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Abstract

This paper analyzes the benefits and costs of policies to reduce nitrogen oxides (NO_X) emissions from electricity generation in the United States. Because emissions of NO_X contribute to the high concentration of atmospheric ozone in the eastern states that is associated with health hazards, the U.S. Environmental Protection Agency (EPA) has called on eastern states to formulate state implementation plans (SIPs) for reducing NO_X emissions. Our analysis considers three NO_X reduction scenarios: a summer seasonal cap in the eastern states covered by EPA's NO_X SIP Call, an annual cap in the same SIP Call region, and a national annual cap. All scenarios allow for emissions trading. Although EPA's current policy is to implement a seasonal cap in the SIP Call region, this analysis indicates that an annual cap in the SIP Call region would yield about 400 million dollars more in net benefits (benefits less costs) than would a seasonal policy, based on particulate-related health effects only. An annual cap in the SIP Call region is also the policy that is most likely to achieve benefits in excess of costs. Consideration of omissions from this accounting, including the potential benefits from reductions in ozone concentrations, strengthens the finding that an annual program offers greater net benefits than a seasonal program.

Key Words: emissions trading, electricity, particulates, nitrogen oxides, No_x, health benefits

JEL Classification Numbers: Q2, Q4

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1. Introduction

The U.S. electric power sector is facing a major and potentially costly change in regulatory limits on its emissions of nitrogen oxides (NO_X). The current policy proposal of the Environmental Protection Agency (EPA) is motivated primarily by concerns about high concentrations of harmful ground-level ozone in eastern U.S. cities, of which NO_X emissions are precursors. The policy will require electricity generators throughout the East to reduce their summertime emissions of NO_X in 2007 by 62% according to EPA estimates, and nearly 70% according to this analysis. The proposal also includes a regional NO_X emissions cap and a trading program in the eastern U.S. during the five-month “summer ozone season.” However, the proposal largely ignores the potentially substantial benefits from reductions in atmospheric concentrations of particulate matter (PM) that would accompany reductions in NO_X emissions, as well as reduced nitrogen deposition into certain ecosystems. Whereas benefits from reducing ozone occur almost exclusively in the summer, the other benefits would be realized throughout the year. When reduced particulate concentrations and other benefits of reductions in NO_X emissions are taken into account, alternative policies may emerge as more cost-effective.

This paper analyzes the benefits and costs of policies to reduce the NO_X emissions from electricity generation in the United States and seeks to identify cost-effective approaches. The investigation makes use of the Haiku electricity market model, which estimates equilibria in the electricity market, including changes in the investment and retirement of specific technologies on a regional basis. The model calculates changes in emissions, which are entered into the Tracking and Analysis Framework (TAF) to estimate changes in atmospheric concentrations of particulates and their health effects, and to value those changes in monetary terms that can be compared with the cost of pollution control. Estimates of other benefits from reduction in NO_X emissions are not modeled directly, but their relationship to particulate concentrations is discussed based on related literature.

This analysis considers three NO_X reduction scenarios that employ caps that vary by geographical and temporal coverage. All the caps are based on an average emission rate for NO_X of about 0.15 pounds per million Btu (MMBtu) of heat input at fossil fuel–fired boilers.

1. SIP Seasonal: a five-month (summer) cap on NO_X emissions in the eastern states covered by EPA's so-called NO_X SIP Call. These are the states required to submit state implementation plans, or SIPs, for reducing emissions, as discussed below.
2. SIP Annual: an annual cap on NO_X emissions in those eastern states.
3. National Annual: a nationwide annual cap on NO_X emissions.

Our results show that the SIP Annual policy offers net benefits (benefits minus costs) that exceed those from the SIP Seasonal policy, the current policy initiative of the EPA, by about 400 million dollars per year (1997 dollars). This measure includes particulate related health benefits only, but we reason confidently that the inclusion of other benefits would only strengthen this finding. The finding emerges because the particulate related health benefits of the SIP annual policy are more than double those of a SIP seasonal policy, yet costs are only slightly greater. On the basis of particulate related health benefits alone, we do not find benefits in excess of costs, though when benefits that we do not measure are included we expect the total benefits to exceed costs. Our main finding is that if a seasonal program is going to be implemented based on ozone related benefits (that we do not model) as is intended by current policy, then the additional benefits of extending the program to an annual basis far outweigh the additional costs.

However, we do not find a justification for extending the program geographically to cover the entire nation, based on particulate related health benefits and compliance costs that we measure. The SIP Annual policy offers net benefits that exceed the National Annual scenario by over 900 million dollars per year.

The effect on electricity price is politically important because of its visibility. Within the SIP Call region, the price under the SIP Annual policy is less than the price under the SIP Seasonal policy even though emission reductions are greater. At a national level the order is reversed, and electricity price is slightly greater in the SIP Annual scenario than in the SIP Seasonal scenario.

Extending the program from a seasonal to an annual basis must be accomplished without increasing summer season emissions if the ozone-related goals of the current SIP Seasonal program are not to be undermined. All of the scenarios we discuss achieve the summer season NOx emission targets of the SIP Seasonal program.

Considered independently, the particulate-related health benefits that are achieved by a reduction in NO_X emissions are less than the costs of compliance in the scenarios. However, the estimates of benefits from particulate reductions are not a full accounting of benefits. When the benefits that are not modeled are taken into account in our literature review in Section 6 - including benefits of ozone reduction and non-health benefits of particulate reduction - each of the three scenarios appears likely to have benefits roughly equal to or in excess of compliance costs.

Further, the inclusion of benefits that are omitted from our analysis would strengthen our main finding that a SIP Annual program is the most cost-effective of the scenarios we examine. Under an annual program, some additional benefits in the non-summer months would be realized in the benefit areas that we do not model. Hence, consideration of the omitted benefits would further increase the estimate of total benefits that result from extending the program to an annual basis, while all of the costs have already been considered.

The conclusion of this analysis is unusually clear for policy analysis. We suggest that the EPA and the affected states should consider replacing or supplementing the current initiative for the eastern United States—a seasonal program to reduce NO_X emissions—with a new initiative aimed at annual reductions.

The paper is organized as follows. In Section 2 we elaborate the motivation for and objectives of the research. In Section 3 we describe the scenarios modeled in this study and the underlying assumptions. In Section 4 we describe the Haiku and TAF models. In the Section 5 we discuss the results, and in Section 6 we summarize and compare our findings with the previous literature. Section 7 provides our conclusion.

2. Motivation

The design of a program to reduce NO_X emissions will have an effect on the choice of technologies for reducing emissions and therefore on the cost and cost-effectiveness of the reductions. The design of the program will also affect the nature and magnitude of the benefits. NO_X is a precursor to secondary pollutants, including ozone and particulate matter. Ozone has a widely recognized effect on human morbidity and potentially on mortality, although the latter effect is not firmly established. The creation of ozone is largely seasonal, and EPA has designed its program to address this seasonality. However, NO_X emissions throughout the year contribute to particulate matter concentrations. Particulate matter has been firmly associated with both morbidity and mortality, and many health scientists consider particulate matter concentrations to be a bigger threat to human health than ozone concentrations, and health economists find that it imposes substantially greater costs on society. In addition, NO_X emissions contribute to the ultimate deposition of nitrates and thus to environmental problems, including acidification of ecosystems.

Both ozone and particulate matter pollution are widespread problems in the United States, and many metropolitan areas have not achieved compliance with National Ambient Air Quality Standards (NAAQS). The electricity sector is an important focus for two reasons. First, it contributes about 25% of NO_X emissions in the United States. Second, these emissions are often emitted through tall stacks at high velocity, causing wide dispersion and contributing to regional pollution problems.

Emissions of NO_X from electricity generation had been loosely regulated until the last decade. The 1977 amendments to the Clean Air Act implemented performance standards for new sources that varied by fuel type and were not constraining for most projects. In 1998 EPA revised the standards to be output based and fuel neutral, and expressed them in units of pollution per megawatt-hour (MWh) of generation. New sources built in areas that have attained the ambient ozone standard set by EPA have to prevent significant deterioration of air quality, and install the Best Available Control Technology (BACT), which translates into an emission rate standard of 0.15 pounds of NO_X emissions per MMBtu of energy input. New sources in nonattainment areas have to install the more stringent Lowest Achievable Emissions Reduction (LAER) technology. Furthermore, in nonattainment areas, new sources must obtain offsets for their pollution through reducing pollution at existing sources. Existing sources were virtually exempt from NO_X regulations until the 1990 amendments to the Clean Air Act mandated a significant reduction in NO_X emissions at existing electricity-generating facilities through technology performance standards that created different emission rate standards for each coal-fired boiler technology across the industry.

Increasing attention has focused on the tendency of NO_X to travel long distances and its contribution to regional pollution problems, especially nonattainment of the NAAQS for ozone. Because pollution drifts from other areas, many jurisdictions found that they would not be in compliance with the ozone NAAQS even if their own emissions were reduced to zero. The regional and transboundary nature of NO_X-related pollution motivated the Ozone Transport Region (OTR), that comprises of eleven northeastern and mid-Atlantic states, to initiate a three-phase reduction program. The first phase applied “reasonable abatement control technology” in 1995 for year-round compliance, essentially requiring low-NO_X boilers. The second and third phases established NO_X emission “budgets” for each state for the five-month summer season (i.e., from May through September), when ozone is commonly a problem. Phase II enabled emissions trading among sources and states, beginning in summer 1999. The total NO_X budget for the region is 219,000 tons per summer (U.S. EPA 1997), a substantial reduction from the 490,000 tons of emissions in the region in the baseline year, 1990. In Phase III, which is expected to begin in May 2003, the summer allocation will be reduced further to 143,000 tons and trading will still be allowed.

The OTR in the Northeast is a subset of the larger eastern U.S. region that is subject to substantial transboundary drift of NO_X. Because the states were concerned that they could not achieve the one-hour ozone NAAQS by the November 1994 deadline, as mandated by the 1990 amendments to the Clean Air Act, an Ozone Transport Assessment Group (OTAG) was formed to study the issue and develop a plan. Its goal was to develop consensus among the states for a coordinated effort to reduce ground-level ozone in the eastern United States. After OTAG, working with EPA, released its final report in June 1997, eight northeastern states (joined by three other states in 1999) filed petitions under section 126 of the Clean Air Act requesting that EPA address emissions of NO_X from sources in upwind states that were contributing to their own nonattainment of the ozone NAAQS.

In response, the EPA proposed a model regional cap-and-trade program for NO_X emissions that addresses the transport of ground-level ozone. On September 24, 1998, the EPA formalized this proposal in a rule widely referred to as the NO_X SIP Call, which required 22 states and the District of Columbia to submit by September 1999 revisions to their SIPs outlining their strategies for achieving NO_X emissions reductions effective May 1, 2003. After various court proceedings, the date for submitting revised SIPs was delayed until October 2000, and the date for achieving the reductions was postponed until May 1, 2004. The courts also modified the SIP Call region so that, in the end, it will probably encompass 19 states and the District of Columbia. At the national level, EPA expects the program to lead to reductions of 22% from an annual baseline level of 5.4 million tons in 2007 to a new annual level of 4.25 million tons, according to EPA estimates. Summer-season emissions in 2007 would fall by 40% from 2.4 million tons to 1.45 million tons (U.S. EPA, 1998a, and 1998b). In the SIP Call region, the program would lead to annual reductions of 34%, from projected baseline levels of 3.51 million tons to 2.33 million tons in 2007. In the five month summer season, the EPA expects the program to reduce emissions by 62%, from 1.5 million tons to 0.56 million tons.

The regional NO_X program comes at a time when calls for more drastic reductions of several pollutants are taking shape as part of a possible reauthorization of the Clean Air Act. Legislation proposed in the last congress would seek reductions in emissions of sulfur dioxide

(SO_2), carbon dioxide (CO_2), and mercury as well as NO_X from the electricity sector. These bills would apply a variety of approaches, ranging from uniform technology standards to emissions trading. For example, one proposal (S.1949) would require NO_X reductions greater than 90% of uncontrolled levels at each plant. Three other bills (S. 1369, H.R. 2645, and H.R. 2980) set specific national caps of 1.66 million to 1.83 million tons per year and would allow trading while two bills (S. 172 and H.R. 25) would set a national cap of about 3 million tons per year and would allow trading. Yet another bill (H.R. 2900) would set a national cap of 1.55 million tons per year and also require existing plants to meet new source performance standards at age 30.

The electricity industry is already switching from coal or oil to natural gas as the preferred fuel for new generation facilities, and the proposals have implications for the rate at which that transition will continue. Emissions of all the mentioned pollutants are much greater from coal or oil than from gas; emissions of SO_2 and mercury are virtually zero for gas. Taken in isolation or as part of a moderate multiple pollutant package, the proposed NO_X emission reductions under the SIP Call are expected to prompt the installation of post-combustion controls at coal-fired plants and many gas-fired facilities as the primary means of compliance. However, they are not expected to accelerate significantly the transition to natural gas.

The ever-changing nature of environmental regulation of the electricity sector raises questions about the design of a program to reduce NO_X emissions, and its cost and environmental consequences. The objective for this research is to investigate the costs and benefits of alternative designs and to identify the most cost-effective option among those being discussed for implementation in the near term. To address this objective, we use the Haiku model to solve three scenarios for NO_X reductions, and we link the results with the TAF integrated assessment model.

3. Scenarios

The calculation of NO_X reductions relies on a definition of a baseline scenario with which other scenarios can be compared. Our baseline includes the NO_X trading program in the northeastern Ozone Transport Region (Phase II) but excludes new policies to reduce NO_X in the multi-state SIP Call region. We assume that there are no policies implemented to reduce CO_2 emissions, and there are no changes in the regulation of SO_2 emissions beyond those established under the 1990 Clean Air Act amendments. We assume no change in economic regulatory policy toward the electricity industry beyond that adopted by states in each of the North American Electric Reliability Council (NERC) subregions as of 2000. The schedule for transition from cost-of-service to marginal cost or market-based pricing by region is reported in Table 1, along with an indication of which states are covered by which regions.

With the baseline scenario as a backdrop, we consider three policy scenarios for NO_X reductions. No other assumptions in these scenarios differ from the baseline. All three scenarios include the flexibility to trade NO_X emissions allowances among all NO_X-emitting electricity generators within the regulated region.

The first scenario is labeled *SIP Seasonal,* and it corresponds to EPA's proposed program. This scenario includes a five-month summer ozone program implemented in the eastern states represented by six NERC subregions, namely NY, NE, MAAC, MAIN, ECAR, and STV, in the Haiku model that are roughly equal to the SIP region. The emissions cap under this policy is 444,300 tons per summer season within the SIP region, compared with an emissions level of 1.445 million tons in the baseline. This emission cap was determined by applying the emission rate of 0.15 lb per MMBtu to fossil-fired generation in the baseline for 1997 in the Haiku model, which is similar to the methodology applied by EPA. Forecast electricity generation varies slightly in our model, and the geographic coverage varies slightly, from the EPA model (U.S. EPA 1998a, 1998b, 1999).

The second scenario is *SIP Annual.* Here, the average emission rate achieved during the five-month summer season for the SIP region is extended to an annual basis. The annual emissions cap under this policy is 1.06 million tons per year within the SIP region, compared with an emissions level of 3.45 million tons in the baseline.

The third scenario is *National Annual.* The SIP Call emission rates are used to calculate an annual emissions cap for the nation. The emissions cap under this policy is 1.66 million tons per year for the nation, which is derived by multiplying national fossil-fired electricity generation in the baseline by an emission rate of 0.15 lb/MMBtu of heat input.

4. The Models

The Haiku electricity market model was developed to contribute to integrated assessment with support from EPA, U.S. DOE, and RFF. The model calculates equilibria in regional electricity markets with interregional electricity trade and includes fully integrated algorithms for investment and retirement of generation capacity, selection of NO_X emissions control technology, and SO_2 compliance. The model simulates electricity demand, electricity prices, the composition of electricity supply, and emissions of major pollutants, including NO_X, SO_2, mercury, and CO_2. Generator dispatch in the model is based on minimization of short-run variable costs of generation. Technical parameters in the model are set to reflect midpoint assumptions by EIA and other organizations regarding technological change, growth in transmission capacity, and a number of other factors.

Two important components of the Haiku model are the Intraregional Electricity Market Component and the Interregional Power Trading Component. The Intraregional Electricity Market Component solves for a market equilibrium identified by the intersection of electricity demand for three customer classes (residential, industrial, and commercial) and supply curves for four time periods (peak, shoulder, middle, and baseload hours) in three seasons (summer, winter, and spring-fall) within the 13 NERC subregions. Each regional supply curve is parameterized using cost estimates and capacity information for up to 45 aggregate “model plants” defined by technology, fuel, and vintage. The Interregional Power Trading Component solves for the level of interregional power trading necessary to achieve equilibrium in regional electricity prices (gross of transmission costs and power losses). These interregional transactions are constrained by the assumed level of available interregional transmission capability as reported by NERC.

The model can be used to simulate changes in electricity markets stemming from public policy associated with increased competition or environmental regulation. In this analysis we adopt a conservative assumption by assuming that regions that have not committed themselves to a schedule of transition to market-based prices continue with cost of service pricing indefinitely over the study period.

Changes in emissions of relevant pollutants are fed into the Tracking and Analysis Framework (TAF). TAF is a nonproprietary and peer-reviewed model constructed with the *Analytica* modeling software (Bloyd et al. 1996; ORNL 1995). TAF integrates pollutant transport and deposition (including formation of secondary particulates but excluding ozone), visibility effects, effects on recreational lake fishing through changes in soil and aquatic chemistry, human health effects, and valuation of benefits.

In this exercise, only changes in health status are evaluated. The population considered is the population of the contiguous 48 states. These values are calculated at the state level and aggregated to the NERC subregion level; changes outside the United States are not evaluated. Health effects are characterized as changes in health status predicted to result from changes in air pollution concentrations. Impacts are expressed as the number of days of acute morbidity effects of various types, the number of chronic disease cases, and the number of statistical lives lost to premature death. The health module is based on concentration-response (C-R) functions found in the peer-reviewed literature. The C-R functions are taken, for the most part, from articles reviewed in EPA's Criteria Documents (for example, EPA Section 812 prospective and retrospective studies). The health effects module contains C-R functions for particulate matter smaller than ten microns in diameter (PM_{10}), total suspended particulates (TSP), sulfur dioxide (SO_2), sulfates (SO_4), nitrogen dioxide (NO_2), and nitrates (NO_3). In this exercise, the potency of nitrates for mortality effects is treated as distinct from the potency of sulfates. Sulfates are considered relatively more potent than other constituents of PM_{10}; and nitrates are treated as comparable to other components of PM_{10}. The specific PM_{10} mortality C-R function used in this analysis is drawn from Schwartz and Dockery (1992). For morbidity PM_{10} is modeled according to a scheme designed to avoid double counting, such as symptom days and restricted activity days, using a variety of studies from the literature. NO_X is included for respiratory symptom days, eye irritation days, and phlegm days.

Inputs to the health effects module consist of changes in ambient concentrations of SO_2 and NO_X, demographic information on the population of interest, and miscellaneous additional information, such as background PM_{10} levels for analysis of thresholds, though no thresholds are presumed to exist in this exercise. The change in the annual number of impacts of each health endpoint is the output that is valued. The health valuation submodule of TAF assigns monetary values taken from the environmental economics literature to the health effects estimates produced by the health effects module. The benefits are totaled to obtain annual health benefits for each year modeled. The numbers used to value these effects are similar to those used in recent regulatory impact analysis by EPA. However, the value of a statistical life (VSL), $3.815 million (1997) dollars, is adjusted somewhat downward, compared with EPA numbers, because the value used by EPA is drawn primarily from studies of prime-age working males facing small risks of workplace mortality. In contrast, particulate pollution primarily affects seniors and people with impaired health status, and it is also thought to have more effect on young children than on the general population. Various authors have suggested that the value of health effects should be responsive to the nature of the injury and issues like age and health status; this controversy is discussed in EPA's recent studies. (Krupnick, Alberini et al., 2000)

5. Results

This section presents the results obtained in Haiku and TAF, beginning with a discussion of the findings on emissions reductions and health benefits. This discussion is followed by a description of compliance strategies and the effect on electricity consumption and price. Subsequently, we discuss economic costs in comparison to benefits, and evaluate our findings in the context of previous research.

The NO_X caps that we examine are implemented by the year 2004. We analyze results for the year 2008 in comparing our three policy scenarios with the business-as-usual baseline. We choose 2008 for analysis because it is sufficiently in the future that full implementation of these policies and adjustments in electricity generation capacity could be achieved.

5.1 Changes in Emissions and Health Benefits

For each policy scenario the total NO_X emissions within a regulated region and time period are given as an input to the model. The SIP Seasonal scenario limits NO_X emissions during the five-month summer ozone season to 444,300 tons in the SIP Call region. In other seasons the NO_X controls are not required to operate, which provides a financial savings by reducing variable costs of generation at these facilities. We find the annual NO_X emissions in the SIP region in the SIP Seasonal scenario, reported in Table 2, fall by more than 1 million tons from the baseline, with nearly all the reductions occurring within the summer season. This estimate of the emission reduction of just over 70% in the summertime months is slightly greater than the EPA estimate of 62% (U.S. EPA, 1998b) due to differences in the models and to different estimates of emissions in the baseline. The reductions in NO_X emissions in the SIP Call region are almost identical to those achieved nationally. The shaded cells in Table 2 indicate the regional and temporal target of each policy.

Extending the NO_X program to the entire year in the SIP Call region under the SIP Annual scenario leads to annual reductions in NO_X emissions of almost 70% from the baseline in the SIP Call region. At the national level, NO_X emissions fall by almost the same amount in absolute terms as within the region. In both the SIP Seasonal and SIP Annual scenarios, the reductions at the national level are slightly less than within the region, suggesting a slight leakage of emissions and generation to outside the region affected by the emission cap.

The National Annual scenario yields slightly lower emissions of NO_X within the SIP Call region than does the SIP Annual scenario because the marginal costs of emission reductions within the SIP region are lower than for the rest of the nation. (Compare the SIP Annual and National Annual marginal costs in Table 9 as discussed in Section 6.) Nonetheless, there are significant additional reductions outside the region. Total emissions nationwide fall by more than 70% from the baseline.

The SIP Annual and National Annual scenarios allow trading between summer and other seasons. However, Table 2 reports that summer emissions differ only slightly among the scenarios. The summer emission cap of 444,300 tons of NO_X emissions that is calculated by applying the regulatory emission rate to generation in the baseline is satisfied in all cases. The difference from the cap is partly attributable to the stopping rule for the iterative process in the model as calculations converge toward the solution. The SIP Annual scenario comes closest to achieving the cap exactly. Summer emissions in the SIP Seasonal scenario are 20,000 tons less; and, summer emissions in the SIP region under the National Annual scenario fall by another 26,000 tons. Furthermore, the summer cap that applies under Phase 3 of the OTR, affecting a subset of northeastern states, is always satisfied. Under the National Annual scenario, emissions in the northeastern states are 58,000 tons below the OTR Phase 3 cap.

The nationwide annual emission results for NO_X are entered into the TAF model to estimate changes in pollutant concentrations as a consequence of atmospheric transport and, in turn, changes in health status. Table 3 reports the monetized values of these health impacts. Typically, the reductions in premature mortality are estimated to be about three and one half times those from changes in morbidity. Emissions changes from electricity generation from the SIP Seasonal policy are expected to yield total particulate-related health benefits of $749 million for the nation over the course of an entire year. The SIP Annual policy yields benefits of almost $1.8 billion. The National Annual policy yields benefits of about $2.56 billion.

The benefit estimates assume that NO_X emissions from other sectors of the economy are not affected by the new NO_X policies imposed on the electricity sector. To the extent that a NO_X policy raises the price of electricity, it could cause some substitution of other fuels, such as natural gas or fuel oil. The amount of additional NO_X emissions created by such a shift depends on the change in the price of electricity, the cross price elasticities of demand for other fuels, and the NO_X emission rates. Shifting from electricity to natural gas will create smaller NO_X emissions "leakage" from the electricity sector and into another sector than shifting from electricity to fuel oil. Our models are unable to estimate the potential size of these shifts. However, the relatively small effect of the policies on the price of electricity suggests that such intersectoral emissions leakages are likely to be very small.

5.2 Changes in Technology, Consumption, and Price

To comply with the cap, emissions can be reduced in three ways. One is the installation of post-combustion controls. We model two types of post-combustion controls: selective catalytic reduction (SCR) and selective noncatalytic reduction (SNCR). A distinguishing feature of these technologies is that SCR is likely to have greater capital costs, somewhat lower variable costs and somewhat higher NO_X removal efficiency than SNCR. Hence, the decision about which type of post-combustion control to install would be influenced by the expected utilization of a facility. Other things equal, a baseload electric generating unit that is utilized many hours of the year would be relatively more likely to install SCR, and a unit that is utilized fewer hours of the year would be relatively more likely to install SNCR (Napolitano, 1999). The post-combustion controls that are installed are reported in Table 4. This table includes only retrofit controls; it does not include controls installed to comply with new source performance standards. In our model results, all of the installed retrofit controls are at coal-fired power plants. Table 5 reports the annual variable cost, which includes the variable and fixed portions of operation and maintenance (O&M) of NO_X control and the annual capital expense for each type of control. The total annual expense is the sum of annual variable and annual capital costs for SCR and SNCR combined. In the SIP Seasonal scenario, the additional total annual costs beyond those incurred in the baseline total almost $2.15 billion. Reductions at facilities that install post-combustion controls account for virtually all of the emission reductions that are achieved in the SIP Seasonal scenario, while emission reductions due to fuel switching or reduction in output are very small.

A second way to reduce emissions is a reduction in output in response to an increase in price. In the baseline in the SIP Call region, electricity price is $64.4 per MWh ($0.0644 per KWh) in 2008. Baseline generation is 2.139 billion MWh. Table 6 reports that under the SIP Seasonal policy, the price within the region would increase by $0.7 per MWh, or 1%. Generation in the region would fall by 20 million MWh (just over 0.5%). At the national level, as reported in Table 7, the price of electricity falls from the baseline to the SIP Seasonal policy by $0.3 per MWh, or 0.5%, and generation is virtually unchanged.

The third way that emissions are reduced is input substitution, which includes switching from coal to gas generation and to some degree switching among coal units with different emission rates. In the SIP region we see a reduction in the use of coal and, to a smaller degree, increase in the use of gas. At the national level, the reduction in coal generation within the SIP region is partially offset by an increase in coal-fired generation outside the region, as well as an increase in gas-fired generation nationally.

The SIP Seasonal policy leads to a small change in generation capacity at the national level. Table 8 indicates that there is a small decline in nationwide coal-fired capacity, commensurate with the small decline in coal-fired generation. There is an increase of almost 3.7% in gas-fired capacity. Wind capacity declines because of the increase in relatively efficient new gas-fired capacity, which has lower variable costs than existing technologies.

The extension of the policy from a five-month summer season to year-round in the SIP Annual scenario would have a small effect on the price of electricity. Within the SIP region, electricity prices would rise by only $0.5 per MWh, or in fact a drop of $0.2 per MWh from the price that would accompany the SIP Seasonal policy. The price decrease is counter-intuitive even though compliance costs would total $2.73 billion, or nearly 20% more than in the SIP Seasonal scenario. At the national level, electricity prices are forecast to increase when moving from the SIP Seasonal to SIP Annual policy.

It may be a surprise that expanded environmental policy may not necessarily lead to an increase in electricity prices. From the data one can see that expanded environmental policy will not necessarily lead to an increase in electricity prices. It is instructive to examine how extending a regional NO_X policy from a seasonal to an annual basis could have a negligible or possibly negative effect on electricity prices. One reason is that the emission allowance price is dramatically less under an annual policy because the cost of NO_X control including capital cost can be divided over a greater quantity of emission reductions to achieve a lower cost per ton reduced. The cost per ton reduced at the margin is determining allowance price, which directly enters the calculation of the variable cost of electricity generation.

The second reason that the effect on price may be negligible has to do with changes in generation capacity, and with how the cost of capacity is reflected in electricity price. Slightly more than half the generation in the SIP Call region is in areas characterized by average cost pricing in the baseline, under which capital and variable costs are annualized and spread over total sales to calculate the price of electricity. In these areas, introducing a new environmental policy that increases the costs of electricity supply leads directly to an increase in the electricity price.

The other part of generation in the SIP Call region is in the marginal cost areas where the electricity price is determined by the variable cost of the marginal generator plus the capacity cost of the marginal reserve unit. Policies that change the relative costs of facilities affect which facility is at the margin and thereby they affect prices, the revenues earned by each facility, and thereby the policies affect capacity investment and retirement. In these areas, introducing a new environmental policy that increases the costs of electricity supply may lead to an increase or a decrease in the electricity price.

Figure 1 illustrates a case in which the extension from the SIP Seasonal to SIP Annual policy reduces the electricity price. The figure depicts the determination of marginal generation cost in a baseload time block, which includes 70% of the hours in the season, in the summer season in 2008 in New England (NE), a marginal cost region. The solid upward-sloping line is the schedule of variable generation costs in the SIP Seasonal scenario, and the dashed upward-sloping line is the schedule in the SIP Annual scenario. The variable cost of a representative unscrubbed coal plant using a particular type of coal is represented by the point indicated on each supply curve.

The latter half of the curve for the SIP Annual scenario lies generally below and to the right of the curve for the SIP Seasonal scenario. The shift downward reflects the fact that the variable generation cost associated with the annual pollution program is less because the cost of a permit is less under the annual program. The cost of the permit (equivalent to the marginal cost of abatement) falls from $3,401 per ton in 2008 in the SIP Seasonal scenario to $1,985 in the SIP Annual scenario. The small vertical difference between the points representing the unscrubbed coal plant results because of the small reduction in variable cost for that plant. However, one can observe other parallel portions of the two curves that indicate a greater effect for some plants.

The shift of the marginal cost curve to the right in the SIP Annual scenario, indicated, for example, by the shift in the point representing the unscrubbed coal plant, results from a change in the variable cost ordering among plants and a change in capacity. The unscrubbed coal plant indicated by the points has been pushed back in the variable cost ordering for electricity generation. The shift is due to the addition of new combined-cycle capacity, which has lower variable costs and appears earlier in the variable cost ordering for electricity generation. The vertical lines in Figure 1 represent the generation of electricity during the time block. Generation increases as marginal generation cost falls in moving from the SIP Seasonal to the SIP Annual scenario. When taking into account the effect in all time blocks, the net effect on electricity price is less than would be anticipated if all costs were passed through to ratepayers, as occurs in average cost regions.

In the third scenario, the National Annual policy, the amount of capacity with post-combustion control increases by nearly 60% beyond the policies aimed at the SIP region only. The vast majority of these controls are SCR. The total annual cost in 2008 for post-combustion controls is $4.43 billion, more than double the expense of controls under the SIP Seasonal policy and 63% greater than the cost of the SIP Annual policy.

The National Annual policy would increase the price by $0.2 per MWh over the SIP Seasonal policy in the SIP Call region and increase the price over the baseline by $0.3 per MWh at the national level. At the national level total generation decreases from the baseline and SIP Seasonal scenarios by about 2%. Furthermore, the National Annual policy would decrease generation from both coal (by 12 million MWh) and gas (by 47 million MWh), compared with the baseline.

We report one sensitivity analysis of special interest. A possible evolution for policy regarding NO_X emissions could be the extension of a SIP Seasonal scenario to a SIP Annual scenario at a later point in time. Some observers have expressed concern that the commitment to a seasonal program could lead to investment in compliance strategies that would be rendered inefficient if the program were eventually replaced by an annual program. To investigate the cost of a sequence of policy decisions we constructed a “SIP Sequence” scenario. The analysis combines a SIP Seasonal policy effective in 2004 with a surprise announcement in 2005 of a SIP Annual program that takes effect in 2008.

Instead of the compliance cost increasing under the SIP Sequence scenario as compared with the SIP Annual policy, we find that the compliance cost decreases. This counter-intuitive result is explained by an increase in imports to the SIP region under the SIP Sequence scenario. The annualized expenditure on post-combustion control in 2008 under the SIP Sequence policy is $282 million (13%) more than under the SIP Seasonal policy, but it is $300 million (11%) less than under the SIP Annual policy. Electricity price in the SIP region in the SIP Sequence scenario increases by about $1.3 per MWh, or nearly two and a half times that of the increase when the SIP Annual policy is implemented directly. At the national level, electricity price under the SIP Sequence policy increases from the Baseline, though it decreases under the SIP Annual policy. The marginal cost per ton abated by post-combustion control is about $1,244 (37%) less than in the SIP Annual scenario. The average cost per ton is about $1,021 (10%) lower than in the SIP Annual scenario.

Instead of installing additional combustion controls in the SIP region to attain the more stringent annual emissions cap in the SIP Sequence scenario, the SIP region increases imports of electricity from outside the region. Under the SIP Sequence scenario, the increase in generation outside the SIP region leads to an increase of 69 thousand tons in NO_X emissions from the rest of the nation, more than twice the increase of 30 thousand tons in the SIP Annual scenario.

In sum, the indirect path to annual NO_X controls in the SIP region that is represented by the SIP Sequence policy leads to an increase in electricity imports to the region, a small increase in emissions outside the region, and an increase in electricity price. From an efficiency perspective, the most important cost would result from the four year delay in realizing the economic benefits of annual NO_X reductions that total roughly $1 billion dollars per year in the

SIP region (the difference in health benefits between the SIP Seasonal and the SIP Annual scenarios).

5.3 Cost Effectiveness of the Policies

Table 9 reports the benefits and costs of emission reduction achieved from a nationwide and annual perspective for each policy. The first column repeats for convenience from Table 3 the particulate related health benefits that are achieved, and the second column repeats from Table 5 the cost of post-combustion controls.

A main result of this analysis is displayed in the third column of Table 9, which reports the value of net benefits (benefits minus costs). The values in this column are less than zero for all policies, suggesting that particulate related health benefits are not sufficient by themselves to justify the costs of the program, but they offset the costs importantly. The main result is that the net benefits are greatest under the SIP Annual policy, making it the most cost effective policy option. The net benefits of the SIP Annual policy are about $400 million per year greater than under the SIP Seasonal policy.

Table 9 reports “partial” net benefits because only the benefits of particulate reductions are considered and other benefits of NO_X reductions are omitted. In the next section, we argue that the inclusion of additional benefits would strengthen the relative cost effectiveness of the SIP Annual policy compared to the SIP Seasonal policy. In addition, only compliance costs of post-combustion controls are accounted for and other aspects of social cost are not included. A more complete measure of economic cost would account for changes in utilization of facilities and associated changes in fuel expenditures, as well as changes in investments in generation capacity. Corresponding to that would be a measure of how the change in electricity consumption affects consumer welfare. To measure these offsetting effects on producers and consumers requires a welfare analysis that captures changes in producer and consumer surplus in the electricity market (Palmer, et al. 2001). Even more comprehensive would be a measure that accounts for interactions among all sectors of the economy and accounted for pre-existing policies including taxes. A recent and growing literature has shown that these interactions may have a substantial effect on the general measure of costs (Goulder et al.,1999), and they may have an effect on the measure of benefits (Williams, 2000). In this study we report only the most common measures of costs and benefits, and in the next section we compare these estimates with those obtained in previous studies.

6. Comparison with Previous Studies

To compare our analysis with previous studies raises a potential point of confusion in the differing quantity of tons of NO_X reduced in each study. We therefore characterize benefits and costs per ton of NO_X emissions reduced on a nationwide annual basis for all policies. The right-hand side columns of Table 9 express particulate related health benefits and compliance costs per ton of emission reductions achieved nationwide and annually in 2008. The average benefit estimate accounts for emission changes outside the SIP region, a consideration that is missing in most of the previous studies. The data indicates that the economic value of emission reductions are greatest inside the SIP region, which is due to the higher concentration of population compared to the rest of the nation, as well as to atmospheric chemistry and meteorology. The particulate related health benefits from mortality and morbidity improvements average to $755 per ton in the SIP Seasonal scenario, $747 per ton in the SIP Annual scenario and $647 per ton in the National Annual scenario.

Average cost is calculated as the cost of post-combustion control divided by the emission reductions achieved on a national and annual basis. In the SIP Seasonal case we find average costs of $2,163 per ton. The average cost in the SIP Annual case falls to $1,147 per ton, and $1,119 per ton in the National Annual scenario.

The final column reports marginal cost, which is equivalent to the predicted price for an emission allowance. In the baseline, a marginal cost of $1,356 per ton is reported, which is the marginal cost of reductions in the northeastern OTR states. In the SIP Seasonal scenario the marginal cost is $3,401 per ton. In the SIP Annual scenario, the marginal cost falls to $1,985 and in the National Annual scenario the marginal costs is $3,884.

For convenience the estimates of average benefits and costs per ton appear in Table 10 for comparison with other studies. Burtraw et al. (1998) examine the reductions in NO_X and SO_2 emissions resulting from the 1990 amendments to the Clear Air Act using the TAF model for atmospheric transport and health effects, and using similar assumptions for the benefit calculations, but using a different model of costs and emissions for electricity generation. They find median benefits due to reduction in premature mortality stemming from reduction in nitrate concentrations to be $570 per ton of reduction in NO_X emissions. The median benefits stemming from reduction in morbidity are $169 per ton of reduction in NO_X emissions. The sum of effects is $739 per ton, accruing from reductions around the nation.

Banzhaf et al. (1996) report on two studies of externalities from power plants in Wisconsin and Minnesota, but they look only at benefits within parts of those states and exclude benefits from long-range transport. They find benefits from mortality and morbidity improvements stemming from reductions in nitrates ranging from about $35 per ton of NO_X reductions for a plant in a rural setting, to $366 for a plant in an urban setting. These numbers would be greater for a larger region or a more densely populated area. They also calculate potential damages for ozone and attribute all the damage to NO_X as a precursor to ozone. They find ozone damages range from $29 (with an uncertainty range including zero) for a plant in a rural setting, to $358 for a plant in an urban setting.

The estimates in Banzhaf et al. include both agricultural effects and human health effects. They find potential health benefits from emissions reductions of NO_X and SO_2 account for 56% to 80% of all damages. Agricultural effects are second, with damages of 15% to 25% of all damages. Materials and visibility effects are third, accounting for about 11% of all damages. The attribution of damages to category depends on the location of the plant. In a broad survey of three comprehensive studies done in the United States and Europe that examined externalities from electricity generation, Krupnick and Burtraw (1996) find that 82% to 93% of all quantifiable damages stem from the air-health environmental pathway when ozone effects are taken into account. The major component of quantifiable damage is attributable to the change in particulate concentrations. Together, these studies justify a focus on particulate-related benefits as a bellwether of the cost-effectiveness of a reduction program.

Rowe et al. (1996) report on a series of case studies using a model specialized to locations in New York State. They find that benefits per ton of reduction in NO_X emissions tend to range from about $1,071 per ton for a natural gas combined-cycle plant to $1,140 per ton for a pulverized coal steam plant in areas away from major population centers. The estimates vary with type of technology because Rowe et al. account for variation in stack height and velocity in modeling atmospheric transport of emissions. The estimates combine the effects of NO_X in secondary ozone formation and secondary particulate formation.

Krupnick, McConnell et al. (2000) examine the costs and benefits of NO_X emissions reductions in a trading program in the summer ozone season. Their model is aimed at NO_X emissions reductions in 12 states and the District of Columbia, which represent the major sources of emissions in the eastern United States. Emissions reductions are achieved over 12 months. Their model also differs from ours in not allowing for changes in utilization of facilities as a way to meet emissions goals. They find that the cost per ton of NO_X reductions in a broad trading program across much of the SIP Call region is $1,032 per ton reduced. Their estimated marginal cost is $4,646. This study also calculates the expected benefits of ozone reductions. In the middle case, benefits from ozone reductions average $167 per ton reduced. However, the benefits are an order of magnitude higher under alternative assumptions about the potency of ozone on human health.

The document that serves as the primary analysis of the expected cost of NO_X reductions associated with EPA's proposed trading program is U.S. EPA (1998b). This study models a scenario similar to the one we model for the SIP Seasonal case. Consequently, we spend some time comparing this study with our own.

In the EPA study (1998b), the average cost per ton of NO_X emissions reduction achieved in the summer ozone season was $1,807. Our estimate was $2,019 per ton. Differences in the characterization of the baseline explain much of this small difference. The EPA baseline includes only Phase I controls in the OTC that mandate reasonable available control technology, but our baseline includes Phase II (trading) with lower average emission rates. Hence, there exist relatively low-cost options in the EPA model that we have already been included in our baseline. Also, our baseline assumes 8.7% greater generation in 2008 than does the EPA baseline (for 2007), resulting from our estimate of greater growth in electricity consumption. Our assumption appears closer to recent updates to the Annual Energy Outlook (U.S. EIA 1999). In addition, the emissions cap is 544,000 tons in the EPA study but the cap is 444,300 in our study; which also contributes to our higher cost estimate. Total reductions are 958,000 tons in the EPA study and 1,090,000 in our study. The EPA study includes the original 22 eastern states plus the District of Columbia; our SIP region varies slightly.

The change in prices in the EPA study (1998b) is about 1.6% assuming marginal cost pricing throughout the electricity sector, and about 1.2% assuming average cost pricing. The EPA study does not clarify whether this applies to the SIP region or the nation. Our rise in prices in the SIP region, which combines average and marginal cost pricing, is about 1.1% in the SIP Seasonal scenario.

The document that serves as the primary analysis of the expected benefits of NO_X reductions associated with EPA's proposed trading program for is U.S. EPA (1998d). This study models the benefits of the scenario described in U.S. EPA (1998b). Alternative low and high assumptions provide a large range of possible benefits. In the low case, ozone health benefits total $34 per ton of NO_X reduced. Particulate-related benefits total $714 per ton, similar to the numbers in our SIP Seasonal scenario. These are almost all health related, with a small fraction stemming from household soiling and visibility effects. In addition, the EPA study finds ozone-related benefits in commercial agriculture and forestry of $325 per ton, and benefits from reduced nitrogen deposition of $297 per ton.

Using the high set of assumptions, the EPA study finds ozone health benefits of $1,689 per ton of NO_X reduction. This large increase is entirely attributable to the assumption of a link between ozone and premature mortality. Particulate-related benefits rise to $2,504. This is also almost entirely attributable to the assumption of a link between nitrates and premature mortality. The estimates for the effects of ozone on agriculture and forestry increase to $717 per ton, and the estimates for nitrogen deposition remain at $297 per ton.

The assumptions we employ in our scenarios conform well to the low case in the EPA study and to others found in the literature. The major source of expected benefits from NO_X reductions is expected to be reduced concentrations of nitrates. These benefits are not seasonally dependent if NO_X emission reductions are achieved year-round. In addition, the nitrogen deposition benefits in the EPA model could accrue year-round with reductions in NO_X emissions. A smaller portion of potential benefits is associated with reductions in ozone concentrations, which are limited to the five-month summer ozone season. Hence, the modeling of particulates as a proxy for the benefits of NO_X reductions provides a useful measure of the benefits that could be anticipated in a seasonal or annual program.

Implementing a regional or national NO_X reduction policy may prove difficult. All three scenarios we examine assume that the prescribed NO_X emissions cap takes effect in 2004. To meet this deadline, a number of electricity generators may need to extend their regular scheduled maintenance outages to allow time to install emissions control equipment. Some industry participants have expressed concern that these extended outages could adversely affect reliability (UARG 1998). Formal analysis of this question by NERC suggests that equipment retrofits could have an effect on reliability in the NERC subregions that include much of the Midwest, but that this effect could be largely mitigated through coordinated planning of outages and by encouraging early retrofits at some plants (NERC 2000). In addition, EPA has set up a compliance supplement pool to extend the dates of compliance for certain generation units (Napolitano 1999). We have not modeled explicitly in our scenarios the effect of pollution control equipment retrofits on the planned outage rates at existing plants. However, by focusing on results for 2008, we are considering a timeframe after which any potential disruptions in generation reliability should be overcome. We do not consider the additional cost that may accompany power supply disruptions during the construction and implementation period.

7. Conclusion

The existing literature consistently finds that potential improvement in human health from reductions in particulate (nitrate) concentrations is the most important category of potential benefits from reductions in NO_X emissions. This paper measures only these health benefits, to the exclusion of other potential health benefits from reduced ozone concentrations and to the exclusion of benefits from other economic endpoints. Hence, this paper is not intended as a full benefit-cost analysis of policy alternatives. Rather, the focus is to use particulate-related health improvements as a proxy for the full slate of potential benefits to learn about the relative cost-effectiveness of the policies from an approximate and partial benefit-cost exercise.

The main result that emerges is that net benefits are $400 million greater under a SIP Annual policy than under a SIP Seasonal policy. On the basis of particulate related health improvements only, and considering only compliance costs within the electricity sector as a proxy for social costs, the net benefits are about -$1.4 billion in the SIP Seasonal scenario, -$0.95 billion in the SIP Annual scenario, and -$1.87 billion in the National Annual scenario.

In all three scenarios, our partial measures of net benefits are negative. Hence, particulate-related benefits alone is not sufficient for any of the three scenarios to pass a benefit-cost test. How would the inclusion of other benefit categories affect the policy ranking from a cost-effectiveness perspective?

Other studies suggest that other compelling benefits exist, and they serve to strengthen our conclusion. EPA's benefit analysis of the NO_X SIP Call (EPA 1998d) suggests an additional source of benefits from reduced nitrogen deposition. These benefits would accrue all year so benefits in the annual scenarios would increase more than in the seasonal scenario, strengthening the justification for an annual approach. The other major additional sources of benefits addressed by EPA are ozone related (health and agriculture), and these benefits would accrue primarily during the summer ozone season. Since the emissions reductions in the ozone season in the SIP region are virtually identical under the seasonal and annual policies, the potential ozone-related benefits would increase total benefits by an equal amount for both the SIP Seasonal and the SIP Annual scenarios. This would change the relevant net benefit estimates in an identical way, by adding the same value to the net benefit of each scenario. So in sum, consideration of omitted benefits reinforces the finding that the SIP Annual scenario is more cost-effective than the SIP Seasonal scenario.

In conclusion, the cost of a policy to reduce NO_X emissions year-round in the eastern states is 27 percent greater than the cost of a policy that targets just the five-month summer ozone season. In comparison, the benefit from a year-round reduction in atmospheric concentration of particulates is more than twice the benefit from a program that targets just the ozone season. If a seasonal program is going to be implemented based on ozone related benefits (that we do not model) as is intended by current policy, then the additional benefits of extending the program to an annual basis far outweigh the additional costs.

Particulate reductions and related health benefits are the most certain and are expected to be the most significant benefits from reductions in NO_X emissions. However, there are many uncertainties associated with this analysis. Consideration of omitted benefits including those stemming from reduction in ozone concentrations suggests that the main finding holds *a fortiori*. That finding leads us to conclude that the EPA and the affected states should consider replacing or supplementing the current initiative for the eastern United States—a seasonal program to reduce NO_X emissions—with a new initiative aimed at annual reductions.

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Table 1. NERC subregions, the year marginal cost pricing begins, and subregions covered by cap and trade NOX policies under modeled scenarios.

NERC Subregion	Geographic Area	Year Marginal Cost Pricing Regime Begins	OTR NO_X Trading Region	SIP NO_X Trading Region
ECAR	MI, IN, OH, WV; part of KY, VA, PA	-		ECAR
ERCOT	Most of TX	2002		
MAAC	MD, DC, DE, NJ; most of PA	2000	MAAC	MAAC
MAIN	Most of IL, WI; part of MO	-		MAIN
MAPP	MN, IA, NE, SD, ND; part of WI, IL	-		
NE	VT, NH, ME, MA, CT, RI	2000	NE	NE
NY	NY	1999	NY	NY
FRCC	Most of FL	-		
STV	TN, AL, GA, SC, NC; part of VA, MS, KY, FL	-		STV
SPP	KS, MO, OK, AR, LA; part of MS, TX	-		
NWP	WA, OR, ID, UT, MT, part of WY, NV	-		
RA	AZ, NM, CO, part of WY	-		
CNV	CA, part of NV	1998		

Table 2. NO_X Emissions in the SIP Call region and nation in the baseline, and change from baseline under alternative scenarios for 2008.

	Annual		Summer	
(thousand short tons)	**SIP Call Region**	**Nation**	**SIP Call Region**	**Nation**
Baseline	3,449	5,533	1,445	2,377
SIP Seasonal	-1,031	-992	-1,024	-1,001
SIP Annual	-2,408	-2,378	-1,004	-995
National Annual	-2,528	-3,962	-1,050	-1,698

Table 3. Nationwide annual mprovements in public health for 2008.

	Health Benefits from NO_X reductions compared to Baseline (million 1997$)		
	Morbidity	**Mortality**	**Total**
SIP Seasonal	160	589	749
SIP Annual	383	1,393	1,777
National Annual	559	2,005	2,564

Table 4. National retrofit post-combustion capacity in baseline, and change from baseline under alternative scenarios for 2008.

	National Retrofit Post-Combustion Control Capacity (thousand MW)		
	SCR	**SNCR**	**Total**
Baseline	0	11.4	11.44
SIP Seasonal	+144.2	+57.4	+201.6
SIP Annual	+169.6	+30.3	+199.9
National Annual	+307.8	+14.3	+322.1

Table 5. Nationwide annual cost of post-combustion control in baseline, and change from baseline under alternative scenarios in 2008.

	SCR (million $)		**SNCR** (million $)		**ALL** (million $)
	O&M	**Capital**	**O&M**	**Capital**	**Total**
Baseline	0	0	16	14	30
SIP Seasonal	+953	+1,070	+42	+81	+2,146
SIP Annual	+1,299	+1,274	+109	+46	+2,728
National Annual	+2,198	+2,188	+29	+19	+4,434

Table 6. Generation by fuel and electricity price in the SIP Call region in baseline, and change from baseline under alternative scenarios, for 2008.

	Regional Generation (million MWh)			Regional Price (1997$/MWh)
	Coal	**Gas**	**Total**	
Baseline	1,095	460	2,139	64.4
SIP Seasonal	-19	+4	-20	+0.7
SIP Annual	+11	-19	-7	+0.5
National Annual	+2	-5	-11	+0.9

Table 7. National generation by fuel and electricity price in baseline, and change from baseline under alternative scenarios, for 2008.

	National Generation (million MWh)			National Price (1997$/MWh)
	Coal	**Gas**	**Total**	
Baseline	1,767	1,182	3,996	62.2
SIP Seasonal	-8	+39	+1	-0.3
SIP Annual	+17	+21	+14	-0.1
National Annual	-12	-47	-79	+0.3

Table 8. National generation capacity by fuel in baseline, and change from baseline under alternative scenarios for 2008.

	National Generation Capacity (thousand MW)		
	Coal	**Gas**	**Total**
Baseline	323	284	876
SIP Seasonal	-0.1	+10.5	+0.3
SIP Annual	-1.3	+7.1	-0.8
National Annual	-1.1	+0.4	+1.3

Table 9. Nationwide, annual particulate related health benefits and costs for 2008.

	Benefits/Costs in Aggregate (million 1997$)			(thousand short tons)	Benefits/Costs per Ton (1997$ per short ton)		
	Particulate Related Health Benefits Only (from Table 3)	**Post-Combustion Control Costs** (from Table 5)	**(Partial) Net Benefits** (Particulate Health Benefits minus Costs)	**NO_X Emissions** (from Table 2)	**(Partial) Average Benefit**	**Average Cost**	**Marginal Cost**
Baseline	-	30	-	5,533	-	-	1,356
SIP Seasonal	+749	+2,146	-1,397	-992	755	2,163	3,401
SIP Annual	+1,777	+2,728	-951	-2,378	747	1,147	1,985
National Annual	+2,564	+4,434	-1,870	-3,962	647	1,119	3,884

Table 10. Benefits and costs of NO_X reductions in the literature.

(1997 dollars) per ton NO_X	**Benefits**		**Costs**	**Comments**
	PM	**Ozone**		
Scenarios:				
SIP Seasonal	755		2,163	Sources in SIP Region and benefits throughout US; summer ozone season
SIP Annual	747		1,147	Sources in SIP Region and benefits throughout US
National Annual	647		1,119	Sources and benefits throughout US
Previous Studies:				
Burtraw et al. (1998)	739			Sources and benefits throughout US
Banzhaf et al. (1996)	35-366	29-358		Benefits in parts of Minnesota, Wisconsin only
Rowe et al. (1996)	1071-1140			Sources in NY State; benefits throughout US and combine PM and ozone
Krupnick, McConnell et al. (2000)		167	1,032	Sources and benefits in subset of SIP Region; average cost includes reductions over twelve months
USEPA (1998b)			1,807	Sources in SIP region; lower Baseline emissions
USEPA (1998d)	*714-2504*	*34-1689*		Health
	297	*325-717*		Only nitrogen deposition for PM, only agriculture and forestry for ozone
	1011-2801	359-2406		Sum of health and other benefits

Figure 1. The schedule of variable generation cost for the New England NERC subregion in baseload timeblock in summer 2008.