
Acid Rain

Causes, Effects, and Control

J. Laurence Kulp

Concern in the scientific community about the effects of acid rain from industrial sources began to grow in the 1970s, but the data then available were minimal. In 1980 Congress established a ten-year research effort, the National Acid Precipitation Assessment Program (NAPAP), to determine the causes and effects of acid rain and to make recommendations concerning its control. NAPAP issued an Interim Assessment in late 1987 and will publish the Final Assessment and State of the Science documents in 1990.

At the beginning of this program, acid rain was suspected to have negative effects on surface waters, crops, forests, building materials, visibility, and human health. Fortunately, the research has shown that the damage from current and historical levels of acid rain has ranged from negligible (for example, on crops) to modest (for example, on some lakes and streams). It is also clear that at current levels of acid rain deposition there will be no significant increase in these measured effects over the next half century. The causes and the distribution of acid rain over the United States through the seasons are now fairly well defined, and rapid technological advances to control the emissions of the precursors of acid rain are occurring.

Although controls on the emissions of sulfur dioxide from new utility generating plants have been required since 1979, there is wide support for

J. Laurence Kulp is a consultant in environmental and energy affairs. He was formerly a professor of geochemistry at Columbia University, vice president of research and development at the Weyerhaeuser Company, and director of research of the National Acid Precipitation Assessment Program.

additional controls to further reduce the emissions in the 1990s. Several bills to achieve this objective are being debated in Congress, the most prominent of which is the president's proposed amendments to the Clean Air Act. Each of these bills would implement a crash effort to cut the emissions of sulfur dioxide from coal-burning plants by roughly one-half (about 10 million tons per year) over the next decade or so, at a cost of tens of billions of dollars.

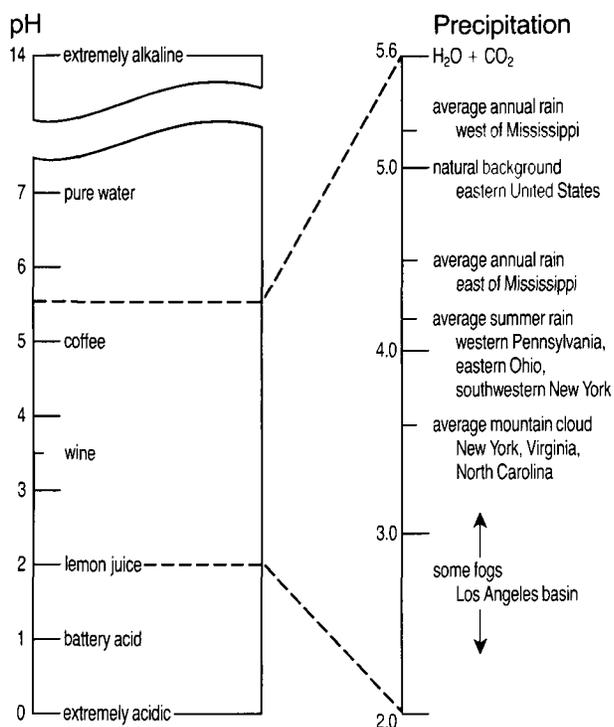
The purpose of this article is to present the current scientific understanding of the causes and effects of acid rain, to examine qualitatively the benefits of control, and to outline a control strategy that could ultimately eliminate any significant environmental damage at minimal cost and with little social disruption.

Defining the Problem

Virtually all rain in nature, before the Industrial Revolution, was acid. The relatively recent term "acid rain" refers to the additional acidity in rain as a result of the emissions of sulfur dioxide (primarily from coal-burning utility plants) and nitrogen oxides (dominantly from vehicles). To define acidity the chemist uses a "pH scale," in which each unit of pH represents a tenfold difference in acid concentration. A pH of 7 means a solution is neutral, a pH of 14 is highly basic, and a pH of 1 is highly acid. Figure 1 shows the relative acidity of various natural waters and other substances.

Preindustrial (natural background) rain over forested areas in the temperate zone has an average pH of about 5.0, while the most polluted rain that falls in western Pennsylvania is about eight times

Figure 1: pH Scale, Acidity of Common Substances, and Acidity of Rain and Fog



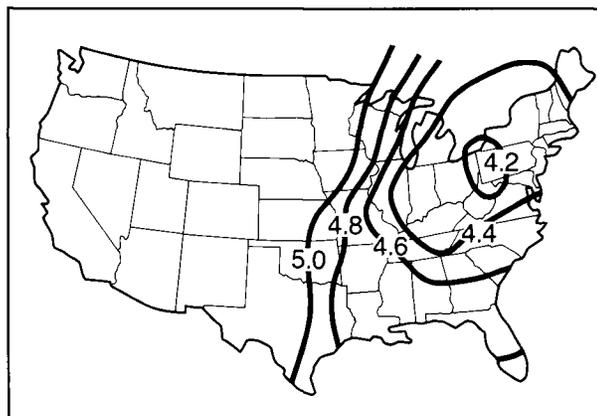
more acid at a pH of 4.2 (Figure 1). Note also that fogs and clouds carry higher concentrations of pollutants than does accompanying rain. Although individual rains and parts of rains differ in their acidity, the annual or seasonal average is generally the most important indicator of effects.

Figure 2 shows the distribution of the average annual acidity of rain over the United States. The area having the highest acidity (lowest pH) in rain—western Pennsylvania, eastern Ohio, southwestern New York, and northern West Virginia—lies about one day's travel time downwind from the Ohio River valley, the region with the highest concentration of uncontrolled coal-burning plants. West of the Mississippi valley, in northern Maine, and in southern Florida the acidity of rain approaches that of the preindustrial, unpolluted level (that is, a pH of 5.0). In the western United States, aside from the heavily polluted Los Angeles basin, the average annual pH of rain is greater than 5.0 because the alkaline dust in the air neutralizes the acid. Also, in the western United States the amount of emissions is much smaller than in the eastern part of the country. This general pattern of acid rain distribution has not changed in the past decade or so.

Causes of Acid Rain

The bulk of the acidity in rain comes from the reaction of sulfur dioxide (SO_2) with hydrogen peroxide in clouds, a reaction that produces sulfuric acid. This is the important mechanism in the summer, when most acid rain falls. The hydrogen peroxide is formed from the photochemical reactions of volatile organic compounds derived from such divergent sources as trees and automobile exhaust. In the eastern United States in the summer the hydrogen peroxide in clouds is commonly sufficient to convert all of the SO_2 to sulfuric acid. In the winter, however, the hydrogen peroxide concentration is considerably lower so that much of the emitted SO_2 goes out to the Atlantic Ocean without reacting. Therefore, controlling SO_2 emissions in the summer would be more effective than in the winter. A minor fraction of the sulfuric acid responsible for acid rain is formed by the reaction of SO_2 with ozone or other oxidants in the air (not clouds). Since we cannot control the emission of volatile organic compounds from natural sources, we can decrease the sulfuric acid component of rain only by reducing SO_2 emissions.

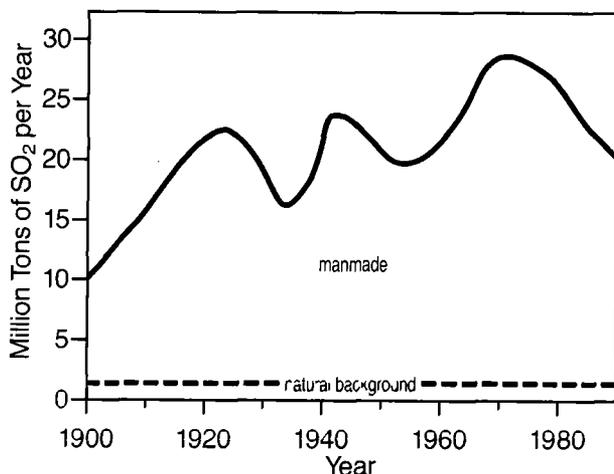
Figure 2: Present Distribution of Acid Rain (precipitation-weighted pH)



While nitric acid, formed by the oxidation of nitrogen dioxide, also contributes to the acidity of rain, its role is minor compared with that of sulfuric acid. In fact, in the case of crops and forests, nitric acid generally provides beneficial fertilization. Therefore, the primary target in reducing the acidity of rain must be control of the SO_2 emissions from large coal-burning utility plants that contribute over 70 percent of the emissions from all sources. Control of nitrogen oxide emissions from these plants would make only a secondary contribution to either acid rain or ozone reduction.

Figure 3 shows the trend in the emissions of SO_2 in the United States since the turn of the century. It is evident that industrial acid rain has been with us throughout this period and so have its effects. The emissions today are about what they were in 1930. Until 1972 the trend reflects coal use. After 1972, when SO_2 emissions reached their all-time high, coal use has increased by about 40 percent, but SO_2 emissions have declined by about 25 percent as a consequence of the emission controls required by the Clean Air Act.

Figure 3: Historical Trend of Sulfur Dioxide Emissions



Since the peak of emissions in 1972, the acidity of rain has not decreased so sharply as the SO_2 emissions. This is probably a result of the concurrent control, also required by the Clean Air Act, of particulate matter, which is generally alkaline and thus has been progressively less effective in neutralizing the acids.

Effects of Acid Rain

Over the observed range of acidic deposition, acid rain has had clearly demonstrable negative effects only on surface waters and atmospheric visibility. There is clearly no negative effect on crops. Some minor effects on forests, building materials, and health have been hypothesized, but not quantified. Further, to assess the significance of the effects of acidity on any of the categories of concern, it is important to distinguish results obtained in experiments where much higher acidities were used from the potential or actual effects under ambient (current) conditions.

Lakes and Streams. All rock minerals are alkaline and therefore help neutralize acidic ground

water. The degree of neutralization depends on the length of time in contact with the minerals and their individual rates of reactivity. The acidity of a lake or a headwater stream therefore depends on these factors and the acidity of the rainfall. Thus, for example, rain averaging a pH of 5.0 can produce lake or stream water with similar acidity if the

To assess the significance of the effects of acidity on lakes and streams, visibility, crops, forests, building materials, and health, it is important to distinguish results obtained in experiments where much higher acidities were used from the potential or actual effects under current conditions.

water falls on a smooth granite surface and runs directly into the lake or stream. If the same water moves slowly through a soil rich in limestone fragments, however, the resulting stream or lake water may be completely neutralized and hence have a pH well above 7. Organic acids from humic layers in the forest soil, with a pH as low as 4, could increase the acidity of the resulting surface waters.

Figure 4: Acidity of Two Adirondack Lakes with Different Watershed Characteristics

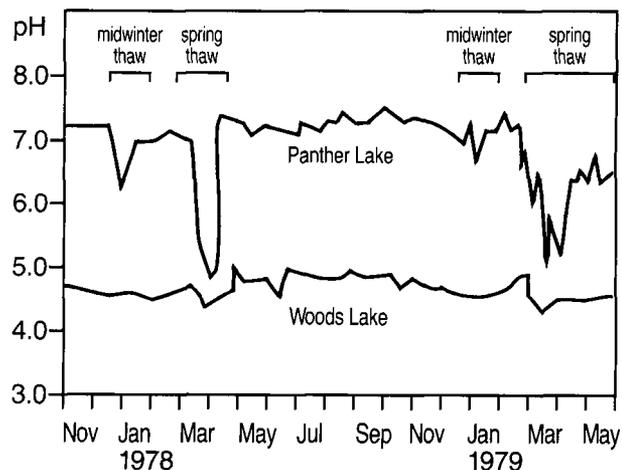


Figure 4 shows the pH of two neighboring Adirondack lakes that have very different watershed characteristics over the 1978-1979 period when the average pH of the rainfall was 4.3 on both watersheds. Most lakes in glaciated terrain will lie between these extremes. Since these lakes are flushed several times a year, the acidity of the lake water is essentially in equilibrium with the average acidity

of the rainfall. Further, since the emissions of SO_2 in the Northeast have been roughly in the same range over the past 50 years, it is likely that the acidity of rain has also been roughly constant on the average over this period and, therefore, so has the lake acidity. Predicting the future acidity of a lake by using adequately calibrated models suggests that if current conditions of acid deposition remain constant, we can expect little change in these lakes

Acid rain has had clearly demonstrable negative effects only on surface waters and atmospheric visibility.

over the next half century. Clearly, if the acidity of the average rainfall changes, the lakes will reach a new equilibrium acidity over time.

The effects on small headwater streams are the same as on lakes, and similar examples can be cited. Small streams may show considerably more variation in acidity during the year because of "acid episodes" that may be brought on by spring thaw and runoff or by summer storms on already saturated ground. In these cases the impact on organisms may be locally severe for a short time. The regional importance of these episodes for fish populations is not yet fully understood. Finally, as would be expected, large lakes with large watersheds and rivers draining large areas are not significantly acidified by acid rain.

Table 1 summarizes the national inventory of lakes in the most sensitive areas—where there are little or no limestone and thin soil. For each region the percent of the lake area (excluding very large lakes like the Great Lakes or Lake Champlain) with a pH less than 5 or less than 6 are given. A pH of 5 occurs approximately when the acid-neutralizing capacity of the lake equals zero. The lake is hence considered "acid." In preindustrial time there were

Table 1: Summary of NAPAP National Lake Survey

Region	Median pH	% of Lake Area by pH	
		<5.0	<6.0
Adirondacks	6.9	2	10
Northeast	6.7	1	6
Upper Midwest	7.4	0	2
Southern Blue Ridge	7.0	0	0
Mountainous West	7.4	0	0

many lakes in these sensitive areas, such as Woods Lake, with a pH less than 6 since the rain was 5.0.

Table 1 shows that the median pH for the lakes in all regions is well above 6. Field observations suggest that most species of sports fish tolerate pH levels above 5.5, but relatively few species can sustain populations in water with a pH below 5.0. The fraction of lakes with a pH less than 6 ranges from zero to small in all these sensitive regions.

The area in the United States most seriously affected is the Adirondack Park of New York, where 10 percent of the fishable lake area has a pH less than 6. This corresponds fairly well to the fraction of lake area with substandard fish populations. Although some of these acidic lakes may have developed their acidity from natural causes, researchers generally believe that the most common cause is acid rain. While the timing of the lakes' acidifica-



tion is not certain, some lakes probably began to increase in acidity by the turn of the century, and many may have been near their present pH by the 1930s.

Visibility. The sulfuric acid produced from the emissions of SO_2 reacts with alkaline compounds in the air to form fine particles of ammonium sulfate and calcium sulfate, among others. These particles produce haze, especially at high levels of humidity. This effect is particularly evident in the relatively clean air areas of the western states. In many of the National Park areas the sulfate creates 50 to 60 percent of the degradation in visibility. In the East it is closer to 70 percent, and the total haze is much greater. It is difficult to quantify the effect over short periods because of the many factors—including

humidity and carbonaceous and soil particles—that contribute to the phenomenon. Nevertheless, historical studies on a regional basis suggest that decreased visibility is related to increased sulfate particle concentration in both the western and eastern United States.

Crops. Numerous controlled experiments in which crops of corn, oats, potatoes, and soybeans have been exposed over the growing season to simulated acid rain have established that current concentrations of acidity in rain observed in agricultural areas do not retard growth. The experiments demonstrate that there is no significant effect on growth even at ten times the acidity now observed in the eastern United States. The nitrate component, and to a lesser extent the sulfate component, of acid rain actually benefit nearly all crops and forests because of their nutritional requirements. This fertilization reduces the amount the farmer or commercial forester must otherwise provide.

Forests. Controlled experiments exposing a wide range of tree species as seedlings to simulated acid rain over the current range of concentrations for up to three growing seasons have shown no effects on growth rates. Extensive surveys in natural forests and commercial plantations over the eastern and northwestern states have failed to identify any regional decline that could not be attributed to natural causes, with the possible exception of red spruce trees in the high elevations of the northeastern Appalachians. (These high-elevation red spruce forests—above the cloud base or about 700 meters—represent less than 0.01 percent of the forested area east of the Mississippi.)

The low-elevation forests in the Northeast, from New York to Maine, that are exposed to relatively high levels of acid rain show no evidence of decline over the period 1950–1980 in the growth of the ten most abundant tree species. All but two species, including sugar maple, showed an increase in growth over the period. Red spruce and balsam fir did show a gentle increase followed by a decrease in the early 1960s, but the investigators attributed this to natural causes.

In the northern Appalachians at elevations of 800–1,000 meters, red spruce has shown a declining growth rate and an abnormal frequency of mortality since the mid-1960s, although the associated birch and balsam fir did not show similar declines. Some researchers have attributed the decline to winter freezing and desiccation injury due to the severe winters of the late 1950s and early 1960s.

Unusually severe drought during the mid-1960s may also have added to the stress. Both acid rain and ozone have been hypothesized as agents that may have contributed to the decline of the red spruce, but experiments with red spruce seedlings on White-top Mountain in Virginia showed no effects from ambient levels of ozone and acidity in the associated clouds over two growing seasons. In fact, at this location the acidity was equal to that in the

Experiments demonstrate that acid rain has no significant effect on the growth of crops, even at ten times greater acidity than is encountered under current conditions. Acid rain apparently has had little or no negative effects up to the present on the forests of the United States, with the possible exception that it may to a small degree reduce the frost hardiness of red spruce in a narrow elevational band in the Northeast.

northeastern clouds, and the ozone levels were higher.

Researchers have been unable to find that acid rain caused direct foliar damage or soil-mediated effects on red spruce. The one remaining possibility for an acid rain effect would appear to be lowering the frost hardiness or the resistance of the tree to winter desiccation. The former phenomenon has been shown to occur at a pH of 2.5 and perhaps at 3.0, but not measurably at the average cloud acidity of pH 3.6. It is possible that acid rain and perhaps ozone contribute to the winter injury of red spruce that is caused primarily by natural climatic conditions. Red spruce is less frost hardy than balsam fir, which may explain the continued growth of fir compared with the decline of red spruce over the past two decades in the Northeast. Most mature spruce trees that were heavily damaged in the 1960s are dead, but younger, less damaged spruce trees are recovering. There are also vigorous red spruce seedlings and saplings in these mountains, despite nearly constant average cloud acidity. Finally, in the period 1870–1880 severe widespread death of red spruce trees occurred across the mountains of the Northeast after extreme winter weather. But this decline happened well before the appearance of significant amounts of anthropogenic acid rain or ozone!

Acid rain apparently has had little or no nega-

tive effects up to the present on the forests of the United States, with the possible exception that it may to a small degree reduce the frost hardness of red spruce in a narrow elevational band in the Northeast. The most recent scientific results from the forests of Germany are consistent with the conclusion that acid rain is not a primary factor in the various types of regional decline in tree species.

Building Materials. Researchers have examined three types of building materials for damage by acid rain: galvanized steel, carbonate stone, and surface coatings. Since all of these materials are also affected by solar radiation, ozone, thermal cycling, moisture cycling, bacterial activity, natural organic acids, and carbonic acid in rain, it is difficult to determine the incremental degree of erosion or corrosion of these materials due to ambient levels of acid rain.

The main effect of rain acidity on galvanized steel is the dissolution of a basic zinc carbonate corrosion product that occurs naturally. Although the acidity of rain contributes to the final removal of the zinc, the rate of corrosion depends on the sulfur dioxide, nitric acid, and formaldehyde already on dew-covered surfaces. Since the SO_2 is 10 to 100 times greater in urban than in rural regional air, the economic damage from exposed galvanized steel occurs largely in cities. Although at present the relative contribution of the SO_2 gas to corrosion is uncertain, the acidity of rain appears at worst to make only a secondary contribution.

Likewise with carbonate stone, SO_2 dissolved in thin water films, often on the underside, is a more corrosive agent than the acidity of rain on the surface. The more acid the rain, the more efficient is the washoff of corrosion products, but again the corrosion rather than the ultimate washoff probably determines the rate of damage to the stones. In addition, the degree to which atmospheric pollutants, including acid rain, accelerate the natural weathering of surface coatings is still unknown, although researchers expect that carbonate paints would be more vulnerable than those with other whiteners.

In all of the above cases, the issue is whether acid rain significantly reduces the expected life of the building material. For example, if the reason for repainting a house is to change its color, the corrosive agent or the rate of corrosion is irrelevant. If a galvanized sheet or tube has rusted beyond acceptable limits for its use, the question is how much ambient acid rain shortened its life. If acid rain only marginally accelerates the replacement

time for a building material, we can ignore the effect of acid rain. Unfortunately, to date we have been unable to quantify the effect of acid rain on the expected life of building materials, and hence we cannot calculate economic loss. With the data at hand, however, it seems doubtful that acid rain will be shown to play a significant role in altering the time for replacement of these materials.

Health. Researchers have not demonstrated indirect health effects from acid rain in drinking water. Where metal concentrations in untreated drinking water have exceeded drinking water standards, these concentrations have not been traceable to differential acidity in rainfall. For example, regardless of the acidity of the rain, cistern water is usually alkaline since it is normally stored in cement containers.

Attempts have been made to relate mercury

With the data at hand, it seems doubtful that acid rain will be shown to play a significant role in reducing the expected life of building materials. Researchers have hypothesized that acid rain has direct and indirect effects on health, but studies have not quantified these effects.

content in fish with lake pH levels, but fish with elevated levels of mercury that could be toxic to humans are found in areas where rain has either high or low acidity.

Researchers have also hypothesized direct health effects involving lung irritation or damage by acidic aerosols. Compared with the exhaustive research on the effect of ozone on human lungs, studies with acidic aerosols have been quite limited. Effects have been detected in experimental human exposures to concentrations in excess of 1,000 micrograms per cubic meter, but the average regional concentrations of sulfuric acid aerosols lie in the range of 1 to 10 micrograms per cubic meter. Animals exposed over long periods of time to concentrations of 250 micrograms per cubic meter have shown changes in some lung functions.

Epidemiological studies comparing the summer-time hospital admittance rate for lung complaints in two Canadian cities that have significantly different levels of air pollution showed a strong correlation between admittance and pollution levels.

Since the polluted air contained relatively high levels of ozone and other contaminants, however, the effect of the acidic aerosol present is indeterminate. We need more research to establish clearly how acidic aerosols may affect human lungs, but the available data suggest that the effect is not very significant.

Future Change in Effects

If acidic deposition were to increase, all effects would, of course, be increased. Experimental data and calibrated models allow us to estimate the degree of enhancement where the effects at ambient levels of acid deposition have been quantified, such as with lakes. Since the public and the political leadership are committed to reducing air pollution, acid rain will not be allowed to increase. In fact, the proposed legislation would require a substantial decrease in SO₂ emissions. The only issues being debated are the rate and extent of the reduction. Therefore, it is not useful to analyze the effects of increased emissions.

In the short term—over the next several decades—a worst-case scenario might assume that present levels of emission and acidic deposition would continue unchanged. If so, the situation described above with regard to human health, the rate of building materials' damage, the decline of high-elevation red spruce trees, crops, visibility, and the percent of lake area made inhospitable to fish would not change. In the very long term, sustained acid rain at present levels might cause the leaching of sensitive soils to the extent that tree nutrition could be affected and some additional lakes and streams would become too acid to sustain healthy fish populations. Effects on other receptors would remain unchanged.

If the emissions of SO₂ were abruptly cut in half, as proposed by some legislation, acidic deposition would be decreased by only about 30 percent since the relationship is not linear. Such a decrease would presumably be beneficial to all receptors, but in the cases where no significant negative effects have been demonstrated—crops, forests, building materials, and human health—we cannot quantify any improvement. Visibility would improve over the long term, but since only a fraction of the interference is due to sulfate aerosols, the improvement would be proportionally less than the 30 percent reduction in acid formation. In the glaciated and other areas where the lake and stream chemistry is essentially in equilibrium with the acidity of the rain, a new equilibrium would be reached in less than a decade. Some of the most affected surface

waters would recover to fishable status, but less than 30 percent of the lake areas listed in Table 1 would do so.

Benefits from Reducing Acid Rain

One can only conclude from the above discussion that the economic benefits from reducing acid rain from its present levels would be small at best. The most definable benefit is probably the recovery of some lakes to fishable status. The NAPAP Interim Assessment estimated that if all lakes in the Adirondacks (the most affected region) that are now fishless because of acidity were restored and were fully used by fishermen, the economic benefit would probably lie in the range of only \$1 million to \$13 million. If similar relationships of acid lake area and the value of fisherman days were extended to

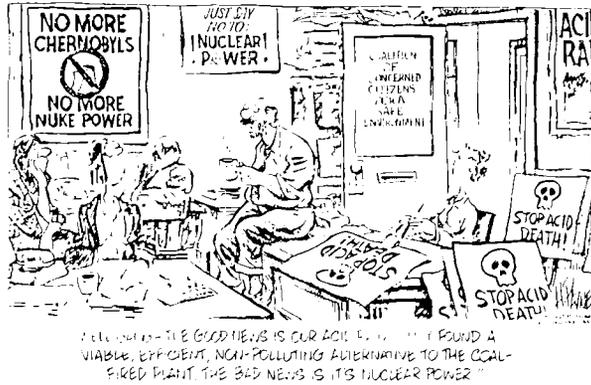
The economic benefits from reducing acid rain from its present levels would be small at best. The most desirable benefit is probably the recovery of some lakes to fishable status. Nevertheless, many people give considerable weight to potential, but unquantified, effects and to aesthetic values in supporting their demand to reduce the acidity of rain.

the rest of the country, the total benefit would not exceed roughly \$100 million or about the cost of one large scrubber! Nevertheless, many in our society give considerable weight to potential, but unquantified, effects and to aesthetic values, such as improved visibility, in support of their demand to reduce the acidity of rain.

Future Emissions

In the absence of any changes in legislation or regulation, the emissions of SO₂ will probably not increase. If the amount of coal burned for electrical power generation increases, the amount of SO₂ emitted will grow, although at a much slower rate than in the past. The New Source Performance Standards (NSPS) established by the EPA in 1979 for new coal-fired plants permit emissions of only about one-tenth of those from previously existing boilers. These uncontrolled boilers, built before 1979, currently produce about 95 percent of the emissions.

Many factors will tend to reduce rather than increase future SO₂ emissions: (1) The replacement of the old, uncontrolled plants with new boilers that must meet the NSPS. (2) The introduction of alternative energy sources for electrical generation, for example, natural gas (particularly in the near term), nuclear and solar power, municipal solid waste, wind, geothermal, cogeneration, and biomass. All of these alternative sources will be encour-



aged as concern for the greenhouse effect arouses the public. (3) New technologies, such as the integrated gasification combined cycle, the atmospheric fluidized bed, the pressurized fluidized bed, the advanced wet scrubber, and the natural gas combined cycle, that can drastically reduce the emissions of new plants below those achieved by the 1979 NSPS plants and still operate at higher thermal efficiencies. These new technologies will also make it possible to repower older plants at higher generation rates while concurrently reducing their emissions to the 1979 NSPS limit.

Control Technologies. The advanced technologies can substantially reduce the SO₂ emissions below the 1979 NSPS, which were based on 1970s technology involving wet scrubbers. All of these technologies have been proven at commercial scale (except for the pressurized fluidized bed, which is now being tested). They were encouraged and supported by the Clean Coal Program of the Department of Energy and based on the Reagan-Mulroney agreement that the United States would invest \$5 billion in developing greatly improved emission control technology at competitive costs.

For comparative purposes, the 1979 standards allow a maximum of 1.2 pounds of SO₂ per million BTU to be emitted, even with high-sulfur coal. This is the same level of emissions that many states have required since 1972 and can be met in some

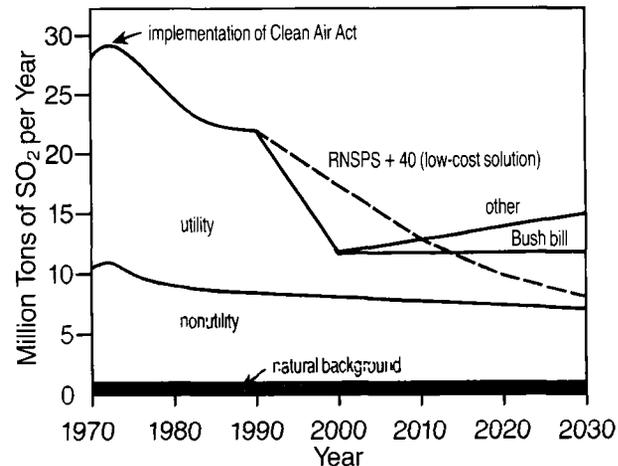
cases simply by using the lowest-sulfur coal. It is also the level required by the Bush bill by 2003. New technology makes it possible to reduce significantly the levels of emissions from those targeted by the 1979 standards. The most environmentally effective technology, the integrated gasification combined cycle, can remove more than 99 percent of the SO₂, so that even the highest sulfur coal on the market can be cleaned to a level of less than 0.1 pounds per million BTU.

The fluidized bed technologies are particularly attractive for the repowering of old uncontrolled units, where their lives can be extended economically. The advanced wet scrubber can be competitive with the fluidized bed technologies in SO₂ emissions, but it is less energy efficient and produces more carbon dioxide per BTU than the other technologies, and thus contributes more to the greenhouse effect. The technology using natural gas with a modern turbine in a combined cycle produces very low SO₂ emissions, and with the present low gas prices is the most economical of all technologies.

Most important, engineering cost analyses based on operation of large-scale demonstration plants show that the four advanced coal technologies are similar in cost to each other and to a pulverized coal-scrubber plant built to the 1979 NSPS.

Scenarios. Figure 5 illustrates projections of future emissions of SO₂ based on different scenarios. Three components of SO₂ emissions are shown: natural

Figure 5: Future Emissions of Sulfur Dioxide



background emissions of about 1 million tons per year, nonutility emissions, which have declined since 1972, and utility emissions, which are the largest portion. All scenarios assume that no further action is taken to reduce the nonutility emissions. This is

unlikely, but at present there are no specific guidelines for increased controls in this sector.

The dashed line (labelled RNSPS + 40) projects future emissions assuming that the 1979 standards for large coal-fired plants are revised (RNSPS) to a standard of *0.1 pounds of SO₂ per million BTU*. This scenario also assumes that by age 40 all pre-NSPS uncontrolled plants must either be shut down or modified to meet a standard of *0.6 pounds of SO₂ per million BTU*. Note that by the year 2030, this scenario reduces the utility emissions to a level about equal to that from natural background emissions.

Without any new regulations or legislation, the future emissions pattern is difficult to predict but probably, for the reasons given above, would lie between the present level of utility emissions—15 million tons of SO₂ per year—and the RNSPS + 40 curve.

A second scenario approximates the provisions of the administration bill, which requires a 10 million ton reduction by 2003 and then a cap on emissions at that level. A third scenario follows other proposals that have required similar reductions (8 to 10 million tons) by about 2000, but without a cap so that future increased coal use (assumed to be 2 percent per year) and emission standards of the 1979 NSPS would produce an ever-increasing level of emissions after 2003.

Legislative Alternatives

Each year during the 1980s acid rain control legislation was introduced in Congress, but for a variety of reasons none was passed. The Reagan administration felt that more research was needed on the causes and effects of acid rain before a rational control policy could be formulated and therefore opposed suggested legislation. Regional concerns, such as who would pay for the expensive controls that had been proposed and which coal-producing areas would be hurt or favored economically, caused serious divisions in Congress. In 1989 bills were introduced in the House and Senate that proposed alternatives for acid rain control, and most important, for the first time one of them was an administration bill. Action and debate now focus on this "Bush" bill.

The Bush bill will require the reduction of 10 million tons of SO₂ from the base year of 1980 by the year 2003 in two phases. Beyond 2003 the bill requires offsets in emissions for new plants so that the absolute limit does not grow in the future. It has considerable merit over earlier bills in that it provides for maximum choice in technology and in

trading reductions within utilities, within states, and ultimately between states. This should enable the reductions to be accomplished at minimum cost. Nevertheless, this bill will cost the country \$4 billion to \$7 billion per year over the next 20 years and would increase the electricity rates of 30 percent of the nation's utilities by 20 percent. It is a rela-

The Bush bill would require the reduction of 10 million tons of SO₂ from the base year of 1980 by the year 2003 in two phases. The bill would probably preclude the use of advanced technologies now being developed. An alternative policy for control of acid rain would be simpler to apply, would ultimately make the emissions so low that all detectable effects from acid rain would be eliminated, and would cost far less than the present provisions in the Bush bill.

tively complicated bill. One of its major disadvantages is that the very short time frame utilities will have to make plans to comply with the requirements of the bill would probably preclude widescale use of the advanced clean-coal technologies now being developed. This is particularly troublesome when the present levels of acid rain are not creating environmental crises and the effects will not get worse in the next few decades, even if the present level of emissions continues.

An alternative policy for control of acid rain would be simpler to apply, would ultimately make the emissions so low that all detectable effects from acid rain would be eliminated, and would cost far less than the present requirements in the Bush bill. As represented by RNSPS + 40 in Figure 5, this policy would both revise (tighten) the New Source Performance Standards for large coal-fired boilers to 0.1 pounds of SO₂ per million BTU and require that after about 40 years of service, coal-fired utility plants be required to meet a standard of 0.6 pounds of SO₂ per million BTU.

Several new technologies can currently meet the RNSPS for new generating plants—the natural gas combined cycle, the integrated gasification combined cycle, fluidized beds, and advanced scrubbers. In the near term, possibly through the 1990s, the technology of choice would be the natural gas combined cycle because of the low capital cost and

the current low cost of the fuel. After the year 2000, the integrated gasification combined cycle technology would probably be the normal choice, since it can use high-sulfur coal, removes most of the NO_x, produces a usable benign solid residue, and has higher thermal efficiency and lower carbon dioxide per BTU. Fluidized beds and advanced scrubbers may be selected for use with low- or medium-sulfur coals in certain situations. In any case, there is no technical reason not to adopt tighter standards, and for new plants there would appear to be no economic penalty over a 1979 NSPS pulverized coal-scrubber plant. Therefore, a dramatic reduction in SO₂ emissions over the long term can

Tightening New Source Performance Standards to take full advantage of new technologies and setting a reasonable age limit beyond which old pre-NSPS boilers must be shut down or controlled could eliminate the acid rain problem at a net cost that is close to zero.

be accomplished at *no* net cost.

The second requirement of this policy will prevent an abnormal extension of the life of uncontrolled coal-burning plants. Since the accounting life of the original plant is normally about 30 years, the writeoff occasioned by decommissioning the plant would be small or negligible. Often, however, much of the infrastructure of the plant—the coal-handling facilities and perhaps the turbine—is still usable. In this situation life extension at age 40 can be done optimally by repowering with a fluidized bed boiler or gasification technologies. This can be designed to increase the generating capacity substantially and to improve the thermal efficiency. The cost of the additional electricity in such a scheme would be substantially less than for a completely new “green field” plant. At the same time, the emissions can be reduced to 0.6 pounds of SO₂ or less for a wide range of coals including the high-sulfur Illinois coal carrying 3.5 percent sulfur. Since the nation will probably need increasing electrical energy for the foreseeable future and since repowering can provide new power at lower cost than can a “green field” plant, again the net cost of the repowering option is zero.

Finally, this requirement could be met by adding a scrubber. This solution would normally not be

the option of choice since it would decrease generating capacity and thermal efficiency and would increase the carbon dioxide emissions per BTU, which would contribute to the greenhouse effect. Meeting the requirement by adding a scrubber would involve a substantial net cost. The shorter the time frame specified in emission control legislation, the more retrofit scrubber technology would be forced on the utilities and the public—a clear case of “throwing good money after bad” rather than moderately extending the time frame and putting all available capital into a permanent long-term solution at a negligible net cost.

Conclusion

The causes and effects of acid rain are now rather well understood. Fortunately, the effects have been limited, and there is no evidence to suggest that they will worsen in the next few decades with present emissions.

Coincidentally, during the 1980s technologies for controlling the emissions of the precursors of acid rain have advanced rapidly. When fully implemented, these will reduce the emissions from coal-fired boilers to such low levels that the effect on the environment will be undetectable.

The crash effort to reduce emissions in the current bills before Congress is estimated to cost on the order of \$100 billion over the next 20 years and will not permanently solve the problem. An alternative policy (RNSPS + 40), which consists of tightening the New Source Performance Standards (to 0.1 pounds of SO₂ per million BTU) to take full advantage of the new advanced technologies and setting a reasonable age limit (40 years) beyond which old pre-NSPS boilers must be shut down or controlled, could eliminate the acid rain problem at a net cost that is close to zero. All that is required for this more optimal solution is a moderate amount of wisdom and patience.

Selected Readings

Kulp, J.L. and Herrick, C.N. *The Causes and Effects of Acid Deposition*. Interim Assessment, National Acid Precipitation Assessment Program. Washington, D.C.: U.S. Government Printing Office, 1987.

Mohnen, V.A. “The Challenge of Acid Rain.” *Scientific American*, Vol. 259, No. 2 (1988).