emissions, to form ammonium nitrate particles, NH_4NO_3. In areas where SO_2 emissions are low, as in some areas of the West, ammonium nitrate particles are the dominant component of fine particle concentrations. Ammonium nitrate formation is more prevalent under cooler and drier conditions and, thus, plays an important role in visibility impairment during the winter months. Under these conditions, fine particles can be decreased

[11]See Weber, R.J., et al., (1999). Geophysical Research Letters, 26:307-310.

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by controlling either the NO_X or the ammonia emissions, whichever is more limiting. In ammonia-rich areas, controlling ammonia has little effect on fine particle formation, and NO_X control has more of an impact.[12] However, in some situations, fine particle concentrations may exhibit nonintuitive sensitivities to NO_X controls due to the linkage between nitric acid formation and the complex oxidant photochemistry described above.[13]

While both nitric acid and ammonia readily deposit on surfaces or dissolve in cloud or fog water, ammonium nitrate and ammonium sulfate do not deposit as quickly. Therefore, once the NO_X or ammonia has been converted to fine particles, it may be transported much farther downwind.

The sensitivity of particle formation to changes in ammonia is dependent on the ambient concentrations of ammonia, nitric acid, and sulfate, as well as relative humidity and temperature. In urban areas where the ambient concentrations of sulfuric acid, from SO_2 emissions, or nitric acid, from NO_X emissions, are high, and ammonia emissions are relatively low, ammonia emissions are likely to increase fine particle formation. In rural areas where sulfuric and nitric acid concentrations are low and ammonia emissions are high, an incremental increase in ammonia emissions may have little impact on fine particle formation.

Acidifying Deposition

In the atmosphere, NO_X contributes to the formation of acid aerosols, while ammonia neutralizes atmospheric acidity. Once deposited, however, derivatives of both NO_X and ammonia can contribute to the acidification of terrestrial soils and surface waters.

While sulfuric acid derived from SO_2 emissions is the most important contributor to chronic acidification in the eastern U.S., nitric acid, derived from NO_X emissions, is a significant contributor to dry or wet acidic deposition nationwide. The relative importance of nitric acid deposition as compared

[12]The Northern Front Range Air Quality Study showed that the Denver area was so ammonia-rich that a 50% decrease in ammonia emissions would result in only a 15% decrease in fine particle formation and a doubling of ammonia emissions would have a negligible effect. [Watson, J.G., et al. (1998). *Northern Front Range Air Quality Study Final Report*. Reno, NV: Desert Research Institute.]

[13]Pun, Betty K. and Christian Seigneur (1999). *Understanding Particuate Matter Formation in the California San Joaquin Valleyan Joaquin Valley*: *Conceptual Model and Data Needs*. Atmospheric Environment 33(29):4865.

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to sulfuric acid deposition varies according to geographic location, season, and nature of the acidifying event.

When deposited on soil, nitric acid contributes a hydrogen ion and a nitrate ion to the soil. If the nitrate ion is taken up by plants, the nitrate ion is replaced by a hydroxide ion, which neutralizes the hydrogen ion, and no net acidification occurs. If the nitrate is not taken up by plants, the hydrogen ion is not neutralized and contributes to acidification. Thus, nitric acid deposition contributes to episodic acidification associated with spring snow melt or storm runoff when plant uptake is not possible and chronic acidification where the ability of the ecosystem to utilize the nitrogen input has been exceeded. Therefore, nitric acid deposition is a more important contributor to acidification in the West than in the East due to the nature of soils, and more important during winter than in summer due to the accumulation in snow pack.[14]

As noted above, ammonia dissolves in cloud water to form ammonium ions in solution or reacts with acids to form neutral ammonium salts. Once deposited on soils, ammonium ions are primarily taken up by plants, which in turn release a hydrogen ion, contributing to acidification. Ammonium ions, however, may be converted to nitrates by microbes in a process known as nitrification. In this conversion, two hydrogen ions are released for every ammonium ion nitrified. If the resulting nitrate ion is taken up by plants, the plants will release a hydroxide ion neutralizing one of the hydrogen ions produced in the conversion. If the nitrate is not taken up by plants, both hydrogen ions contribute to acidification. Thus, ammonium deposition usually contributes to chronic acidification and can be an especially significant contributor to episodic acidification when deposited on snow where microbial nitrification can occur but plant uptake is not possible.

When deposited on water, ammonia or ammonium ions may stay in solution as ammonium ions, be taken up directly by aquatic plants, undergo microbial nitrification contributing to acidification, or undergo subsequent microbial denitrification increasing the pH of the water. Any nitrogen input into an aquatic system will have an effect on the alkalinity, or acid neutralizing capacity, of the water. However, the direction and magnitude of the effect is dependent on both the form of nitrogen deposited and the chemical and physical properties of the water body. The nutrient effects of nitrogen deposition are discussed in the following section.

The extent to which either ammonium ion, nitrate, or nitric acid deposition affect the

[14]U.S. EPA (1995) Acid Deposition Standard Feasibility Study Report to Congress. Washington DC: Office of Air and Radiation, EPA 430-R-95-001a.

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acidification of soils or surface waters in a given location depends on a number of site-specific variables, including the level of nitrogen saturation of the ecosystem; the composition of the soil, including organic matter and base cation concentrations; and the acid neutralizing characteristics of the water body. As in the case of fine particle formation, it is difficult to generalize about whether NO_X or ammonia is more damaging. With respect to chronic acidification, nitric acid deposition only contributes to acidification where the soil is saturated with nitrogen, whereas ammonium ion deposition contributes to acidification where the soil is not nitrogen saturated. The extent of nitrogen saturation across the United States is uncertain, but there is some empirical evidence of nitrogen saturation in some locations.[15] With respect to episodic acidification, nitric acid is an important contributor, but ammonium ions can actually have twice the impact of nitric acid on a molar basis if the ammonium is nitrified in the snow pack. Given these effects, it appears that there are at least some situations where it would be more important to limit emissions of ammonia than to limit emissions of NO_X to avoid impacts of acidification.

Nitrogen Deposition and Eutrophication

When oxidized or reduced nitrogen is deposited on soils or surface waters, the nitrogen serves as a biological fertilizer, regardless of whether the nitrogen came from NO_X or ammonia emissions, respectively. In surface waters, especially coastal waters and estuaries, nitrogen deposition stimulates the growth of organic matter, an effect known as eutrophication. The results of eutrophication include the growth of algal blooms and the depletion of dissolved oxygen, both of which can be toxic to higher marine and estuarine plants and animals. Similar effects occur in terrestrial ecosystems when nitrogen supply exceeds plant and microbial demand. Nitrogen saturation of soils may lead to impacts on vegetation including changes in the uptake of nutrients, increased acidification, increased susceptibility to damage or attack, altered reproductive processes, and ultimately, changes in species composition and diversity. While the speed and mechanisms by which aquatic or terrestrial biological systems make use of the nitrogen may differ depending on whether the nitrogen is in oxidized or reduced form, the overall fertilization effect is the same. Thus, on the basis of these impacts, the tradeoff between NO_X and ammonia emissions should be made in favor of the option that decreases the total amount of oxidized or

[15]U.S. EPA (1995) Acid Deposition Standard Feasibility Study Report to Congress. Washington DC: Office of Air and Radiation, EPA 430-R-95-001a. [Add other references that show saturation, including Stoddard]

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reduced nitrogen being emitted.[16]

With respect to the range of influence or potential for long range transport, nitric acid, derived from NO_X emissions, and ammonia have similar lifetimes in the atmosphere and, thus, similar potential for long range transport. PAN and ammonium sulfate, however, are longer lived and can spread the influence of both NO_X and ammonia sources over a wide area. Nationally, a significant fraction of NO_X emissions come from the tall stacks of electric power plants and other combustion sources, which propel the emissions high into atmosphere, enabling the nitrogen to travel long distances before being deposited. Ammonia emissions come primarily from ground level sources, such as agricultural operations, and thus, the nitrogen contained in ammonia emissions tend not to travel as far. In the case of combined cycle natural gas turbines and associated control equipment, both NO_X and ammonia are emitted from a stack and would have relatively similar potentials for long range transport.

Global Warming and Stratospheric Ozone Depletion

As noted above, to the extent that it reduces displacement of coal, oil and gas steam generation, the addition of SCR on new natural gas combined cycle generating capacity may reduce the CO_2 benefit of this type of plant. There is also a negligible power penalty associated with SCR of between 0.2 percent to 0.25 percent[17].

A small fraction of ammonia emissions, once deposited on soils, is converted by soil microbes to nitrous oxide (N_2O), a powerful greenhouse gas and a stratospheric ozone depleter. As described above, soil microbes oxidize ammonium to nitrates in a process known as nitrification. Microbes further convert nitrates to molecular nitrogen, NO_X, and nitrous oxide in a process known as denitrification. While some nitrous oxide is produced as a by-product during nitrification, denitrification is a larger source and acts equally on nitrates regardless of whether the nitrogen originated as NO_X or

[16]In terms of nitrogen emitted, 1 ton of ammonia is equal to 1.7 tons of NO and 2.7 tons of NO_2.

[17] *Investigation of Performance and Cost of NO_x Controls As Applied to Group 2 Boilers*, US EPA, August 1996, (Docket A 9528, IVA-4). The Proposed New Source Performance Standard for NO_x for New Fossil-Fuel Fired Steam Generating Units assumes an efficiency of 32% with an energy penalty of 0.4 percent for SCR on coal-fired power plants. Assuming the efficiency of natural gas combined cycle plants to be 50 percent the corresponding energy penalty for SCR would be 0.25 percent. (62 FR 36958, July 9, 1997)

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ammonia. On the basis of impacts associated with nitrous oxide, once again, the tradeoff between NO_X and ammonia emissions should be made in favor of the option that decreases the total amount of oxidized and reduced nitrogen being emitted.

Ammonia Safety

Some permit applicants and turbine manufacturers have cited ammonia safety concerns as an issue that mitigates the benefit of using SCR to control NO_x on natural gas combined cycle electric generating turbines. Ammonia is identified by EPA as an extremely hazardous substance.[18] It is toxic if swallowed or inhaled and can irritate or burn the skin, eyes, nose or throat. Vapors may form an explosive mixture with air. None-the-less, ammonia is a commonly used material. OSHA regulations require that employees of facilities where ammonia is used be trained in safe use of ammonia, and it is typically handled safely and without incident.[19] Facilities that handle over 10,000 pounds of anhydrous ammonia or more than 20,000 pounds of ammonia in an aqueous solution of 20 percent ammonia or greater must prepare a Risk Management Plan (RMP) and implement a Risk Management Program to prevent accidental releases. The RPM provides information on the hazards of the substance handled at the facility and the programs in place to prevent and respond to accidental releases. The accident prevention and emergency response requirements reflect existing safety regulations and sound industry safety codes and standards. The Chemical Emergency Preparedness and Prevention Office (CEPPO) received RMPs from 97 electric generating facilities that use ammonia to control air emissions. Facilities that have filed RMPs report storing either anhydrous ammonia or aqueous ammonia.

Industry sources were unable to provide information on ammonia related accidents as a result of SCR use and the Institute for Clean Air Companies is unaware of any releases of ammonia used for catalytic control that resulted in a workplace injury. CEPPO's RMP database, however, reports that of the 97 power plants that prepared Risk Management Plans a total of six accidental releases ammonia were reported at three facilities using ammonia for catalytic control since 1992. This is a somewhat

[18] NO_2 is also toxic if inhaled in high enough concentrations. The EPA has set a primary and secondary National Ambient Air Quality Standard (NAAQS) for NO_2 equal to an annual arithmetic average concentration not to exceed 100 ug/m3. While potential violations of the ambient standards for NO_X should be taken into consideration in any permitting decision, these levels are high enough that it is unlikely that the types of emissions being considered here will violate the NO_2 standards.

[19] *Chemical Emergency Preparadness and Prevention Advisory*, USEPA, September, 1991, (OSWER 91-008.2).

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better record than the overall accident record for all substances for facilities that submitted RMPs. There were no deaths or environmental damage reported for the ammonia related accidents but there were 12 reported injuries. All of the facilities that reported accidents were handling anhydrous ammonia. GE reports that plants "typically" transport and store ammonia in aqueous form.

As discussed earlier, the Environmental Appeals Board, in reviewing a challenge to a BACT determination requiring the use of SCR, In Re Kawaihae Cogeneration Project, 7 E.A.D. 107, 116 (EAB 1997), addressed the issue of possible catastrophic releases of ammonia. In upholding the permitting authority's decision to require SCR, the Board held that the permit applicant had failed to show that "any facility anywhere utilizing SCR technology had experienced such a catastrophic failure" nor, that there were unusual circumstances specific to the facility that would make ammonia safety concerns a compelling reason not to use SCR.

Waste Issues

The use of SCR systems results in spent catalyst waste. The amount of spent catalyst waste generated is dependent on the amount of catalyst used,[20] the life of the catalyst, and the amount of recycling of spent catalyst that occurs.

Catalysts need to be replaced when they degrade to the point that they cease to function effectively. When used with combined cycle gas turbines, it becomes necessary to replace catalyst mainly because of thermal degradation. Conservative cost estimates assume that catalyst life for these units is about 7 to 10 years. However, real experience indicates that SCR catalysts can last much longer on gas turbines.[21] In addition, coal-fired units have easily achieved catalyst lives of 7 years[22], thus a gas-fired unit should be expected to achieve a longer catalyst life.

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[20]Note that using more catalyst results in lower NO_X and ammonia slip emissions, but higher costs and more spent catalyst waste.

[21] One the first installations of SCR on an all natural gas-fired turbine occurred in 1986 is still operating without catalyst replacement. The ammonia slip was originally at 2 ppm and is now operating with a slip of 4 ppm. Telephone contact on February 15, 2000 did not wish to be identified by name or company.

[22] *Performance of Selective Catalytic Reduction on Coal-Fired Steam Generating Units*, US EPA, June 1997.

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Given low catalyst replacement rates, SCR users must dispose of spent catalyst very infrequently. Most catalyst manufacturers offer a disposal service for spent catalyst. Catalyst manufacturers can reactivate the catalyst for reuse, or recycle catalyst components for other uses or dispose the catalyst as waste.[23] Currently, no data is available on how much catalyst is recycled or reused and how much is disposed of as waste. Spent catalyst is not a listed hazardous waste and therefore (when abandoned) would only be subject to the hazardous waste regulations if it exhibits one or more of the hazardous waste characteristics (i.e., ignitability, corrosivity, reactivity, or toxicity).[24] In general, spent catalyst should not meet these hazardous waste characteristics and therefore would not be classified as a hazardous waste.

[23] *Selective Catalytic Reduction (SCR) Control of NOx Emissions*, ICAC, November 1997.

[24] Straus, M.A., Memorandum to John L. Cherill. September 4, 1986.

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