The *I-Ching* of Acid Rain

Peter Huber

"BEFORE HEAVEN AND EARTH had taken form all was vague and amorphous. [Then] the combined essences of heaven and earth became the yin and yang. . . ." Two thousand years later, the story of acid rain begins to unfold.

Acid and alkali are both abundant in nature, and like the yin-yang complements of the *I Ching*, acid-alkali balances also follow a Book of Changes. In balance, acid and alkali are an integral part of every living system and every ecology. Out of balance, acidity or alkalinity can be toxic. The hot question today is whether the acidity in eastern rainfall has reached ecologically hazardous levels.

The name was coined by Angus Smith, a British chemist, in 1872, but purists now prefer to speak of acid "deposition," which also includes acidic snow and dry acidic particles. By any name, however, acid rain today is a multi-billion dollar regulatory controversy. With the apparent demise of nuclear power, many environmentalists have made acid rain their newest and most pressing cause. Canada is upset about it, Congress is considering sweeping new legislation, and the federal courts are beginning to flex their regulatory muscle. Whether or not acid rain is an environmental problem, it has most certainly become a social and political corrosive.

Peter Huber is a consultant on matters involving energy and the environment.

So it is not surprising to find that acid rain has spawned a large, complex, and often contentious literature. No short survey can cover all that has already been written. But the plot of the acid rain story is finally becoming clear, even though it remains difficult to determine how the story must end. This acid rain chronicle comes in two chapters. The first deals with the science of sulfur—the chemistry, transport, and ecological impacts of the element as it moves from coal mine to ocean. The second addresses the regulatory options—how sulfur emissions might be reduced or their environmental impacts mitigated, at various stages of the coal-sulfur cycle.

I. THE SCIENCE OF SULFUR

A solution's acidity is a description of its chemical composition—specifically, a measure of the percentage of hydrogen ions ("pH") it contains. Water becomes acidic or alkaline depending on what is dissolved in it. Ammonia or calcium carbonate (lime), for example, dissolve in water to make it alkaline; carbon dioxide, sulfur oxides, and nitrogen oxides make it acidic. The effects counteract each other—add a little sulfuric acid to the water and a little lime, and the solution remains neutral. The gross chemistry of acid rain is relatively simple.

Pure water falling through pristine air would pick up a little carbon dioxide and would therefore be slightly acidic from that source alone. Lightning and other "all-natural" processes may add a little more acidity from nitric oxide. Naturally occurring contaminants such as dust may have a "buffering" effect, adding alkalinity that neutralizes acidity and that may even cause rain to become slightly alkaline. More severe acidification, if it occurs at all, derives mostly from man-made pollutants.

Nitrogen oxides are one cause of acidification. The nitrogen and oxygen are already abundant in the air; and high temperature from a car engine, or a boiler, or perhaps a bolt of lightning causes some of the nitrogen to oxidize. About 21 million tons of nitrogen oxides are emitted into the atmosphere annually from man-made sources. But the most important acidifying pollutant is sulfur dioxide (SO_2). It has twice the acidifying potential of nitric oxide, and it is emitted in larger quantities. The main source of sulfur dioxide is coal.

As it comes out of the ground, coal varies in sulfur content from about 0.2 percent (by weight) for the cleanest coal to 5.5 percent for the dirtiest. When coal is burned in an industrial boiler, one pound of its sulfur yields two pounds of gaseous SO_2 and, in the normal course of things, the SO_2 disappears up the smokestack. That is the fate of about 27 million tons of SO_2 a year at current rates of emission. Two-thirds of that amount, or about 15 to 20 million tons of SO_2 a year, comes from electric utilities, the largest burners of coal. Other industrial boilers and processes account for the rest. Coal-burning power plants are scattered all over the country, but are especially concentrated in the Great Lakes region and the Midwest.

Atmospheric Chemistry and Transport

Sooner or later, somewhere or other, SO_2 that goes up into the air comes down again. Estimates suggest that of the total sulfur emitted to the atmosphere from sources in the eastern half of the United States, about one-third blows out to the Atlantic Ocean, one-sixth is exported to Canada, and the rest is deposited back on land in this same general region. If atmospheric conditions are unfavorable, SO_2 will first be oxidized (to a "sulfate" ion), then dissolve in water, and finally come down as acid deposition. There is, however, a good bit of uncertainty about where the sulfur dioxide comes to earth, and in precisely what form.

Linearity. In the aggregate, does all the sulfur dioxide that goes up contribute to an increase (somewhere or other) in the acidity of rain that comes down? Clearly not. Some is neutralized before it reaches the ground and, perhaps most important, some is never oxidized and so not converted into acidic form. One key scientific question for the regulator is whether a given percentage reduction in SO_2 emissions will translate into a corresponding reduction in the acidity of anybody's rain.

The assumption of a "linear" relation between SO_2 emissions and acid deposition is reasonable but not necessarily correct, just as it is reasonable but not necessarily correct to assume that the amount of cake you can make depends on how much flour is at hand. The formation of acid rain may be limited by the availability of SO_2, in which case a linear relation is likely to prevail, or it may be limited by the atmospheric oxidizing agents that convert SO_2 into acid, in which case marginal reductions in SO_2 emissions may produce no change whatsoever in the acidity of the rain. Reducing the amount of flour does not change the number of cakes you can make if what you are really short of is sugar.

There has been much debate about the linearity hypothesis. A fairly large body of European data suggests that a given percentage reduction in SO_2 emissions would yield much less than the same percentage reduction in the rain's acidity. Indeed, European data collected from 1960 to 1975 show significant increases in SO_2 emissions coupled with constant or declining depositions of sulfate. On the other hand, data from the Hubbard Brook Experimental Forest in New York suggest that emissions and acid deposition go hand in hand. In late 1983, based on its analysis of the European and U.S. data, the National Academy of Sciences said this:

> On the basis of currently available empirical data and within the limits of uncertain-

> ty associated with the data and with estimating emissions, we . . . conclude that there is no evidence for a strong nonlinearity in the relationships between long-term average emissions and depositions in North America.

The double negative ("no evidence" of "nonlinearity") was deliberate, not to be confused with the affirmative conclusion that there *is* a linear emission-deposition relationship. The National Academy noted that its conclusion was "clouded" by three types of uncertainties —a severe paucity of experimental data, a lack of understanding of the meteorological and chemical processes that connect what comes down with what goes up, and ignorance concerning "natural variability" in the acidity of rain. But even the academy's nonconclusion on nonlinearity has been challenged by other scientists who would give more weight to the conflicting European data.

The "source-receptor" relationship. A largely independent question is the geographical one—not *how much* less acid rain we are likely to get for a given reduction in emissions, but *where* the benefit is likely to be felt if (say) emissions are reduced in the Ohio valley. Whose emissions, in other words, are causing whose acid rain?

In the old days, smokestacks were short—which meant that emissions stayed close to the ground and therefore relatively close to home. . . . Regulators, however, thought they knew better.

This used to be relatively easy to answer. In the old days, smokestacks were short—which meant that emissions stayed close to the ground and therefore relatively close to home. Ohio pollution for the Ohioans. The system had a certain rough justice.

Regulators, however, thought they knew better. The original Clean Air Act was built around "no-hot-spot" ambient standards—levels of pollution that are not to be exceeded in anybody's air, regardless of local emission rates. One way to reconcile the apparent contradiction of high local emissions (which are convenient for industry) and low local levels of pollution (which the legislation demands) is to disperse pollutants very broadly. And so it has come to pass that the 1,000-foot smokestack is now a fixed feature of our industrial landscape.

But, as Tom Lehrer's couplet informed San Franciscans some years ago, "The breakfast garbage that you throw into the bay / They drink at lunch in San Jose." Much the same seems to be true for air pollution, though the scientific details, once again, are cloudier than Lehrer acknowledged.

Even with tall smokestacks, it is possible that the bulk of pollutants stays reasonably close to home, or remains confined in a largely unmixed, downwind plume. But available evidence suggests that the air above the entire eastern region of the country may behave more like a well-stirred pot: salt sprinkled into the cauldron at any point on the surface is quickly dispersed, fairly evenly, throughout the entire soup. This assumption finds support both in theoretical models of wind dispersion of pollutants and from limited experimental data that correlate local deposition levels with emission levels averaged over many states.

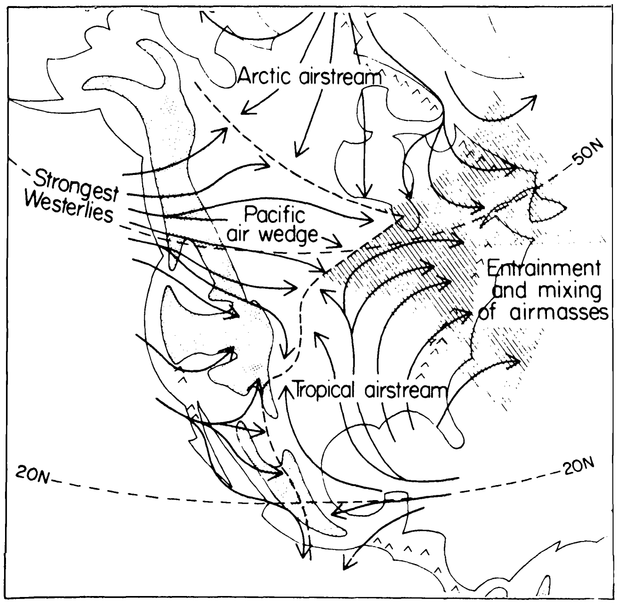
Nevertheless, the well-stirred-pot model of the eastern atmosphere has, at this stage, less than overwhelming scientific support. Other atmospheric mixing models suggest that pollution distributions look more like a marble cake, with the individual streaks traceable to identifiable local sources upwind. Surveying the available data and theoretical models, the National Academy concluded:

> On the basis of currently available empirical data, we cannot in general determine the relative importance for the net deposition of acids in specific locations of long-range transport from distant sources or more direct influences from local sources. We regard the problem of relating emissions from a given region to depositions in a given receptor region to be of primary importance and recommend that high priority be given to research relevant to its solution.

Tracer studies, in which inert chemicals are injected into plumes and then followed downwind, are under way.

Notwithstanding these uncertainties, we do have a fairly clear picture of three gross factors: which way the prevailing winds blow

Figure 1: Prevailing Wind Patterns



Source: National Academy of Sciences, *Acid Deposition*, p. 36.

(Figure 1), where SO_2 emissions are concentrated (Figure 2), and where the rain delivers most acidity (sulfate) back to the surface (Figure 3). And the picture here is not particularly ambiguous. It is quite reasonable to surmise from these three charts that what goes up comes down, and comes down pretty much where one might expect—downwind.

Bookkeeping at the Surface

When acid rain or dry acidic deposits do reach the lakes or land, a new set of complex chemical balances comes into play. Acid rain is one among many sources of acid and alkali; it will acidify the soil or water on which it falls only if the bottom line in a much longer list of entries in the acid-alkali books comes out litmus red.

The best understood entry is, unsurprisingly enough, man's own contribution. Current emissions stand at about 27 million tons of SO_2 a year. Under the well-stirred-pot model, that amount of pollutant is dispersed over perhaps 2 million square miles (a 1,500 x 1,500 mile area) of land and ocean—which translates to about 0.1 ounces of SO_2 deposited per square yard of surface each year. (For purposes of comparison, several day's production of human urine contains comparable amounts of inorganic sulfate.) But even if all the SO_2 is converted into acid, we still know nothing about the acid rain's impact on soil or lake acidity until we have assessed numerous other factors.

The chemical composition, thickness, and texture of the bedrock and soil are probably the largest natural variables in the acidification bookkeeping. Acid rain falling directly into a lake may be neutralized by the lake's alkaline bedrock—if the bedrock *is* alkaline and if the available "buffering" capacity of the lake has not already been exhausted by prior acid deposition. And rain that reaches the lake over or through the soil can be neutralized—or further acidified—by chemicals encountered along the way.

Geology and geography are therefore an integral part of acidification chemistry. Certain regions of North America have much less geochemical capacity than others to neutralize acid deposition, as Figure 4 shows. Soil in the Adirondack region of New York, for example, starts off as among the most acidic in the world. And the topography of the terrain surrounding the lake and the levels of snowpack may be important too. Faster runoff during spring melts may mean that acid snow has less opportunity to be neutralized in the soil, and so may cause "acid shock" to lakes and streams just when fish are spawning.

Trees can also add to soil acidity. The replacement of deciduous trees by conifers increases acid runoff, and the return of farmland acres to a more forested condition may have a similar effect. Forest fires, on the other hand, help counteract acidification by generating alkaline ash. Wetland bogs can also play an important role in acidification. For a long time beavers were thought to be prime culprits in acidification: their engineering proclivities increase acid by increasing shoreline organic decay.

Like the SO_2 emissions of man-made origin, these natural entries on the acid-alkali books are all variables that can change over time. In the Adirondacks, according to New York's Department of Environmental Conservation, the number of conifers has increased by 70 percent in this century, while farmland acreage has dropped by half; and in New York, the number of acres burned has decreased over 90 percent in recent decades due to (what was thought to be) improved forest management. There are, doubtless, other static and dynamic factors that affect acid chemistry in the woods and wetlands.

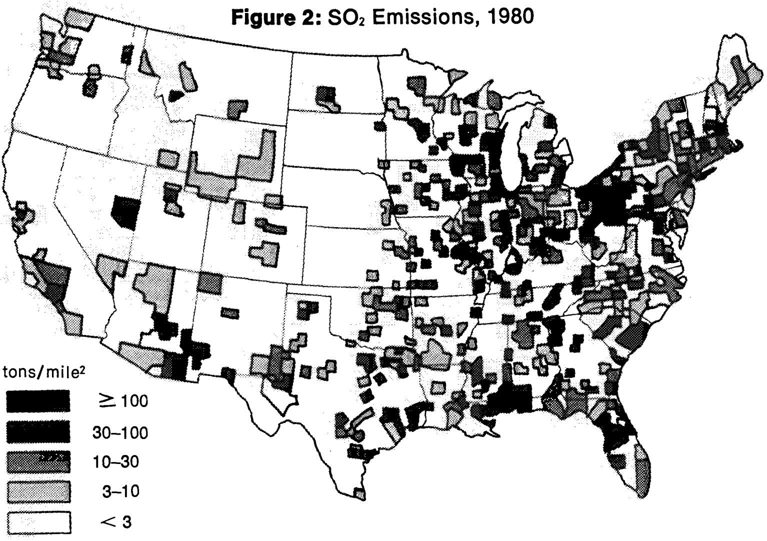
In some instances these various contributors to the acid-alkali balance may well be entirely overwhelmed by acid deposition of human origin. In others it is certainly the atmospheric SO_2 that plays the negligible role. What is beyond dispute is that keeping a full set of acid-alkali books for any large and complex ecological system is well beyond current analytical capabilities. Any one factor may shift the acid balance from "innocuous" to "grave"—or back again to innocuous. And it is very hard to anticipate, much less to quantify, every factor that is important. The scope of the acid rain problem, in other words, cannot be evaluated by a simple inspection of SO_2 emissions followed by quiet armchair reflection on the chemistry of the problem.

Measuring the Bottom Line

But one need not necessarily count every bean to determine how many end up in the bag, or how rapidly the bag is being filled. The acidity of soils and lakes can be measured directly and quite simply. The simplicity of the measurement, however, often obscures the complexity of the question to be answered.

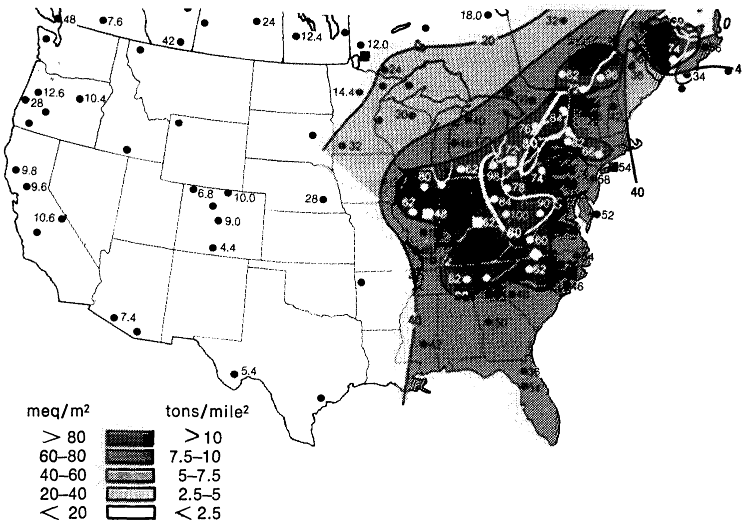
Before and after data. One large body of nonevidence receives much attention. "I've been to the mountain top," the disquisition often runs, "and I've seen the acid lake." This may be oratory, but it is not science. A Rawlsian insight into the lake's "original condition" is also needed. Sellers of diet programs and baldness cures know that their advertisements must contain *two* photographs, not just one, and acid rain science requires no less. The best evidence of human-induced acidification is a cor-

Figure 2: SO_2 Emissions, 1980



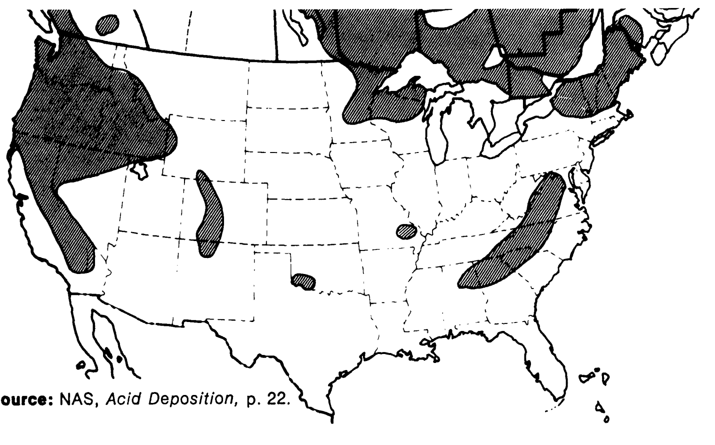
Source: Office of Technology Assessment, *Acid Rain*, p. 64.

Figure 3: Sulfate Depositions, 1980
(in milliequivalents/meter² and tons/mile²)



Source: OAS, *Acid Rain*, p. 67.

Figure 4: Regions with Low Capacity for Neutralizing Acid Deposition



Source: NAS, *Acid Deposition*, p. 22.

relation between historical levels of acidity in soils or lakes and emissions levels in nearby or distant areas.

There are indeed data of this character, and they reveal quite convincingly, that some lakes, in some areas, have increased in acidity over the past fifty years. But the data are very sparse.

Oceans and large rivers and lakes have abundant buffering capacity and for the most part have simply shrugged off man's acid contributions without difficulty. Evidence of acidification trends has been found almost exclusively in smaller lakes and streams, especially those at high elevations (above 1,000 feet). The most studied region is the New York Adirondacks, and the most widely cited studies have been by the New York State Department of Environmental Conservation. The department's first study, issued in 1976, surveyed 214 of the 2,800 Adirondack Parks lakes. Between 1929 and 1937 about 10 lakes were quite acidic. By 1975 that number had increased to about 105—or about 52 percent of the sample. The trend in this study is indisputable, but the percentages measure only the prescience of the investigators in their selection of which lakes to study. A later study, issued in 1984, sampled 1,047 lakes and ponds in the same region; it found 19 percent of the lakes acidified, representing less than 4 percent of the surface area of the water that was sampled.

Fish-population histories in lakes and rivers have supplied an indirect biological indicator of acidification trends, because fish cannot survive in excessively acidic water. Once again, there *is* some sign of acidification trends here: fish populations have indeed declined in some lakes and rivers in New York, Ontario, and Nova Scotia in recent years. But once again the evidence is very limited. The 300-page report on acid rain released by Congress's Office of Technology Assessment (OTA) in 1984—a report that I read as distinctly sympathetic to proposals for more regulation—contains less than two pages summarizing scientific correlations between historical changes in SO_2 loadings and observed changes in lake and stream acidity or fish populations:

> Directly comparing current conditions to historical data, only a small number of surface waters in North America are *known* to have acidified. . . . In the Adirondack mountains, the only U.S. location in which scientists have documented *fish population* declines, . . . New York State . . . has reported the disappearance of fish populations in about 180 lakes. Four other areas [outside the U.S.] are known to have experienced losses of fish populations associated with surface water acidification. . . .
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> Acid deposition may not be the sole cause of the changes. . . . Other man-induced stresses and natural processes can also alter surface water chemistry. However, the largest numbers of acidified and extremely sensitive lakes and streams are located in regions currently receiving the highest levels of acid deposition.

The only other before-and-after evidence that I have come across consists of core samples taken from the bottom of lake beds in the Adirondacks. These present a record of quite alkaline conditions prevailing until about 1 million B.C., neutral conditions until 10,000 B.C., and gradual acidification from then on. There *is* a trend here—but over a time scale much longer than that associated with SO_2 emissions of human origin.

The "Brand X" approach. If you cannot use before-and-after salesmanship, it is quite reasonable to turn to comparisons with the competition. This is an acceptable scientific method, but once again, the data currently available leave much to be desired.

In one major recent study commissioned by OTA, The Institute of Ecology (TIE) compared surface acidity levels in northwestern Ontario and northern Minnesota—regions that are *not* exposed to high SO_2 levels—with acidity levels in geologically similar areas of the northeast that *are.* On the basis of this comparison TIE concluded: "We estimate that about 3,000 lakes and 23,000 miles of streams—or about 20 percent of those in sensitive areas—are now extremely vulnerable to further acid deposition or have already become acidic."

What's shaky in this? A good bit. At the outset, the alarming 20-percent figure measures only one thing: how successfully TIE anticipated its own conclusions. The area studied by TIE was a carefully selected checkerboard of regions expected at the outset to be "sensitive" or "vulnerable" to acid deposition. A "better" definition of what area to study could, in other words, have raised the percentage to one hun-

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dred. But if percentages had been stated instead in terms of the neutrally defined eastern area in which acid rain falls, the OTA-TIE percentage would probably have been lowered by a factor of five or more.

More fundamentally, the measure of the "extremely vulnerable" or "already acidified" water area depends entirely on how fairly the "brand X" referent was chosen. That, in turn, depends on our very poor understanding of what makes areas "similar" for purposes of acid-alkali bookkeeping. Geology is certainly important, and the TIE study attempted to match the two regions it compared on that basis. But we can say with confidence that two regions are similar in all important respects other than acid rain deposition only if we fully understand all the important contributors to the acid-alkali economy. Identifying truly similar regions, in other words, depends on our ability to count the acid and alkali beans in a given ecological bag. And as already noted, that is a task well beyond current capabilities. Numerous variables other than geology may contribute to the acid balance, and no one has a clear idea of precisely what they all are, or just how important each one is.

Predicting the future. When we lack a clear picture of how acidified we are today, predictions about where we will be tomorrow start at a certain disadvantage. This has not, however, deterred people from trying to make them. The easiest (and therefore most popular) approach has been to set about determining how many lakes are "sensitive" or "vulnerable" to further acid precipitation. The technique is simple enough—current levels of alkalinity in lakes are measured, and the lakes with low levels are declared to be sensitive.

This type of investigation formed the basis of the recent OTA-TIE study, which concluded:

> About 17,000 lakes and 112,000 miles of streams lie within . . . sensitive areas. As a "best guess," about half of these lakes and streams have such limited ability to neutralize acid that they will acidify if enough acid pollutants are deposited.

Once again, one may pass over the percentage figure ("about half") as a pure artifice of TIE's own selection of what region to study. Much more dubious is the definition of just which bodies of water are "critically acidified" or "sensitive" to further acid deposition. Recall that man-made emissions deliver something on the order of 0.1 ounce of SO_2 per square yard of surface a year. If that surface is a lake, the TIE study labels it sensitive to the acid deposition if about two feet of the lake's depth currently contain insufficient alkali to neutralize that equivalent amount of acidity.* The method is delightfully simple. Too simple.

To begin with, the two-foot figure seems more than a little arbitrary. Why not two inches or twenty feet? More important, however, is that water alkalinity levels tell us absolutely nothing about the condition of the surrounding soil, bedrock, and chemistry of the ecology, and all scientists agree that those factors play a central role in the acidification dynamic. Lakes collect water not only from direct precipitation on to the lake's surface, but from the entire local watershed. Total acid deposition per unit area of lake will thus be much larger than that from rainfall directly on to its surface—but the alkali available to neutralize the acid can also be vastly larger than what is already in the lake.

In short, TIE's "best guess" of how many lakes will acidify if "enough" pollutants are deposited is certainly a guess; "best," no doubt, is an assertion of sincerity and good faith, but not an indication of good or even adequate underlying science. To be sure, it may be extraordinarily difficult to make a better guess. But a mechanical measurement of current alkalinity levels in the water nevertheless tells us very little. The crucial questions are where that alkalinity came from, how much more is available, or where alkali levels will go if acid depositions continue. Those questions are simply not answered or yet answerable. "All is flux," wrote Heraclitus two thousand years ago, "it is not

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*The study does not use the two-foot figure as such. Instead, it labels a lake "sensitive" if the alkalinity concentrations fall below 200 micro-eq/l. A two-foot depth of water contains about 500 l/m^2 of surface. Combining the two numbers, the lake is labeled sensitive if a two-foot depth contains alkalinity of less than 100 meq/m^2. And 100 meq/m^2 is very roughly the alkaline equivalent of about 0.1 oz. of SO_2 per square yard. I use yards, ounces, and feet of lake depth not because these are the conventional scientific units but because they are likely to be more familiar measures to most readers. My numbers are all very approximate, and deliberately so.

possible to step twice into the same river." The same is true for an acid lake in 1984. Today's state of the lake is a poor predictor of tomorrow's conditions, most especially when the prediction is that they will be very different.

Environmental Impacts

The last and surely most important question is why anyone cares whether rain, lake, or soil acidity is changed. Five categories of risk from acidification are usually flagged for closer attention.

Aquatic resources. If acid rain does culminate in the acidification of water systems, there is little doubt that at least some environmentally adverse consequences will follow. Fish and other biota do not take well to acid lakes. Acidity can disrupt the fish's own internal chemistry to the point where it is unable to function, or may injure fish eggs and fry. Acidification can also mobilize metals such as aluminum from the soil and bedrock, and these can also be toxic to fish. Of particular concern is "acid shock" from high concentrations of pollutants delivered suddenly into lakes during snowmelt. There is, in short, a reasonably firm consensus that if wide-scale acidification of lakes and streams occurs, it will have significantly adverse ecological impacts. These, in turn, can adversely affect sport fishing, tourism, and other economic or aesthetic values.

Forests. The second large ecological issue concerns the impact of acid rain on forests and woodlands. The Electric Power Research Institute (EPRI)—an institution funded by electric utilities—notes:

> Trees, primarily conifers, have been damaged or are dying at unusually rapid rates in recent decades in certain areas of the northeastern United States and Europe. According to quantitative documentation, red spruce have declined atop summits in Vermont's Green Mountains, a decline that has also been observed in New Jersey's Pine Barrens. And in West Germany, large areas of Norway spruce and fir have died or appear to be injured. What troubles researchers is that all these areas receive large amounts of acid rain and other pollution.

It is not difficult to postulate mechanisms by which acid deposition could affect forests—both favorably and unfavorably. Some forests are sulfur-poor, so SO_2 deposition there may promote growth. In others, acid deposition may remove nutrients stored in leaves or in the soil. Most forest soils exhibit no deficiencies in the types of nutrients that acid deposition would leach out, but a study of the Adirondack Mountain forest suggests that some northeastern forests are notable exceptions. Finally, acid deposition may mobilize toxic metals such as aluminum that are also harmful to trees.

But both EPRI and OTA agree that there are other possible causes for the impacts on forests that have already been observed, and that the link between acid deposition and forest damage is speculative in all but the most severe cases of acid deposition. (The widely discussed damage to the forests in Germany is associated with exceptionally high levels of SO_2 loading.) In the vast majority of instances, acid rain, ozone, heavy-metal deposition, drought, severe winters, or a combination of these factors are all possible causes of the observed forest damage. OTA concludes:

> To summarize the potential for long-term forest productivity effects from both acid deposition and gaseous pollutants, at the present time OTA can state only that such interactions might occur and that their probability of occurrence is greatest in . . . regions of the Eastern United States. . . . The mechanisms involved and the relative importance of those mechanisms to forest growth must be studied further in order to better describe and eventually quantify these potential effects.

Agriculture. No direct link between acid rain and crop damage has been established in the field. The evolving consensus has been summarized in the 1982 annual report of the National Acid Precipitation Assessment Program: "The most consistent conclusion to be drawn from agricultural research at all scales and with all species has been 'no effect' at current average ambient pH levels of 4.0 to 4.2." This is not surprising in light of the high levels of acidic fertilizers and alkaline lime that farmers regularly add to their soils.

Materials. Sulfur dioxide and other air pollutants can corrode a broad range of materials, including stone, metals, textiles, leather, and paint. Damage can occur to both culturally significant statues, structures, and monuments, and to routinely used construction materials. The damage is qualitatively similar to that resulting from natural weathering, so estimating its extent and severity is very difficult.

One recent study (produced by Mathtech Inc. for EPA's Office of Air Quality Planning, 1982) estimated that a 30 percent reduction in current ambient SO_2 levels would produce about a $300 million savings annually for about half of the households and a tenth of the production sector. The calculation as it stands contains large uncertainties; it cannot, in any event, be extrapolated to the nation as a whole. Apart from this study, there is abundant anecdotal and qualitative information about the potential for pollution-induced damage, but almost nothing that is reliably quantitative.

One might list, along with materials damage, impairment of visibility. Once again, this is not a problem of acid rain proper, but is linked to its precursors, SO_2 and sulfate. There is little doubt that pollution impairs visibility.

Human health. In high enough concentrations, sulfur dioxide itself (as distinguished from acid rain) may have harmful health effects, particularly to members of the population already suffering from respiratory disease. Some researchers have found a significant association between SO_2 levels and mortality, though others conclude there is no substantial link. But in any event, health problems from SO_2 itself are already addressed through EPA's ambient SO_2 standard and are quite distinct from the issue of acid rain.

Sulfuric acid and ammonium sulfate particles, the atmospheric byproducts of SO_2 chemistry that *are* part of acid rain, could conceivably have independent health effects of their own. It is also possible that these pollutants act synergistically with others, such as metallic ions, nitrates, and fine soot particles, to cause observable health effects. There is, however, no direct evidence showing any detectable human health effects from the highest concentrations of sulfuric acid or sulfate particles presently found in the environment.

Acidic water can dissolve aluminum, copper, lead, mercury, and other toxic metals from the soil, and from plumbing systems. While the chemistry suggests that a problem here is conceivable, once again no direct link between drinking water contamination and acid rain has been established. In any event, the acidity of municipal water systems can be monitored and corrected quite easily.

Uncertainty and Ideology

All of which leaves us nowhere in particular. While it is not difficult to describe acid rain's possible environmental consequences in the abstract, it is enormously difficult to assess them quantitatively. There is certainly no scientific consensus on how widespread, imminent, or irreversible the ecological damage might be.

Much of the current alarm about acid rain is voiced in the pseudo-science of "maximum conceivable harm" or some synonym thereof. This is a weapon that has been used to devastating effect against the electric power industry at least once before, in the attack on nuclear generation. One must keep in mind, however, that "maximum conceivable harm" measures nothing but the fertility of the human imagination. The maximum conceivable accident in a single bathtub is one in which the citizens of the nation line up, fall in, and drown, one at a time. This particular terror, "conceivable" though it manifestly is, has yet to attract widespread regulatory attention, and perhaps for good reason.

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When we cannot say with confidence *whether* science supports regulatory action, there is bound to be more than a little disagreement over *how quickly* regulatory action should be taken. Damaged forests and lakes certainly do not recycle quickly, at least not without expensive help, but it is most uncertain whether we are in fact on the brink of any widespread injury from acid rain. Those who adopt the most pessimistic interpretation of the available scientific evidence readily conclude that prompt reductions in SO_2 emissions are urgently required; even maintaining emissions at current levels will lead to serious cumulative damage. Those who read the evidence in a more optimistic light can conclude, equally readily, that if the acid rain problem exists at all, it is not a problem that calls for hasty change in the regulatory climate.

Even more uncertain is how quickly ecological benefits would be realized if emissions were reduced. This last scientific question of the acid rain debate is of considerably more than academic interest, though it is often given little attention. If a new regulatory initiative were followed by prompt, visible, improvement in environmental conditions, there would, of course, be little more to debate. But, as Chris Whipple of EPRI has pointed out, the *failure* to see prompt environmental improvement following the implementation of a new regulatory program could be interpreted as proof that either (1) the controlled sources were not the cause of the problem or (2) a larger control program was needed. Undoubtedly a certain sense of *déjà vu* would accompany this dilemma if it were to arise.

Why, one might ask, has acid rain generated such large amounts of political heat from so little scientific light? Environmentalists, of course, have little affection for the coal economy and much aversion to air pollution. And Canada and a number of northeastern states are seriously and legitimately worried about the environmental effects of acid rain. Their concern is greatly amplified by the perception—not fanciful, but not solidly anchored in science either—that it is not primarily *their* acid rain (which conveniently blows out over the Atlantic) but rather acid rain from numerous power plants in the Midwest that is causing the problem. Environmental ideology and inter-regional rivalries of this character strongly affect where and how dogmatically most of us come down on the unresolved scientific questions.

II. THE REGULATORY OPTIONS

The gravity of the acid rain problem—a measure of the potential benefits in a regulatory calculus—involves scientific questions that are far from settled. But if we *are* to regulate acid rain, a largely distinct question is how we should set about doing so. Some of the technical aspects of the regulatory options are mundane enough. But the policy planner can nevertheless take delight in the rich range of opportunity for regulating wisely or foolishly, frugally or profligately, progressively or so as to entrench the acid rain problem forever.

Tear down the Stacks?

Let me start where no one else seems willing to begin. The acid rain controversy is fueled largely by inter-regional and international finger-pointing. So why not bring the nub of the dispute back home? The average height of utility smokestacks has tripled in the 1970–84 period, largely to meet EPA "ambient air standards" by dispersing pollutants very broadly rather than by curtailing their emission. We *could* just cut the tall stacks back down to size. Short smokestacks keep pollution closer to home, where, in fairness, it would seem to belong.

I recognize, however, that shorter smokestacks are not high on anyone else's list of preferred regulatory options. Moreover, dilution may in fact be a very good control strategy. As countless cancerous rats might attest, many things are harmful in large concentrations but innocuous or even beneficial in smaller ones. It would be a pity to tear down the stacks if the result were an increase in local harm greater than the offsetting benefit at remote locations.

Tall stacks, it is therefore plain, are likely to remain tall. But Congress did respond to the tall stack problem in 1977, so in the future at least, dilution is likely to be used less often as a strategy for attaining local ambient standards. The Clean Air Act Amendments of that year deny polluters emission control "credit" for the locally favorable effects of smokestacks built taller than would be dictated by "good engineering practice." Prodded by a federal court order, EPA recently proposed new rules that will require some tall-stack emitters to add pollution control equipment or switch to cleaner fuel. The rules are expected to eliminate between 0.8 and 2.8 million tons of SO_2 emissions a year, costing industry from $0.9 to 4.6 billion in capital expenditures and from $0.3 to 1.4 billion in annual operating expense.

Control Possibilities and Prices

In the larger picture, however, tall stacks are only a regulatory idiosyncrasy. And so we turn to emission controls. Sulfur dioxide can be contained or controlled at almost every stage of the fuel cycle—in the choice of fuel at the outset, during the combustion process, or after deposition in a lake or forest.

Changing fuel. The first possible answer to excess emissions of SO_2 is to work with a lower-sulfur fuel. Natural gas, hydroelectric power, uranium, and most oils are all obvious candidates. But natural gas is expensive, and its use for electric power generation has been discouraged by federal law. Oil is expensive too. Hydroelectric power is not much of an option in the flat Midwest where SO_2 emissions are highest. Uranium is the sulfur-free fuel most engineers would probably select as the alternative of choice, but it too is believed by some to entail unacceptable environmental consequences.

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This would appear to leave only coal as the main short-term alternative fuel to coal—a distressingly narrow range of choice. Still, some coals are much cleaner than others, and coal switching can cut emissions considerably. But clean coal sells at a premium price, and the premium would be likely to rise if regulatory requirements were tightened. Coal switching can also cut plant efficiency, because boilers are often designed to perform optimally only with fuel of particular quality. One broadly cited estimate (by PEDCo. Environmental Inc. for the Department of Energy) suggests that switching coal to cut annual SO_2 emissions by 6 million tons would cost utilities about $1.4 billion a year (1982 dollars), or about $250 per ton of SO_2 removed. Coal switching also entails indirect costs for producers of dirty coal in northern Appalachia and the Midwest, at the same time that it represents a boon for producers of clean western coal.

A separate fuel-switching option is to buy dirty coal and clean it before burning it. The technology of physical coal cleaning is already available and in use. A Department of Energy study estimates that coal cleaning could yield a 1.5 million ton additional reduction in SO_2 emissions, at about $580 per ton of SO_2 removed. Other coal-processing options, including chemical cleaning and coal gasification, are also under study, but not yet at the stage where they can be priced or quickly put into effect.

Combustion and emission controls. The next possibility is cleaner burning. Several types of potentially efficient and cheap new technologies—the limestone multistage burner and the fluidized bed combustor—are under development, but none is yet in widespread commercial use. As a result, no very reliable estimates of their costs are available. One EPRI publication suggests that emission reductions might be achievable at about $800 per ton of SO_2 removed.

Scrubbing flue gases comes next in the chain of control possibilities. The smoke from the burner is sprayed with large volumes of an alkaline water-limestone mixture, the sulfur is chemically captured, and the large volumes of scrubber sludge are carted off to landfills. The technology is already well developed—EPA requires scrubbers in all new coal-fired power plants—but costs are high. Up front capital costs for a mid-size plant are typically in the range of $80 to $200 million—with higher unit costs for attaching scrubbers to smaller boilers. Scrubber operation is also expensive. Typical bottom line costs are in the range of $700 to $1,000 per ton of SO_2 removed.

And this brings us to a critical variable that cuts across all the regulatory options—the question of timing. Retrofitting scrubbers on to old plants—a favorite quick fix in some quarters—costs 10 to 40 percent more than building scrubbers into new plants as the old ones are retired. And a uniform, do-it-now, scrubber prescription also precludes the phased introduction of nonscrubber control technologies that are potentially cheaper and even cleaner. The owner of an old power plant with a new scrubber, like the owner of an old car with a recently installed new transmission, has a strong incentive to nurse the plant along for as many more years as possible, to recoup the investment that has been made. One cannot place any certain figures on the price of a hasty or prescriptive cleanup program, but EPRI has estimated that savings of $4 billion a year are possible under a regulatory program that encourages the use of new technology and permits a phased reduction in emissions.

Watershed management. Once SO_2 goes up the stack, little more can be done until it comes down again. But acidity can be neutralized in lakes themselves, or environments can be managed to cope with higher levels of acidification. Sweden, for example, has conducted an intensive liming program for several years, in which large amounts of crushed limestone or lime are added to the water or applied to the adjacent soil or forest. Smaller scale liming has also been attempted in Norway, Canada, and the United States.

The costs of liming lakes in New York have ranged widely from $30 to $300 an acre. A recent study placed a $2 to $4 million a year price tag on liming several hundred acidified lakes in the New York Adirondacks. This is very cheap as acid rain solutions go. But liming is a simple and straightforward solution to precisely the same extent that acid rain is a simple and straightforward problem—which is not at all. Nevertheless, if lake acidification ultimately proves to be a largely localized and uncommon problem, liming may still prove to be a viable control option. The introduction of acid-resistant breeds of fish is yet another possible response to low levels of acidification.

The Economists Dream On

The variety and complexity of the emission- and damage-control alternatives suggests that choosing among them is a task that is much too delicate to be resolved efficiently by the visible hands in Washington. If there is to be regulation, perhaps the market might play some small role in shaping its final form.

Suppose that Congress in its wisdom should decide to shoot for what has already been proposed in the most ambitious bills—a 10-million ton cut in annual SO_2 emissions. The accompanying table contains OTA's (in my view optimistic) estimates of total and marginal costs of a least-cost emission control program. The marginal cost for the last million tons of SO_2 emission reduction would be in the vicinity of $1,000 per ton. This pleasantly round figure therefore represents a reasonable guess about the "right" price to place on SO_2 emissions under a tax-incentive regulatory scheme.

COSTS OF REDUCING SO_2 EMISSIONS IN THIRTY-ONE EASTERN STATES
(costs in 1982 dollars)

Allowable Emissions (lb. SO_2/MMBtu)	Emissions Reduced (million tons SO_2)	Total Cost ($ billions/yr.)	Average Cost of Reductions	Costs per Marginal Ton Reduced
2.5	4.6	0.6–0.9	170–240	320
2.0	6.2	1.1–1.5	200–280	440
1.5	8.0	1.8–2.3	260–330	700
1.2	9.3	2.6–3.4	310–400	740
1.0	10.3	3.2–4.1	350–440	830
0.8	11.4	4.2–5.0	400–480	1,320

Note: Estimates exclude costs to meet current state implementation plans or to offset future emissions growth; they assume that each utility chooses the most cost-effective control method.

Source: Office of Technology Assessment, *Acid Rain and Transported Pollutants,* p. 169.

> **. . . there is no doubt that congressional enactment of a pollution tax is about as likely as a visit from the Tooth Fairy. . . . But the idea of an emission tax nevertheless provides some food for thought.**

Now there is no doubt that congressional enactment of a pollution tax is about as likely as a visit from the Tooth Fairy. Hostility to emission taxes runs deep in industry as well as among many environmentalists, and with enemies as varied as that, who needs the friendship of a few economists? But the idea of an emission tax nevertheless provides some food for thought.

The tax would put at least one emission control strategy into effect within days of its enactment—years faster, in other words, than scrubbers, and months faster than coal-switching alternatives. Utilities currently use "economic dispatching" of power supplies—that is, as daily demand rises and falls, cheaper generating units are brought on line first, and turned off later, than more expensive ones. But dirt, under the current regulatory structure, is cheap, so dirtier units are often used in preference to cleaner ones. The obvious alternative is to use the cleaner units first and most, the dirtier ones last and least. An emission tax immediately encourages this "environmental dispatching" option.

More important is that a regulatory tax surely promises much more environmental improvement than any prescriptive program. Avoiding taxes, as most of us discover every April, brings out the very best and most creative that human ingenuity and cupidity have to offer. The scrubber-only regulatory proposals recently considered in Congress would have cut off 10 million tons of annual emissions in a one-shot, unimaginative solution—and thus would have left 17 million tons entirely untouched. An emission tax, in contrast, would maintain a steady pressure for more control, even while it permitted regulatees to select control strategies efficiently in time. A tax has the added advantage of fairness, since it could be assessed not only against giant electric utilities—everybody's favorite deep-pocket target—but also against other polluters who account for almost one-third of total SO_2 emissions.

To be sure, an emission tax also has some potential problems. First, emissions must be monitored. This is administratively less convenient than supervising the one-time installation of a scrubber. But with potential savings from efficient regulation in the billions of dollars it would certainly be possible to afford the necessary inspectors and monitoring equipment.

A second possible difficulty concerns managerial psychology. Most utilities are regulated monopolies, reimbursed by ratepayers on a "cost-plus" basis. It is conceivable that industry executives would simply pass the emission tax on to their consumers and worry no more about acid rain. But not likely. Public utility commissions do not pass through to ratepayers costs incurred through "imprudent" management choices. If cost-effective control strategies are readily available, pollution as usual would surely be discouraged.

The real difficulty with a pollution tax is choosing the "right" marginal rate. All one can say is that this would be much less of a problem than setting out a command-and-control regulatory program in all its detail. And readjusting a poorly chosen tax would surely be much easier than excising 1,000 pages of prescriptive regulation from the *Federal Register*.

Where's the Pork?

The emission tax is surely a thing of market beauty, but it is also political poison. The first problem with a $1,000-per-ton tax on SO_2 would be too much revenue—about $20 billion a year, from the residual 20 million tons or so of emissions not eliminated. Spread over 50 million eastern and midwestern households the resultant rate shock (partly in consumer electric bills, and partly in increased costs for goods manufactured by electric-intensive industries) would be in the range of $400 per year—this in addition to $150 or so attributable to emission-control expenditures by utilities.

But the emission-tax revenue could, of course, simply be returned to the utilities, and hence to the consumers. The refund obviously would not be in proportion to the amount of SO_2 each utility emits, but rather in proportion to the amount of electricity each generates. The marginal cost of SO_2 emissions would then remain close to $1,000 per ton, while the industry-wide average cost of generating electricity would not increase at all. Dirtier-than-average utilities would simply subsidize cleaner ones, and inter-utility environmental dispatching would be encouraged.

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The regulatory burden would nevertheless still fall particularly hard in the Midwest, where SO_2 emissions are highest. And the evolving consensus seems to be that because acid rain falls equally on the just and unjust, the just must share equally in the cost of doing something about it. This notwithstanding the fact that it is the unjust who earlier absconded with the umbrella. It may seem perverse to ask the consumers served by clean utilities to subsidize cleanup efforts by dirty ones, most especially since clean generation already (not surprisingly) costs more. But if we should decide to regulate, Congress would probably insist that the polluted pay along with the polluters. One proposal has been a tax on eastern non-nuclear electricity consumption to create a trust fund for buying scrubbers.

But why be so specific about how the money is to be spent? Even under a "polluters-are-paid" principle, the inefficiencies of command-and-control regulation could be avoided. The mirror image of the emission tax is a subsidy for not emitting. If each utility's 1985 emission levels were grandfathered onto the books, a $1,000-per-ton payment for emissions reduced would create efficient pollution-control incentives almost as well as a tax on emissions at the same rate. (But not quite as well. A tax on pollution emitted would increase the price of electricity and so lower electricity consumption and SO_2 emissions more than a subsidy for pollution reduction at the same marginal rate.)

Regrettably, the baksheesh would probably not stop even here. Any incentive structure that encourages cost-efficient reductions in SO_2 emissions will end up weighing heavily on eastern producers and miners of dirty coal, because burning clean coal is by far the cheapest way to limit emissions. Which means that if polluters *are* to be paid, the miners of dirty coal will also be in the receiving line.

Once again, the money can be raised from whomsoever Congress thinks should pay—most likely all eastern consumers of fossil-generated electricity. The question then will be *how* to deliver this particular kickback. The expensive way is to insist on the use of scrubbers as the means for controlling emissions. We already do this with new power plants, in a monstrosity of regulatory policy crafted by a bizarre legislative alliance between environmentalists and dirty-coal producers. This indirect form of subsidy has worked all right, but, as Paul Portney has calculated, at a trifling price of $320,000 a year for each coal miner's job protected (*Regulation,* November/December 1982).

Surely the miners and producers of dirty coal can be bought off for somewhat less. The key is to pay them in cash, rather than in the specie of command-and-control regulation. Once again, it may be perverse to reward people for not doing something judged to be antisocial—the very idea gives a tantalizing new meaning to "wages of sin." Be that as it may, it is certainly insane to spend more for the purpose than is absolutely necessary.

The Regulation-as-Usual Impasse

Whether it takes the form of efficient tax or inefficient prescription, direct regulation of coal-fired power plants can undoubtedly curtail some part of acid rain emissions. Some part indeed—a relatively small one. Even at $5 to $10 billion a year, the most ambitious proposed programs would leave almost two-thirds of current SO_2 emissions untouched. Regulation-as-usual will thus, more than anything else, largely preserve and entrench the status quo—with at least 17 million tons of SO_2 still emitted into the atmosphere every year.

With electric power, in other words, the promise of more regulation has finally reached a dead end, a result that should be wholly unsatisfactory to *both* environmentalists and electric utilities. How do we come to find ourselves in such a fix?

Nature, to start with, has been less than kind. The sulfur in coal most undoubtedly is of natural origin, derived either from coal's vegetable precursors in the Carboniferous period of this continent's history, or from the geological habitat these plants selected for their anaerobic graves. Technology is also less than perfect. Electric power plants (or even electricity conservation measures) of any description always entail environmental consequences of some type: perfect cleanliness, like perpetual motion, still eludes us. But the regulatory system itself can also claim some large measure of credit for bringing us to where we are now—glumly contemplating a gigantically expensive dose of regulatory medicine that promises, at best, only a one-third cure.

Our electricity supply, it must be remembered, was not always so tightly linked to coal. Electricity can also be generated using oil, gas, hydroelectric power, or nuclear fuel, or even (conceivably) some of the "renewables" such as solar or wind power. There is, in addition, the option to stretch what we have further through efficient use and conservation. But in recent years, ample reserve capacity and modest demand have impelled our legislators and regulators to say no to almost everything but coal. We reject natural gas as an electric generator fuel because it may be in short supply for home heating. We reject oil because its use increases our dependence of foreign supply. We reject hydroelectric power because it floods valleys or threatens anadromous fish, the furbish lousewort, or the snail darter. And we reject uranium because Jane Fonda and Meryl Streep tell us it's too dangerous.

Which may explain why about all that is left and economically feasible in 1984 is coal;

after all, the "no" pigeons having been shot from the sky, the "yes" pigeon finally came home to roost. But coal, it would appear, may mean acid rain. And acid rain may prove for the environment to be the least acceptable choice of all. The environmental-regulatory complex, in short, spent the last twenty years forcing utilities to use what may prove to be the most environmentally damaging generating technologies, and is now exhorting them to spend the next twenty crafting a silk purse of clean electricity from the sow's ear of dirty coal. When you see environmental regulation of this character, reach for your gas mask. And grab your wallet.

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The Deregulatory Option

There are limits to what can be achieved through regulation. This is a lesson that has been learned the hard way once before. Five hundred years ago environmental regulators made it a capital offense to burn coal in London. It was already clear then that coal burning emitted noxious fumes, whereas there was abundant "clean" wood available. In the end, of course, people switched to coal anyway, once England's forests had all been consumed for fuel. The forests never returned.

Today, ironically, it is the continued use of coal that threatens forests on this side of the Atlantic. All of the extant acid rain proposals accept the perpetuation of a coal-dominated electric economy, and all provide for still more regulation of coal furnaces. What is most striking about the numbers in these proposals is that even the most ambitious offer so very little. As noted earlier, the prescriptive, scrubber-based scheme for controlling acid rain is (at its most optimistic) a 10-million-ton bandaid on a 27-million-ton per year SO_2 hemorrhage. If environmental impacts of acid rain are cumulative, as many environmentalists suggest they are, the scrubber-retrofit proposal is a fraud that would only postpone, for a few years, the inevitable environmental catastrophe they expect.

There is another way to curtail acid rain—less visible than a new, multi-billion-dollar regulatory program, certainly less dramatic, but in the longer term more effective. In a comprehensively regulated industry such as electric power, where all the statutory presumptions are against new technology and new generating capacity, far-reaching change demands a selective *deregulation* of environmentally preferable alternatives.

Federal regulatory reform could do much to encourage the use of cleaner fuels, including gas, uranium, and water. State public utility commissions have the power in their hands to facilitate the capital turnover needed to speed the retirement of old (dirty) plants and their replacement with new (cleaner) ones. The courts, by curtailing the opportunities for litigating every new initiative to death, could help restore to the electric power industry the confidence that is needed to encourage technological experimentation and change. Technological change and capital turnover are inseparably linked to environmental protection; only a regulatory system receptive to the former can achieve much with the latter.

Better generating technologies are in fact already available or on the engineering horizon. Limestone injection and the fluidized bed furnace hold out the promise for both cleaner and more efficient coal combustion. The helium-cooled fission reactor is essentially incapable of meltdown, and so might displace a good bit of coal while answering some of the current concerns about water-cooled nuclear power systems. There are still possibilities for more (and more efficient) development of hydroelectric power. Safer and more effective means of conservation can also be found.

None of these solutions is environmentally perfect, and many have yet to be proved in commercial operation. Some will surely not live up to environmental or economic expectations when they are tried. But if we confront acid rain's uncertain science honestly, we must recognize that there is no real choice but to seek out and experiment aggressively with these new alternatives. If acid rain *does* present a real and long-term problem, we must search for equally real and long-term regulatory solutions.

III. DRAWING THE YARROW STRAWS

In the end, the scientific side of the coal-sulfur economy and the existing proposals for new regulation must of course be weighed together. Where does the cost-benefit balance come out? It is still impossible to say.

The costs of regulating acid rain are certainly clear enough. All the regulatory proposals are unquestionably expensive. But the environmental stakes are very large as well, even though they remain much more uncertain.

The fairest conclusion on the scientific side of acid rain—the benefit half of the regulatory calculus—is that for North American conditions, no fair conclusion can yet be reached. It is quite clear that acid rain has already caused some damage; it is equally clear that evidence of the damage is still confined to very small regions of this country and Canada. There can be no disputing that acid rain "might" in the future cause severe and widespread ecological harm, because this is not a disputable statement of fact or science. "Mays" and "mights" are issues of faith and ideology; scientific claims are made of the much sterner stuff of stated and defended probabilities. The scientific community is as yet unwilling to reach firm conclusions about the likelihood of the widespread ecological risks of acid rain that some have hypothesized.

Scientific uncertainty about the impact of acid rain is, however, not a reason to take sides on the proposals to regulate it. Cost-benefit balancing, it has been charged, is no more objective or neutral than the literacy tests in the old South. To give lie to that colorful claim, we must concede that certainty on the cost side of the scales does not necessarily outweigh uncertainty on the benefit side. Scientific uncertainty, like science itself, is—or at least should be—politically neutral. Ignorance supports "emissions as usual" no more (and no less) than it supports a firm change in regulatory policy. In many areas of regulation—with drugs, pesticides, food additives, nuclear power, and aircraft, for example—ignorance about health, safety, and environmental consequences is translated by statutory presumption into a regime of strict—not lenient—regulation. There is no scientific reason why the imponderables of acid rain should, or should not, be treated any differently.

One thing, in any event, is quite clear: If we *do* conclude that a new regulatory initiative is in order, we must recognize that, from the national perspective, there are distinctly better and worse ways of implementing it. The short-term, scrubber-based remedies that have been proposed are built on the unsupportable speculation that a 10-million ton a year quick fix is both necessary and sufficient to make a difference. While some fragments of scientific analysis have been wheeled out to rationalize this particular regulatory target, they have found few adherents in the mainstream scientific community. Real, long-term solutions to acid rain lie instead in the aggressive promotion of cleaner coal and noncoal technologies. The regulatory system has a large role to play here. Over the past two decades, environmentally regressive regulatory pressures have driven utilities inexorably toward an all-coal, old-technology electric economy. These pressures should be relieved. Regulators will have to learn to do less, not more, with regard to those technologies that hold out the best promise for environmental progress.

So where *should* one stand on acid rain? It is still largely a matter of faith. Recall that the *I Ching* believer draws yarrow straws to determine the yin-yang hexagrams that will control his life and demeanor. The science of the process is certainly important, and oriental sages have spent much time and effort analyzing the sixty-four arcane patterns that the yarrow straws can combine to create. But because the science itself is more than a little cloudy, the faith of the drawer also plays a crucial role in the exercise. And so it still is with acid rain. ■

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