Chapter V

ENVIRONMENTAL IMPACTS

Chapter V.- ENVIRONMENTAL IMPACTS

Chapter V
ENVIRONMENTAL IMPACTS

INTRODUCTION

Memories of the era when coal dominated the U.S. energy supply are blackened by visions of **soot-laden cities, discolored** streams, and scarred landscapes. Since the heyday of coal, **Americans** have become not only "spoiled" by the cleaner **fossil fuels** —oil and natural gas — but also more protective of their natural environment. They want to breathe clean air and drink pure water, and they insist that, after its resources have been removed, the land remain capable of supporting both natural ecologies and a thriving agricultural economy. Thus, if coal is to return to prominence in U.S. energy plans, its comeback must be staged under environmentally sound methods of extraction, cleaning, transportation, and combustion.

The "residuals"-unintended products that may affect the environment — from each operation involved in handling coal are illustrated in figure 19. The avenues of disturbances to the environment are abundant, and the intensity of even the minor disturbances will be magnified by the large quantities of coal forecast by most current energy projections. The most vociferous objections to coal use have stemmed from concerns about the pollutants released to the air during combustion and the variety of damages to land and water that result from mining. Most of these impacts are now addressed by Federal legislation, as indicated in figure 20. In general the legislation establishes either ambient air, land, and water quality standards, or minimum pollution control performance standards that can be achieved economically and effectively by the best state-of-the-art technology. **In response to the passage of this large** body of environmental legislation, public attention is shifting to questions of whether the new laws and technology are adequate, whether they are effectively enforced, and whether they are themselves the cause of environmental problems—such as the pollution of one environmental medium by the wastes collected to protect another.

Figure 19 **summarizes** only the byproducts of coal-related activities and not the resulting effect on public health or on the ecosystem at large. These effects may vary in their severity — from the annoyance and property damage of blasting to a possible tragic increase in ill-ness or mortality from air pollution. The effects also vary in their temporal and regional extent— from the short-term creation of dust at a local minesite to the possible long-term global alteration of climate by carbon dioxide (CO_2). The environmental effects of coal also differ from region to region, not only because of the unequal concentrations of coal extraction and combustion activities but also because of the difference in geologic, demographic, topographic, and climatic factors. Thus, for example, surface mining may be more benign in the lignite fields of Texas than on the steep slopes of Kentucky. As another example, the most significant impact of a coal-fired powerplant in New England might be to worsen the urban air breathed by millions, while that of a utility in Utah might be to degrade the quality and visibility of the clean air that is a major resource in that region.

Figure 19 emphasizes that each environmental impact may be envisioned as primarily affecting one of the three media–air, land, and water. This viewpoint is adopted as the organizational structure for this chapter, although it should not obscure the very extensive interactions among the three media. Each of the next three sections examines the impacts of coal use on one of the three media, describes the resulting effects on health or ecosystems, and assesses the ability of relevant legislation and control technology to mitigate these effects.

This chapter draws selectively on analysis of future energy impacts available in the liter-

Figure 19.— Environmental Disturbances From Coal= Related Activities
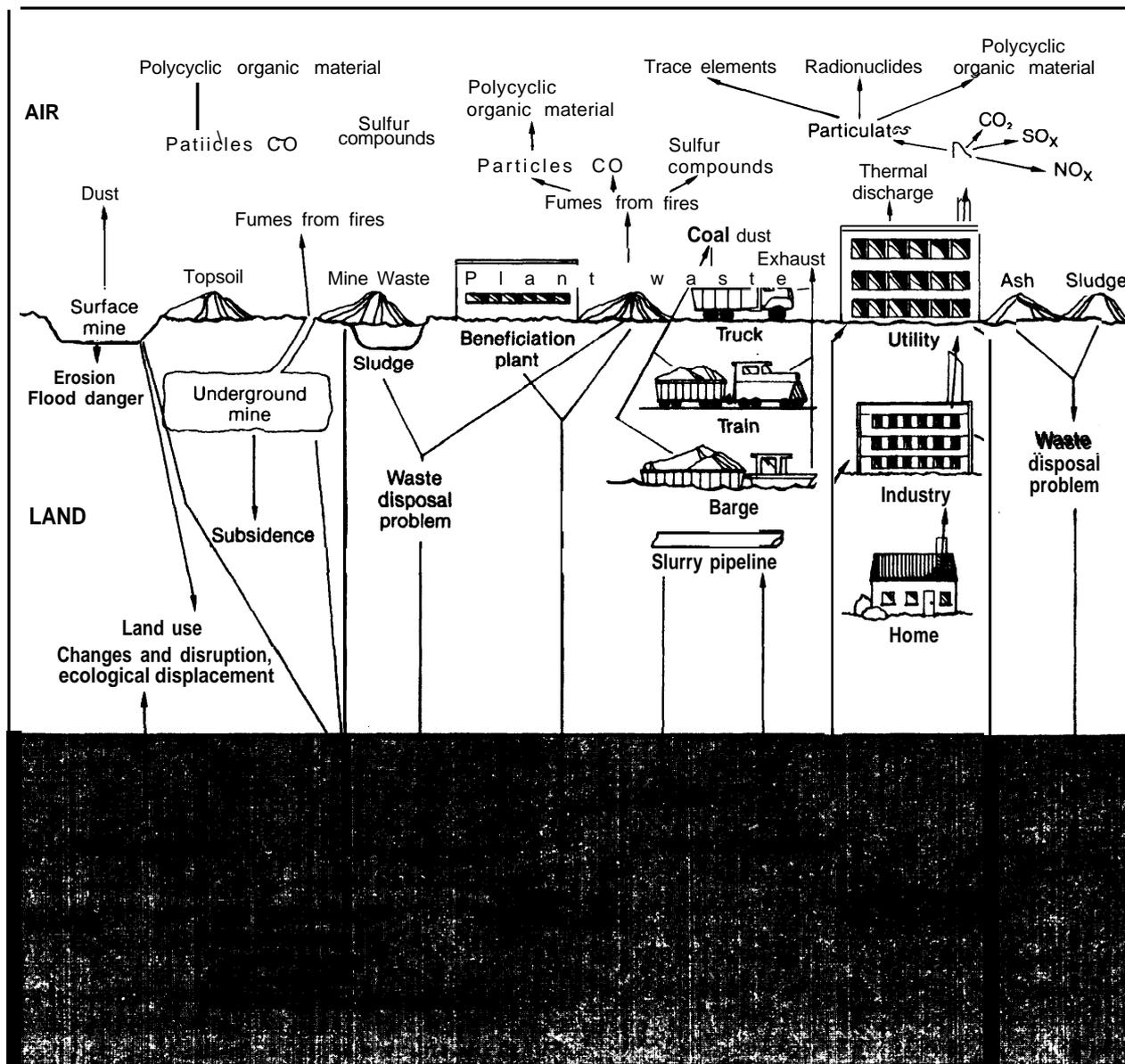
ature — and especially on the 1978 National Environmental Forecast No. 1 (NEF #l)[1] —to illustrate the level of residuals that would be generated by future increases in coal development. The forecast uses a "business as usual" scenario developed by the Department of Energy's (DOE) Energy Information Administration, which assumes medium economic growth, medium energy supply expansion, and constant (corrected for inflation) world oil prices. The scenario assumes an electricity growth of 4.8 percent *per year,* with total energy demand growing from 70.6 quadrillion Btu (Quads) in 1975 to 94.6 Quads in 1985 and 108.5 Quads in 1990 (see table 22 for a more complete breakdown of the projections). Coal use is assumed to double by 1990 to 25.4 Quads, from 12.8 Quads in 1975. Table 23 presents the environ-

[1] **1978** *National Environmental Forecast No. 1,* Division of Environmental Impacts, U.S. Department of Energy, September 1978 (draft).

mental control assumptions used to predict future emissions of the three principal air pol- lutants. This projection is similar to scenario B in chapter ll.

Figure 20.—Jurisdiction of Federal Control Legislation
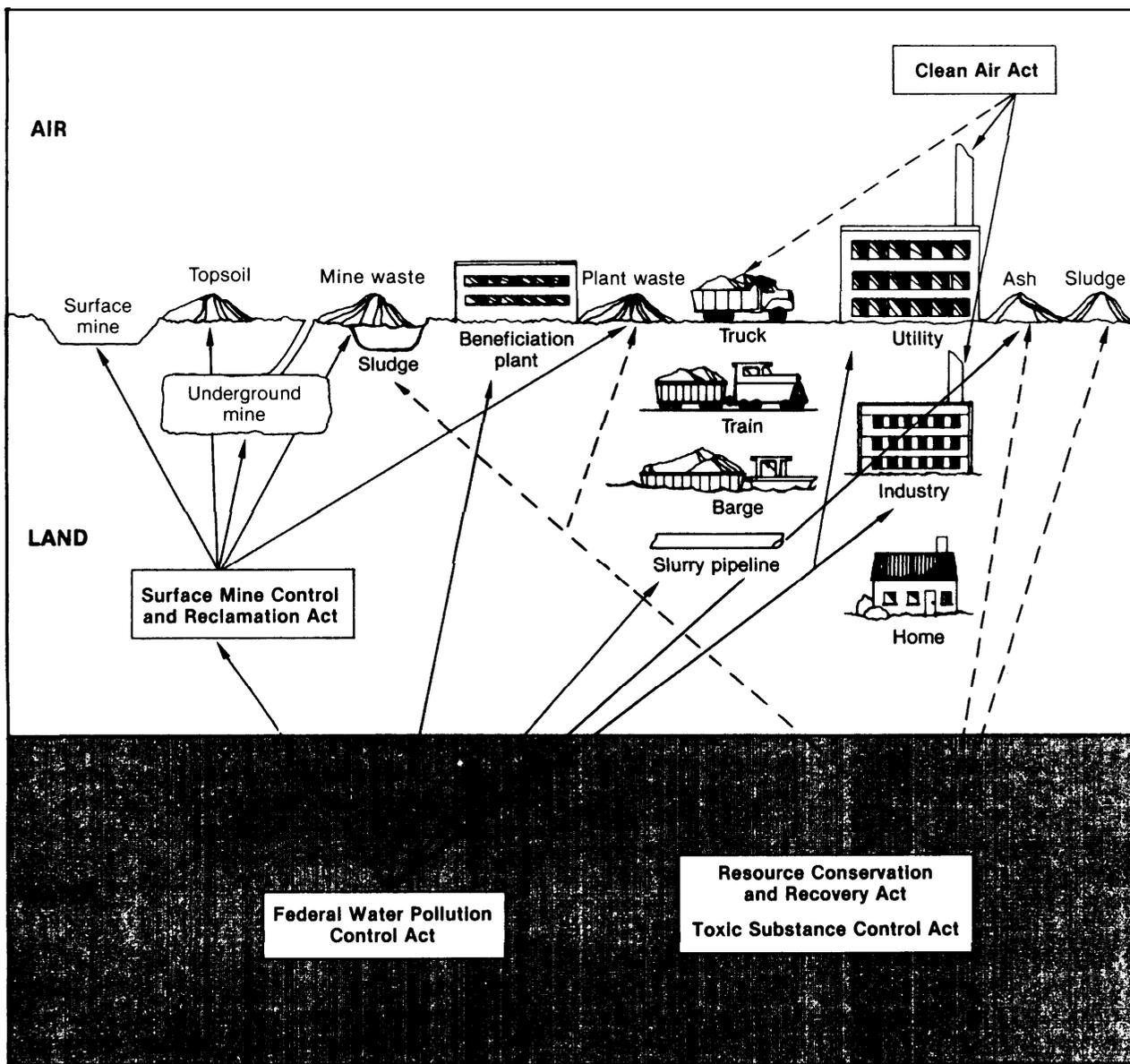
Table 22.—Energy Demand Projection Used to Develop DOE'S "National Environmental Forecast No. 1"
(quadrillion Btu per year)

	1975	1985	1990
Domestic Consumption			
Oil	32.8	43.9	48.5
Natural gas	20.0	19.1	19.3
Coal	12.8	21.2	25.4
Nuclear	1.8	6.2	10.3
Hydro & geothermal	3.2	4.2	5.0
Total domestic consumption	70.6	94.6	108.5
Exports			
Coal	1.8	1.9	2.1
Refinery loss	.2	.4	.3
Total consumption & exports	72.6	96.9	110.9
Domestic consumption by sector			
Residential	14.7	19.0	21.2
Commercial	11.3	13.5	15.0
Industrial	26.0	40.7	49.0
Transportation	18.6	21.4	23.3
Total domestic consumption	70.6	94.6	108.5

Table 23.—Environmental Control Assumptions Used to Develop DOE'S "National Environmental Forecast No.1"

Pollutant	Revised NSPS		Industrial boilers under 25 MWe
	Electric Utilities	Industrial boilers 25MWe or greater	
TSP	Revised NSPS .05 lbs/MM Btu	Revised NSPS .05 lbs/MM Btu	Revised NSPS .05 lbs/MM Btu
SO,	Revised NSPS (scrubber efficiency 89 percent)	Revised NSPS (scrubber efficiency 89 percent)	Revised NSPS 1.5 Ibs SO_2/MM Btu
NO,	NSPS (.7 lbs/ MM Btu) Schedule: For revised NSPS, all new utilities on line in 1984 and after.	NSPS (,7 lbs/ MM Btu) Schedule: For revised NSPS, all new boilers on line in 1981 and after.	None Schedule: For revised NSPS, all new boilers on line in 1981 and after.

AIR POLLUTION IMPACTS

Pollutant Emissions

Coal Activities Other Than Combustion

Most concern about air emissions from the coal fuel cycle centers on coal combustion, the emissions of which can affect natural ecosystems as well as human health and welfare over a broad region. The other portions of the fuel cycle also have important impacts on man and nature, although these impacts tend to be confined to a more local area. Mining impacts involve primarily the fugitive dust from surface and underground mines. After combustion, the dry disposal of ash or waste from flue-gas treatment produces particulate loadings that can be, on the site, in excess of Federal standards.[2] This dust problem is naturally of greater intensity in arid climates. Other sources of particulate are the construction activities at each stage of the fuel cycle, the transportation of coal in open hopper cars or on barges, the storage of coal or coal wastes in piles, and coal processing and cleaning. All particulate emissions that include either coal dust or ash contain quantities of trace elements and radionuclides that may exacerbate the health and environmental impact of these emissions.

Additional releases can result from uncontrolled fires at mines or within mine piles. Such fires, not uncommon, may smolder for years. In January 1973, a survey counted 59 uncontrolled fires in abandoned mines in Appalachia and 185 uncontrolled fires in unmined coal seams in the West.[3] Another survey by the

'Report of the Committee on Health and Environmerita/ Effects of Increased Coal Utilization ("Rail Report"), F. R., vol. 43, no. 10, Jan. 16, 1978; "App. on Coal Ash and FGD Sludges, " U.S. Environmental Protection Agency,

'Underground Coal Mining: An Assessment of Technology, Electrical Power Research Institute, AF-219, July 1976,

Bureau of Mines in 1968 registered 292 fires in coal refuse banks, principally in Appalachia.[4] Because such fires burn under oxygen-deficient conditions, they generate a somewhat different spectrum of air pollutants than coal-fired boilers. Table 24 presents a crude estimate of the emissions of carbon monoxide (CO), hydrocarbons, sulfur oxides (SOx), nitrogen oxides (NOx, and fine particulate due to such fires. Other releases include hydrogen sulfide and ammonia. It is reasonable to speculate that a significant portion of the hydrocarbon emissions could be polycyclic organic matter, which is particularly dangerous; however, appropriate data are not available.

Table 24.—Gases Emitted From Burning Coal Mine Refuse Banks in 1968

	Emissions — 10' tons	Percent of total nationwide emissions
Carbon monoxide.	1.2	1.2
Sulfur oxides.	0.6	1.8
Hydrocarbons.	0.2	0.6
Nitrogen oxides	0.2	1.0
Fine particulate.	0.4	1.4

SOURCE Nationwide Inventory of Air Pollutant Emissions. 1968, National Air Pollution Control Administration, AP-73, August 1970

Development of controls for these air emissions has not received the attention given to air emissions from combustion. Dust from mining operations is not always completely controlled, and may be a serious occupational health problem. Coal dust from trains can be avoided by covering the hopper cars if spontaneous combustion of the coal can be avoided. The dust from waste disposal sites can be kept to a minimum by wetting agents and its impact reduced by a buffer zone around the site. Dust from coal hauling usually is controlled by watering the roadbeds. Unfortunately, most of these controls are not required by Federal regulations, and State and local requirements vary widely and often are not strictly enforced.

The general techniques for prevention of mine or refuse pile fires are to reduce air cir-

culation to the combustible material, minimize the concentration of combustible material, and promote cooling. For abandoned mines these techniques may not always be possible to apply. The best means of prevention is to remove the excess combustible material and seal holes where feasible. The Surface Mining Control and Reclamation Act of 1977 requires that combustible materials exposed, used, or produced in underground mining (including exposed coal seams) be treated, if necessary, and covered. The Act also requires that all openings to the surface be capped, sealed, or backfilled when no longer needed for mining. Presumably, enforcement of these provisions will substantially decrease the incidence of new-mine fires.

Combustion

The air pollutants released in large quantities by combustion units include the oxides of sulfur, nitrogen, and carbon, as well as particles of ash that become entrained in the hot flue gases. Smaller quantities of trace inorganic elements, radionuclides, and hydrocarbons are also emitted; these are often adsorbed on the surface of the ash particles. Once emitted to the atmosphere, most of these substances may be transformed by a variety of chemical reactions, and all will be transported and deposited under a variety of different meteorological conditions. The pollutants may react with other pollutants from the same or different source or with natural atmospheric components. The nature and extent of resulting human health hazards and environmental damage depend on the types and rates of reactions in conjunction with the atmospheric transport and deposition, as well as the nature of the "receptor" —the ecosystem and/or human population. This discussion examines the emissions of each coal stack component. The following sections discuss the transport and transformation of each component. Understanding of these factors is crucial to predicting and mitigating the health or environmental impacts of coal combustion.

Sulfur oxides receive more attention than any other emission from the combustion of coal, primarily because of the large quantity of

---

[4]*Coal Refuse fires, An Environmental Hazard* (Washington, D. C.: U.S. Department of the Interior, Bureau of Mines, 1971) I.C 8515

emissions, the diversity of and controversy surrounding the potential impacts (human health effects, acid rain, crop damage, etc.), and the great expense involved in SO_x controls.

Coal combustion is a major source of man-caused sulfur emissions, and all of these sources may now exceed the emission of sulfur compounds from natural processes worldwide.[5] Estimates of the fraction of man-caused sulfur emissions range from about one-third to about two-thirds.[6] In industrialized parts of the United States the man-caused emissions may be at least an order of magnitude greater than natural emissions.[7]

Coal burning contributes more than half of man-caused sulfur emissions and 80 percent of the sulfur emitted from stationary fossil fuel combustion. All stationary combustion sources together release 70 percent of man-caused sulfur, with industrial processes running a distant second.[8]

The regional sulfur dioxide (SO_2 "emissions densities" (emissions per unit area) shown in figure 21 exhibit a wide geographic variation. The peaks in emission density do not necessarily correspond to peaks in ambient sulfate concentrations shown in figure 22, because of complex transport phenomena that may carry pollutants far from their source.

Total emissions of S0x may be expected to decline slightly in the next decade if current State implementation plans (SIPs) for air pollution control are strictly enforced, because the effect of existing sources coming into compliance with local regulations in the next few

years should more than balance the addition of new sources. NEF #l computes the following total SO_x emissions for its moderate coal use scenario:

1975 ....., ...29.9 million tons
1985 . . . . 28.8 million   tons
1990 . . . . 30.6   million   tons

After full compliance has been achieved, SO_x emissions will begin to creep upwards. Coal burning– and especially that from the electric utility industry— plays a major part of this trend. Electric utilities and industrial boilers burning coal are projected to remain at their present 70 percent of the total emissions through 1990. Existing coal-fired powerplants had **1975** emissions of 18.7 million tons; these will decline to about 15 million tons if full compliance is achieved, then drop only as existing plants are decommissioned. Utilities commissioned after 1975 would have a maximum (no control) emission of 15 million tons by 1990 under moderate growth conditions; given the strong controls listed in table 23, actual net emissions will be about 3 million tons. This imbalance between old and new source emissions is a critical point, because it illustrates the need to consider existing sources in devising a national S0x control strategy. Proposed New Source Performance Standards (NSPS) for steam electric utility boilers will cost tens of billions of dollars over the next few decades but will reduce total emissions less than 10 percent under emissions produced under the current standards (as projected by the Environmental Protection Agency (EPA) and DOE in a joint, ongoing analysis). Meanwhile, the major sources of S0₂ emissions for the next several decades—coal-fired powerplants already in existence— are allowed to operate with far less control —and sometimes none.

Industrial coal combustion also plays an important role in SO_x emissions. Because industrial use of coal is expected to grow substantially in the next few decades, the NSPS will affect a higher percentage of the total emissions than is the case with powerplants. Existing industrial plants emit about 2 million tons of SOx/year . By 1990, new plants will emit about half this amount if maximum control is as-

[5] R. B. Husar, et al., "Report on the International Symposium on Sulfur in the Atmosphere," Third *National Conference on the Interagency Energy/Environment R&D Program, 1978,* p. *77.*

[6] E. Robinson and R. C. Robbins, "Gaseous Sulfur Pollutants From Urban and Natural Sources," J. *Air Pollut. Assn. 20, 1970;* Kellog, et al., *1972,* "The Sulfur Cycle," Science, 175; and J. P. Friend, "The Global Sulfur Cycle" in Chemistry of the Lower Atmosphere, S. 1. Rapeol (ed.) (New York: Plenum Press, 1973).

[7] R. B. Husar, personal communication.

[8] *Preliminary Emissions Assessment of Conventional Stationary Combustion* Sources: *Volume II-Final* Report, GCA Corporation, GCA/Technology Division, EPA-600 2-76-046b, U.S. Environmental Protection Agency, March 1976.

Figure 21 .—S02 Emission Contours—Emission Densities in g/m²/year
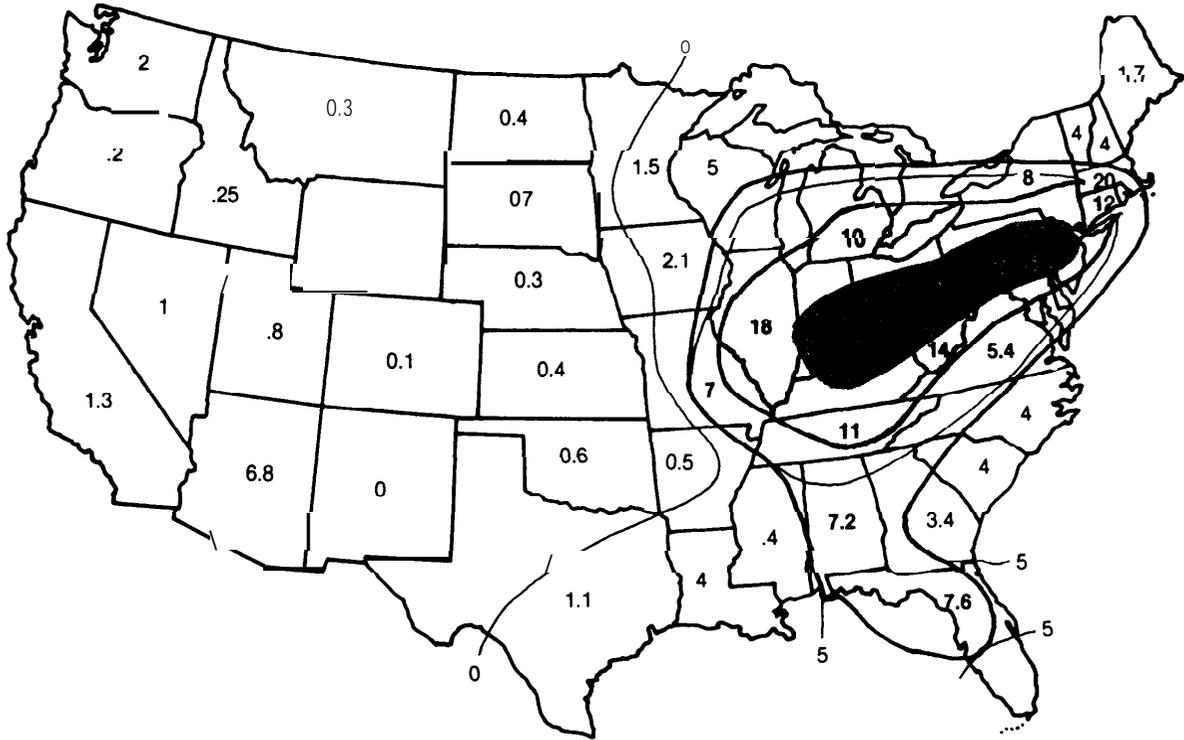
sumed. However, final emission standards for industrial sources have not been established.

More than two-thirds of the S0x emissions occur in the industrialized Middle and South Atlantic States and in the Midwest, both in 1975 and 1990, although emissions will decline in the Middle Atlantic and Midwest if existing sources comply with local standards according to schedule. Substantial emission increases should occur in the Southwest and Northwest as coal begins to replace natural gas as the dominant fuel.

Nitrogen oxides from coal combustion are associated with some plant damage, possible health effects, acid rain, and production of deleterious secondary pollutants. Unlike the sulfur compounds, however, man-caused sources produce only 10 percent of total NO_x emissions (50 million tons per year compared to 500 million tons per year from natural sources). NO_x in the atmosphere consist pri-

marily of nitric oxide (NO), nitrogen dioxide (NO_2), and small amounts of nitrous oxides.

About 95 percent of the NO, of manmade origin is emitted from fossil fuel combustion. The direct product is primarily NO, which is readily converted in the atmosphere to the more toxic NO_2 and corrosive nitric acid (HNO_3).

The amount of NO produced is determined partly by the composition of the fuel itself. Coal has considerable fuel-bound nitrogen, and most of the NO produced by a normal boiler is created by the reaction of this nitrogen with the oxygen in the combustion air. NO is also produced by the high-temperature reaction between the oxygen and nitrogen in air; this reaction is the sole NO source from the combustion of nitrogen-free fuels (such as natural gas). Coal's high nitrogen content explains the major NO_x control strategy for coal boilers, which is to burn the coal initially in a

Figure 22.— Yearly Average Sulfate Concentrations, µg/m³
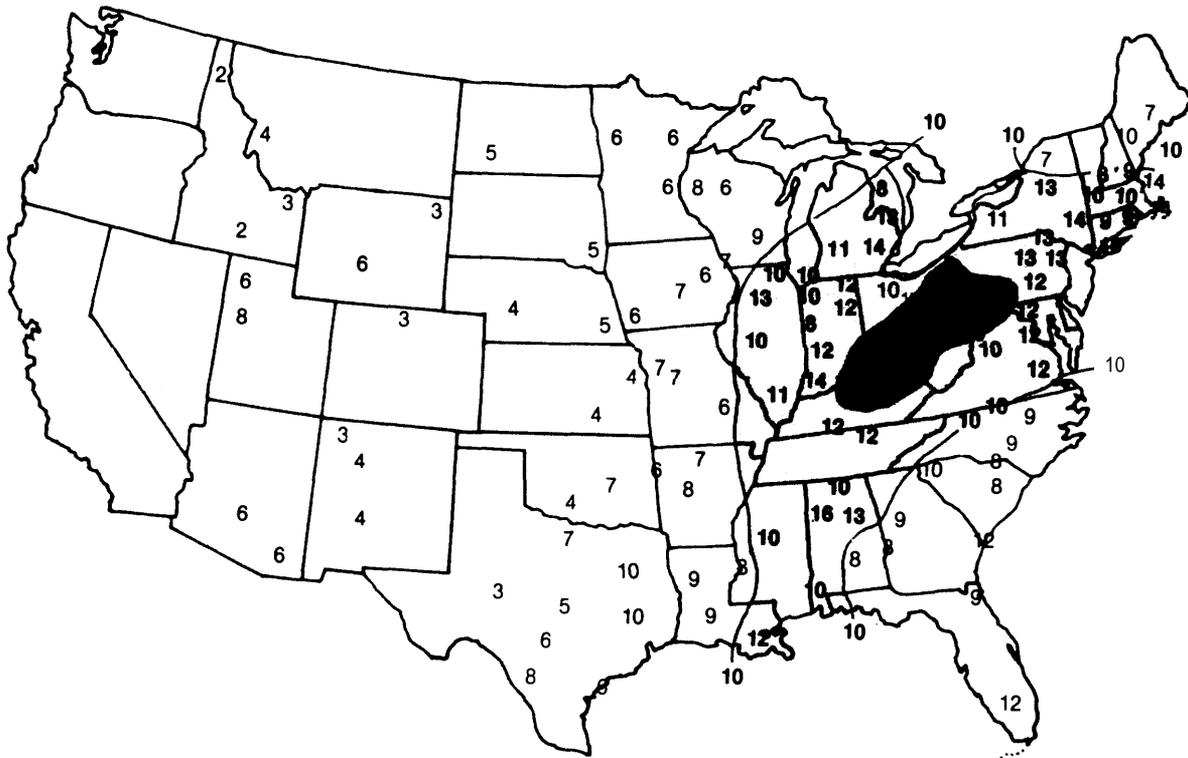
SOURCE: Report on the International Symposium on Sulfates in the Atmosphere. in EPA-600/9-78-022, Energy/Environment III, U.S. Environmental Protection Agency, Office of Research & Development, October 1978.

fuel-rich condition that promotes reduction of NO to nitrogen gas (N_2), and then to allow complete combustion after the fuel-bound nitrogen has been depleted.

Combustion of coal accounts for 24 percent of all NO_x produced by man, and about 49 percent of NO_x from stationary fossil fuel combustion. Mobile and stationary sources contribute about equally to the NOx national emissions. Although manmade sources are only 10 percent of all NOx sources globally, they can result in high local concentrations. Thus, although the natural background for NO_x is about 8µg/m³, the national standard is 1 OOµg/m³, on an annual average, and short-term local concentrations can be much higher. Figure 23 shows the 1973 national emissions densities for NO_x.[9] Spatial variability of NOx

'*National Emissions Report 1973: National Emissions Data System (NDES) of the Aerometric and Emissions Reporting Systems (A EROS)* (Washington, D C.: U.S. Environmental Protection Agency, 1976), E PA-450/2-76-O07.

levels and composition is related to the quantities emitted, the availability of ultraviolet light to affect chemical transformation, meteorological conditions, and the presence of other contaminants in the atmosphere. Because of the very large amounts of NOx emitted by stationary and mobile sources, urban areas tend to have the highest NOx levels. Figure 24 shows the ambient NO_3 concentrations on a nationwide basis, averaged by State.

Levels of NO_x are subject to temporal as well as spatial variation, because of the complex relationship of NO and NO2 to light intensities as well as to the variation in time of emission levels from industrial and automotive sources (strong time-of-day variations have been observed and some evidence exists for seasonal variations).

Although NO_x emissions from automobiles are supposed to decline in the next few decades, the lack of effective controls on station-

Figure 23.— Nationwide Ambient NO3 Levels, μ9/m³
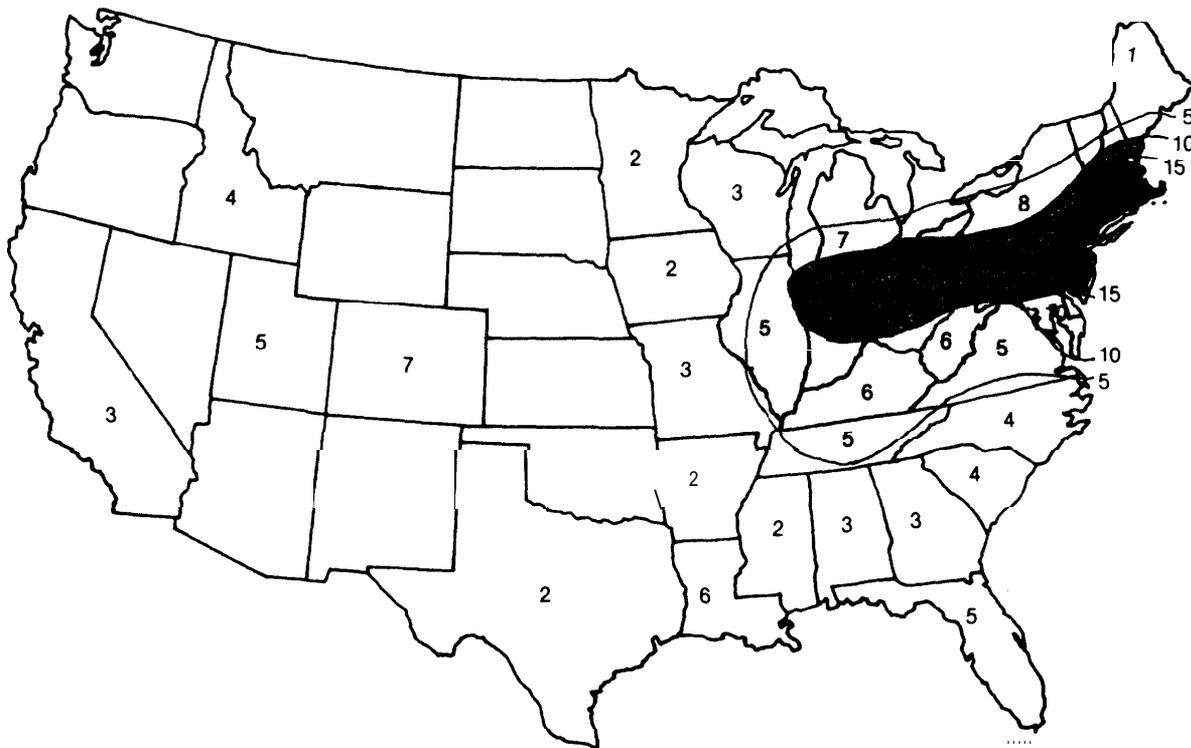
SOURCE: "Air Quality Data for Non-Metalllc Inorganic Loss 1971-1974 from the National Air Surveillance Networks," Gerald G. Akland, EPA-600/4-77-003, Research Triangle Park, NC

ary sources will lead to a substantial increase in total emissions. N E F #1 projects national emissions to increase by 21 percent by 1990, from 19,4 million to 23.5 million tons, reflecting both increased energy production and a shift from gas to coal (coal combustion produces more NOx than natural gas combustion; although the ratio varies, it is about 3:1 for powerplants). Coal combustion by electric utilities and industrial boilers will play an increasing role in these emissions. In 1975, these sources produced 4.6 million tons of NO_x, or 24 percent of total emissions; with a moderate growth in coal use they will produce 8.7 million tons or 37 percent of the total by 1990. The shift in emissions away from automobiles and toward powerplants and industry should be accompanied by an increase in NO_x concentrations in rural areas and possibly a slight decrease in urban areas.

Coal combustion produces particulate either by direct emission of primary particles

(fly ash) or by release of gases that are "precursors" to the formation of secondary particles. Secondary particulate include sulfates, nitrates, and particulate hydrocarbons.

Although particulate emissions from fuel combustion sources are generally well controlled, the most common control mechanisms are less efficient in controlling fine particulate (those less than 3 μm in diameter). Thus, proportionately more particles in this size range escape capture and are emitted. In addition to this direct emission, most secondary particles (particles formed by chemical transformation of gaseous pollutants) are also in this size range.

Fine particulate have a greater impact on visibility and are more likely than coarse particulate to become lodged deep in the lungs and to travel great distances. I n addition, directly emitted fine particulate have a larger surface area than an equal weight of larger

Figure 24.—National NO$_x$ Emission Densities, g/m^2/year
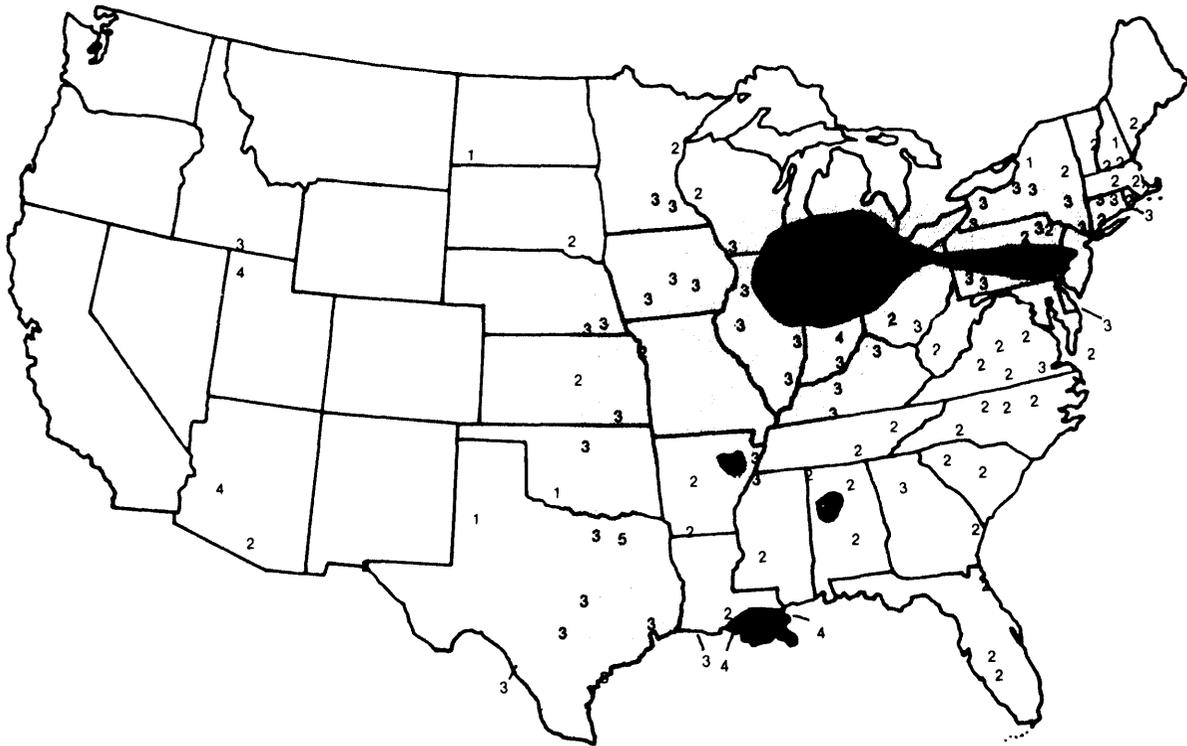
particles and thus tend to adsorb on their surfaces a disproportionate share of the toxic elements in the flue gas.

Present regulations and measurement techniques are based on total concentrations of particles, which may have little relevance to their chemical or biological behavior. In recognition of this, EPA has recommended setting a standard for particulate matter of less than 15 µm, and examination of the effects of particles smaller than 2 pm. Information gathered by this examination may provide the basis for a new " inhalable particulate matter" standard. 10

Natural sources of particulate far outweigh manmade sources but are difficult to measure. Coal combustion yields 33 percent of the man-

made particulate and 90 percent of those from stationary fossil fuel combustion sources. All stationary combustion sources account for 36 percent of U.S. emissions, the second largest source after industrial processes, which constitute 49 percent (NE F ##1).

Because compliance with all SIPs is far from complete today, total particulate emissions may decline quite significantly despite continued economic growth if compliance is achieved according to schedule. NEF #1 projects a decrease in the total emissions from 14.5 million tons in 1975 to 8.2 million tons in 1985, with a rise (to 9.1 million tons in 1990) thereafter that is characteristic of the assumption that future controls on both existing and new emission sources will not change. Clearly, at some point controls on particulate and other pollutants will have to become stricter if continued growth without unacceptable en-

'""Health Effects Considerations for Establishing a Standard for Inhaled Particulate Matter, " EPA-HERL, internal publication, January 1978

vironmental degradation is to occur. Also, none of these projections is likely to hold for fine particulate, where emissions could increase sharply unless control strategies shift to devices that are more efficient in collecting particles in this size range.

The role of utilities and industrial boilers will shrink from its present one-third contribution of total national emissions to one-fourth by 1990 despite the substantial shift to coal. The major portion of these particulate is contributed by coal combustion.

These trends differ substantially by region. Slight increases in particulate emissions are expected in New England and the Southwest, while substantial decreases should occur in those regions that now have many noncomplying sources—the Middle Atlantic and Midwest.

Hydrocarbons from coal combustion may be divided into two main groupings, corresponding to the way they are emitted. First, there is a volatile fraction composed mostly of low molecular weight species that are emitted as vapors. Second, there is a fraction of higher molecular weight species that are emitted as fine particulate or are preferentially adsorbed on the surfaces of fine particulate. Although EPA has recently increased its efforts to characterize these emissions, little reliable information exists on their composition. Available data indicate that for moderate to large boilers (greater than about 25 MW), the volatile fraction (measured as methane) and particulate fraction (measured as benzene soluble organics) are emitted in amounts of the order of only a few milligrams per cubic meter in the flue gas. Emissions of polycyclic organic matter (POM), species of which are known carcinogens, are emitted in quantities considerably smaller. The available data indicate, however, that both the total hydrocarbons and the proportion of POM to the total may increase substantially as boiler or furnace size decreases. For example, hydrocarbon concentrations in the flue gas of boilers less than 1 MW in capacity were found to be more than 60

times as great as those from utility boilers more than 500 MW, while POM concentrations were several thousand times as great (but still less than 1 percent of the total hydrocarbon emissions). [2] Recent EPA-sponsored tests on a 10-MW industrial boiler, on the other hand, indicated that POM emissions were either zero or below the limits of detection of the available equipment. [3] There are now 12 million tons of coal burned each year in the residential/commercial sector, presumably in small boilers and furnaces in populated areas. The potential of these units, and additional units in the future, to generate quantities of the more toxic hydrocarbons is uncertain but a source of concern.

Coal combustion plays only a minor role in total hydrocarbon emission and will continue to do so in the future. In 1975, coal-fired utility and industrial boilers emitted about 70,000 tons of hydrocarbons, only one-half of 1 percent of national emissions. By 1990 these boilers may double their hydrocarbon emissions and increase their share of the total to 1.4 percent. During this time, strict automotive controls should (if the standards are successfully enforced) cause a sharp decline in national emissions from about 14 million tons in 1975 to 10 million in 1990. A notable exception to this sharp decline will occur in those areas slated for new petroleum and organic chemicals development. Thus, hydrocarbon emissions in Louisiana will increase somewhat in the next decade, while emissions in Texas and Delaware, sites of expected new refineries, will remain relatively stable.

Inorganic trace elements and radionuclides are emitted during coal combustion in particulate form or as vapors that can condense or be adsorbed on the particulate in the flue gas as it cools. These elements can be divided into three classes:

1. those that are not volatilized and thus are either left in the slag and bottom ash or become entrained in the flue gas as particulates,

"N. Dean Smith, Organic Emmissions *from Conventional Stationary Combustion Sources* (Research Triangle Park, N C , U S Environmental Protection Agency, August 1977)

' 'lbid

"Personal communication with Wade Ponder, U S Environmental Protect Ion Agency, Research Triangle Park, N C.

percent more than natural gas for the same energy value. [5] By projecting worldwide uses of fossil fuels and by modeling CO_2 exchange processes between the atmosphere and the oceans and the biosphere, a number of studies have developed estimates of atmospheric CO, levels over the next several centuries. Most show peak levels in the 21st and 22nd centuries from two to eight times higher than today. However, these estimates and their projected effects are subject to considerable uncertainty. (See CO_2 under Ecological Effects.-)

Sensitivity of Emission Estimates to Assumptions

Predictions of emissions are sensitive to assumptions about rates of growth, energy technologies used, environmental controls installed, quality of fuels burned, and other factors. Changes in the following assumptions are especially important:

- State Implementation Plan compliance. - Virtually all forecasts of future emissions assume full compliance by 1985 with existing State standards. There is substantial pressure in many States to revise emission standards upwards, especially for powerplants. The Mitchell and Kammer plants in West Virginia recently won adjustments in their SO_x emissions reduction requirements, and the requirements for several large plants, including Cliftie Creek in Indiana and Labadie near St. Louis, Me., are under review. Also, assumptions of compliance for other sources—especially for automobiles — may be too optimistic.

- Growth rate.–The growth rates of electricity and coal demand are critical factors in determining emissions, yet are highly uncertain. As an example of the effect of varying growth rates, emissions from a "moderate growth" scenario (5.8-percent electricity demand growth for 1975-85, 3.4-percent growth for 1986 to 2000, 1 billion tons of utility coal demand by 2000) and a "high growth" scenario (5.8 percent for 1975-85, 5,5 percent for 1986

to 2000, 1,900 million tons demand by 2000) are compared for the year 2000.

Utility Emissions, Millions of Tons/Year[16]

	Moderate	High	
SO,	140	171	(assuming 90-percent control for new plants)
	156	207	(assuming 80-percent control).
NO,	95	175	

Higher growth rates will have a maximum effect on those pollutants that are not efficiently controlled by available equipment. Thus, (NO_x and fine-particulate emissions are of particular concern in a high-growth situation.

- **Environmental controls. -Most** forecasts examine different versions of soon-to-be-enacted New Source Performance Standards (NSPS) for steam-electric powerplants but assume constant control levels after enactment. This is unlikely, as EPA must periodically review these standards. The very high levels of control achieved in Japan for scrubbers imply that future SO, emission standards may become more stringent, thus lowering national SO_2 emissions below expected levels. Other control variations that would affect emissions levels are:

—"Ful/ scrubbing" versus "sliding scale. " Although national utility SO_2 emissions are not significantly different (in 1990, 19.6 million tons versus 20.2 million tons) for the EPA proposal (for a uniform percentage removal requirement) and the DOE proposal (to allow utilities using low-sulfur coal to apply only partial scrubbing), SO_2 emissions would be significantly higher in Western clean air areas under the DOE proposal.

— NOx controls. Since NO_2 emissions are expected to increase substantially from expanded coal use, pressure for further controls is likely to increase. The probability of such additional control depends primarily on the success of EPA's

[15]*Analysis of the Proposed National Energy Plan* (Washington, D C : U.S. Congress, Office of Technology Assessment, 1977), p 161.

"*Review of New* Source Performance Standards *for* Coal-Fired *Utility Boilers, vol* 1 (Washington, D C.: U.S. Environmental Protection Agency, August 1978), E PA-60017-78- 155A.

NO, control program. A particularly promising control technology appears to be a low-NO$_x$ burner that has achieved 85-percent emission reductions on a single full-size burner in the laboratory. Preliminary indications are that there may be little or no cost penalty for using these burners in a new facility. However, it is unlikely that sufficient full-size demonstrations can be completed and an NSPS promulgated before the mid-1980's.

— *Particulate standards.* Electrostatic precipitators (ESPs) are less effective at capturing fine particulate than are baghouses (fabric filters) but are generally less expensive and can achieve required emission reductions except when used with low-sulfur coals. Thus, the effect of SO$_2$ standards on low-sulfur coal use will also affect particulate control choices and, consequently, fine-particulate emissions.

It is clear that certain future conditions could lead to levels of emissions substantially greater than those projected. For example, a greater than expected level of coal development coupled with a significant relaxation of SIP control requirements could lead to significant increases in emissions of SO$_x$ and fine particulate. NO$_x$ emissions would be significantly increased if energy demand increased at a more rapid rate than projected.

Chemical and Physical Transformation and Removal

As soon as each of the pollutants considered here is released to the atmosphere, it is free to participate in a complex series of chemical and/or physical processes that alter its form and location. Before the specifics of atmospheric chemistry are addressed, the following general relationships and conditions should be understood:

. ɪndividual pollutants in the atmosphere are not static. That is, they react with other pollutants to give more or less harmful products, they decay, and they are ultimately deposited to varying degrees on soil, waterbodies, forests, farms, residential developments, and all other areas of the Earth's surface.

● On a large spatial scale, pollutants in the atmosphere are not well mixed. Consequently, many air pollution problems are localized over cities and large metropolitan regions. Further, climatological phenomena (such as inversions), topographic features (such as the Los Angeles Basin and the Appalachian Chain), and development patterns (such as the concentration of powerplants along the Ohio River) can influence what pollutants are present, in what quantities, and what types of reactions are taking place.

● The nature of the atmospheric chemical reactions is exceedingly complex and, at present, incompletely understood. Important factors that determine the rate at which the reactions occur are:

— *The form of the reactants* (gases or aerosols).

– *The presence of catalysts* (metals, light, and other reactants). Some of these may be present in the same emission as the reacting substance, or may come from other emission sources (including natural sources); some may exist only at certain times of the day or in certain seasons.

– *The concentration of reactants and type of reaction.* Doubling or halving the amount of a particular pollutant present in the atmosphere will not necessarily double or halve the rate of formation of reaction products; reactions often are nonlinear with respect to concentrations. This same nonlinearity applies to the eventual atmospheric concentration of the reaction products; thus, reductions in "precursor" pollutants could, depending on the circumstance, produce proportionately greater or lesser reductions in ambient concentrations of the secondary pollutants.

● Considerable uncertainty exists as to which chemical reactions predominate under various atmospheric conditions. This uncertainty results in severe difficulties in predicting the effects of new con-

trol strategies on concentrations of secondary pollutants.

Reactions *involving SOx* have been the most intensely studied to date. The predominant set of reactions involves the conversion of SO_2 to some form of sulfate. The reactions believed to be of major importance are summarized in table 26. The importance of understanding the mechanism of production is quite obvious from the table. For example, indirect photooxidation requires free radicals often present in a polluted atmosphere, and indicates that conversion to sulfates may then proceed more rapidly in urban centers, especially in daylight or summer conditions. As another example, the fourth reaction requires ammonia to convert sulfuric acid to a sulfate salt. This buffering action could be important where acid rain was an important problem; in such circumstances, controlling atmospheric ammonia could be undesirable.

Removal of sulfur pollutants from the atmosphere takes place by gaseous, dry, and wet deposition. Dry deposition (particles settling out or colliding with surfaces) occurs continually, and is more important close to the SO_x source. Wet deposition (scrubbing of the atmosphere by precipitation) is sporadic and may be more important in regions remote from the source. The relative importance of the two mechanisms depends on the climate and the form of the sulfur pollutant. However, from observed data in temperate climates, wet and dry removal of all SOx is believed to be of roughly equal importance. [7] The relative importance of each deposition mechanism is different for each sulfur species, however; wet deposition is 10 times more important for sulfates than for SO_2. Thus, keeping track of precipitation is crucial in considering long-range transport of sulfates.

The mean residence time in the atmosphere for SO, is about 1 day. For sulfates it is 3 to 5

---

[7] R. B Husar, et al., see note 5

Table 26.—Reactions in the Atmosphere

Reaction type	Reaction	Catalyst/special conditions	Comments
Indirect photooxidation	$SO_2 \xrightarrow{\text{Free radicals}} H_2SO_4$	Smog, sunlight, water vapor, Ho·, Ho·$_2$, CH$_3$O$_2$ radicals	Important reaction rates up to 5 percent per hour giving half-life of SO_2 of $1/2 \longrightarrow 2$ days. Rate depends on SO_2, hydrocarbons, NO_x levels, amount of sunlight.
Heterogeneous catalytic oxidation	$SO_2 \xrightarrow{O_2} SO_4 =$	Liquid water; metal ions	Because of dependency upon catalyst concentration, probably important in plumes and polluted urban atmospheres; probably minor in rural atmospheres. Virtually zeroth order in SO_2.
Heterogeneous oxidation by strong oxidants	$SO_2 \xrightarrow[H_2O_2]{O_3} SO_4 =$	Water droplets	Importance in dispute, rate estimates vary by a factor of 100.
Heterogeneous oxidation in the presence of ammonia	$SO_2 \xrightarrow{H_2O} H_2SO_4$ $NH_3 + H_2SO_4$ $\rightarrow NH_4^+ + SO_4 =$	Water droplets	Rates unknown, dependent upon availability of ammonia and pH of droplet.
Surface catalyzed reactions		Soot	Soot has been shown in the laboratory to catalyze oxidation of SO_2. Importance unknown.

days and for particulate S, about 2 to 3 days. At a speed of 500 km/day, which is typical in the Midwest, half the particles or molecules would travel over 500 km, 1,500 to 2,500 km, and 1,000 to 1,500 km respectively. [8] I n temperate climates, 20 to 50 percent of SO_2 is converted to the sulfate ion before removal. Overall rates of conversion ordinarily range from about 1 to 4 percent per hour during the day and less than 0.5 percent per hour at night for an average daily rate of 1 to 2 percent per hour during the summer. [9] This gives a summertime SO_2 half-life of from about 11/2 to 3 days, Figure 25 shows, in schematic form, sulfur removal mechanisms and the relative contribution of wet and dry deposition.

The *transformation of NO* from coal combustion is less well understood than that of SOx Although a variety of reactions involving NO_x are known, no reaction rates for actual atmospheric conditions can yet be assigned to them. Important inorganic reactions involve transformations between the oxides NO and NO_2 formation of N_2O_5 and reaction with water to form HNO3. Organic reactions of NO_x

are particularly important. These result in various complex organic nitrogen species, including peroxyacyl nitrate (PAN) and peroxybenzoyl nitrate (PBN). PAN and PBN are extremely damaging to plants and irritating to animal tissues.

Gaseous, wet, and dry deposition are the sinks for atmospheric NO_x, with the first two of roughly equal importance and the dry deposition somewhat less important.

The chemistry of formation of polycyclic hydrocarbons is both complex and incompletely understood. This subject requires more research, especially with respect to formation of benzo(a)pyrene and other species of POM from advanced coal technologies.

Atmospheric Transport

Superimposed on the chemical interactions just discussed are the largely physical mechanisms that govern not only the degree and duration of the mixing among pollutants but also the direction and distance to which the reaction products are transported. These physical factors may be divided roughly into mechanisms that primarily affect shorter range transport and those that determine the extent of long-range transport.

---

[8] Ibid.
[19] Ibid,

Figure 25.— Flow Diagram of Sulfur Transmission Through the Atmosphere. Over Half of the SO2 is Removed or Transformed to Sulfate During the First Day of Its Atmospheric Residence
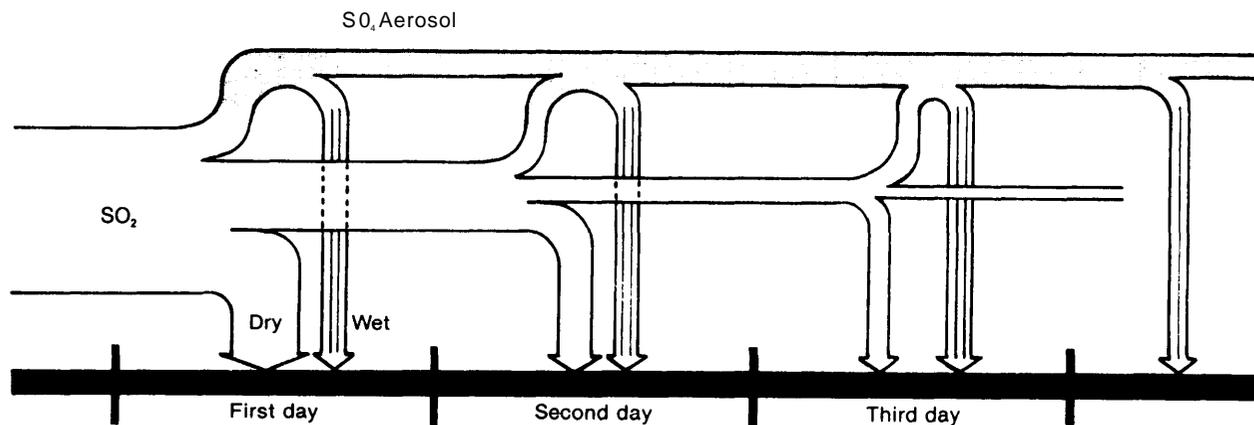
The short-range geometry of the plume is critical to both short- and long-range transport. Under some conditions, the plume spreads quickly to the ground level ("fumigation") and high concentrations of primary pollutants may result. Under other conditions, the plume remains isolated in a narrow vertical layer that disperses little and travels far ("fanning"), carrying high levels of secondary products far from the source. A variety of other possibilities falls between these two. Each type of plume behavior is associated with different atmospheric conditions.

An important factor in the short-term dispersion of pollutants is the vertical temperature variation with altitude. I n daylight hours of intense sunlight, air that is heated by the warm surface continually rises, causing the atmosphere to be unstable and well mixed. These conditions promote the local deposition of pollutants, especially when persistent surface winds are light. Under the conditions of a temperature inversion (warmer temperatures at higher altitudes)–whether it is caused by nighttime cooling of the surface faster than the air or by a cold air mass sliding under a warm air mass—the air layers are stable and do not mix. At these times, effluents from moderate stack heights may be trapped below the inversion, while those from tall stacks may become embedded in the layers above, and hence subject to longer range transport. Nighttime conditions often lead to fanning plumes that remain in a narrow region and may be transported especially rapidly by a nighttime jet stream.

Other local factors determine the extent of, vertical mixing of a plume. One is the wind turbulence caused by rough terrain, surface obstacles, or variation of wind speed with altitude. Another is the local wind pattern, such as the urban-rural wind or the land-sea breeze. If the local wind system becomes a temporary closed loop, pollutants can be sloshed back and forth with no real dispersal, and production of secondary products can further deteriorate the air quality until the cycle is broken.

Once the plume type has been determined by short-range transport mechanisms, several long-range factors govern the way the pollut-

ants travel. Before 1973 there was little documented evidence to suggest that air pollutants were transported in significant quantities to regions remote from their origin.

Numerous studies since then have confirmed that this phenomenon does indeed occur.

One such example is the plume of the Labadie Power Plant, outside of St. Louis, Me., which has been extensively tracked by the EPA's Project MI STT. This plume has been followed for more than 180 miles, and at that distance its width was not much greater than 15 miles. Other examples include the Electric Power Research Institute's (EPRI) SURE program's observations that sulfate episodes in West Virginia occurred only when the air mass over the area had first traveled over high-emission regions; satellite tracking of "hazy blobs," masses of polluted air that have been observed over the Midwestern and Eastern United States, lasting for more than a week; and observations and analyses of acid rain in Europe, where Scandinavian rivers and lakes have apparently been degraded by long-range transport of NO_x and SO_x from the United Kingdom and other Western European countries .[20]

One of the four factors important in long-range transport is the blend of local factors, discussed above, that determine dispersal of pollutants from a given source. Local conditions promoting long-range transport are tall stacks, nighttime or cloudy conditions, and relative constancy of wind speed and direction with altitude.

A second factor is the persistence of surface winds, These have been studied in great detail at many stations in recent years. It has been found that many regions are characterized by surface winds that persist for 6 hours or more in a given direction (or, to be more accurate, within a narrow angular sector). They help determine the dominant direction(s) of transport.

A third factor is the type of winds prevailing at the altitude typical of plant stack heights. These, too, are characterized by dominant directions that often may differ only slightly

[20] Altshuller, et al, "Appendix on Transport and Fate, " *Rail Report.*

Photo credit: EPA —Documerica

Conditions leading to long-range transport of a plume from a coal-fired powerplant: persistent winds,
and **a stable atmosphere**

from that of the persistent surface winds. Thus, the two often couple positively to carry pollutants still longer distances from their point of generation.

These last two factors can contribute to the additive effect of pollutants from several sources. Because the winds tend to blow more frequently in some directions than others, any emission sources lined up in the same direction will contribute to intensification of pollution concentrations. For example, powerplants clustered along the Ohio River are also in line with prevailing winds blowing to the northeast; occurrence of these winds has been correlated with high pollutant concentrations in Pennsylvania and other States to the northeast.

A final factor is the large-scale meteorological conditions resulting from the relative movements of low- and high-pressure systems.

These conditions can create large regional areas of stagnation.

Several research organizations are developing long-range transport models and are currently using such models primarily in an experimental mode. Models in current use have not undergone extensive peer review and thus are not likely to be immediately acceptable for regulatory purposes. This situation could change drastically within a short time— perhaps a year– and conceivably lead to greater regulatory attention to long-range transport problems.

Although long-range transport models are still not fully verified, regions of the United States can be surveyed for some of the key factors in long-range transport mentioned above. Data compiled by Teknekron for EPA on re-

gional air quality and aerometric parameters yield the following brief survey .2'

One potential air quality problem lies in the West, especially in the northern Great Plains and southeastern Utah, an area slated for considerable future powerplant development. Many areas nearby currently are designated as Class I (i.e., areas where air quality is to be strictly protected, with very little development allowed), and many of these lie in the direction of extremely persistent winds coming from

---

²¹An Integrated Assessment of Electrlc Utlllty Energy Systems Briefing Material s," prepared for EPA/NASA Meeting on Cooperative Program on Synoptic Regional Air Pollution Problems, Sept 11-12, 1978, by Teknekron Inc , Berkeley, Calif , and Waltham, Mass/pt 2, Aerometric Data Compilation and Analyses for Regional Sulfate Modeling

areas with a large number of current and projected urban and utility emissions sources. In addition, the prevailing winds tend to be from the south and may entrain elevated levels of sulfates from smelters in the Southwestern United States.

The gulf coast is expected to increase its utilization of coal, partly in response to the growing development of lignite fields. These fields lie primarily in eastern Texas and are alined approximately parallel to the prevailing wind direction (from southwest to northeast). If powerplants develop along the same line, intensification of concentrations may result.

The region that has been the most heavily studied for air pollution transport is the Ohio River Basin. This region not only contains a large cluster of coal-fired powerplants but also

exemplifies some of the meteorological factors that contribute to long-range transport. Extremely persistent winds in the Basin lead to intensification of pollution levels from a string of sources. Prevailing winds in the Upper Basin blow predominantly east and north, carrying polluted air as far east as Pennsylvania and beyond, while winds in the Lower Basin carry pollutants north into Canada.

Several regions in the Eastern United States have been found to be susceptible to prolonged atmospheric stagnation. Many of those cases are centered over a line from southern West Virginia to Georgia. Although emissions are generally low along this region, they are expected to grow.

Health Effects**

Introduction

It is known that very high levels of air pollution cause illness and death. Present ambient air standards are well below these levels, and it is unlikely that episodes of high concentrations of "criteria pollutants" similar to the notorious catastrophes that occurred in Donora, Pa., in 1948 and London in 1952 will be repeated in this country. However, occasional episodes of adverse meteorological conditions such as those that occurred in the Northeast during November 1966 could lead to high (and possibly dangerous) levels of currently unregulated pollutants. Also, elimination of acute, high-concentration episodes does not preclude the possibility of chronic damage and life shortening as a result of exposure to low levels of pollution. The existence of these types of effects is quite difficult to establish because the damages may take the form of common illnesses (e. g., bronchitis, asthma, cancer) that are known to have other causes and would not necessarily be attributed to air pollution. The effects, if any occur, would also tend to be masked by the very widespread dis-

---

¹²This section summarizes a detailed and extensively referenced report on health effects to be published separately as an appendix to this report. Full referencing of source material was considered impractical for this summary

tribution of air pollution and the large number of different pollutants usually present.

Increased coal combustion will eventually increase the ambient concentrations of SO_x, NO_x, fine particulate, and other pollutants, as discussed in the previous section. The population exposed to the increased concentrations will be large because pollutants travel long distances and, due to prevailing wind patterns, will be concentrated along the heavily populated Eastern seaboard. The present regulatory structure fails to address this problem directly.

If present and projected levels of ambient pollutant concentrations are shown to cause severe chronic effects, the implications for coal use and the degree of control to which it is likely to be subjected will be profound.

Evaluating Health Effects

The determination of the potential of a substance for causing adverse health effects can be accomplished by combining the results of: 1) short-term tests, 2) animal bioassays, 3) chamber exposures to human beings, and 4) epidemiologic studies on human populations.

Short-term tests expose tissue, cellular, and microbial cultures to controlled levels of pollution to measure toxic effects, such as cellular or bacterial death, or mutagenic changes reflecting alterations in genetic structure.

Animal bioassays are used to measure acute and certain chronic effects. Tests for acute toxicity may measure the dose that causes death or impairment of target organs such as the lungs, kidneys, liver, reproductive system, etc. Chronic effects might include gradual impairment of target organs (e. g., chronic bronchitis through long-term insult to the lungs), teratogenic effects, or carcinogenesis.

Exposure studies using human beings are restricted, for ethical and legal reasons, to (usually) short durations and exposure levels no greater than might be expected in the normal working or outdoor environment. Further, "health effects" induced by controlled human exposures are limited to those responses that are known to be reversible, such as increased carboxy-hemoglobin levels in the blood or

changes in airway resistance. Controlled studies of the short-term effects of air pollutant exposures to human beings provide a vital link between toxicologic animal studies and large population epidemiologic studies.
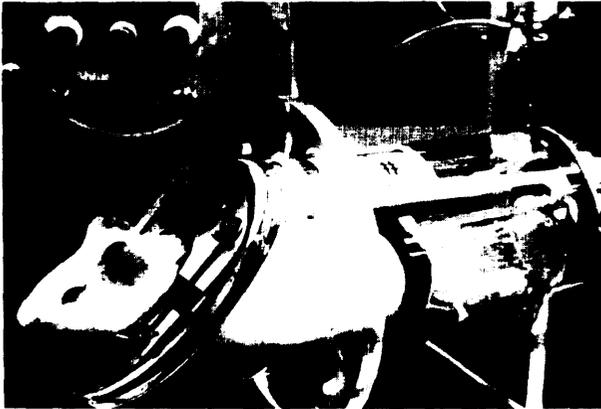
Photo credit: EPA — Documerica

Tests on mice are used to measure acute and chronic health effects
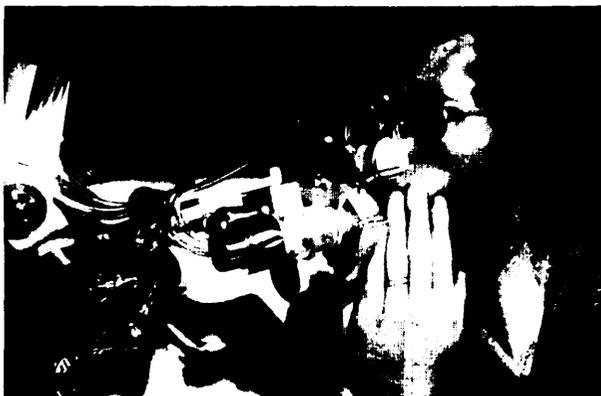
Photo credit. EPA —Documenca

Clinical studies on humans **are** limited to pollution levels that result**in treatable health problems**

Epidemiologic studies are statistical examinations of illness and death rates, air pollution levels, and other variables–studies that seek to discover whether there is a direct correlation between a suspect air pollutant and adverse health effects. As such, they extend beyond the function of short-term tests and animal bioassays that are used to identify the mechanism of damage and the dose response function of the substance under study, and attempt to quantify those effects in human beings.

All of these methods of assessing health effects are necessary to establish the damage potential of a substance. Animal tests are insufficient by themselves because a biological effect in any living system cannot always be applied to a biological effect in others. Although the cellular or subcellular effect may be similar, the clinical effect may be quite different. The chamber tests can show human sensitivity to the substance, but it is impossible to infer from studies exposing 5 to 20 subjects to low levels of the substance for relatively short times what the chronic morbidity or mortality effects on the entire population may be, Finally, epidemiologic studies can establish statistical associations between a substance and damage to human beings, but they cannot prove cause and effect; the short-term and animal tests, by establishing the existence of damage mechanisms, and the chamber tests, by demonstrating human sensitivity, provide credibility to the cause-and-effect argument,

The epidemiologic studies have proven to be a weak link in the analytical chain needed to establish air pollution standards that will guard against chronic health effects. The studies that have attempted to examine the effects of low levels of pollution on the health of the general population have run into several problems:

- heterogeneous populations with different thresholds to particular toxic substances and different socioeconomic characteristics;
- very poor measurements of pollution levels — in most cases, the limited number of monitoring sites and the failure to incorporate levels of pollution indoors lead to poor determination of the pollution levels that the population is actually exposed to;
- outright failure to measure some potentially important pollutants (such as fine particulate);
- lack of data on variables (such as smoking habits) that are important determinants of health;
- wide variations of pollution levels with time, raising the question whether any observed health effects are caused by the mean levels or the occasional peaks; and

● presence of multiple pollutants that might act in combination.

Some of these problems are discussed in more detail later in the context of epidemiologic studies of sulfate damage to human health.

Effects of Specific Combustion Pollutants

Coal combustion releases a mixture of gases and particles into the atmosphere. These include sulfur compounds, nitrogen compounds, fly-ash particulate, CO, CO_2, hydrocarbon vapors and particulate, radionuclides, and many trace metals. These emissions may lead to the formation of secondary pollutants, including photo-oxidants and particulate. Human beings are exposed to a complicated mixture that may act additively, competitively, or synergistically. However, clinical studies have seldom examined more than two pollutants in combination. Even epidemiologic studies, in which the populations are exposed to the entire gas-aerosol mixture, rarely attempt to sort the effects of more than two of the pollutants of the mix. This adds to the uncertainty of predicting health effects from future coal use.

The following discussion summarizes the health effects of specific pollutants from combustion. Table 27 presents the acute and chronic effects of specific gases, elements, and particulate compounds that are emitted from coal combustion. Little is known about the actual magnitude of the effects attributable to increased coal use. The ambient concentrations of radionuclides, organic compounds, and various trace metals due to increased coal combustion are projected to be very low. However, these pollutants are still a concern because of multiple exposures from other sources. Health effects from these pollutants are likely to appear first in the population working in coal conversion or related technologies because exposures will be higher.

Total suspended particulate (TSP) are composed of many different substances. The ambient aerosol (suspension of solid and liquid particles in air) includes trace metals, radionuclides, and organic compounds, as well as silica and other minerals. TSP can be roughly divided into fine (usually defined as less than 2 or 3 pm in diameter) and large particulate. This differentiation is important because:

1. Fine particulate are not explicitly regulated and are not as efficiently controlled by existing technologies as the large particles.
2. The most significant route of exposure to air pollutants is through inhalation. Fine particulate can pass through the filtering mechanisms of the upper respiratory tract and penetrate deeply into the lungs. Several studies using zinc ammonium sulfate and sulfuric acid aerosols have demonstrated that small particles result in greater functional and structural changes in the lungs than result from larger particles of the same substance.
3. Toxic substances, either gases or recondensed metal vapors, can be transported into lung tissues by inhaled fine particles. A unit mass of fine particulate has a greater total surface area than the same mass of large particulate, hence can transport more toxic material on its surface.

Thus, although there is not much explicit evidence defining their impacts on health, fine-particulate emissions are a primary concern in considering the impacts of expanded coal combustion.

Both chemically inert and active aerosols have been shown to alter the mechanical behavior of the lungs, The principal response of different aerosols as measured by animal and human control led studies is to increase air flow resistance in the lungs, This indicates that lung airways are in some way altered. Several physical mechanisms are known to cause this symptom: reflex constriction of the trachea and bronchi, excessive secretions of mucus, edema, and local enzyme stimulation causing smooth muscle constriction. In general the deeper that relatively insoluble particles are deposited in the lungs, the longer the time required for their clearance, Some particles, such as asbestos fibers, penetrate the lung lining and lodge in the interstitial space or are carried by the lymphatic and circulatory sysens to other body sites. In these cases, the

manifest health effects may not be respiratory, but rather carcinogenic or systemic. The toxic elements contained in insoluble aerosols may ultimately affect extrapulmonary tissue irrespective of where they enter the body.

Besides changing airway resistance or causing systemic changes, aerosols can cause harm by altering lung clearance, transporting dissolved gases that may damage lung tissue, and affecting the compliance (tissue elasticity) of the lung (the importance of the transport of dissolved gases makes it very difficult to consider the health effects of specific chemical compounds or particulate in general without considering gas-aerosol interactions). A number of coal-related aerosols have been studied in animals and human beings. These include several sulfates, chemically inert dusts, metal oxides, and fly ash. Surprisingly, the effects of nitrate aerosols have not been reported.

Table 27.—Some Gaseous and Particulate Substances From Coal Combustion[a]

Substance[b]	Toxicity		Sources of Pollution	Environmental standards	Comments
	Acute	Chronic			
Particulates					
Total suspended particulates	With SO_2 in episode conditions contributes to mortality and morbidity.	Pulmonary irritation, chronic obstructive and restrictive lung disease.	Soil erosion, natural volcanos and fires, industrial activity, fossil fuel combustion: coal and oil, secondary atmospheric conversion of gaseous compounds.	260 μ/m³24 hour max. 75 μg/m³- annual ave.	A very broad class, undifferentiated by particle size or chemical composition.
Sulfates	Increased respiratory disease; breathing difficulty in asthmatics.	Respiratory disease and increased mortality suspected.	Conversion of SO_2 to sulfates in the atmosphere, therefore primary sources are SO_2 emissions from coal and oil combustion. Smelters, kraft paper mills, sulfuric acid plants also produce sulfates. Natural sources—H_2S emissions, volcanos, sea salt.		
Nitrates, nitrites	Increases infant susceptibility to lower respiratory infection due to conversion of nitrates to nitrites.	May combine with amines to form carcinogenic nitrosamines, also mutagenic and teratogenic. Nitrites a direct animal carcinogen.	Conversion of NO_2 to nitrates and nitrites in the atmosphere; therefore primary sources are NO emissions from fossil fuel combustion, fertilizer production, munition production, chemical plants, auto and industrial emissions.		
Organic matter	Unknown for many compounds. Specific toxicity for others.	Long-term is potentially carcinogenic and mutagenic.	Fossil fuel direct and indirect use— combustion, refining, plastics, tars, coking, chemical production.		Higher concentrations likely to be associated with nondirect combustion of fuels.

Table 27.—Some Gaseous and Particulate Substances From Coal Combustion[a]–Continued

Substance[b]	Toxicity		Sources of Pollution	Environmental standards	Comments
	Acute	Chronic			
Arsenic (oxide forms)	Effects large to small depending on form and route of exposure; rarely seen.	Carcinogen, and teratogenic cumulative poison.	Weathering; mining, and smelting; coal combustion; pesticides; detergents.	**0.05** mg/1 drinking water.	
Beryllium	Short-term poison at high concentrations, especially toxic by inhalation.	Long-term systemic poison at low concentrations; carcinogenic in experimental animals	Industrial; combustion of coal, rocket fuels.	0.01 pg/m³ hazardous air pollutant	
Cadmium	Very toxic at high concentrations; to animals and aquatic life. Toxic by all routes of exposures.	Possible carcinogen, cumulative poison; associated with hypertension, cardiovascular disease, kidney damage	Weathering; mining and smelting, especially of zinc; iron and steel industry; coal combustion; urban runoff; phosphate fertilizers.	0.010 mg/1 drinking water 40 ~g/1/day proposed effluent standard (withdrawn)	Chronic cadmium poisoning resulting in illness and death has occurred in Japan, where cadmium mobilized by mining contaminated daily diet. Margin of safety—measured levels of cadmium in renal cortex compared to threshold for renal dysfunction-is low: 4 to 12.5.
Chromium	Hexavalent form most harmful; skin and respiratory tract irritant	Carcinogenic; workers engaged in manufacture of chromium chemicals have incidence of lung cancer, no evidence of risk in nonoccupational exposure.	No chromium now mined in U.S. Emissions from industrial processes, including electroplating, tanning, dyes; coal combustion.	0.05 mg/i drinking water	
Mercury	Methyl mercury and mercury fumes very toxic; other forms of variable toxicity	Methyl mercury very toxic, cumulative poison; affects central nervous system	Weathering; volcanoes; mining and smelting; industrial; pharmaceuticals; coal combustion; sewage sludge; urban runoff; fungicides.	0.002 mg/l drinking water; maximum of 2,300 grams mercury in emissions from stationary sources; 20 μg/l/day proposed effluent standard (withdrawn)	Environmental pollution leading to contamination of fish and shell fish caused illness and death in Japan; contamination of fish in U.S. has caused closure of waters to commercial fishing.
Selenium	Soluble compounds are highly toxic	Probable carcinogen; also essential for life.	Natural; mining and smelting; industrial process; coal combustion.	0.01 mg/l drinking water	interacts with other metals, increasing or decreasing toxicity.

Table 27.-Some Gaseous and Particulate Substances From Coal Combustion[a]—Continued

Substance[b]	Toxicity		Sources of Pollution	Environmental standards	Comments
	Acute	Chrome			
Gases					
Sulfur dioxide	Increased respiratory impairment—morbidity and mortality-in combination with particulate.	Increased respiratory disease and decreased respiratory function with parlculates.	Sulfur contained in fossil fuels, smelters, volcanoes	365 μg/m³-24 hour max 80 μg/m³-annual mean	Coal combustion presently represents between 60% and 70% of U.S. SO_2 emissions.
Nitrogen dioxide	Increase respiratory infections	Changes suspected in lung function; emphysema.	Nitrogen fixation in high temperature combustion, and from nitrogen contained in fossil fuels: coal, oil, gasoline combustion.	100 μg/m³-annual mean	Organically bound fuel nitrogen is a more important component for coal NO emissions than for the other fossil fuels.
Carbon monoxide	Behavior changes, nausea, drowsiness, headaches, coma, death	Increase risk of coronary heart disease-arterial sclerosis suspected	Incomplete combustion of fossil fuels: coal, oil, gas, gasoline combustion.	40 mg/m³ 1 hr. max. 10 mg/m³ 8 hr. max	
Ozone	Increased respiratory infection, eye irritation, headaches, chest pain, impaired pulmonary function	Unknown	Photochemical reactions involving hydrocarbons, nitrogen oxide and other compounds in lower atmosphere; reaction of atomic oxygen and oxygen in upper atmosphere.	160 μg/m³ 1 hr. max.	
Aromatic hydrocarbons	Fatigue, weakness, skin paresthesia (> 100 ppm)	Irritation, leukopenia and anemia. Certain compounds are mutagens and carcinogens.	A broad class of compounds naturally evolved from organic material, and from the evaporation and combustion of fossil fuels and other organic industrial chemicals.	non-methane HC 160 μg/m³ 3 hour	Higher concentrations likely from less efficient and smaller boiler operation. Higher concentrations possible proximate to coal conversion facilities. Standard designed for photochemical oxidant control.

a This table is provided merely to indicate some of the substances which are potential environmental hazards along with some Information on each regarding toxicity, sources, standards, etc. It is not to be interpreted as definitive.

b Th substance listed is not necessarily the form in which it becomes a potential environmental threat in some cases the oxide or some metabolite, rather than the substance Itself, is the culprit

Controlled exposures to sulfates represent the vast majority of aerosol-health effects exposure studies. Overall, the aerosol studies report "health effects" at levels many times higher than common urban levels. There is evidence that chronic exposures below these levels adversely affect health by increasing respiratory disease (although a recent review of health effects literature concluded that "research on the toxicity of aerosols has not infrequently led to an overinterpretation of technically weak or insufficient data. "[23] Some studies suggest that particulate pollution,

[23] Airborne Particles, National Academy of Sciences, National Research Council (Baltimore University Park Press, 1978)

much of which is sulfur compounds, can initiate the development and progression of bronchitis and emphysema. Ambient particulate pollution has been associated with the development of lung cancer; the benzo(a)pyrene component of soot has been advanced as the causal factor. Although benzo(a)pyrene is a known carcinogenic material, it may be serving as a surrogate for a class of hazardous organic compounds found in urban aerosol samples.

Polycyclic organic matter (POM) is a fractional constituent of particulate matter emitted during coal combustion. POM emissions appear to vary inversely with combustion efficiency. There is a factor of approximately 10,000 difference between POM emission factors (emissions per pound of coal) for hand-stoked coal stoves and large new utility coal boilers.[24] Therefore, the major health risk of POM is not from the large sources but with the older, less efficient utility and industrial boilers near populated areas. Depending on dispersion characteristics, POM from these coal sources may add to POM concentrations from other sources such as refuse burning, coke production, and motor vehicles. Also, any substantial increase in residential and other small-source coal combustion could aggravate problems with POM emissions.

Nitrogen dioxide health effects are normally associated with exposures close to the pollution source, because NO_2 is reactive and takes part in complex reactions within the atmosphere that produce ozone, PAN, and other complex organic nitrogen species.

The Clean Air Act Amendments of 1977 require EPA to promulgate a short-term NO_2 standard (not more than a 3-hour averaging time) by 1980. An extensive review of NO_2 is reported in the EPA Office of Research and Development's draft document "Health Effects for Short-Term Exposures to Nitrogen Dioxide," March 1978. Although this draft document does not contain a synthesis, it does contain extensive review with some critical interpretations and serves as a draft criteria document. EPA has requested public comment

---

[24]N, Dean Smith, see note 11

on a 1-hour NO_2 concentration in the range of 500 to 1,000 $\mu g/m^3$. It is expected that the proposed standard will most likely be at the lower end of the range.

NO_2 oxidizes molecules in cell membranes, attacks connective tissues, and interferes in metabolic reactions. Several small mammal species are affected by 1,000 $\mu g/m^3$ of NO_2 exposure repeated or continuous over the course of a week or more. Epithelial cells are damaged and biochemical changes occur in a manner that might be expected in human tissues. Furthermore, defenses of normal mice against massive bacterial infection are reduced at that concentration, perhaps mimicking the response of a severely impaired animal to a normal exposure to bacteria.

The airway resistance of normal subjects is not highly sensitive to the irritant effect of NO_2; bronchitics and others with chronic obstructive lung disease are sensitive; asthmatics are very sensitive. If the lower limits of the ranges of concentrations of NO_2 producing effects in human beings are correct, there would be respiratory resistance in sensitive individuals at concentrations above 200 $\mu g/m^3$. Thus, the short-term concentration patterns of NO_2 in the immediate vicinity of coal-burning facilities may represent an increased public health concern. However, the evidence from in vitro studies and from controlled NO_2 exposure studies with asthmatics at these relatively low concentrations is not universally accepted. In fact, the World Health Organization (WHO) has recommended a short-term (1 hour) NO_2 standard of 320 $\mu g/m^3$.

Table 28 summarizes the reported effects of low-level, short-duration exposure to NO_2, the levels reported in U.S. cities, and the proposed WHO and EPA standards.

Ozone may act by itself or in synergistic combination with other pollutants to damage human health. Our ability to quantify the health impacts of ozone attributed to increased coal combustion is severely limited by an inadequate understanding of NO_x transformation processes and the long-range transportation characteristics of ozone and its precursor pollutants. Table 29 summarizes some of the existing data on ozone health damage.

Table 28.—Nitrogen Dioxide: Levels and Effects

Comments	Concentrations	Reported Effects *(exposure time)*
	µg/m³, ppm	
	2000 ── 1	● infectivity, mouse (3 hr. interpolated, 17 hr.)
	1800 ──	
	1600 ──	
	1400 ──	
	1200 ──	
	–1000 ── .5 ┐	● multiple biochemical changes, guinea pig (8 hr/day, 1 week)
		● increase in protein uptake by lung, guinea pig (4 hr/day, 8 days)
		● infectivity, mouse (1 week)
		● tracheal mucosa & cilia, autoimmune response, mouse (one mo.)
		● cilia, clara cell, and alveolar edema, mouse (10 days)
peak levels ── ── ── ── in four cities	– 800 ── .4	● acid phosphates and serum proteins enter lung, guinea pig (1 wk.).
EPA lowest suggested 1 hr std	– 600 ── .3 ┐	● detected in blood, monkey (9 minutes)
		● human dark adaptation impairment (immediate)
		● collagen, rabbit (20 hr/wk for 24 days)
peak levels ── ── ── ── in many cities	400 .2	
WHO highest (320) lowest (190) suggested 1 hr std	200 ── .1 ┐	● human asthmatics provoked resistance, (1 hr)
		● bronchial epithelial cells, alveolar macrophages (1-2 hr, *in vitro*)
	0	

SOURCE Health Effects Appendix

Although there is extensive literature on experiments relating health effects of ozone and other oxidants, assessment of a safe standard is difficult. The problems parallel similar difficulties with interpreting health effects from other pollutants. First, questions are raised by the specificity and accuracy of ambient monitoring used in epidemiological studies. Second, there are uncertainties in extrapolating from cell and organ studies, as well as from whole animal studies, to estimates of human damage. Finally, field studies measure only the ozone component of total oxidant levels but are actually observing the effects of all oxidants. The evidence is consistent that nose, throat, and eye irritation occurs in the range of 200 to 294 pg/m³(0.1 to 0.15 ppm) of measured ozone. Breathing difficulties in exercising adults and chest pain in children exposed to

ozone have been reported in the range of 200 to 400 pg/m³(0.1 to 0.2 ppm). Decreased running performance has been associated with similar ozone levels. More severe symptoms of chest discomfort and coughing have been reported in healthy young adults at measured ozone levels of about 725 µg/m³(0.36 ppm) and at 490 µg/m³(0.25 ppm) in hypersensitive individuals, Levels high enough to cause these more severe symptoms occur in Washington, D. C., Houston, Tex., Philadelphia, Pa., and Los Angeles, Cal if., with some regularity.

Japanese investigators have observed that the frequencies of several symptoms in school children, including sore throat, headache, cough, and dyspnea, are higher on days when maximum hourly oxidant concentrations equaled or exceeded 0.15 ppm than on days

Table 29.-Ozone (OJ: Levels and Effects
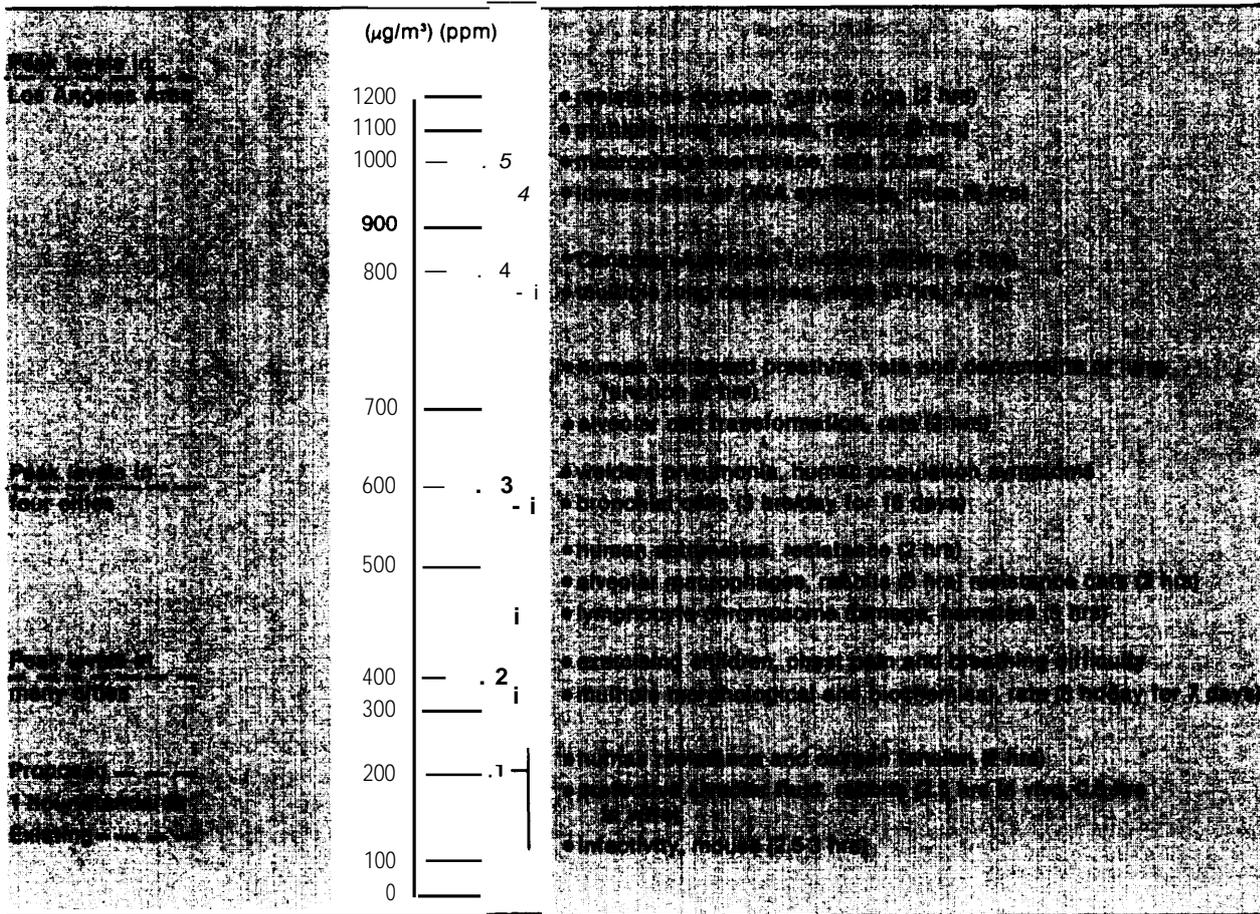
SOURCE: Health Effects Appendix.

when corresponding concentrations were below 0.10 ppm.[25] in Japanese studies, the number of individuals experiencing symptoms has generally been more strongly associated with ozone concentrations than with total oxidant concentrations. The Japanese studies also suggest that people with allergic tendencies are more susceptible to short-term photochemical oxidant exposure than are other segments of the population.

Japanese studies have generally shown oxidant- or ozone-associated effects at lower oxidant or ozone concentration than have American studies. The consistent difference between Japanese and American findings raises several questions, including whether the components of oxidant pollution in Japan are different from those in Los Angeles, or indeed, from those in any U.S. location. It is possible, for instance, that oxidants in Japan are accompanied by higher SO_x levels than in the United States. In any case, the Japanese results underscore the point that epidemiological results gathered in one area can be generalized to other areas only with the greatest caution. The Japanese results also demonstrate the need to gather comprehensive data in U.S. locations other than Los Angeles.

Because the discrepancy among these results is along national lines, it is of particular

[25] J. Kagawa and T. Toyama, "Photochemical Air Pollution: Its Affects on Respiratory Function of Elementary Schoolchildren, " *Archives of Environmental Health,* **30: 117-122,1975.**

interest to note the results of a study on nine new arrivals to the Los Angeles area.[26] They showed substantial decreases in pulmonary function for ozone exposures of 800 µg/m³ for 2 hours, whereas six local residents did not show measurable effects. In a further study,[27] four southern Californians and four Canadians were exposed to 700 µg/m³ for 2 hours with light intermittent exercise. The Canadians exhibited discernible decreases in lung function, but the Californians did not. Thus, either a possible adaptation or a "selective migration" effect is inferred. ("Selective migration" occurs when people moving into or out of an area show a sensitivity to a pollutant that is markedly different from the average). Any adaptation would indicate an altered lung surface due to air pollution, which is an effect that should arouse considerable concern. This observation is consistent with the observation that at low ozone levels smokers are generally less reactive than nonsmokers. An alteration in the lung would also be consistent with deactivated surface cells in the bronchi, which may lead to long-term respiratory problems.

In his comprehensive review of health effects from exposure to low levels of air pollution, Ferris concludes:

> Because of the highly reactive character of O₃, prudence dictates that we should abide by the present standard until more valid data have been collected. Chamber studies will be useful to define acute or short-term effects but cannot identify subtle long-term effects. For these we shall have to turn to epidemiologic studies which have many confounding variables. To date there is no evidence that health effects result from chronic exposure to levels of oxidants that currently occur in Los Angeles, but careful studies to confirm this have yet to be done. "

26 J. D.Hackney, et al , "Studies in Adaptation to Ambient Oxident Air Pollution: Effects of Ozone Exposures in Los Angeles Residents vs New Arrival s," in *Environmental* Health *Perspectives, 18:* 141-146, 1976.

27). D Hackney, et al., "Effects of Ozone Exposure in Canadians and Southern Californians, " *Archives of Environmental Health, 32:* 110-116, 1977.

[28] *B. G.* Ferris, Jr., "Health Effects of Exposure to Low Levels of Regulated Air Pollutants, A Critical Review, "). *Air Poll. Control Assoc., 28:482 (1978).*

As yet, no convincing association has been shown between short-term oxidant exposures and rates of mortality due to any cause. Although a positive association has been observed in one study, a re-analysis appears to negate this conclusion. Interpretation of mortality studies has been hampered by limitations in statistical methodology. It has not been possible to fully separate the effects on mortality of oxidants, other pollutants, and meteorologic factors, most notably temperature.

Sulfur dioxide.–Although there have been many studies of SO_2, there is little evidence of acute adverse effects at ambient levels (usually below 0.4 ppm). The gas is soluble and removed almost entirely by the upper airways. At levels much higher than the ambient standard of 0.14 ppm for 24 hours, controlled exposure studies have demonstrated increased airways resistance in subjects. These and other reversible effects occurred at 1 ppm (2- to 3-hour exposures) and higher. Long-term animal exposures in the range of 340 to 15,000 pg/m³ (0.1 3 to 5.72 ppm) show no functional or structural lung damage. All long-term exposure studies on human beings have involved a simultaneous exposure to the gas-aerosol mixture. However, it would appear on the basis of a lack of cumulative functional or structural impairment of the lungs from high-SO_2 animal exposures that SO_2 alone at ambient levels is not hazardous for human beings. The observed effects are shown in table 30.

Sulfur dioxide and particulates.-Exposure to SO_2 virtually always occurs in the presence of particulate and other gases. Generally, there is a heightened response from the dual exposure that is not observed from single exposures. A popular explanation of this synergism is that the aerosol acts as a carrier for the SO_2 (which would otherwise be screened by the lung's defenses), thereby delivering a higher fraction of the gas to the deep recesses of the lungs. An alternative explanation is that chemical reactions can occur between the gas and particle, forming new compounds (such as sulfuric acid) that are more toxic. Both explanations are supported by laboratory animal .

Table W.—Health Effects of Sulfur Dioxide

	μg/m³	ppm	
		10	● edema, necrosis, desquamation of respiratory epithelium (24 hrs) ● most effects in nasomaxillary turbinates, Giddens et al. (1972)
	5214	2.0	● change in antibody formation, mice; Zarkower effect alone or with carbon particles
Short-term concentration experienced adjacent to point sources	2607	1.0	● decrease human mucus flow rate (1-3 hr) ● decrease cross-sectional nasal area } Anderson ● decrease FEV₁.₀, FEF₂₅%-₇₅% ● increased reactivity to acetylcholine, dogs (1 hr) Islam ● decreased clearance on 20th day post challenge, Ferin and Leach ● decreased clearance (1.5 hr exposure 2x/day, 5 day/week, 1 yr)
		0.26	● mean exposure (0.03-0.65 range) for 12.8% increase in guinea pig flow resistance, Amdur
EPA 24 hr. standard	365	0.14	
EPA annual standard	80	0.3	
		0	

SOURCE: Health Effects Appendix.

studies using combined exposure of SO_2 and various particles.

Short-term health effects from simultaneous exposure to high concentrations of SO_2 and particulates have been investigated in many European and American cities. Respiratory symptoms, including general lung function impairments and increased asthma attacks, have been associated with 24-hour 200 to 300 μg/m³ concentrations of SO_2 and 150 to 350 μg/m³ concentrations of particulates. Similar lung effects have been reported for long-term (yearly averages) levels of about 100 μg/m³ SO_2 and 150 μg/m³ particulates.

Gas-aerosol interactions have been documented in the laboratory and observed in population studies at levels slightly higher than the present standards. Given that these potentially harmful reactions are quite complex, perhaps impossible to understand completely, violations of National Ambient Air Quality Standards (NAAQS) by coal combustion may be damaging to human health.

Sulfate particulates. -Over the past decade emissions of SO_2 have remained fairly stable, but their distribution has changed substantially. Urban SO_2 levels have decreased considerably as powerplants and other sources have either moved away or come into emissions compliance. At the same time, however, sulfate levels in most cities have not declined. This can be attributed to the formation of sulfate from the SO_2 emitted by new rural sources, and its long-range transport to the urban areas. Sulfate particulate can travel more than 1,000 km, with atmospheric residence time of between 2 and 4 days. The available data indicate that large regional reductions in total SO_2 emissions would be required to reduce sulfates. Thus, current policies designed to reduce ambient pollutant concentrations are not fully successful because they inade-

quately deal with long-distance transport of pollutants across jurisdictional and international boundaries.

Review of the available human experiments and epidemiologic studies indicates that high levels of some sulfates irritate eyes and the respiratory tract, decrease lung function, aggravate emphysema, asthma, and chronic bronchitis, and may increase mortality.

Research seems to indicate that sulfates function independently of SO_2 in producing health and ecological effects. Sulfates exist as several chemical species. Sulfuric acid mist and several species of sulfate particles have been demonstrated to be more toxic than SO_2, as measured by flow resistance in pulmonary airways in animals, while at least two sulfate species appear less toxic than the SO_2 gas. It has also been demonstrated that for a given concentration of a sulfate compound, toxicity increases with decreasing particle size. Atmospheric sampling has repeatedly shown that more than half of the mass concentration of sulfate is found in the aerosol fraction of particles less than 1.0 μm in diameter.

The most extensive epidemiological study of SO_2 and sulfate is the Community Health and Environmental Surveillance System (CHESS) study conducted by EPA.[29] As a consequence of many valid criticisms, it is generally felt that insufficient information exists in the CHESS results to propose a standard for sulfate.[30] Upon re-analysis, the CHESS results do not substantiate the original conclusions that ambient sulfate levels are associated with respiratory symptoms in asthmatic adults and acute lower respiratory illness in children. However, other CHESS results are not inconsistent with other findings and represent a large body of epidemiological data. [31]

29 *Health* Consequences of *Sulfur Oxides: A Report From CHESS, 1970-71* (Washington D. C.: U.S. Environmental Protection Agency, May 1974), E PA-650/l-74-004.

[30]B. G. Ferris, Jr., see note 23.

31 "R. S. Chapman, discussion in: "Health Effects of Exposure to Low Levels of Regulated Air Pollutants: Discussion Papers, " *Journal of the Air Pollution Control Association,* vol 28, no 9, September 1978, pp. 887-889

Laboratory studies provide mixed evidence on the adverse health effects of sulfates on both human beings and experimental animals. Airway resistance has been measured in animals at sulfate levels higher than those experienced in ambient exposures. Impaired lung clearance in animals has been reported in the upper range of ambient exposures. Some human studies show effects at levels below 100 μg/m³ for short-term exposures. However, these observations are not confirmed in other studies. Table 31 summarizes the data available over the range of ambient exposures.

In summary, animal and human respiratory studies indicate health effects for sulfates by themselves and in combination with other gaseous pollutants at levels higher than current ambient exposure. Further, these studies distinguish among sulfate compounds. Ammonium sulfate, the principle constituent of airborne sulfates, is less hazardous than other sulfate compounds. Sulfuric acid aerosol, also detected in urban atmospheres, is the most hazardous. At times, urban and rural sulfate levels are almost exclusively comprised of sulfuric acid.

Effects of Air Pollution on Death Rates

Several epidemiologic studies of mortality (death) rates have shown an association between sulfate and TSP levels and community mortality rates. Most of these studies are "cross-sectional;" that is, they examined differences in mortality, air pollution, and other variables among geographical areas over one time period. Increased levels of mortality are observed at or near air pollution levels that prevail in urban regions of the United States. Although different studies show a considerable range of pollution/death rate associations, the majority of these studies derived coefficients of air pollution-induced mortality (deaths per unit population exposed per unit of pollutant concentration, or annual number of deaths that would be expected to occur if 100,000 persons were exposed to an average of 1 μg/m³ of pollution) that indicate that several tens of thousands of premature deaths annually are associated with current pollution levels. Owing in part to limitations in the pollutant

Table 31.—Health Effects of Sulfates

Exposure	Conc. (µg/m³)	Health Effects
	500	• Increase in breathing resistance in animals
	100	• Reported decrease in clearing mechanism in healthy adults
24-hour levels frequently occurring, summer, N.E. U.S.	25	• Increased daily mortality (24 hour) • Aggravation of heart and lung disease in elderly (24 hour)
	10	• Increase risk, chronic bronchitis • Increase some respiratory disease in children (yr)
Non-urban levels N.E. U.S.	5	• Aggravation of asthma (24 hour) • Increased risk chronic bronchitis in nonsmokers
	0	

measurements (several important pollutants were unmeasured), it is impossible to determine from these studies whether sulfates and suspended particulate are the true causes of the statistically observed deaths, or whether they serve as a measure of some other pollutant or combination of pollutants. In the absence of a plausible alternative hypotheses, however, any other causative pollutants appear likely to have been the products of the same (fossil fuel combustion) sources that produced the sulfates and TSP.

These studies have been widely criticized in the health community for deficiencies similar to those described earlier on pages 202 to 204, and their results have been rejected by many. Statements of the more frequent arguments against the studies and discussions of the arguments' validity are presented below:

1. These studies typically use data from a single monitoring station to represent the exposure to the residents of a metropolitan region. Measurements taken at a single point are a poor measure of the mean exposure of the population.

   Discussion: The effect of using poor data is, if the error is random, to bias downward the estimated coefficient of the independent variable being measured. It is likely that the error introduced by using central station data as measures of population exposure would make it less likely that the analyst would find a positive association between air pollution and mortality. Thus, this is not a logical argument against a positive finding.

2. The single monitoring station is typically located in the center of the urban area, which often coincides with the areas of highest pollution exposure. This biases results.

   Discussion: The bias produced by location of monitors in areas of relatively high pollution may be either positive or negative, depending upon the relative gradients of exposure among the cities under consideration.

3. It is unlikely that current air pollution exposure is an adequate exposure parameter. Past exposure or cumulative history of exposure is undoubtedly more relevant.

   Discussion: It can be demonstrated that regardless of whether air pollution levels are increasing or decreasing, it is possible that this bias could operate in either direction. To the extent that present exposures are less than perfectly colinear with past

exposures, there will be a tendency to underestimate the true magnitude of the relationship. Also, efforts to include measures of cumulative exposure have generally failed to increase the explanatory power of air pollution mortality models.

4 The studies have been confounded by the similarity of patterns of certain critical socioeconomic variables with patterns of air pollution. Whereas the researchers believe that they are seeing the relationship of death rates to pollution, they are actually seeing the relationship of death rates to occupation and other factors that happen to be somewhat colinear with pollution in the United States. If these variables were taken into account, the pollution/mortality association would disappear.

Discussion: Confounding is possible in any epidemiologic study. This can influence results in two ways: either an important variable is not included or two or more seemingly independent variables are really measures of the same thing. In statistical studies on mortality and air pollution, smoking and occupation are frequently cited as confounding variables left out of regression analyses. The effect of confounding would be the production of seemingly valid but spurious association. For confounding to occur, the variable must be a cause of disease, and must be highly correlated with the variable of interest, air pollution.

a. Smoking. It is certainly reasonable to argue that smoking may be confounding the results. Data on the smoking habits of metropolitan populations are virtually nonexistent. It is generally accepted that smoking can induce lung cancer, induce and/or exacerbate bronchitis and emphysema, and reduce life expectancy. Therefore, if there were substantial differences in the amount of smoking across metropolitan areas–differences that varied similarly to air pollution — then smoking may be the real cause of mortality now attributed to air pollution. There is mixed evidence on this issue. Several investigators have independently examined the mortality experience of men and women

in relation to air pollution exposure. In most of this work, air pollution exposure appears to have a stronger effect on men than women. Combining this with the knowledge that historically men in the United States smoke more heavily (and more men smoke) than women, two hypotheses become possible:

    i. smoking is confounding the association;
    ii. smokers have more respiratory diseases, and thus are more susceptible to air pollution.

Because of a lack of data on community smoking habits, cross-sectional studies can do little to resolve these two hypotheses. However, it is important to note that a very high correlation between air pollution and the smoking habits of entire urban populations would be required to account for the mortality differences now attributed to air pollution. It is unlikely that this is true.

b. Occupational exposure. It is argued that the regional differences in heavy manufacturing and other industrial activities vary similarly to the air pollution concentrations and that the differences in mortality reflect the hazards of working rather than breathing outdoor air.

When occupational variables such as the percentage of the work force employed in each of the following categories — agriculture, construction, manufacturing, transportation, trade, finance, education, white collar, and public administration —are added to regressions, the amount of mortality associated with air pollution is reduced. This indicates that adequate accounting for the occupational variable could reduce the effect attributed to air pollution. Lave and Seskin[32] suggest an alternative interpretation. They argue that occupational variables are surrogates for unmeasured air pollutants that affect the general population. If differences in occupation patterns are correlated with air pollution levels, this

[32]L. B. Lave and E. T. Seskin, *Air Pollution and Human Health,* John Hopkins U. Press, Baltimore and London, 1977

represents a limitation of the air pollution mortality associations derived from cross-sectional studies. Currently available data do not permit resolution of this issue.

c. Differential/ *migration.* Occasionally it is argued that people have been moving out of the heavily polluted Northeast and East Central United States to the less polluted Southeast, South, Mountain States, and West. It is well established that those who move tend to be relatively young and healthy. Thus it is possible that selective outmigration from the polluted areas might result in a spurious association between air pollution and mortality. Lave and Seskin have approached this problem by splitting their data base into areas of "high" and "low" migration and performing independent analyses on these two groups. The coefficients of air-pollution-induced mortality derived from the low-migration data set were about half as large as those from the high-migration data. Differential migration may be partially confounding the results, but a positive association remains for air pollution.

These arguments are the most important of many criticisms of cross-sectional studies of air-pollution-induced mortality. Others are considered in volume 11, appendix IX. Although the findings and interpretations of these cross-sectional studies are still being debated, a positive relationship between air pollution and mortality cannot be rejected.

Quantitative Assessments of Health Damage From Future Pollution Levels

The coefficients of air-pollution-induced mortality derived from the studies discussed above can be used to project the deaths that might result from future coal development. In conducting such a projection, the analyst must develop a "scenario" that describes the development, compute its air quality effects, and overlay those effects on the population.

The Biomedical and Environmental Assessment and the Atmospheric Sciences Divisions of Brookhaven National Laboratory (BNL) have developed a methodology for quantifying the

mortality associated with fossil-fuel-derived air pollution.[33] The Atmospheric Sciences Division has applied a long-distance trajectory model to predict the ground-level concentrations of a number of pollutants emitted from coal combustion. The model is capable of incorporating alternative siting and emission patterns to show the air quality implications of various scenarios. The modeling effort:

1. projects pollutant emission from 1,088 coal-fired sources (71 1 industrial point sources and 377 utility point sources) using 1985 and 1990 emissions projections, and assuming 80-percent SO_x control for existing sources and 85-percent SO control for new sources;
2. computes the resulting ground-level air quality concentrations with a model which accounts for long-range transport and chemical conversion (i. e., SO_2 and S0x concentrations are calculated by the BNL model); and
3. calculates the annual population weighted sulfate exposure with 32 x 32 km grids for the entire country.

Figure 26 displays the calculated sulfate annual concentrations for the 1990, 25.7 Quads coal-use scenario. The pattern reflects very high sulfate concentrations in the Northeast with peak levels in the region of eastern Ohio, western Pennsylvania, and West Virginia. After obtaining population sulfate exposure, BNL applied to them a mortality coefficient of 3.25 deaths per year for every 100,000 people exposed to a 1 $\mu g/m^3$ annual averaged sulfate level. This coefficient is a "most likely" coefficient of mortality derived from BNL's examination of the available cross-sectional mortality studies and their data bases. In the BNL work the mortality coefficient is expressed in a probability function that ranges from no health effects (actually a negative coefficient) to four times this "most likely value. " In this way the

[4] For example, see L. D. Hamilton, "Alternative Sources and Health, " in CRC *forum on Energy,* ed. Robert. T, Budnitz, by CRC Press, Cleveland, 1977 and M. G. Morgan, et al, "A Probabilistic Methodology for Estimating Air Pollution Health Effects from Coal-Fired Power Plants, " in *Energy Systems and Policy,* vol. *2, No. 3,* Crane Russak & Co., Inc., 1978

**Figure 26.—Annual Concentrations of Sulfate for a 199025.7 Quads Coal-Use Scenario
(Brookhaven National Laboratory, 1978)**
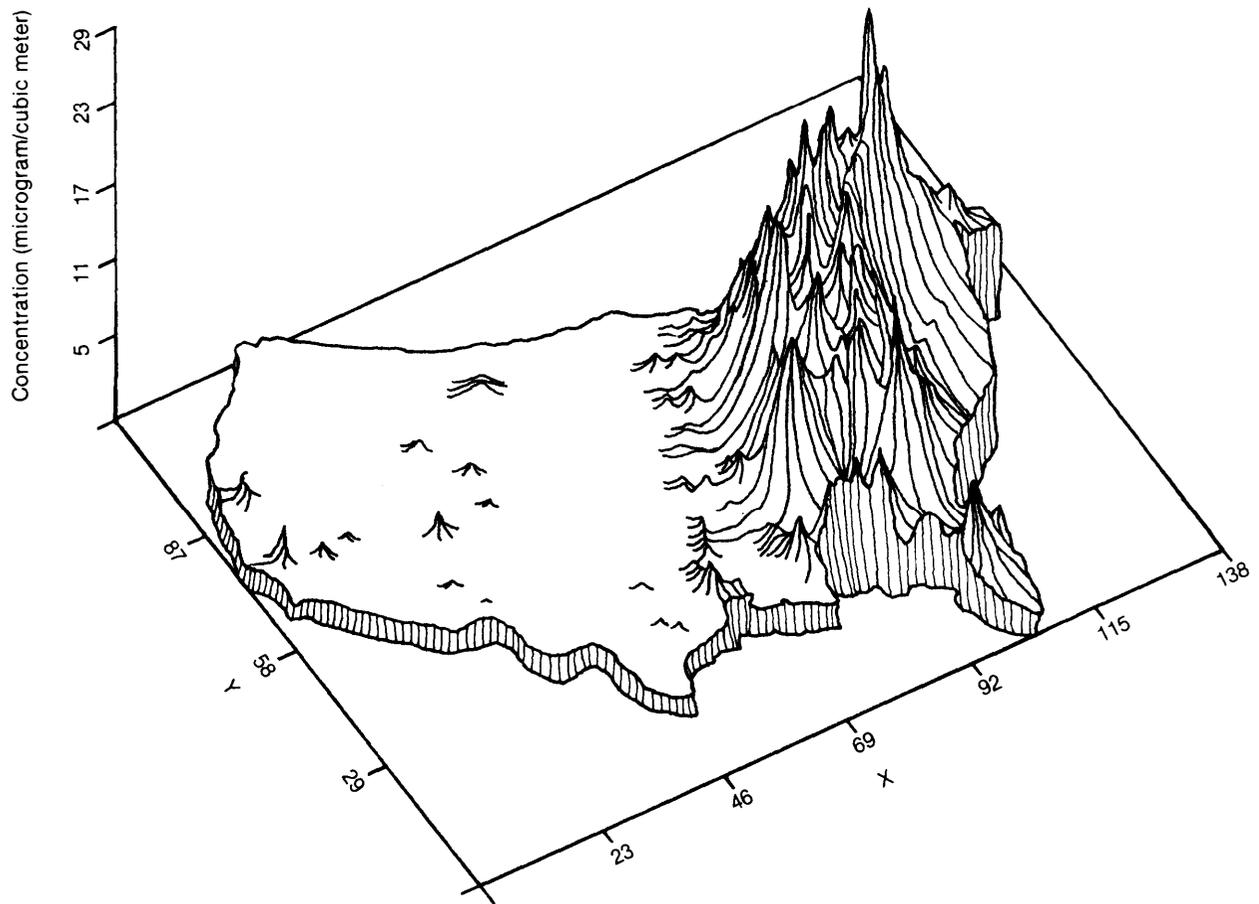
BNL excess mortality, as shown in table 32, is approximately the 50th percentile. That is, there is a 50-percent chance that the actual expected mortality is greater than the estimates presented, based on the BNL probability function for the mortality coefficient.

The implications of the estimates shown in table 32 are startling. First, they imply that coal emissions are responsible for approximately 2.5 percent (48,000 deaths) of the total annual mortality in this country. The second implication is that an increase in coal use could raise the air-pollution-caused annual mortality by approximately 7,000 in *1990.* In comparison to the more than doubling in coal use, the projected annual air pollution mortality would increase by less than **20** percent over

the current air pollution mortality estimates. This increase is approximately 0.4 percent of the annual total U.S. mortality.

The credibility of estimates of this type has been severely challenged by many in the health community. As noted above, there is widespread skepticism that any air pollutants at current levels of concentration are killing people in large numbers, Furthermore, even the supporters of the air pollution/mortality associations used in the analysis generally agree that sulfates may not be the "guilty" pollutant. Other problems with the analysis include potential inaccuracies in the sulfate projections and the use of a simple linear model for health effects. However, this work is the first comprehensive attempt to formulate a

Table 32.-Annual Projected Mortality From Coal Combustion

Year	Quads of coal use	Expected mortality
1975.	11.3	48,120
1985.	*22.5*	*49,543*
1990.	25.7	55,835

NOTE: Proportional Mortality Model—3.25 deaths/y r/100,000 populations/(1 µg/m^3—annual average for sulfate).

SOURCE: Based on population exposures from: Meyers, R. E., Cedarwall, R. T., Kleinman, L. l., Schwartz, S. E., and McCoy M, "Constraints on coal utilization with respect to alr pollution production and transport over long dtstances: summary," Oct. 2, 1978 (draft report), Brookhaven National Laboratory.

quantitative methodology for assessing air pollution health effects. Even if the damage coefficient is not accepted, the model can identify population exposures to sulfates and related pollutants and can identify the relationships between regions of high exposures and regions with multiple pollution sources; this information can be used to evaluate the relative effects of alternative siting patterns.

Research Needs

DOE, EPA, the National Institutes of Health (NIH), and other agencies support air pollution health effects research in areas of bioscreening for hazardous substances, cellular toxicology, animal toxicology, human exposure studies, and risk analyses. This research is funded through the Federal Interagency Energy Environmental Research and Development Program, as well as the basic contract and grant programs of various agencies. Health effects research programs related to fossil fuels are reviewed in volume 11, appendix IX.

Quantification of mortality and morbidity from fossil fuel air pollutants is currently limited because:

1. Population exposures to pollutants are poorly defined.

2. The mechanisms of biological injury induced by specific pollutants are not adequately understood.

3. Insufficient epidemiologic evidence exists to relate mortality and/or morbidity to ambient levels of air pollution.

Significant improvement in the ability to quantify the effects of coal combustion is contingent upon continued development in exposure assessment, health effects research, and quantitative applications.

Exposure.-Comprehensive pollutant monitoring is fundamental to epidemiologic studies. Present monitoring assesses outdoor concentrations of relatively few pollutants. Particulate, for instance, are determined on a weight basis only and are not differentiated by size or chemical composition. Encouragingly, EPA is conducting a nationwide fine-particulate monitoring program. The relationship of outdoor air pollution to indoor exposures and, in fact, the total integrated dose of pollutants to the individual are not understood. Integrated exposure assessments that measure the human body burden from multiple exposures to pollutants are urgently needed. Moreover, to facilitate epidemiologic work, the exposure of entire urban populations must be better characterized by implementation of more "dense" monitoring networks, including personal monitors.

Damages.-The specific mechanisms causing biological injury from many atmospheric pol-

lutants are unknown. Knowledge of these mechanisms will provide a firmer scientific basis for epidemiologic investigation of specific health damages and pollutants and, consequently, a foundation for effective pollutant-specific control strategies.

Ideally, understanding of the biochemical and metabolic fate of pollutants is desired. However, the precise fate of pollutants is often impossible to determine. When this is the case, research must be focused on understanding the grosser, aggregate effects of pollutant insults. For example, pollutant effects may manifest themselves as increased susceptibility to infect ion, or as inhibition of lung-clearing mechanisms. In pursuit of a better understanding of these effects, new techniques and traditional research for assessing defense mechanism inhibition should be expanded. New techniques are currently being developed for noninvasive methods for mapping particulate deposition and particle retention in the lungs. These techniques would permit rapid surveying of pollutant loadings in human lungs; they may allow the detection of health effects in human populations before the onset of clinical symptoms.

As the result of suggestive evidence on synergistic interactions of multiple pollutants, additional studies examining the combined effects of two or more pollutants should be begun. Few clinical studies of this type have been done. Federal health organizations as well as EPRI have recently recognized this fact. A few animal and human studies of multiple pollutant exposures have started; however, more such studies should be encouraged. In addition, there have been too few controlled exposure studies on subjects under stress. Stress may be induced by exercise or with medication. Stress-pollutant studies are important in determining biomedical effects in sensitive individuals.

Epidemiology .-Epidemiologic studies will be necessary for monitoring possible changes in morbidity and mortality as the total popula-

tion exposure to coal-related air pollution increases. Such studies must receive long-term funding commitment to comprehensively examine multiple health indicators while properly assessing pollutant exposures.

Until direct information from controlled toxicologic and epidemiologic studies is available, quantitative assessments of health impacts from fossil fuel combustion must rely on cross-sectional statistical studies. These studies can be improved by a more accurate measurement of socioeconomic variables. For example, as noted above, differences in regional smoking habits have not been adequately accounted for. This deficiency could be corrected if social, economic, and geographic smoking patterns were assessed as part of the National Census.

In order to resolve the question of whether long-term health effects are caused by peak exposure or are the cumulative effect of mean exposures, studies should be undertaken of the effects of periodic exposures to sulfate, nitrate, ozone, and fine particulate. Summertime "episodes," where these and other pollutants are elevated for hours to days over large areas of the Northeast, have been documented in ongoing field monitoring studies. Selected populations must be closely monitored for respiratory and other physiological changes before, during, and after such episodes.

Conclusions

The discussions in this section and in appendix IX indicate that there are grounds for speculation (for example, our knowledge of the ability of fine particulate to penetrate deeply into the lungs) and some positive but not conclusive statistical evidence that current and expected future concentrations of coal-related pollutants may be dangerous to human health. A significant segment of the health community considers the statistical evidence to be meaningless. Several of the objections they raise are valid but do not appear to justify rejection of the evidence.

Policy makers are faced with a difficult tradeoff. More stringent regulation of air pollution can involve very large costs and can even incur new environmental damages. For example, an insistence on full scrubbing will cost several tens of billions of dollars by 1990 and create a substantial disposal requirement for millions of tons of scrubber sludge. On the other hand, a failure to control incurs the risk that significant health damages may occur. The tradeoff is complicated by the current inability to definitely associate the (statistically observed) health effects with one specific pollutant; although sulfates have been implicated by most of the statistical analyses, they may be an indicator for another pollutant or mixture of pollutants.

Uncertainty in environmental policymaking is inevitable. However, the level of uncertainty and the stakes in coal policy are very high. There is thus a high premium on reducing the uncertainty by improving predictions of future coal-related health effects. The research needs identified above (increased monitoring, improvement in the capability to conduct cross-sectional and time series statistical studies, and expanded investigations of the mechanisms of pollution-caused biological injury) are critical elements in this process.

Ecological Effects

Sulfur Oxides

As emphasized in the discussion of pollutant transformation and transport, SO_2 may retain its chemical identity or may convert in the atmosphere to sulfuric acid or to a variety of sulfate salts. Within about 40 km of a coal-fired powerplant, the form of sulfur most likely to be deposited is SO_2. To place experimental evidence in proper perspective, one must compare levels at which damage is observed both to levels mandated by the current air quality standards and to those actually prevailing near and far from powerplants. The secondary NAAQS SO_2 standard is 0.5 ppm (3-hour average) and the primary standards are 0.14 ppm (24-hour average) and 0.03 ppm (annual average). In the United States as a whole in 1975,

the annual average ambient levels were under 0.01 ppm.[34] Levels near a plant vary greatly depending on the pollution controls, combustion conditions, weather, and topography. The SO_2 level calculated for an area within a few kilometers of an "ideal" 1,000-MW plant (meeting NSPS, having a 500-foot stack) is 0.04 ppm (24-hour average), with the concentration dropping by a factor of 10 within 5 to 10 km of the plant.[35]

Experiments have shown that levels as low as 0.02 to 0.05 ppm of SO_2, even at relatively brief exposures, can cause significant physiological disorders in important crops such as Eastern white pine,[36] ryegrass,[37] alfalfa,[38] and some others. Still more evidence exists for significant plant damage at doses that are higher than 0.05 ppm but lower than the current secondary standard.

From an economic standpoint, long-term yield losses are equally as important as the more visible signs of injury to vegetation. Yield loss may occur even without the manifestation of visible symptoms, especially in forest tree species and alfalfa (see appendix X, volume II). Usually, however, yield loss in crops is accompanied by the visible leaf damage that has come to be associated with the effects of SO_2 pollution.

Lower plant species — mosses, ferns, lichens, and liverworts — are even more sensitive to SO_2 than are agricultural and forest crops. Field studies indicate that many such species are sensitive to levels as low as 0.03 ppm. Numerous lichen species have already become extinct downwind of large cities in Europe, North America, and Asia.

[34] *Energy/Environment Fact Book* (Washington, D.C.: U.S. Environmental Protection Agency, 1978), EPA-600/9-77-041, p. 10.

[35] *An Analysis of the Impact on the Electric Utility Industry of Alternative Approaches to Significant Deterioration: Volume II* (Washington, D.C.: U.S. Environmental Protection Agency and Federal Energy Administration, October 1975).

[36] C. R. Berry, "Age of Pine Seedlings with Primary Needles Affects Sensitivity to Ozone and Sulfur Dioxide," *Phytopathology* Vol. 64 (1971), pp. 207-209.

[37] Bleasdale, *Nature* 169 (1952), pp. 376-377.

[38] J. H. Bennett and A. C. Hill, "Acute Inhibition of Apparent Photosynthesis by Phytotoxic Air Pollutants," *Am. Chem. Doc. Sym.* series No. 3 (1974), pp. 115-127.

Although ambient levels near powerplants usually are below the current secondary standards, much higher values can occur during plume touchdowns. The SO_2 levels during a touchdown, as well as the frequency of touchdowns, strongly depends on local factors surrounding a given powerplant. Measurements of concentrations during these episodes are scarce, although measurements 3.6 miles from an Indiana powerplant showed nearly 100 episodes per year of l-hour SO_2 concentrations above 100 pg/m ^{3} (.037 ppm) in the direction of persistent winds.[39] Better documentation exists for the actual damage done by plume touchdowns, or fumigations, from coal-fired powerplants and industrialized sources. These fumigations have caused acute foliage burning to commercial soy beans,[40] ponderosa and lodgepole pine forests, Douglas fir forests,[41] and to other plants.

Damage caused by mixtures of pollutants have been shown in the field and in chamber studies over a wide range of environmental conditions, including variations in soil type, temperature, light, and humidity. Combined effects appear to take place through several mechanisms. The most common seems to be that the combination of pollutants reduces the plant's threshold of injury; frequently the effect of the more toxic of two pollutants is enhanced.

A wide variety of field, vegetable, fruit, nut, forage, and forest crops have been shown to be sensitive to SO_2—even at levels below the Federal secondary standard – in mixtures with common pollutants (ozone, nitrous oxides, hydrofluoric acid, and peroxyacetyl nitrate). Such pollutant mixtures disrupt critical plant functions, including growth, yield, root/shoot ratios, photosynthesis, and respiration. The

physical appearance of produce can also be injured by the combined impact of different air pollutants. As a result, the marketability of vegetables and ornamental may be reduced.

Damage to animals occurs at far higher doses of SO, than those levels at which plants are affected. Rather than being affected directly by SO_2, animals may be more seriously endangered by its indirect effect; sulfur compounds can destroy or alter their natural habitat.[42]

SO_2 is transformed in the atmosphere to various forms of sulfate that are damaging to plantlife. Plants are directly injured when excessive sulfates accumulate in their tissues. The rate at which this occurs varies according to the plant species and according to the amount of sulfur already available in the soil (some possibly stemming from chemical fertilization). The California Air Resources Board has reported growth and yield reductions from sulfate accumulation in cotton, oats, rye, tomatoes, barley, and in forests in New Hampshire. Other studies have shown damage to spruce needles from sulfate accumulation over periods of time as brief as 10 to 100 days.

Some sulfates, notably ammonium sulfate, can act as plant fertilizers. Nevertheless, even apparently beneficial sulfate compounds may be deposited at times not conducive to good farming practices, and the deposition of such sulfates may interfere with the individual farmer's schedule of chemical fertilization.

As discussed previously, the emission of SO_x from all sources may be relatively stable in the next 10 years (at moderate coal use growth rates), although emissions may begin to grow again unless controls are placed on older powerplants. DOE projections show that the emissions in the eastern portion of the United States will generally decline during this period. This is fortunate because that is where the brunt of SO_x impact is now borne. However, some impacts –for example, the acidifying effects of acid rain – may be somewhat cumulative and thus could become more intense unless changes in control strategies are forth-

[39]"Results of Multiscale Air Quality Impact Assessment for the Ohio River Basin Energy Study," Teknekron, Inc., Berkeley, Calif., and Waltham, Mass., 1978.

[40]C. C. Gordon and P. C. Tourangeau, "Biological Effects of Coal-Fired Power Plants," *Fort Union Coal Field Symposium,* University of Montana, pp. 509-530.

[41]C. E. Carlson, M. D. McGregor, and N. M. Davis, "Sulfur Damage to Douglas Fir Near a Pulp and Paper Mill in Western Montana," U.S. Department of Agriculture, Forest Service, Northern Region, Division of State and Private Forestry, Report No. 74-13.

[42]N. R. Glass, cd., "Appendix on Ecological Effects, " U.S. Environmental Protection Agency, p 6, *Rail Report.*

coming. An intensification of SO_x controls on existing combustion sources is the only practical alternative available, as the proposed NSPS is near the present limits of control technology and increased requirements on new plant facilities would have only minor effects in this period.

Nitrogen Oxides

The direct action of man-caused NO_x on the ecosystem is difficult to analyze because nitrogen is an element essential to all biological systems and because natural sources of NOx (especially anaerobic bacterial action and chemical decomposition of nitrate) account for more than 90 percent of global levels.[43] The limited evidence suggests that NO, is more toxic than NO and that the most susceptible receptors in the terrestrial ecosystem are the higher plants, among them oats, barley, tobacco, apples, and lettuce. Still, the threshold for almost all observed effects on ecosystems is well above the NO_x levels in most U.S. cities. NOx is not nearly as obviously damaging to vegetation as either SO_x or photochemical oxidants at similar levels of concentration. Also, very high NO_2 concentrations are required to produce morbidity or mortality in most animals, 44

However, there are some poorly understood areas of ecosystem effects that may be a cause for concern. For example, soils absorb NO and NO_2 quite readily and change them to nitrate, decreasing soil pH and possibly affecting the micro-organisms in the soil. The effects of chronic low-level or intermittent NO_2 exposures on vegetation also deserve attention.

The role of NO_x in the formation of photochemical oxidants is of greater concern than NO, by itself, for oxidants are the most damaging air pollutants affecting agriculture and forestry in the United States.[45] NO, is the one primary "criteria pollutant" (pollutant regulated by a NAAQS under the Clean Air Act) that is likely to increase significantly in the next few decades. The 21-percent increase in NO, projected for 1990 by DOE (NEF #l) may

lead to an increase in concentrations of ozone and peroxyacyl nitrates. However, the degree of increase is complicated by a certain degree of quenching of oxidants by NO_x and by an expected decline in hydrocarbon emissions, which are also oxidant precursors and may be the limiting component for oxidant production.

Any increase in oxidants appears particularly worrisome when it is recognized that elevated ozone concentrations caused by long-range transport of pollutants from urban areas have become a severe regional problem throughout the United States. "Repeated episodes during 4 to 6 months of the year . . . cause obvious foliage injury, impaired photosynthesis, and growth reductions of sensitive species populations, in both agricultural and forest ecosystems.''" Oxidants have caused well-documented damage to agricultural crops, forests, and native vegetation in southern California as well as widespread damage to crops in the East, and have become a new stress on ecosystems in the Southwest. Although animals do not appear to be sensitive to existing levels of oxidants, they are affected by the loss of cover and food accompanying such levels.

N O_x, like SO_x, has the potential for synergistic effects. It may facilitate the creation of nitrosamines, which are known carcinogens, and it also seems to have more adverse effects when present together with SO_x.

Finally, the most serious effect of NO_x may be its involvement with SO_x in the formation of acid rain, which is discussed separately below.

Acid Rain

Both NO_x and SO_x are implicated in the occurrence of acid rainfall at many locations around the world. "Normal" precipitation is expected to have a pH of about 5.7, based on theoretical calculations that postulate an equilibrium with CO_2.[47] Precipitation samples from various points in the United States indicate that in large portions of the Eastern

"I bid,, p. 10.

"I bid., p. 13.

"Ibid., p. 19.

"Ibid.

"J. N. Galloway, C. E. Likens, and E. S. Edgerton, *Science, 194,* p. 722,1976.

United States, the pH falls between 3 and 5[48] (see figure 27). In northwestern Europe, where acid rain has been more intensely studied, a network of monitoring stations yields evidence that the pH of the precipitation has dropped over the past 20 years.[49] It has been widely stated that the region of acid precipitation in the United States is extending westward and southwestward. 50 The data available are strongly suggestive of this statement, but are neither systematic nor extensive enough to be considered conclusive. EPA and the Forest Service are currently establishing networks of monitoring stations that will provide better data in the future.

One effect of acid precipitation is to lower the pH of bodies of water into which it falls. If the pH dips below 5.0, fish such as trout or salmon may perish, for they are very sensitive to pH. Fish kills have in fact been reported in areas such as New York's Adirondack Mountains, where 51 percent of the lakes now have a pH below 5.0, and where 90 percent of these support no fish populations.[5'] A valuable recreational trout industry has thus been endangered. In Norway the losses to the salmon fisheries attributed to acid rain are estimated in the tens of millions of dollars.52 Other aquatic effects include reduction in algal communi-

[48]*Energy/Environment Fact Book,* p. 70.
[49]L. S. Dochinger, paper presented at the *Third Annual Energy/Environment R&D Conference,* June 1978.
[50]See, for example, G. E. Likens, "Acid Precipitation," *Chemical and Engineering News,* Nov. 22, 1976.

[5']G. E. Likens, *Science* 22, p. 720, 1976.
[52]L. S. Dochinger and T. A. Seliga, "Acid Precipitation and the Forest Ecosystem," *Journal of the Air Pollution Control Association* 25, p. 1104, 1975.

Figure 27.–Regional Impact of Acid Rainfall

pH greater than 5.5

pi-i between 50 and 5.5

pH between 4,0 and 5.0

pH less than 4.0
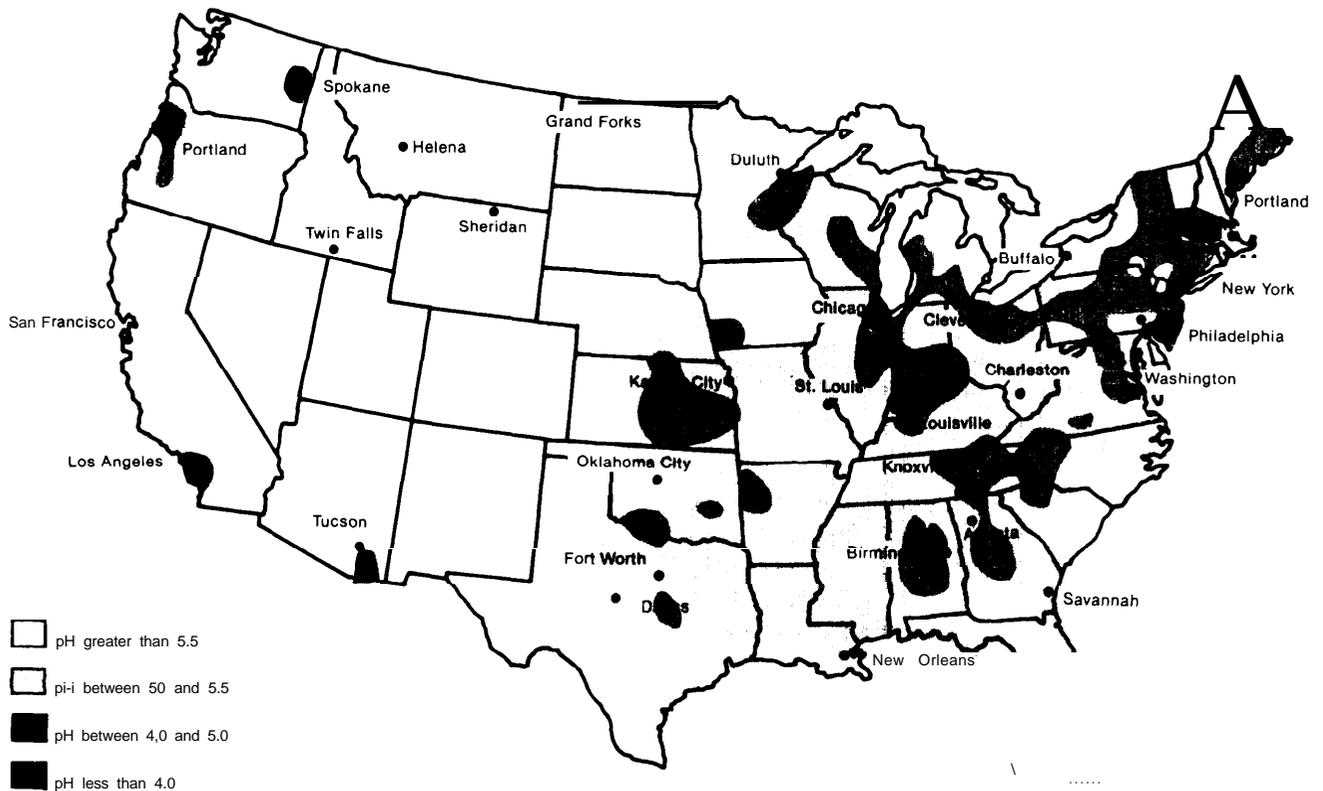
SOURCE: Environmental Challenges of the President's Energy Plan: Implications for Research and Development. Report of the Subcommittee on Environment and the Atmosphere, Committee on Science and Technology, U.S. House of Representatives, 95th Congress, October 1977.

ties, growth of thick mats of benthic moss, and hindrance of nutrient recycling.

The evidence for damage to terrestrial vegetation is somewhat more elusive. An association has been postulated between acid precipitation and the decline in forest growth observed in both the Northeastern United States and in southern Sweden, where growth declined between 2 and 7 percent from 1950 to 1965.[5'] The ecosystem is unfortunately too complex for the cause to be laid so unequivocally at the door of just one of many environmental stresses. Nevertheless, numerous experimental studies have shown that acid rain can harm terrestrial systems in several ways: it may "damage foliage; accelerate cuticular erosion; alter responses to associated pathogens, symbionts, and saprophytes; affect the germination of conifer and hardwood seeds and the establishment of seedlings; affect the availability of nitrogen in the soil; decrease soil respiration; and increase leaching of nutrient ions from the soil. "[54] Acid rains have been strongly implicated in causing extensive damage to Christmas tree farms in West Virginia downwind of the Kyger Creek coal-fired powerplant in Ohio. The disease afflicting the trees has been duplicated in at least two independent laboratory studies using sulfuric acid mists. In other studies, several important food crops and trees were adversely affected by simulated acid rain and mist. It has also been shown that increasing acidity of rain significantly increases the uptake of cadmium and other toxic substances by plants that may subsequently be included in human and animal diet.[55]

The effects of acid precipitation depend largely on the buffering capacity of the region on which the rain falls. The damage may be quite dramatic in Scandinavia, for example, because 80 percent of the forest land in Sweden is acid podzolic soil and thousands of its lakes are underlaid with granitic bedrock.[5'] By contrast, in the Western United States, where indications are that rainfall may be growing more acidic and may continue to do so, the effects may never become serious because the soils and lakes are so alkaline. More studies must be initiated to identify sensitive regions with low buffering capacity and to understand the processes that affect the buffering capacity of soils, such as acidification by natural processes and by chemical fertilization.

Any increase in soil acidity may alter the delicate balance of soil calcium, magnesium, and potassium to aluminum. Essential nutrients, including nitrogen, potassium, and phosphorus, can form compounds that are not useful to plants, or they may be leached from the soil altogether. The living organisms of the soil are very sensitive to pH changes in their environment, and these include not only important lower plant forms such as algae, lichens, and fungal associates of higher plants, but also the nitrogen-fixing bacteria, which are essential if airborne nitrogen is to be made available for use as a nutrient by plants. Current high nutrient erosion rates from soils subjected to acid precipitation of 4.0 pH or less in remote forested areas of the Adirondack Mountains[57] and elsewhere are evidence that forest soils in the Northeastern United States are becoming acidic at an accelerated rate.

Fossil-fueled powerplants may be major contributors to the occurrence of acid rain through their generation of NO_x and SO_x. Researchers in Scandinavia attribute its acid rain to the long-range transport of sulfates from the heavily industrialized areas of northern Europe and England. Data from New York and New England indicate that about 60 to 70 percent of the acidity in precipitation there is caused by sulfuric acid, with the contribution from nitric acid becoming increasingly important.[58] Because the background of air pollutants from stationary and mobile sources varies with locale, these figures may not universally represent the composition of acid rain.

"Ibid , p I105

"L S Dochinger, see note 49

[5'] Shen-Miller, M B Hunter, and J Miller, "Simulated Acid Rain on Growth and Cadmium Uptake in Soybeans, " *Plant Physiology, vol 57 (1976),* p *50*

"L S Dochinger, T A Seliga, p 1104

"C W. Cronan, R C. Reynolds, Jr,, and G, E Lang, "Forest Floor Leaching: Contributions From Mineral, Organic, and Carbonic Acids in New Hampshire Subalpine Forests, " Science, vol. 200 (1978), pp 309-11.

[58] G. D Likens, "AC id Precipitation, " *Chemical and Engineering News 22,1976.*

Future increases in energy development, and in coal use, may seriously aggravate acid rain problems through two mechanisms. First, although tall-stack emissions of SO_2 will not increase rapidly if best available controls are applied, serious increases in NO, emissions will be inevitable if Federal emission standards–which require only about 50-percent control — are continued. As noted earlier, success of EPA's lo w- N O$_x$ burner will be a primary determinant of this required control level. Second, there is a possibility that the fraction of sulfates and nitrates that are in the strong acid form – currently thought to be about one quarter– may rise because of exhaustion of the neutralizing capacity of the atmosphere. If exhaustion occurs, a l-percent increase in emissions would subsequently lead to a 4-percent increase in acid rain. 59 Very little is known about the atmosphere's neutralization capacity. Finally, as some of the impact of acid rain may be cumulative, even a stable level of acidity may lead to an increase in acid rain damages.

Visibility Reduction

S0x emissions from coal combustion have been strongly implicated as a major factor in the occurrence of visibility reductions throughout the United States. The evidence consists of the following.

● Sulfate particles formed as the result of the atmospheric transformation of SO_2 emissions tend to be in the size range of fine particles that are most effective in scattering light and hence in producing haze.

● Field studies by EPA indicate that powerplant S0$_2$ emissions are converted to sulfates at significant rates.

● Sulfates account for about half of the particles in the "maximum light scattering" size range in industrial regions.[60]

● Visibility reductions and sulfate concentrations have been strongly correlated; for example, large-scale polluted air masses characterized by decreased visibility, or "hazy blobs, " as they are sometimes

called, have been tracked over periods longer than a week as they moved over large portions of the United States. These "blobs" are correlated closely with sulfate level s."

● Visibility substantially increased during the 1967-68 Southwest copper strike and shutdown of SO_2-producing copper smelters.[62]

Visibility degradation has recently become a major concern in the West, where clear blue skies are still a common and valued sight. In fact, some studies indicate that visibility in the Southwest appears already to have deteriorated significantly over the past two decades, although it is still quite good.[63]

Although the prevention of significant deterioration (PSD) restrictions in the Clean Air Act amendments are designed in part to protect western visibility, the present inability to compute the long-range impacts on visibility of new coal-fired powerplants may considerably complicate the enforcement of these restrictions until acceptable long-range transport and visibility models are available to enforcement agencies.

Visibility degradation will present a special problem in those areas of the West that are expected to sustain considerable increases in SO_x emissions. The largest increase is expected in the Southwest (New Mexico, Texas, and Oklahoma), with an increase of 67 percent between 1975 and 1990. The expected upturn in national SO_x emissions by the late 1980's is an indicator that visibility problems could substantially increase on a nationwide basis by 2000.

Particulates and Associated Trace Elements

Because of the widespread use of controls that remove large particles with high efficiency, the major ecosystem impact of particulate emissions from coal-fired powerplants will be

[59]"Appendlx on Transport and Fate, " *Rail Report.*
[60]" Appendix on Ecological Effects, " *Rail Report*

[61]"Husar, R. B., et al, "Ozone in Hazy Air Masses," *International Conference on Photochemical Oxidant Pollution and its Control,* E PA-600/3-77-0010, 1977.
[62]"Visibility in the Southwest," U.S. Environmental Protection Agency, E PA-600/3-78-039.
[63]Ibid.

caused almost exclusively by fine particulate and the associated trace elements and hydrocarbons that are preferentially adsorbed on their surfaces. Although total particulate loadings will be substantially reduced in the future as the result of strict controls on new plants and progress in obtaining conformance with State regulations from existing plants, emissions of fine particulate are unlikely to decline unless controls that are effective on fine particulate (such as baghouses) are retrofitted on older plants as well as being installed on new ones.

Fine-particulate effects on ecosystems may be more of a regional than a local problem. Glass" notes that more than 95 percent of the particulate emissions from a large powerplant with an ESP travel beyond a 20 km radius, and most studies of trace element contamination near powerplants have shown few significant effects. 65

Soils are the principal repository for fine particulate, and there is some concern that the heavy metals contained within or on the surface of the particles could eventually alter the normal soil processes associated with nutrient recycling and with soil micro-organisms. Plants are also an important sink for fine particulate, which are captured by the fine hairs on plant surfaces. Plants are generally not considered to be endangered by such pollution; Van Hook[bb] notes that "there is no reason to expect acute effects on plants . . . the potential chronic toxicity is relatively low except in local areas already enriched with a particular element. " However, more subtle effects, such as reduction in photosynthesis due to reduced light or interference with stomatal function, and foliar lesions have been attributed to fly ash. [b']

Both inorganic trace elements and trace hydrocarbons present a potential danger to animals in water and on land. Biomagnification, whereby trace materials can be concentrated as they move up the food chain, is a par-

ticular problem in aquatic ecosystems (see table 33). Another source of concern is the extent to which trace element impacts are cumulative; logic argues that many will be cumulative, although the ambient levels caused by coal combustion are not likely to be high in most instances. Although the uncertainty surrounding these effects is very great, concentrations of polycyclic aromatic hydrocarbons that have been demonstrated to be damaging to fish have been observed in Norwegian rainwater.[68] However, the potential for significant impacts on either terrestrial or aquatic ecosystems is clearly a very speculative area that requires considerably more evidence before firm conclusions can be drawn.

Carbon Dioxide

CO_2 concentrations measured at Mauna Loa, Hawaii, and elsewhere have increased at a rate that appears to be tied to fossil fuel combustion. [b'] The combustion of coal yields 11 percent more CO, than oil and 67 percent more than natural gas. 70 The confluence of these two facts has led to concern about the role that increased coal development might play in altering the Earth's climate.

CO_2 is relatively transparent to short-wave radiation (sunlight), but absorbs long-wave (infrared or heat) radiation. Thus, atmospheric CO_2 admits incoming sunlight that warms the Earth, but absorbs a portion of the infrared heat radiation coming from the surface of the warmed Earth and re-radiates part of it back to the surface. The heat is "trapped" in the atmosphere in the same way that heat is trapped inside a greenhouse, or an automobile with its windows closed; hence the "greenhouse effeet. " (See figure 28). Although no effects on global temperatures have yet been measured, most scientists believe that a continued increase in CO_2 levels must eventually affect the Earth's temperature.

""Appendix on Ecological Effects, " *Rall Report*
ᵇᵇ" Appendix on Trace Elements," *Rail Report.*
"Ibid.
""Appendix on Ecological Effects," Rall *Report.*

"Ibid.
"C. Marland, and R. M. Rotty, "The Question Mark Over Coal; Pollution, Politics and CO, " *Futures,* February 1978,
"'*Analysis of the Proposed National Energy Plan, 1977.*

Table 33.—Biological Concentration Factors for Selected Trace Elements in Aquatic and Terrestrial Environments

	Biological Concentration Factor"				
	As	Cd	Hg	Pb	Zn
Aquatic					
Water	1	1	1	1	1
Plants	170	1,000	1,000	200	1,000
Invertebrates	330	2,000	100,000	100	10,000
Fish	330	200	1,000	300	1,000
Terrestrial					
Soil	1	1	1	1	1
Plants	0.01	0.3	0.4	0.07	0.4
Invertebrates	0.01	17		0.02	8
Mammals	0.001	0.008	5	0.001	0.6
Birds	0.001		50	0.001	

a concentration in organism to concentration in substrate.

SOURCE Van Hook, R 1, 'Transport and transformation pathways of hazardous chemicals from solid waste disposal," *Environ. Health Perspectives* (in repress)

Figure 28.— Heat Radiation Emitted to Space by CO^2
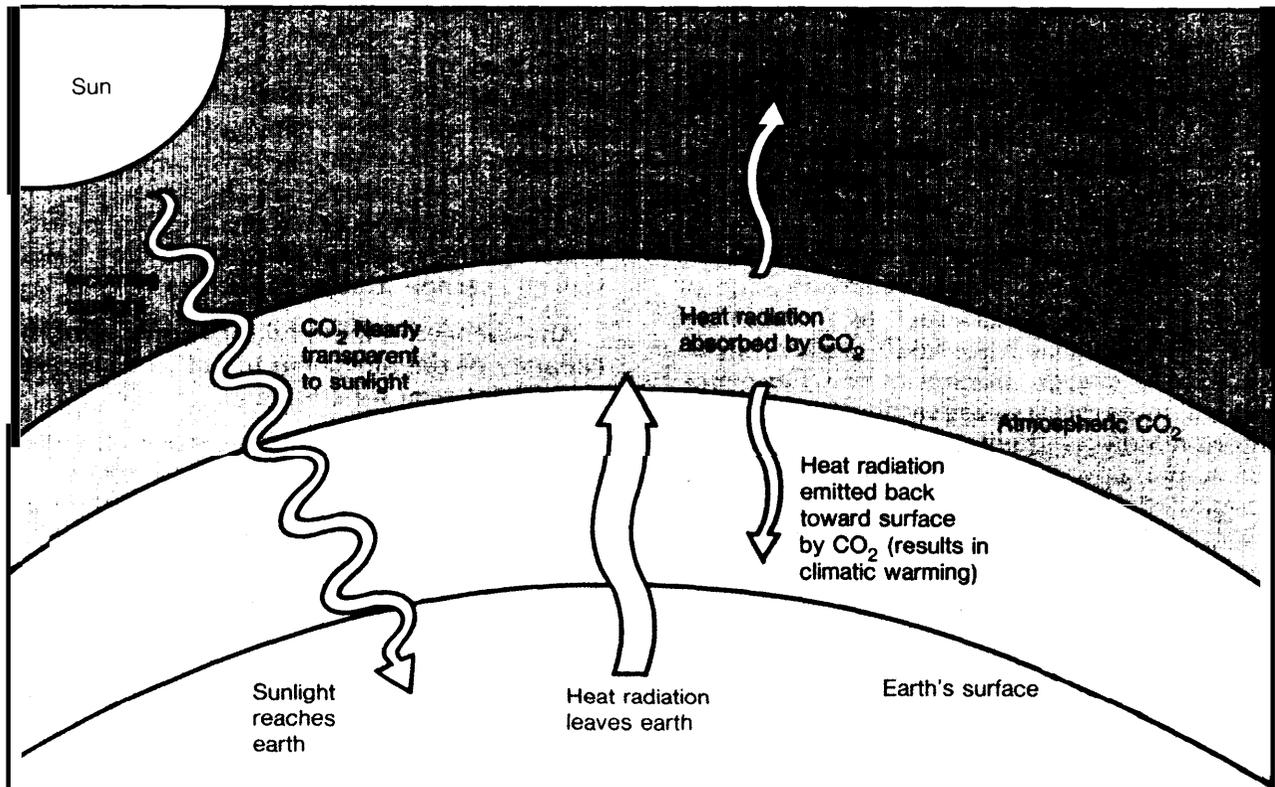
The legitimacy of environmental concern over the climatic influence of coal production hinges on the answers to two critical questions:

● How will future atmospheric CO_2 concentrations be affected by fossil fuel combustion and other activities such as forest clearing?

● What effect will increased CO_2 in the atmosphere have on global climate?

Considerable uncertainty clouds both quest ions.

CO_2 Concentrations.–There is general agreement about the amounts of carbon currently being released as CO_2 through fossil fuel combustion (about 5 billion kilograms per year) and the increase in the amount of carbon in the atmosphere (about 2.3 billion kilograms per year) .[7'] Until recently, scientists thought they could readily explain where the remaining 2.7 billion kilograms per year went; a maximum of about 2.5 billion kilograms per year was thought to be absorbed by the oceans, and the remainder by the biota-forests, grasslands, etc. A number of researchers have now challenged this view based on evidence that the largest and most intensive pool of carbon in the biosphere— the forests (both the trees themselves and their humus floors)— are shrinking significantly in area because of wood harvesting and clearing for agriculture and other development. This is especially true of the tropical rain forests such as those in the Amazon Basin, which are said[72] to play the major role in carbon storage in the biosphere. Thus, a net carbon release rather than a net absorption now is theorized. Woodwell [73] estimates this release from the biosphere to be about 8 billion kilograms, although he estimates the range due to uncertainty to be 2 billion to 18 billion kilograms per year. Other researchers have developed lower estimates, ranging from about one-tenth to one-third of the fossil fuel contribution. [74]

Accepting even the lower value still leaves an enormous gap in the existing models of carbon balance; it is not known where all this excess carbon is going. However, if Woodwell is correct that the biosphere is a CO_2 source rather than a "sink, " this means that an unknown mechanism, capable of removing and storing atmospheric CO_2 at a substantial rate, must exist and might be available to remove excess CO_2 from fossil fuel combustion if the shrinkage of the forests could be halted

Uncertainty also is added by a lack of full understanding of the various known mechanisms involved in oceanic uptake of CO_2. For instance, carbonate ions in the surface layers of the ocean react with and remove atmospheric CO_2. As the pressure of CO_2 increases and the carbonate ions are used up faster than they can be replaced by mixing, the ocean's absorption of CO_2 from the atmosphere could slow and the atmospheric CO_2 buildup could accelerate. On the other hand, increased acidity of surface waters caused by greater dissolved CO_2 concentrations could increase the dissolution of calcium carbonate and thus increase the supply of carbonate ions. The extent of these potential changes presently is unknown. Uncertainty also is caused by the lack of understanding of the effects of increased CO_2 on ecosystems and the corresponding effect on their photosynthetic production and carbon storage capacities.

Any changes in these factors would alter the capacity of the biosphere to act as a sink — or source — of atmospheric CO_2.

Despite these uncertainties, however, probably few scientists would disagree with the statement that continued reliance on fossil fuels, in the absence of drastic measures to change worldwide development patterns that are radically altering the biosphere, will result in substantially increased levels of CO_2 in the atmosphere. Kellogg's[75] estimate of a 400-ppm CO_2 concentration by 2000 and a doubling of that level by 2040 (if fossil energy trends continue) should be taken quite seriously.

"G. M. Woodwell, "The Carbon Dioxide Question," *Scientific American,* January 1978, vol 238, No 1.

"lb Id.

"Ibid

"R A. Kerr, "Carbon Dioxide and Climate: Carbon Budget Still Unbalanced, " Science, vol. 197, pp. 1352-1353, Sept 30,1977.

"W. W Kellogg, "Global Influence of Mankind on the Climate," in Climate *Change, J. Gibbin,* cd,, Cambridge University Press, 1978.

Climatic Effects. -Even if precise forecasts of future atmospheric CO_2 concentrations were possible, the effects of these concentrations on the climate and on man would be uncertain owing to several confounding factors. One factor is that the climate, with or without man's influence, may be changing as part of a natural cycle. Scientists disagree as to the nature of these changes. Secondly, the "anthropogenic " (man-caused) effect on global temperatures includes several effects aside from the "greenhouse effect. " Their role complicates the calculation of the temperature effect of man's activities. Finally, the translation of more precise knowledge of the "greenhouse effect" and the other temperature-changing factors into a global climatic effect is a modeling problem that requires considerably more knowledge and sophistication than is currently available. It is the distribution of temperature and other effects, rather than the global average temperature effect, that is critical to understanding the changes that will occur in actual living conditions.

There are three major schools of thought on the nature of future climatic cycles. [76] The first is that the recent climatic record is not sufficient to allow accurate forecasts of future climate. The second is that the Earth is due for a short period of cooling followed in the early 21st century by mild warming, and that man's activities will not affect these trends. The third and most widely accepted is that global warming will occur sometime in the next century or so as a result of man's activities, and that any manifestation of natural climatic cycles will eventually be overwhelmed by this induced warming.

In addition to the "greenhouse effect, " the other man-created effects that may affect global temperatures" include:

● Change in reflectance of the Earth: continued injection of particles into the upper atmosphere will lead to increased reflection of incoming solar energy and, consequently, a cooling effect.

● Changes in cloud cover: the increasing level of fine particulate (which act as condensation nuclei), the increasing areas of irrigation projects, the expanded use of cooling towers, and any warming trend (leading to increased evaporation rates) would al l tend to increase the cloud cover of the Earth and increase its reflectance. This provides a "negative feedback" to compensate for the greenhouse effect,

● Thermal pollution of the atmosphere: by the year 2050, the total heat added to the Earth's atmosphere by energy production will approach 10' ^{9}Btu per year, which is on the order of one-half of 1 percent of the solar energy reaching the Earth's surface. A 1- percent increase in this energy "flux" would generate about a 10 F increase in global temperatures.

A reliable computation of the climatic (rather than the mean temperature) effect requires "a model that includes a fully coupled and interactive atmosphere and ocean, and an improved simulation of ice and snow."[78] No accepted model of this sort now exists. However, a simpler general circulation model predicts that a doubling of atmospheric CO_2 concentration will yield temperature increases of 2° to 3° C at the equator and 10° C at the poles.[79] This geographic variation in warming is ominous from the standpoint of the survival of the polar ice caps.

The concept of massive changes in the Earth's climate—in essence, a retrogression to a warmer climate characteristic of the Earth several thousand years ago—sounds more like a science fiction theme than a plausible projection for the near future. Realistic projections are hampered by the complexities of climatic modeling, the substantial uncertainties involved in the potential feedback effects of the atmosphere, the incompletely understood system of sources and sinks of CO_2 and the substantial differences in alternative energy projections. Nevertheless, the scientific

[76]J. Norwine, "A Question of Climate," *Environment*, vol. 19, no. 8, November 1977.

[77]R. M. Rotty, "Energy and the Climate," Institute for Energy Analysis, Oak Ridge Associated Universities, September 1976.

[78]J. Williams, "Global Energy Strategies; The Implications of CO_2,"*Futures*, August 1978.

[79]Ibid.

community generally agrees that the probability of significant global warming and other climatic changes is sufficiently high to warrant exceptional attention in form of expanded research and monitoring, and caution in weighing any decisions that might tend to tie us irrevocably to a fossil-based energy economy.

It must be stressed that the "scenarios" postulated by the more pessimistic researchers would involve massive disruption of the world economy and well-being. A 20 to 30 C change in mean world temperatures could lead to melting of the polar icecaps sufficient to cause flooding of coastal regions. Another critical effect would be significant shifts in the viability of the world's food-producing areas owing to massive shifts in rainfall distribution. 1 n the long run, such shifts might not lead to a net decrease in potential worldwide productivity. However, the transient effects would be severe. Given appropriate climatic conditions, overall agricultural viability depends upon existing land use, ownership patterns, transportation, water, and other resource availability, etc. These factors represent a massive physical and societal infrastructure that would have to be virtually torn down and rebuilt to make a successful transition to a warmer climate. Problems with such a transition process could mean food shortages and social and economic disruption on a massive role.

Effects on Materials

Although human health and ecological effects are the most serious problems associated with air pollution from the coal fuel cycle, damage to nonliving materials from this pollution is substantial today and may remain a potent policy issue because of memories of coal's past. The soiling problem commonly associated with coal combustion has been all but eliminated by extensive controls on particulate emissions and the phasing out of most of the small coal-fired furnaces. However, problems that remain include the deterioration of building materials and works of art, fading of dyes, weathering of textiles, and corrosion of metals.

A 1970 estimate of total damage to materials from air pollutants (not limited to emissions from powerplants or coal combustion sources) is $2.2 billion per year. The relative contributions of the four major pollutant components are: SO_x— 41 percent, particulates —27 percent, ozone —26 percent, and NO_x—6 percent. [80]

There are five major causes of damage:

- abrasion by high-velocity and/or sharp-edged particles,
- direct chemical attack,
- indirect chemical attack —where the pollutant becomes harmful only after a transformation when in contact with the material,
- electrochemical corrosion —where pollution increases conductivity of thin surface films of moisture and helps to destroy protective films on material surfaces, and
- discoloration by particulate.

Each mechanism depends on a variety of independent variables, including moisture, temperature, sunlight, etc. If estimates of future pollution levels are a guide, one might expect that acid rain and ozone damage caused by powerplant NO, emissions will rise in the future, that SOX-caused damage will not undergo radical changes if best available control technology (scrubbers) is enforced, that particulate soiling damage should decrease with substantial decreases in particulate emissions as all new powerplants control to better than 99-percent efficiency and existing particulate emitters comply with State and local control requirements, and that chemical damage due to particulate might increase because of increases in emissions of fine particulate.

Regulations

Air pollution from coal combustion is regulated under the Clean Air Act, which sets ambient air quality standards and establishes limits on the emissions from a variety of sources in order to achieve and maintain those standards. The legal framework of the Clean Air Act is discussed in chapter VI 1; this section

---

[80]T E Waddell, "The Economic Damages of Alr Pollution, " U S Environmental Protection Agency, E PA-600/5-74-012, May 1974

summarizes the way the Act seeks to regulate the health and ecological effects of the pollutants.

National Ambient Air Quality Standards (NAAQS) have been promulgated under the Clean Air Act for six pollutants: S0x particulate matter, NO_z, photochemical oxidants, hydrocarbons, and CO. There are two types of NAAQS: primary standards are those needed to protect public health, allowing an adequate margin of safety. The secondary standards are intended to protect the public welfare from pollution damage to soil, plants, animals, materials, and other factors not directly related to human health. The NAAQS are based on air quality criteria that reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects of a pollutant on public health or welfare. These criteria must include information about variable factors, such as atmospheric conditions that may alter the effects of a pollutant, and about interactive effects among pollutants.

The Clean Air Act is implemented at the State level through a variety of regulatory programs designed to achieve and maintain the NAAQS. First, State Implementation Plans (SIPS) must include control strategies designed to reduce the contribution of existing sources to airborne pollutant loadings, generally through the application of reasonably available control methods. Second, the Act establishes performance standards for large new sources that mandate the use of the best technological system of continuous emission reduction as well as a percentage reduction in emissions over those from the uncontrolled combustion of untreated fuel. Third, in those areas where air quality now exceeds the NAAQS (nonattainment areas), new sources must meet the lowest achievable emission rate (LAER) by applying stringent technological controls and must secure emission reductions from existing sources in the area that will more than offset the emissions from the proposed facility. Fourth, in order to prevent significant deterioration of air quality in areas where the air currently is cleaner than the national standards, the Clean Air Act specifies maximum allowable increases in pollutant concentrations as well as ceilings for ambient concentrations,

and requires large new sources to use the best available control technology. Finally, the Act requires the retrofitting of pollution control technology on existing large sources near areas primarily important for scenic values (such as national parks) in order to protect visibility.

There are problems associated with implementation of the Clean Air Act to protect public health and welfare. As of mid-1976, 178 of the 313 air quality control regions (AQCRS) or State portions thereof had not attained the primary particulate standard, while 46 had not achieved the primary SO_2 standard. Most conventional stationary sources (such as coal-fired powerplants) in these nonattainment areas are either in compliance with the standards or are on compliance schedules. The particulate violations tend to arise because of fugitive emissions, fugitive dust, and fine particulate, all of which are more clifficult to monitor and control, and which are not now explicitly regulated under the Clean Air Act.

No deadlines have been set for attainment of the more stringent secondary standards. Rather, the States are given a reasonable time to achieve the secondary standards, where "reasonable time" depends on the degree of emission reduction needed to attain the standards and on the social, economic, and technological problems involved in implementing a control strategy adequate to achieve and maintain the standard. Thus the secondary standards are not being enforced, and soil, plants, animals, materials, and other environmental factors are unprotected to the extent they require greater protection then that afforded by the primary standard.

The air quality criteria on which the NAAQS are based were published in 1969-71 and reflect the scientific knowledge current at that time about the effects of the various pollutants. However, in 1969-71 the phenomena of pollutant transformations and long-range pollutant transport had not been documented. Consequently, the Clean Air Act and the regulatory programs that implement the Act generally treat SO_2 and particulate matter as static pollutants that do not convert. The transformation products, such as sulfates and acid precipitation, are not regulated. In addition, current EPA regulations limit the applicability

of air quality modeling techniques to a downwind distance of not more than 50 km from the source (because of EPA's judgment that the models are not reliable beyond this distance). Although the 1977 amendments to the Clean Air Act include procedures for the prevention and abatement of interstate air pollution problems attributable to particular sources, longer range transport that may contribute to air quality problems farther than 50 km downwind currently is unregulated.

The 1977 amendments to the Clean Air Act include two provisions designed to remedy these problems. First, they require EPA to review the NAAQS and the criteria on which they are based, and revise them if necessary by 1980 and every 5 years thereafter. Thus more recent evidence on health effects and on pollutant transformations and transport should be reflected within a couple of years in the standards and in the programs that implement them. Second, the amendments require the States to revise their implementation plans by 1979 in order to provide for achievement of the primary standards by 1982. However, this requirement may be largely moot if the standards are made more stringent in 1980, and it does not address the problem of implementing the secondary standards.

IMPACTS TO WATER SYSTEMS

The impurities in coal that are released to the air and land in all stages of the fuel cycle may wend their way eventually into the waterways. Thus water may become the ultimate repository for many of the byproducts of coal activities. The water system can transport these impurities both geographically—from the local source to distant sites—and biologically —from micro-organisms on up the food chain, often in ever-increasing concentration.

The uses for which our water systems are needed include — roughly in order of increasing demand for water purity — navigation, recreation, irrigation, industrial processing, watering of stock and wildlife, maintenance of aquatic life, and drinking water supply. A lowering of water quality may affect these uses and consequently the health, economy, or quality of life within a community.

The various activities of the coal fuel cycle affect not only water quality but also water quantity and hydrology. For example, mining can cause stream flows to change and water tables to decline, and in some instances may affect the intensity of floods. Of particular concern is the potential alteration of the ground water system.

Sources, Effects, and Control of Water Pollution

Coal Mining and Cleaning

Surface Water Impacts. -In mining, huge slices are made into the earth, and layers once deeply buried are brought to the surface to be deposited, often only temporarily. In surface mining, the top layers of overburden are placed in "spoil banks" until time for reclamation. In underground mining, the waste material is heaped at the surface, and the mine walls often remain exposed when the mine is abandoned. At the preparation plant, where impurities are removed from the coal, still more waste piles are generated. As long as these once-buried materials remain exposed and unstabilized, they are subject to runoff and erosion, and become the source of chemical and physical alteration of local streams. These impacts are addressed by a variety of State laws and, as discussed later, by Federal water pollution and surface mining laws.

Within the coal production waste piles are many soluble components that dissolve as rain water percolates through them. A consequence is an elevation of *total dissolved so/ids*

(TDS) within the local watershed. TDS is a parameter of water quality that very generally indicates the presence of soluble ions such as (in the case of coal waste runoff) sulfates, calcium, carbonates, and bicarbonates (hardness). Elevated concentrations of these ions make water largely unpotable by altering its taste but otherwise have only minor human health effects. TDS and hardness can also degrade the use of water for agricultural and industrial uses. Regions that will absorb substantial TDS as a result of expanded coal mining are the Middle Atlantic (sulfate and fluoride from underground mining), and the Midwest and North Central (sulfate from strip mining).

Acid mine drainage is a particularly severe byproduct of mining in those regions –Appalachia and parts of the interior mining region (Indiana, Illinois, Western Kentucky)–where the coal seams are rich in pyrite (iron disulfide), The mining process exposes the pyrite to water and air, causing a reaction that forms sulfuric acid and iron. The lowered pH also tends to dissolve heavy metal compounds, adding metal ions (aluminum, manganese, zinc, nickel, etc.) to the acidic drainage water.

Acid drainage is a problem with active and inactive mines, and with both surface and underground mines. Recent data are not readily available, but in the 1960's underground mining accounted for fully three quarters of the problem (see table 34). About 10,000 miles of streams and rivers, principally in Appalachia, have been degraded by acid drainage. The effects are most severe in Pennsylvania and

Photo credit. EPA —Documerlca

Acid mine drainage from abandoned underground mines and other sources still affects thousands of miles of streams in Appalachia

West Virginia, while less severe in southern Appalachia. "

Table 34.—Acid Drainage in Mines

Source	Acidity 1,000 lb/day	Percent
Underground, active	614	9
Underground, inactive	1,712	53
Surface, active	28	01
Surface, inactive	361	11
Combined, active[a]	60	02
Combined, inactive[a]	238	07
Other	245	07
Total	3,258	100

aIncludes sources where underground could not be separated from surface

The environmental effects of acid mine drainage are severe. The acid and heavy metals are directly toxic to aquatic life, and render the water unfit for domestic and industrial use. Zinc and nickel, often present in substantial quantities, are known carcinogens.[82] Other carcinogenic trace elements are present in smaller concentrations but may have additive effects.

Many of the metals found in acid mine drainage can become concentrated as they move up the food chain. Adsorption of these metals can occur on the surfaces of small suspended solids and sediments; thus, the largest reservoir of trace contaminants resides in the bottom sediment and is available to the rest of the ecosystem according to a complex web of factors. An additional ecosystem impact is the smothering of stream bottom-dwelling organisms by precipitated iron salts.

The acid content of the mine drainage also causes substantial material damage by eating away metal structures and destroying concrete.

A variety of measures exists to control acid mine drainage from active and inactive surface and underground mines. All involve preventing the formation of acid by controlling oxygen flow to the pyrites, preventing a dis-

[81]"Appendix on Acid Mine Drainage and Subsidence," R. D. Hill and E. R. Bates, *Rall Report*, U.S. Environmental Protection Agency.
[82]Little, "Inorganic Chemical Pollution of Freshwater," U.S. Environmental Protection Agency, 1971.

charge by controlling water flow in the mine, or treating the discharge by neutralizing the acid (or by using reverse osmosis or ion exchange techniques, at much higher costs). Although neutralization treatment can increase hardness and dissolved solids content, it is the commonly used method for controlling acid mine drainage from active surface and underground mines and is considered an effective control. Surface mines also must utilize drainage control and special mining techniques to properly control acid drainage.

The only major problem facing successful control of acid damage from active surface mines is enforcement, which has been a long-standing problem with the smaller mines. This situation is essentially duplicated with the control of inactive surface mines: available reclamation techniques can control acid drainage from most inactive mines, but enforcement efforts on small mines must be strengthened to ensure adequate control. Also, a small percentage of mining situations still defy acid control attempts. For instance, a few mines in West Virginia have been found to produce acid seepage from horizontal water movement through buried spoils. However, strict enforcement by the new Office of Surface Mining and continued development of control techniques for the remaining problem situations should ensure an acceptable degree of control.

Unfortunately, available controls for inactive underground mines are not likely to be as successful. When an underground mine is being closed, the techniques for stopping acid drainage are:

- sealing the mine to prevent air infiltration;
- filling the mine with water;
- preventing water infiltration by grading, sealing, aquifer control, etc.;
- backfilling the mine; and
- removing mine pillars and allowing the mine to collapse.

Although these techniques can be effective in some circumstances, success in preventing a continuing significant flow of water has been intermittent; the technology available to control acid drainage from most inactive underground mines must be considered inadequate.

An alternate approach to controlling drainage in new mines, both during active operations and after abandonment, is to mine "down dip"—i.e., in mining a sloping seam, to mine the coal from the top of the seam on down—rather than the usual "up dip." In this type of mining, water will accumulate at the "working face" during operations and must be pumped out. In a mine examined during an EPA study[83] acid levels in the drainage were extremely low. After deactivation, the mine can be flooded, shutting off oxidation of the pyrites, without the need for a watertight seal. The extent to which this technique is applicable has not been adequately demonstrated, but it is a promising approach to permanent acid drainage control.

As the shallower deep-minable coal reserves become depleted, underground mining will begin to shift to seams deep enough to be below the water table. Many of these mines can be flooded without the use of a watertight seal, allowing the seams to be shut off from air and preventing acid drainage problems after the mines are closed. Based on this expectation, and on the expectation that reclamation of abandoned mines (under provisions of the new surface mining legislation) will proceed as planned, projections of acid drainage to the year 2000 show a declining trend.

Regions with alkaline soils, such as the West, do not have problems of acid mine drainage but may have a problem with increased *salinity* caused by dissolution of soluble ions such as sulfates and chlorides. The impact depends on the elevation of TDS levels (for example, a 10- to 20-percent increase has little effect on aquatic biota) and on the uses to which the water is put. The impact of salinity in the northern Great Plains, where water is used for irrigating largely salt-resistant crops, may be less severe than in the Colorado River Basin, where water is needed for more salt-sensitive plants. In times of low water levels in the streams, TDS concentrations may rise.

The chemical pollution caused by coal preparation includes treatment water, often bearing organics used in the processing, as well as runoff from waste piles. The latter is similar in content but smaller in amount than the acid drainage from mines. Techniques are available to control these pollution sources. Federal standards for coal preparation plants require zero discharge of pollution, which should eliminate impacts from at least the larger plants. Enforcement of these standards on the smaller plants has been uneven in the past, and future performance clearly depends on State and EPA regional office resources.

The disturbances of land by mining results in physical as well as chemical pollution of streams. Erosion of unstabilized waste piles or of denuded land produces large quantities of *suspended solids* and subsequent heavy *siltation* of local streams. Erosion is greatest from surface mines in areas with rugged terrain and rainy climates, such as southern Appalachia. Research in Kentucky indicates that sediment yields from lands strip-mined for coal can be as much as 1,000 times that of undisturbed forests.[84] In more level and dry regions such as the Midwest or West, the problem is less serious. Sudden violent storms that occur in parts of the West, however, may wash large amounts of silt into local waterways.

One effect of the siltation is to alter the character of stream bottoms. It may, for example, interfere with the spawning of fish eggs. Siltation also causes material damage by shortening the life of reservoirs and increasing the need for channel dredging.

Coal mines are never the major cause of suspended solids pollution on a regional basis, but they have severe local impacts. At present, mining causes significant consequences in the Middle Atlantic (30,000 tons/yr, mostly underground mining) and Midwest (17,500 tons/yr, mostly surface mining) regions and lesser impacts in the South Atlantic and North-Central regions. Implementation of controls on both surface and underground mining will sharply reduce sediment loadings in most areas, and mining-caused suspended solids should de-

[83]John W. Mentz and Jamison B. Warg, "Up-Dip Versus Down-Dip Mining," EPA-670/2-75-047, June 1957.

[84]C. R. Collier, R. J. Pickering, and J. S. Musser, "Hydrologic Influence of Strip Mining," U.S. Geological Survey professional paper 427-C, 1970.

cline significantly in the future. For example, loadings in the Middle Atlantic are projected to decrease to one-third of 1975 levels by 1990. One notable exception to this trend may occur in the North-Central region, where sediment loadings may increase sharply by 1990 unless better controls are devised and implemented.

Flooding potential is affected by several factors related to surface mining:

. permeability of land surface,
. vegetation cover of surface, and
● carrying capacity of streams.

The mining and reclamation process may act to increase surface permeability and thus allow the ground to soak up more water in a given period than the premined surface could. The loss of vegetative cover that acted as a water retention mechanism will tend to counteract this effect. In addition, increased erosion and consequent siltation lead to decreased carrying capacity of streams and greater flooding potential. Studies of the effect of surface mining on flooding potential thus have tended to conflict, with one study of strip-mined watersheds in Kentucky showing increased flooding potential and studies in Indiana indicating the reverse.[85] An examination of these factors leads to the tentative conclusion that flooding potential may be decreased by area mines, while contour mines may cause increased flooding. Indeed, several studies now appear to support the association of surface mines with flooding in steep terrain. More studies, of surface mine hydrology, soil mechanics, revegetation techniques, and the positive impacts of methods to stabilize benches are needed to settle this issue. However, the only practical control of this problem in some flood-prone areas may be a limit on surface mining.

A final group of impacts is the *alteration of the hydrology* of local water systems. Surface streams often are diverted around mines to lessen the degree of siltation or acid or alkaline drainage. Some surface water may have to be impounded for entrapment of silt or sludge

*85 "Appendix on Reclamation," Coal Extraction Land Reclamation Group," Argonne National Laboratory, *Rail Report.*

from treatment of acid mine drainage. More water also may be demanded for irrigation of revegetated surface mines, especially in the West where reclamation is more difficult. The quantities of water are comparatively small (see table 35) but may nevertheless become a public concern in arid regions where competition for water is becoming critical. However, the potential for water conservation in the West is great enough to offset any potential regional shortages if the legal and political barriers to conservation can be dealt with (see chapter IV, *Water Availability).*

Ground Water Impacts. -Mining is likely to have significant effects on ground water as well as surface waters. Mining operations can both contaminate ground water and cause severe physical dislocations of aquifers,

A primary mechanism of ground water contamination is the seepage of acid mine drainage into aquifers via joints and fractures in the rock or via direct interception of the aquifer. Inadvertent connection of two aquifers also can lead to contamination; this is more of a problem in the West, where deep saline aquifers abound. Coal spoil banks also can be the source of this contamination through leaching and penetration of the soil. Investigations of ground water contamination typically have shown high local effects but extremely variable effects some distance from the m inc.

Direct interception of aquifers and other physical disturbances can substantially affect the quantity of ground water as well as its quality. Where a mine is located below the water table, seepage of water into a mine pit can lower the water table and dry up wells in the vicinity. (Thus, the trend towards deeper mines, identified as providing a benefit in reducing acid drainage, can cause additional ground water problems.) Blasting may rupture the impermeable strata below an aquifer and cause water to seep to a lower level, or may inadvertently connect two aquifers. The process of mining and reclamation will change the permeability of the overlying soil, altering the rate of ground water recharge, and affecting flooding potentials (as discussed in the preceding section).

Table 35.-Water Requirements for Coal System Activities

| Coal activity | Size | Water consumed by energy facility | | Peak water requirements associated with population increases[*] | |
| | | | | Peak | |
		Acre-ft per year	Gallonsl/10⁶ Btu in product	Construction (acre-ft yr)	Operation (acre/ft/yr)
Surface mine	12 MMtpy	3,400	4	71	323
Underground mine	—	0	0	275	1490
Power generation	3,000 MWe	29,000	54 (thermal) 157 (electric)	853	260
Lurgi gasification	250 MMscfd	6,700	28	1570	350
Synthane gasification	250 MMscfd	9,100	38	1570	350
Synthol liquefaction	l00,000Bbl day	17,500	28	1750	1800
Slurry pipeline -...-..=.	25MMmtpy	18,400	14	Not considered	Not considered

[*]Assumes 150 gallons per capita per day, multiplier of 2 to account for added service personnel during construction, and a multiplier of 3.5 to account for families and service personnel during operation.

SOURCE White et al., "Energy from the West", EPA-6OO/7-77.O72a, July 1977

Transportation

Coal energy transportation systems—trucks, railroads, coal slurry pipelines, barges, and transmission lines– can directly or indirectly affect water quality. New clearing of rights-of-way and construction of facilities will increase sediment loadings. Where herbicides are used for clearing and maintenance, excess application can lead to both surface and ground water contamination. Both coal slurry pipelines and barge transportation on canals "consume" water, the former by exporting water (approximately 500 acre-feet per mill ion tons of coal) out of arid regions, the latter by exposing more water surface to evaporation.

Transmission generally has insignificant direct effects on water quality. The major indirect effect is associated with powerplant siting. A mine-mouth plant with long-distance transmission lines may be sited in an arid region, where the impact on water availability is greater than if the coal were shipped to another site with abundant water.

Coal Combustion

Coal combustion releases thermal as well as chemical effluents into water systems. The waste heat from a coal-fired boiler represents that percentage of the energy originally present in the coal (about 60 percent in a modern utility) that is not converted to electricity. This thermal energy is transferred to an adjacent river, lake, or cooling pond and to the local atmosphere, in proportions depending on the cooling system. The thermal pollution problem is not unique to coal-fired utilities but is shared to the same degree with oil and gas plants and to a greater degree by nuclear plants (which currently are less efficient than fossil-f uel-f i red plants and thus produce more waste heat).

The large quantity of heat that emanates from a coal-fired utility boiler is bound to affect at least the local environment. If heat is released in an open cooling cycle (that is, water is withdrawn from a source such as a river, lake, or ocean, circulated within the plant's heat exchanger, and released at higher temperature, usually to the original source), many properties of the receiving waters are altered by the resulting temperature rise. Changes occur in such properties as salinity, vapor pressure, etc.; the amount of dissolved oxygen in the water will decrease owing *to* lowered volubility and re-aeration rates, while TDS will increase because of the increased volubility of many compounds with increasing temperature. These changes in turn alter the life functions of organisms within the water.

Higher temperatures also may elevate metabolic rates of organisms, thus influencing oxygen demand, total energy needs, foraging ability, reproduction, migration, and susceptibility to disease. Heated effluents accelerate the consumption of dissolved oxygen by organisms; when coupled with lower oxygen levels as a result of the physical mechanisms noted above, oxygen content can become critically low within the thermal plumes.

In addition to the thermal effect, physical impacts are caused by small organisms or even fish eggs and larva being drawn through the cooling system of the plant. This entrainment may damage these organisms and affect not only their own lifespans but those of large fish that feed on them.

These impacts can be mitigated by careful siting of powerplants and construction of cooling intakes and outflows. However, complete control can be obtained only with cooling systems that emit heat into the atmosphere or into a small artificial body of water. These are called "closed-cycle" cooling systems.

Current Federal regulations require that, with certain exceptions, closed-cycle cooling systems be used in large, steam electric-generating plants built after 1970 and certain smaller units built after 1974. Thus, closed-cycle systems will be essentially standard equipment on new powerplants, and open-cycle ("once through") systems will be used only in the limited cases where exemptions can be obtained (see chapter VII, section on *Present Federal Coal Policy).*

The two major water impacts of closed-cycle, or evaporative, cooling systems stem from water consumption and "blowdown" disposal. Although water consumption by evaporative cooling towers and cooling ponds depends on many site-specific and design factors, in general the evaporative systems associated with powerplants are the largest water consumers in the coal fuel cycle (see table 35). Their widespread use causes the issue of water use for energy to be a major concern nationwide, and especially in the arid Southwest (see *Water Availability,* chapter IV). However, the use of relatively water-' 'conserving" once-through (open-cycle) cooling, in those areas where a sufficient volume of water would be available, would still consume a large amount of water (50 to 60 percent of evaporative tower consumption) because of the evaporative cooling that takes place in the river or other body of water into which the heated water is discharged. This fact has not always been considered by critics of the current requirements for closed-cycle systems.

The environmental effect of massive consumption of water by powerplant cooling systems is twofold:

● The amount of water available to dilute downstream discharges is reduced, and water quality is thus degraded. This effect is especially evident in the Colorado River, where massive water consumption (by agriculture, in this case) coupled with substantial pollution loadings have elevated salt concentrations in the River to the point where desalinization plants are required to keep water quality within standards.

● In critical watersheds, the physical quantity of water remaining in the streams may fall below that needed to support the water ecosystem. The recognition that this "instream use" of water is a "beneficial use" within the legal system established for allocating water rights is a recent one, and thus protection of water ecosystems from destruction by sheer lack of water is a recent development.

The concentrating effect of evaporation increases the levels of mineral salts in the circulating water of an evaporative cooling system. This water must be continually bled from the system and replaced with freshwater to maintain system operation. This bleed water, which is extremely high in salt concentration, is called "blowdown. " Although the majority of the "pollution" in the blowdown water is the same mix of salts as in the water source (with a small concentration of biocides to keep the tower clear of fungae and algae, and some dust scrubbed out of the air), this water can be damaging locally because of the high salt concentration levels, or when the water enters ground water or surface water other than the source. In some cases, the local effects of the biocides may be more damaging than those of the high salt concentration.
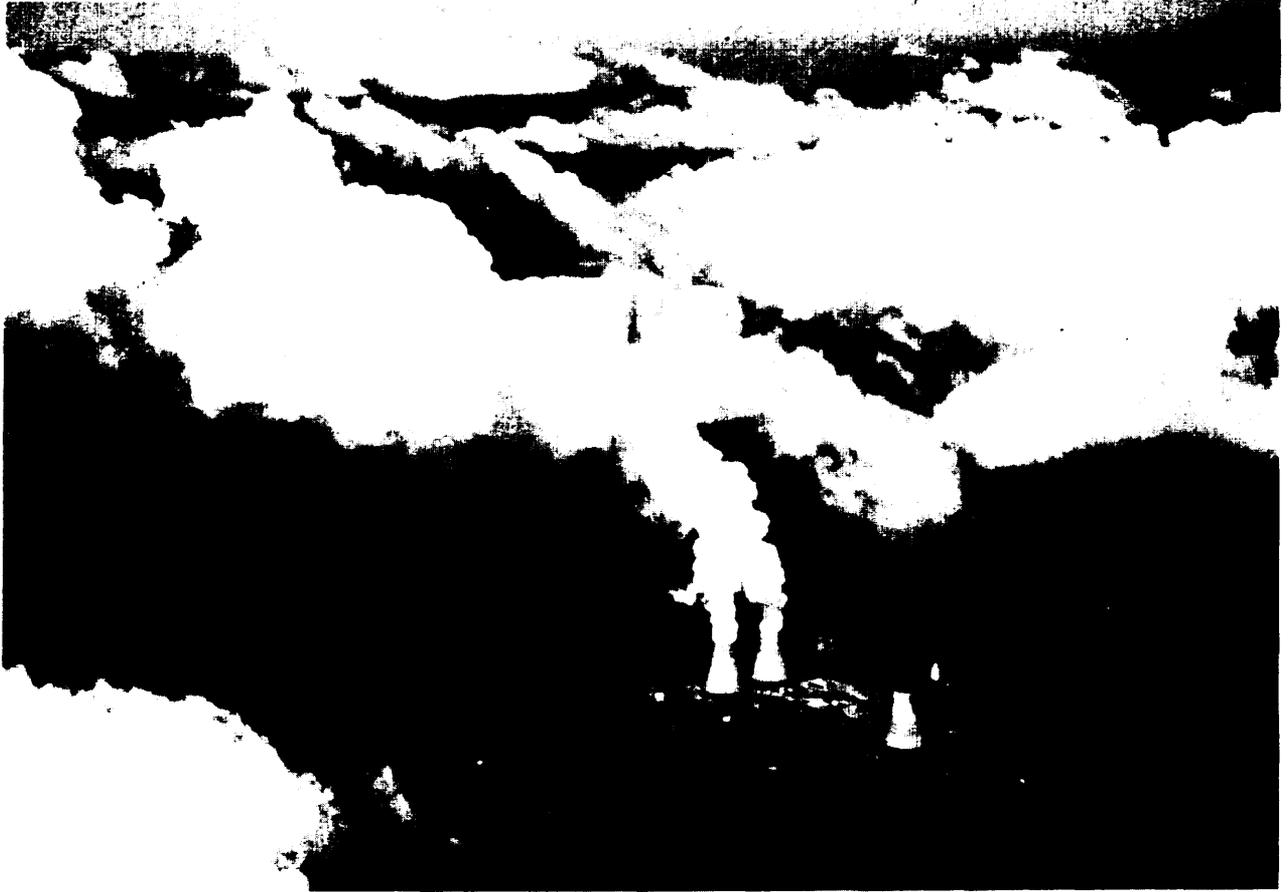
The enormous quantity of water that must be evaporated to cool a large generating facility
is graphically illustrated by these cooling tower "plumes", which overshadow the plume from the plant's stacks

Uncertainty about the precise level of controls that will be required is considerable. Present EPA effluent guidelines forbid the discharge of biocides but allow the discharge of the salts originally present in the intake water. However, if the cooling process uses a significant portion of the water source, the blowdown could violate water quality standards by substantially increasing the overall salt concentration; in these cases, some level of treatment will be required. Also effluent standards for new powerplants in some parts of the West require totally closed-cycle operations, with blowdown being concentrated and either discharged to evaporation ponds or else undergoing further treatment and disposal as a sludge. Disposal problems are similar to those associated with disposal of fly ash and flue-gas desulfurization (FGD) sludge, except that trace elements should not be a problem.

The dissolved solids loading that electric utilities impose on the Nation's waterways as a result of blowdown (from both the cooling system and the boiler) is extremely large. Utilities produced nearly 6 million tons, or nearly 28 percent of the total national dissolved solids discharge in 1975 and may increase this to 10 million tons by 1990. The share of this burden contributed by coal-fired utilities was nearly 4 million tons in 1975 and will be around 6.6 million tons in 1990 with moderate coal growth. Increases in utility coal burning play important roles in the projected substantial growth in TDS by 1990 both nationally and in several regions: South Atlantic, Midwest, North-Central, and Central.

The large water requirements associated with operation of a coal-fired powerplant can be reduced substantially by the use of air-

cooled or "dry" cooling systems, either by themselves or in combination with evaporative systems. In the combination or "wet/dry" system, the air-cooled tower may fulfill the total cooling requirements of the powerplant in winter and be supplemented by the wet tower when weather conditions lower the cooling capacity of the ambient air. Using either system, the cost of building and operating the powerplant increases substantially because of the large capital cost of the cooling systems, lessened efficiency of the plant due to a lower cooling capability, and the increased capital cost of turbines designed to operate in a higher pressure environment. In a strictly economic tradeoff, a decision to use these systems would be correct if the cost of water began to approach $700 to $1 ,000/acre-foot. In few circumstances would this tradeoff be made today, but these systems still might be utilized where water is unavailable for physical or political reasons.

In addition to the environmental impacts associated with their cooling systems, powerplants generate additional water pollutants in the form of a blowdown from the boiler and acid drainage from coal storage piles. However, these pollutant sources are relatively minor compared to their counterparts from the cooling and extraction portion, respectively, of the fuel cycle

Wastes From Coal Combustion

Under current and future combustion control technologies, coal impurities are removed from the air– only to reappear in solid or slurried form. An air pollution problem is thereby transformed into a waste disposal problem. The concentrations of undesirable constituents within the wastes demand strict attention to disposal methods to prevent contamination of surface or ground waters.

The wastes generated by coal combustion facilities are the fly ash from particulate control devices: the bottom ash and slag from the boilers, and the sludge from FGD systems. In the future these wastes may include spent sorbent from fluidized-bed combustion (FBC) units. By 1985, the quantities of ash and slag requiring disposal may total 80 million tons,

and that of sludge may be 19 million tons assuming moderate coal growth. These wastes represent approximately half of the Nation's total noncombustible solid waste and industrial sludges, respectively. By 1990, the quantities of coal combustion waste requiring disposal may grow to 90 million tons of ash and slag, and 35 million tons of scrubber sludge (NE F #1).

The major ash-producing areas are the Middle and South Atlantic and Midwestern States. By the end of the century, the Southwest is expected to join these regions as a major ash producer. With the exception of New England and the Northwest, the rest of the country should also experience substantial increases in ash production in the near future. Although sludge production is relatively minor now, by the end of the century the South Atlantic and Midwestern States should be major sludge producers, with the New York/New Jersey, Middle Atlantic, Southwest, and Central regions being major contributors.[86]

The potential disruption of water quality by these ash and FGD wastes depends largely on their chemical and physical structure. The ash is an alkaline material consisting primarily of insoluble inorganic elements (most of which are enriched in concentration compared to their natural abundance), as well as elevated levels of radionuclides. Up to 10 percent of the ash consists of water soluble species, principally calcium, magnesium, potassium, sulfate, and chloride. The presence of these materials creates a strong potential for leaching of ash components into surface and ground waters unless the ash is carefully disposed. [87]

The sludge from FGD systems varies with the scrubber design and operation but in general consists primarily of calcium sulfite or calcium sulfate with some carbonates, inert elements, and insoluble ions.[88] Calcium sulfite hemihydrate (the major species in the lime/limestone scrubbers) consists of small, thin crystals that settle very slowly, making the sludge difficult to dewater and contributing to its physical instability.

---

[86]" Appendix on Ash and Sludge, " *Rail Report.*
[87]"Ibid , p. 11,
[88]1 bid., p. 13
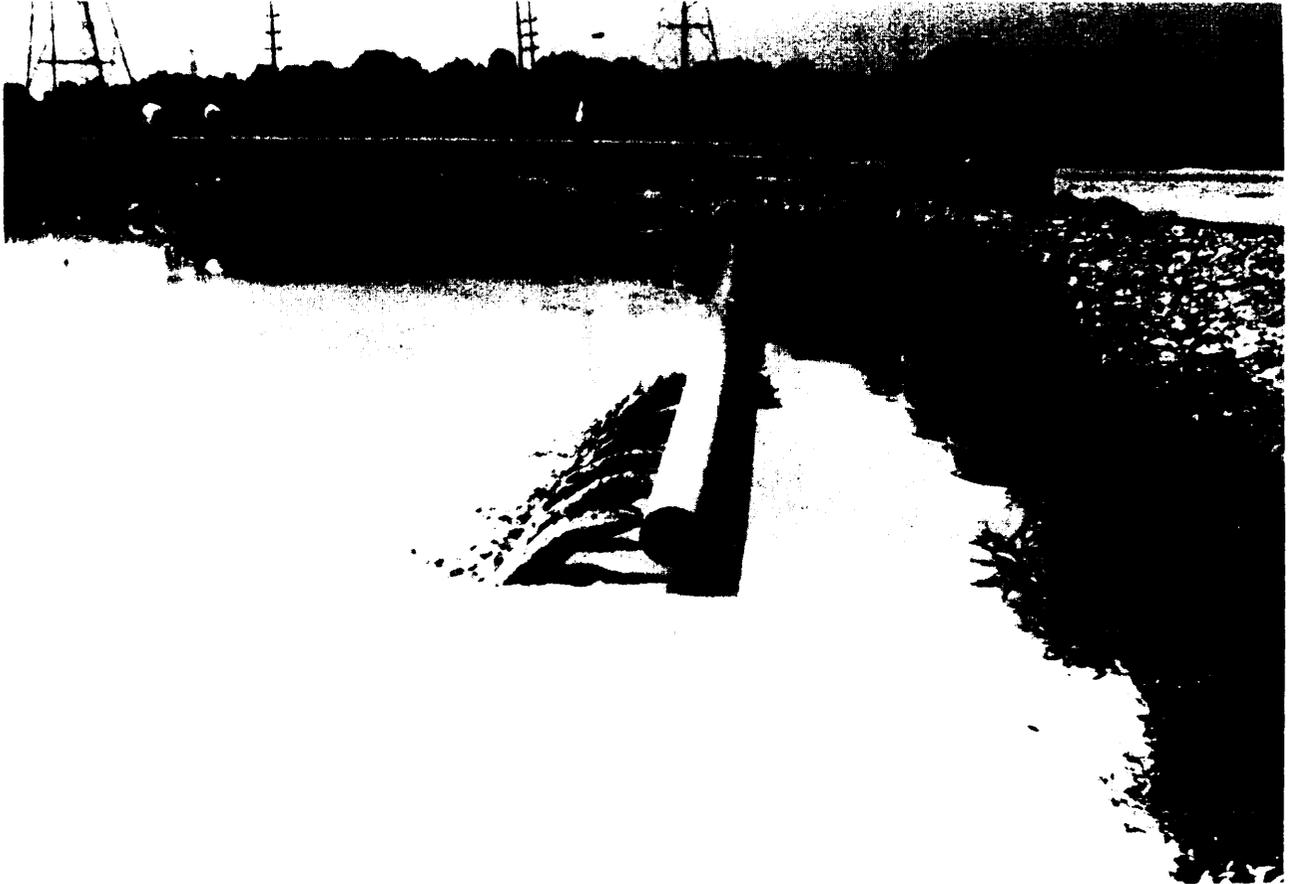
Photo credit: EPA — Documer/ca

FGD sludge pond–Commonwealth **Edison's Will County powerplant**

The concentration of trace elements in FGD sludge is much smaller than that in fly ash; those that are present tend to be elements that escaped the ESP in gaseous form or that came from the sorbent used. Often fly ash and FGD sludge are combined for disposal, and the mixture may be referred to as flue-gas cleaning (FCC) wastes. The ash helps increase the solids content of the sludge but also contributes a substantial load of trace elements to the mixture.

Whether these undesirable elements in FCC wastes enter surface or ground water depends on the disposal method used. The disposal methods traditionally used for ash and currently being considered for FGD are impoundments (ponds), landfill, and utilization, in decreasing order of common use for ash. Open-cycle ponds allow direct discharge of

ash transport water to receiving streams. *Some* of the solids and trace metals that are not in solution in the alkaline ash medium may dissolve as the pH is lowered in the receiving stream. If the ash transport water pH exceeds 9, it may have to be treated with sulfuric acid, causing the formation of a precipitate (floe) that can affect the receiving stream.

In addition to direct discharge to surface waters, ponded wastes may leach to ground water. In the case of sludge, the leaching comes both from the fluid (liquor) initially present and from the dissolution of sludge solids once the fluid is gone, The major soluble species in most FCC (combined) wastes are chlorides and sulfates (primarily in calcium, sodium, and magnesium salts). 89 These species

"Ibid , p 11

have been found in high levels in FCC leach-ates and would increase the TDS of ground and surface waters if leaching or surface discharges occurred. In addition, trace elements present in the ash may be leached out and added to the potential groundwater con-taimination.

The characteristics of FCC discharges that are most important from an environmental impact standpoint are the:

- presence of small particles,
- high trace element concentrations, and
- reducing capacity of sulfite-rich sludge.[90]

Trace element contamination of surface and ground water can lead to ingestion by aquatic organisms and contamination of soils (and, in turn, crops). Iron oxide floe and the FCC sludge itself can coat the bottom of streams and disrupt bottom communities. The oxygen demand of sulfite-rich sludge can cause serious stresses on aquatic life by depleting oxygen supplies. These and other impacts, coupled with the very substantial increases expected in FCC waste generation, focus attention on the importance of appropriate specification of required controls for waste disposal.

Virtually all of the above pollution impacts of waste disposal are controllable with available techniques, as discussed below, and both surface discharge and leaching to ground water fall under existing regulations (discussed in the following section). Although leaching of salts and trace elements into ground water generally is considered a major problem with FCC disposal, the actual impact is extremely dependent on site-specific factors. In some cases, it could be quite small because of the attenuation of pollutants as they pass through soil layers. Unfortunately, gaps in our knowledge of the pollutants present, the attenuative nature of different soils, and the actual physical characteristics of ground water systems complicate the specification of potential environmental effects.

As noted previously, the options for coal combustion waste disposal include impound-

ment, landfill, and utilization. Considerable experience exists with the disposal of ash by all of these methods. Pending has been the most common because it is the easiest and cheapest method; ash is sluiced to a lagoon near the plant, and the water is either returned or discharged. The imminent restrictions on ash transport water discharge and the declining availability of land near powerplants may discourage future use of ponds (at least open-cycle ponds) for ash disposal.

Ponds are less satisfactory for disposal of FGD sludge (either alone or mixed with ash) than they are for ash. The use of a pond for sludge disposal represents a long-term commitment of the land; pending of untreated sludge (and perhaps even some treated sludge) does not result in the degree of settling that would be required for future development on the site.

The problems of leaching associated with pending of wastes mandate attention to possible lining of the pond, selection of a pond site with highly impermeable soil, and treatment of the sludge itself to reduce its porosity and permeability. In addition, continual removal of the surface layer of water that develops in the pond from rainwater or other runoff is necessary.

These problems with pending appear to be turning more plant operators in the direction of landfill for FCC wastes,[9'] despite its higher cost. For landfill purposes the ash is collected dry and the sludge is dewatered and/or treated to improve its structural properties. In this form the wastes are more easily transportable than the wet sludge, allowing the landfill site to be further from the powerplant, perhaps in a less valuable location. However, the cost of transporting the dried and treated sludge is high, and onsite disposal will be favored where it is possible. Land impacts are decreased with landfill because of the smaller area and shorter retention time required before the land can be developed. As a tradeoff, the air pollution from fugitive dust (especially for a dry ash landfill in an arid climate) is greater during

---

[90]1 bid

"J. Jones, "Disposal of Power Plan:t Wastes, " pr_e-sented at the Third *National Interagency Energy/Envirorr-mental R&D Conference,* Washington, D.C, June 1978

transport and disposal. This effect is highly local and may be mitigated by use of a wetting agent or by a buffer zone around the site.

Before sludge may be used for landfill it must undergo some physical or chemical treatment to improve its structural stability and reduce its volume, permeability, and porosity. One method is to alter the operation of the scrubber itself to force the oxidation of sulfite to gypsum. Alternatively, one might exploit the finding that some modes of scrubber operation seem to produce forms of calcium sulfite that are easier to dewater. 92

The FGC wastes may be dewatered by several physical techniques such as vacuum filtration, centrifugation, or gravity settling in order to increase the percentage of solids (65 to 70 percent is desirable). Adding ash to the sludge also increases the solids content and lends structural strength.

Several commercial chemical sludge treatment processes have been developed and are being used by coal-fired plants. Field tests of chemically treated wastes demonstrate significant structural improvement and a reduction in permeability, as well as a reduction in the concentration of dissolved solids in the leachate and a decrease in the actual volume of leachate. " An additional benefit of sludge treatment is the improvement in handling characteristics, which allows better sludge placement and thus additional control of leaching.

Another disposal method for FCC wastes is burial with the mine wastes. This technique is felt to be too expensive for underground mines but may be feasible for surface mines. The concept is made more appealing by the coal transportation link that connects a mine with a plant. Alternatively, the plant may be a mine-mouth plant with close ties, both geographically and economically, to the mine. The mine may welcome the wastes as additional fill to restore the original land contour and, in the East, as alkaline material to help neutralize some of the acid wastes. It is not known

whether the economics and institutional links between mine and plant are favorable enough on a large scale to promote widespread use of this disposal method.

Another disposal method for FCC wastes is to dump them in the ocean. The idea is appealing for northeastern utilities that are close to the coast but have little space to store wastes. The concept is further encouraged by the fact that the major chemical constituents in FCC wastes are already in relatively high concentrations in seawater. Promising forms of disposal are concentration of treated FCC wastes in bricklike form or dispersion of treated or sulfate-rich FCC wastes in either deep ocean or on the Outer Continental Shelf .94 The environmental impacts of ocean disposal are being investigated by EPA.

The utilization of wastes is more appealing from a resource conservation standpoint than is disposal, but it is not always as economically attractive. About 20 percent of all ash is now used for some purpose, and the National Ash Association is actively pursuing new uses for ash. The most promising use is in the manufacture of portland cement. Approximately one-third of the 1980 fly ash production could be used for this single application .95 Other uses are as a light aggregate for construction, as a filler for asphalt, as an abrasive, and as a soil additive. In addition, extraction of valuable minerals from the ash may be economically feasible.

The potential uses for sludge are not as numerous. In Japan, scrubbers are operated so as to produce gypsum, which is then used for wallboard and portland cement. However, the economics are not favorable enough for FCC wastes to penetrate the market in this country.[96]

An alternative to sludge disposal is to avoid sludge generation altogether. Several "regenerable" systems have been developed for FGD. These typically produce elemental su!fur or sulfuric acid. Some wastes are emitted as a

---

[92]Ibld , p 12
[93]" Appendix on Ash and Sludge, " *Rail Report*

"J. Jones, "Disposal of Flue-Gas Cleaning Waste, " *Chemical* Engineering, Feb. 15, 1977
"Jones, *R&D Cont.,* p 1
"Ibid , p 2

bleed stream, but the volume is far less than wastes from nonregenerable systems. Sulfur is unfortunately not a scarce element but may become valuable when present sources are depleted.

Only general statements can be made about the waste disposal problems associated with the spent sorbent from FBC, because no large-scale demonstration yet exists. The amount of sorbent waste generated will depend on the chemical balance needed to assure adequate removal of sulfur in the coal, but indications now are that the volume will be greater than that of sludge for a plant of comparable size burning the same coal. By contrast with Sludge, however, the sorbent has a much higher solids content and greater structural stability. Among the possible uses being investigated is as an agricultural fertilizer.

A key to the actual waste disposal alternative selected will be the application of the Resource Conservation and Recovery Act (RCRA) described in the following section. Designation of sludge as a "hazardous" material under RCRA will result in extensive use of liners, chemical fixation, and landfill disposal of scrubber sludge. DOE has estimated that such a designation could increase sludge disposal costs by about 20 percent over costs incurred by a "nonhazardous" designation" to a total of about $600 million per year by 1990. Similarly, designation of ash as hazardous material is estimated to yield a 30-percent increase over the costs incurred with a nonhazardous designation, to a total of about $1 billion by 1990 for utilities. As even a nonhazardous designation will require an upgrading from present practice, the total cost of disposal for sludge and ash is estimated to increase up to 45 percent over present practice for a nonhazardous designation, and up to 84 percent if both are designated hazardous. The incremental cost of waste disposal on electric generation was estimated to range from 1.22 to 2.01 mils/kWh under RCRA; in comparison, continuation of current practice would cost approximately 1 mil/kWh (NEF#l). All of these cost estimates have been challenged by the utility industry as

being severe underestimates of the costs that will have to be borne under RCRA.

These costs must be balanced against the protection of ground waters and reduction in land use impacts provided by the increased controls. An unfortunate side effect of a hazardous designation for ash might be the elimination of the ash byproduct market, but this is clearly dependent upon the precise nature of EPA's regulatory stance,

Regulations

Impacts to water systems are regulated under the Clean Water Act, the Surface Mining Control and Reclamation Act (SMCRA), and RCRA. These are discussed in detail in chapter VII and summarized below.

The Clean Water Act sets effluent limitations for chemical and physical discharges from steam electric-generating plants, coal preparation plants, and coal mines. For generating units, limitations have been established for discharges of: total suspended solids and oil and grease from low-volume waste sources, ash transport water, metal-cleaning wastes, and boiler blowdown; copper and iron from metal-cleaning wastes and boiler blowdown; free available chlorine from once-through cooling water and cooling tower blowdown; and materials added for corrosion inhibition, including zinc, chromium, and phosphorus, from cooling tower blowdown. In addition, discharges of total suspended SO l ids from material storage and construction runoff are regulated.

For coal mines and coal preparation plants, limitations have been established for discharges of iron and total suspended solids from acidic and alkaline mine drainage, and for manganese from alkaline drainage. In addition, the pH of all discharges from generating units, mines, and preparation plants must be in the range of 6.0 to 9.0.

The Clean Water Act also limits thermal discharges from steam electric-generating plants. Standards of performance for new units provide that there shall be no discharge of heat from the main condensers; existing units (with

"National Environmental Forecast No 1.

some exceptions) must meet this limit by 1981. In addition, the Act requires that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts such as impingement and entrainment of organisms.

Effluent sources must obtain a permit under the National Pollutant Discharge Elimination System (NPDES), which includes all applicable effluent limitations. Variances are available only for sources that can demonstrate that factors related to the equipment or facilities involved, the process applied, or nonwater quality impacts (such as economic factors) are fundamentally different from the factors considered by EPA in establishing the effluent limitations.

For the most part, the effluent limitations established under the Clean Water Act are intended to achieve a water quality goal that provides for the protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water by 1983. Stricter l imitations designed to eliminate all pollutant discharges will not be enforced until at least the late 1980's.

No Federal regulations deal with water consumption by coal combustion facilities. Water rights traditionally have been regulated by the States, and the means of allocation vary widely by region. The 1977 amendments to the Clean Water Act reaffirmed this system by stating that the Act in no way impairs the authority of each State to allocate quantities of water within its jurisdiction. However, the Act does require that water resource management be considered in State water quality planning.

SMCRA sets performance standards for surface mines and for the surface operations of underground mines that are designed to prevent acid and other toxic drainage as well as runoff containing suspended sol ids, and to prevent disruptions in local water supplies. Mandated practices to control surface mine-related water pollution include stabilizing disturbed areas, diverting runoff, regulating the channel velocity of water, lining drainage channels, mulching, selectively placing and

sealing acid-forming and toxic-forming materials, selectively placing waste materials in backfill areas, achieving rapid revegetation and, where necessary, maintaining water treatment facilities. In addition, all surface drainage from disturbed areas must be passed through at least one sedimentation pond.

Additional requirements for underground mines include designing mines to prevent gravity drainage of acid waters and sealing and controlling subsidence. Similar provisions apply to support facilities such as coal loading and storage facilities, roads and other transportation facilities, and mine buildings.

SMCRA also requires mine operators to minimize hydrologic disturbances. Overland flows and stream channels may be diverted when necessary to comply with other performance standards in the Act and when the diversion meets specified engineering standards. In addition, mine reclamation must restore the premining capability of the area to transmit water to the ground water system. The mine operator also must replace water supplies used for domestic, agricultural, industrial, or other uses when they become contaminated, diminished, or interrupted as a result of mining activity.

In order to obtain a mining permit, the mine operator must demonstrate that these requirements will be met and that they will be adequate to comply with all applicable Federal and State water quality standards and effluent limitations.

The disposal of combustion byproducts is regulated under the Clean Water Act and RCRA. Where the wastes are discharged to receiving waters, they come under the Clean Water Act; an example, as discussed above, is ash transport water. Land disposal of the wastes is regulated under RCRA, which seeks to control open dumping of wastes under a system of State plans and permits for waste disposal. The Act distinguishes hazardous and nonhazardous wastes and places more stringent restrictions on the former. If either ash or scrubber sludge is determined to be hazardous, the disposal options for these substances are constrained. For example, sludge ponds

would have to be constructed in a manner that would prevent any leaching to the ground water. Similarly, burial of wastes or their use in landfills or in roadbeds would be prohibited where there is any possibility of leaching. In addition, disposal of hazardous wastes would be prohibited in wetlands or floodplains (where most large combustion facilities such as powerplants are located), adding substantial transportation costs to the waste disposal costs.

IMPACTS TO THE LAND

The impacts from air pollution provide an interesting contrast to the direct impacts to the land caused by the use of coal. The air emissions from the coal fuel cycle stem primarily from coal combustion. Many of the impacts are subtle or are masked by other factors; others take a long time to become manifest.

By contrast, the land impacts of the use of coal stem primarily from the mining and waste disposal portions of the fuel cycle. These impacts are more site specific and often cause acute and drastic alterations of a local area. The land impacts of mine activities are more likely to damage plantlife, animals, or human beings by mechanical harm (such as that resulting from removal of habitat or from landslides and floods) than by chemically induced damage. Some land disruptions, such as blasting damage, may be short term. Others, such as subsidence, may linger for many years.

A variety of impacts to other media result indirectly from perturbation of the land by coal extraction and waste disposal. These include air pollution from coal mine fires and fugitive dust or water pollution from waste pile runoff. Although the specific details are treated in the sections concerned with the air and water media, the interaction of the three media should not be forgotten.

Sources, Effects, and Control of Land Impacts

Surface Mines

Although estimated future coal production levels, and therefore land use impacts, vary considerably with assumptions about environmental policy and economic conditions, most studies show a very substantial increase in surface mining in the northern Great Plains and, to a lesser extent, in the Southwest. Surface production in the Midwest fluctuates widely in the long term with varying assumptions, although it is unlikely to increase much by 1985.

As shown in table 36, Western surface mining disturbs considerably less land per ton of coal extracted than do Eastern and Central surface mining. This occurs because many Western coal seams are over 50 feet thick, allowing extraction of more tons per mined acre.

The most obvious land impact of a surface mine, while it remains active, is the complete removal of the land from its normal uses. The

Table 36.—Land Affected by Coal Utilization

Facility	Acres over 30-year period
Mining: 10^{T5} Btu's per year[a]	
Western strip ....4...	15,000-96,000
Central strip	216,000
Central room and pillaP	525,000
Eastern contour	470,000
Eastern room and pillar[b]	560,000
Gob and refuse disposal[c]	15,000
Combustion/Conversion: °Input of 10^{15} Btu's/year	
Powerplants	13,600
Lurgi gasification	6,500
Synthoil liquefaction	6,300

[a] For a high heat value coal (e.g., Eastern coal with 12,000 Btu's/lb) this is equivalent to approximately 42 million tons per year. For a low heat value coal (e.g., Western coal with 8,500 Btu's/lb) this is equivalent to approximately 59 million tons per year. For a medium heat value central coal of 10,000 Btu's/lb, this is equivalent to 50 million tons pr year.

[b] Includes undermined land which is potentially subject to subsidence.

[c] A 1,000 MWe (megawatt-electric) powerplant would "consume" approximately 59 × 10^{12} Btu's/year; thus it would take nearly 17 such plants to consume 10^{15} Btu's/year. Similarly to use 10^{15} Btu's of coal per year would require about 8 Lurgi gasification plants of 250 million cubic feet per day and about 3 Synthoil liquefaction plants each producing 100,000 barrels per day.

SOURCE: Calculated from White et al , "Energy from the West", EPA—60017-77. 072a, July 1977.

surface covering, which may have been agricultural crops, range land, forests, or desert, is replaced by the sights of excavation and the sounds of blasting. Wildlife, deprived of food and cover, must migrate if possible to other areas. The unsightliness may degrade both property and scenic values, impacting a distance beyond the mine equal to the extent of the vista. Thus the surface mining of one mountain can alter the recreational quality of a large geographical area.

Once the coal resource has been extracted from a given area, the land generally can be recontoured and revegetated so that it can support former uses. There is sufficient reclamation experience with most of the coal-producing areas to suggest that successful reclamation will occur with the appropriate commitment of resources. Doubts about the success of reclamation procedures, however, have been fostered by the poor attention given to reclamation in the past. Some 420,000 acres of mine lands are unreclaimed. Although more stringent regulations and keener public awareness should produce a better record in the future, the past can serve as a reminder of the importance of constant monitoring. Doubts about reclamation also stem from lack of experience in reclaiming some of the more ecologically fragile regions to be mined in the future. In particular, experience with revegetating strip mines in the arid or semiarid regions of the West is not extensive. A key issue here is whether apparently successful reclamation efforts may degrade over time, especially in the face of periodic droughts.

The concern over reclamation centers on lands that play a unique vital role in a region, and many of these critical lands are protected by the 1977 SMCRA. Among these are the alluvial valleys, which often form the backbone of the ranching and farming economy in semiarid regions. Even though only 3 percent of the coal leases in an eight-State area of the West underlie such valleys, the shallow overburden there makes these lands most attractive for mining. " Some fear that even strip mining in the lands adjacent to alluvial valleys, where 10 percent of the strippable coal exists, may have

hydrological impacts that would affect the agricultural productivity of the valley floors. As discussed below, SMCRA strictly regulates mining on alluvial valley floors, but interpretation and enforcement of the law's provisions is critical to the actual degree of protection afforded these lands.

Another type of land where surface mining might threaten the resumption of a vital function is the agricultural farmland of the Midwest. Before passage of SMCRA, new strip mining would have encroached on prime agricultural lands. For example, in 1976, about 75 percent of the surface mine permits issued in Illinois were for lands classified as prime agricultural lands by the Soil Conservation Service. The main concern surrounding agricultural lands is that the ecology of the soil system is too little understood for the success of reclamation to be guaranteed. Only recently have researchers begun to treat soil as an ecosystem rather than as a mineral. [100] It is not known whether the soil productivity deteriorates as the soil layers are removed, separated, piled, and stored.

Some concern also centers on stands of hardwood timber in southern Appalachia that require decades or even centuries of natural forest succession to become re-established. The Ponderosa pine forests in the West also are believed to be quite difficult to re-establish. A final concern is that some areas (southern Appalachia in particular) have such steep slopes that reclamation is unfeasible. The rapid erosion of soil prevents successful rooting of vegetation.

Surface mine reclamation usually proceeds in parallel with excavation; the overburden and topsoil from the active area are placed in the area of the previous cut. The overburden is backfilled, graded, and compacted. The topsoil is removed and replaced as a separate layer. The land is then replanted with some species of vegetation.

Besides merely replacing topsoil and overburden separately, these materials must be

---

9"'Appendix on Reclamation, " *Rall Report,* p 27

"Department of Mines and Minerals, "1976 A n n u a l Report – Surface Mine Land Conservation and Reclamation, " Springfield, Ill , 1976

'100"'Appendix on Reclamation, " Rail *Report,* p 35

replaced properly: toxic or acid-producing layers in the overburden must be identified and covered by sufficient depth of acceptable material to prevent containinants from entering the aquatic environment; layers must be ordered to prevent fine topsoil particles from being swallowed by coarse particles. Finally, a thick layer of subsoil must underlie the topsoil. All plans for soil layer replacement must be based on thorough analysis of the overburden in the area.

In prime agricultural lands, the permanent provisions of SMCRA require the segregation of topsoil horizons so that the root zone can be reestablished. Before a permit is granted for a new surface mine in such areas, the operator must demonstrate that the original soil productivity will be restored. Some operators currently mining prime farmlands contend that they have indeed done this, but the regulations require proof in the form of scientifically valid experiments.

The provision to return land to its approximate original contour will help minimize any permanent disruption by surface mining in most locations. However, universal application of this requirement may be inappropriate. I n the steep terrain of Appalachia, reclamation of slopes greater than 300 may be hindered if the land must be returned to its original slope, as the long, uninterrupted slopes will promote erosion. (The law does, however, allow the use of terracing and other erosion control measures to alleviate this problem.) In other areas, local governments and residents might prefer alternative configurations to allow new uses (or enhance old uses) of the land. For instance, land contour shaping can be used to trap water and allow growth of important wildlife cover in portions of the arid West.

Underground Mines

Although less conspicuous than surface mines, deep mines nevertheless can have severe impacts on the land. Aside from their impacts on hydrology, underground mines have a potential for subsidence. This problem occurs when the support of the mine roof either shifts or CO I lapses. While subsidence can occur during the active operation of a mine, it is more likely to be delayed for many years as the mine pillars slowly erode and collapse. The altered ground slopes can damage roads, water and gas lines, and buildings. The subsidence may further change natural drainage patterns and river flows, intercept aquifers and existing springs, or create new springs and seeps.

The extent, severity, and timing of the subsidence are complex functions of soil composition, overburden thickness, and mining method, to name only a few relevant factors. The difficulty in predicting and preventing subsidence complicates land use planning greatly. Just the potential for subsidence may reduce the land available for construction of homes and businesses. Even farming of the land may be discouraged by possible future unevenness of the surface.

Unfortunately, reliable surveys of subsidence do not exist, although a sizeable percent of the 8 million acres undermined to date have experienced some degree of subsidence, and more of this acreage may yet subside in years to come. Future subsidence impacts will depend heavily on the success of preplanning and control measures, and upon the degree to which underground mines will contribute to the future U.S. coal supply. A Bureau of Mines report estimates that a potential 1.5 million acres would be affected by subsidence by 2000. [101] A study of the environmental impact of the National Energy Plan assumed that 35 percent of coal production would come from underground mines by 2000. The study predicted that, in that year, underground mines would account for three-fifths of the land disturbance by total coal production. Most of the impact would be in the Middle and South Atlantic regions, where underground mines could affect up to a few percent of the total land in those regions. [102]

The amount of land potentially disturbed by underground mines is greater than that for surface mines of the same production capacity, as illustrated in table 36. This table compares the land affected by 30 years of various types of coal activity that produce or consume 1 Quad of energy. This comparison between the effects of surface and deep mines must be made cautiously. Surface mining disturbs all the land, but for a limited time. For deep mines, one can cite only the maximum amount of land that could be disturbed, with the actual acreage, duration, and degree of disruption subject to greater uncertainty.

Subsidence problems can be addressed by both preventive and corrective measures. The common preventive measure for subsidence is to leave a considerable portion of the coal itself — sometimes as much as half — in place as a roof support.

Another strategy is to allow subsidence to occur but in a controlled manner. In this scheme, called longwall mining (see chapter I II) each section of the mine is collapsed after all the coal is extracted. This allows surface subsidence to occur sooner than with room and pillar mining, and the subsidence also occurs more evenly with major disruptions only at the perimeter of the mined area. Thus, future plans for the land may be made with greater certainty. Longwall mining is used extensively in Europe, but there has been less experience in the United States.

One of the few corrective measures that can be applied to existing mines is to backfill them with mine waste or other materials (including FGD sludge). At first glance this suggestion seems to solve the waste disposal and subsidence problems at the same time. More extensive studies, however, reveal that this method is quite expensive, involves considerable hazard to workers and may release contami-

---

[101] "Appendix on Acid Mine Drainage and Subsidence," *Rail Report,* p 37.

[102] *Annual Environmental Analysis Report, Vo/ume I Technical Summary* (Washington D C U S Energy Research and Development Administration, Office Of Environment and Safety, September 1977)

nants into the ground water. I n addition, some mine wastes and untreated sludge lack the structural strength to provide the needed support for the mine roof. An additional technique that is quite feasible for some of the shallower mines is "daylighting;" it involves surface mining to obtain the remaining coal and reclaiming the entire area. This technique is a cure for acid mine drainage as well as subsidence in abandoned mines.

Regional Factors

The regional variation of the extent of land disturbed is largely a function of the thickness of the predominant coal seams. Western coal, although low in heating value (and thus at a certain disadvantage when comparing impacts on a unit energy basis), affects strikingly less acreage than either Eastern or Central coal because of the extreme thickness of the coal seams (seams greater than 50 feet in thickness are not uncommon). On the other hand, many Appalachian seams are only a few feet thick and thus require the disturbance of considerably greater acreage to extract the same coal energy. In fact, virtually all of the effects of mining vary greatly with geographical factors, so it is instructive to give an overview of the pertinent characteristics of each general province.

The major coal-producing area in the East – Appalachia —can be divided into two regions, based on differing concerns over mining. In northern Appalachia, stretching upwards from the northern coalfields of West Virginia, the topography is not rugged, and the soils contain substantial acid-forming materials. The region is densely settled, and the land is dotted with small farms and forested primarily with softwoods. By comparison, southern Appalachia has more steep, rugged terrain and smaller concentrations of acid-forming strata. The population is less dense and the forests are mainly hardwoods.

These characteristics make the impacts of acid drainage more severe in the northern region and necessitate careful attention to proper management of toxic spoil banks there. In addition, the subsidence problem is of greater impact in northern Appalachia, for more lands are subject to residential or agricultural development. A considerable fraction of the subsidence problem in Pennsylvania has resulted from the underground mines in the urban areas of the anthracite region.

The problems of surface mining are more severe in southern Appalachia because of steep slopes and heavy rainfalls. The stands of hardwood forests require much longer times to reestablish than do the softwood forests of the northern region.

Surface mining in the Illinois Basin will be limited in those portions that are designated as prime farmland, as discussed earlier. In other regions, reclamation is facilitated by relatively flat topography and favorable rainfall. The impact of subsidence from underground mining in this region is relatively unknown, but subsidence may pose serious problems for agricultural lands.

Over the next several decades, surface mining is expected to dominate coal extraction in the northern Great Plains. The key problem in reclamation will be the scarce water supply and rainfall, coupled with the lack of experience with reclamation in this region. The alluvial valleys in these regions are protected by the SMCRA, as discussed earlier.

Surface mining also will be the dominant mining method in the gulf coast, where lignite reserves are concentrated in Texas. Except in the areas south of the Colorado River, rainfall appears adequate and potential land impacts minimal.

In the Rocky Mountains, most mines in western Wyoming, western Colorado, and Utah will be underground. The low population density and infrequent farms should minimize economic damage from subsidence. By contrast, the subbituminous coal deposits in New Mexico and Arizona will most likely be surface mined. The limited rainfall could hamper reclamation efforts, but some mines have been successfully revegetated when irrigated. Therefore, the surface mine impact there is uncertain.

Mine Wastes

Both surface and underground mines generate large quantities of wastes that impact both water and land. The waste is of three types:

1. the solid waste from underground mines, which commonly is called "gob" and corresponds in composition to the overburden removed in surface mining;
2. the refuse from coal washing and preparation, which consists of coal waste and other impurities; and
3. the sludge resulting from treatment of acid mine drainage.

The total amount of solid waste generated by coal mines in 1975 was estimated to be almost 50 million tons.

Although the percentage of coal that is washed has decreased from about 65 to 41 percent between 1965 and 1975, the fraction of coal that is discarded has increased from about 20 percent to around 29 percent. One reason for the larger quantity of waste from coal cleaning is the greater use of automated equipment that digs less selectively than the hand-mining methods of the past. A second reason is that most coal is now being extracted from seams that are less rich and hence contain more impurities. More than 3 billion tons of waste lie in **3,000 to 5,000** refuse banks in Eastern coalfields.

One of the most obvious impacts of these unsightly wastes is the degradation of local property values and destruction of esthetics. The land used for waste disposal, unless reclaimed, is no longer available for other uses. Furthermore, the gob, refuse, and sludge create dangers of many kinds if effective disposal techniques are not applied to them. First, the refuse piles contain flammable material that makes them susceptible to spontaneous combustion. They are also vulnerable to landslides and erosion because they usually are comprised of mixed, poorly graded, and uncompacted material. These wastes have been used to construct dams near the minesite for impoundment of water or slurry, a use to which they are poorly suited. The danger of this practice was dramatized in 1971 when such an impoundment, in Buffalo Creek, W. Va., broke during a heavy rainstorm and flooded the valley below, causing more than 125 deaths and millions of dollars in property damage. A 1974 study of dams in the East, only 40 percent completed, found 30 similar water impoundments that were classified as imminent flood hazards and 176 additional structures that were classified as potential flood hazards [3]

A major concern about coal gob and refuse piles — especially in the eastern regions — is their content of acid-producing materials. Exposure of these layers to air and water causes the leaching of coal impurities into surface and ground waters. Erosion of these wastes also contributes sediment and dissolved sol ids to local waterways, as was discussed in the section on water impacts.

Transportation and Transmission

The key factors determining the land requirements for the various coal energy transportation modes are the right-of-way requirements, disturbances outside the right-of-way, the directness of the route, barriers created, other uses of the right-of-way, and other uses of the mode. Transmission and waterways generally require the widest paths, typically about 200 feet. Waterways may also produce flooding for a much wider distance, or require extensive areas for disposing of dredged material, Slurry pipelines may disturb large areas during construction. Rails, waterways, and highways may act as barriers to people or wildlife. These three modes can be useful for other purposes, while slurry and transmission lines are dedicated to one product. The rights-of-way of the latter, as well as those of waterways, however, may have multiple uses such as pathways or farming, which may provide a land benefit. In the case of very high-voltage transmission lines, multiple use may be compromised because of the possibility of electrical effects. The existence of these effects remains a controversial issue.

"" *The National Strip Mine Study– Vol. 1, Summary Report,* (U S Department of the Army, Corp of Engineers, Washington, D.C. 1974)

Coal Combustion

As noted earlier, both the ash and the scrubber sludge produced by utility and industrial boilers represent a very sizable disposal problem. With particulate collectors on most large coal-fired boilers, 92 percent of all fly ash generated in the United States is now collected. This collection efficiency should increase with time because Federal standards now require greater than 99-percent collection for moderate and large boilers. Also, provisions for requiring technological controls for SOx will yield increasingly large amounts of scrubber sludge requiring disposal. As noted in the previous section, the total solid waste— fly ash, bottom ash, and slag–generated in 1985 is projected to be approximately 80 million tons per year, while scrubber sludge is expected to be about 19 million tons assuming moderate coal growth. [04] Although this weight of sludge is only about one-quarter of that projected for ash wastes, the two materials may necessitate comparable storage volumes because of the high water content of the sludge. For example, the sludge produced in 1 year by a "typical" 1,000-MW powerplant (3.5 percent sulfur, 90 percent SO_2 removal, 12 percent ash, 6,400 hrs/yr, 20 percent excess lime, 50 percent oxidation, 0.88 lb coal/kWh) requires 630 acre-feet of pond volume if it is 40-percent solids and 270 acre-feet if the sludge is dewatered to 70-percent solids. The ash produced in 1 year would occupy about 140 acre-feet. Over a 30-year lifetime, the plant would require about 600 acres for waste disposal (assuming the ash and dewatered sludge are mixed and placed in a 20 feet thick storage area). By the year 2000 or so, the cumulative storage area devoted to these wastes could approach 100,000 acres, or well over 100 square miles (based on the same assumptions).

Although the land use requirements for sludge disposal are similar to those for ash disposal, the actual land impact attributed to the sludge could be considerably greater than that of the ash if pending remains a predominant sludge storage mechanism; in that case, the land utilized will be unavailable for devel-

opment for a considerable period. The choice of disposal technique, if not dictated by RCRA, should depend largely on the value of land, Of the major sludge-producing regions, the more densely populated ones–the Midwestern, New York/New Jersey, and Middle Atlantic regions — might be expected to lean heavily toward landfill disposal. As the major problems associated with obtaining suitable land disposal sites may fall on industrial coal users rather than on utilities — because the industrial plants may be expected to locate closer to urban centers– industrial users may also be expected to lean more heavily toward landfills. However, other factors, such as the importance and vulnerability of ground water and the State and local regulatory climate, should play a major role in disposal decisions.

Regulations

The land impacts of coal production and use are regulated primarily under SMCRA and RCRA, which are directed at mining and waste disposal practices that tend to cause land impacts. In addition, a variety of provisions cover the potential land impacts of transportation and transmission. These laws are summarized below and discussed in detail in chapter VI 1.

The primary purposes of SMCRA are:

- to ensure that surface coal mining operations are conducted in a manner that protects the environment,
- to ensure that adequate procedures are undertaken to reclaim surface areas as contemporaneously as possible with mining operations, and
- to strike a balance between protection of the environment and agricultural productivity and the Nation's need for coal as an essential source of energy.

i o accomplish these ends, SMCRA mandates State permit systems in accordance with Federal guidelines that include comprehensive performance standards for surface mining operations and for the control of surface effects of underground mining.

'("National Environmental Forecast No. 1.

For surface mining, the environmental performance standards regulate the removal, storage, and redistribution of topsoil; siting, erosion control, drainage, and restoration of coal haul roads; protection of water quality and the hydrologic balance; waste disposal; backfilling, grading, and revegetation, and postmining land uses. This section discusses those provisions of SMCRA that relate to areas of special concern, such as alluvial valleys and prime farmland. The overall legal framework of the Act is discussed in chapter VI 1.

Minimum performance and reclamation standards for alluvial valley floors in the arid and semiarid areas in the Western United States are intended to preserve existing or potential agricultural uses and productivity. An applicant for a mining permit in these areas must demonstrate that the operations will preserve the essential hydrologic functions of an alluvial valley floor by maintaining the geologic, hydrologic, and biologic characteristics that support those functions. These requirements apply both to disturbed and adjacent undisturbed areas. I n addition, surface mining and reclamation operations may not interrupt, discontinue, or preclude farming on alluvial valley floors unless the premining land use is undeveloped rangeland or the area affected is small and production is negligible. The mine operator must conduct environmental monitoring to ensure that these requirements are met; where the monitoring shows they are being violated, mining must cease until approved remedial measures are taken. However, mines that were permitted or in production before August 1977 are exempt from these SMCRA requirements.

SMCRA also includes regulations designed to minimize the effects of surface mining on prime farmland so that the land will have equal productivity after mining and is not lost as a resource. Each soil horizon used in reconstruction of the soil must be removed before drilling, blasting, or mining in a manner that prevents mixing or contaminating the soil horizon with undesirable material. When replaced and reconstructed, the soil material must be at least 48 inches deep and must create a final root zone of comparable depth and quality to that which existed prior to mining. In addition, the surface soil horizon must be replaced in a manner that prevents excessive compaction and reduction of permeability and that protects against wind and water erosion. Finally, the operator must apply nutrients and soil amendments as needed to establish quick vegetative growth.

Protection of timber stands under SMCRA is not as rigorous as that afforded to alluvial valley floors and prime farmland. In general, mine operators must establish a diverse, effective, and permanent vegetative cover of species that are native to the area or that support the approved postmining land use. Introduced species may be substituted only if they are of equal or superior utility for the postmining land use and if they meet the requirements of State or Federal laws. Specific provisions for forest land in the Eastern United States, as measured 5 years after planting, require an average of 600 trees of commercial species of at least 3 years of age per acre. ı n the Western United States, where shelter belts, wildlife habitat, or commercial or other forest land is the approved postmining land use, the operator must conduct a premining and postmining inventory of vegetation. The density and number per unit area of trees and shrubs on the restored land must be equal to or greater than 90 percent of the premining density and number. The success of the reforestation, in terms of species, diversity, distribution, seasonal variety, vigor, and regenerative capacity of the vegetation, is evaluated on the basis of the results that reasonably could be expected from the approved reclamation plan.

Finally, regulations promulgated under SMCRA provide special environmental performance standards for operations on steep slopes. Spoil and waste materials may not be placed on the downslope; the highwall must be completely covered with compacted soil and graded to the original contour; land above the highwall may not be disturbed; woody materials may not be buried in the backfill area, and unlined or unprotected drainage channels may not be constructed on backfiils unless they are stable and not subject to erosion.

COAL MINING.—This was a coal mine pit 3 years ago. Arch Mineral, operator of the Medicine Bow Coal Mine in Wyoming, follows rigorous reclamation, regrading worked over areas into gentle contours and reseeding with native grasses

Problems of subsidence from underground mining also are regulated under SMCRA. In general, the regulations require that underground mining be conducted so as to prevent subsidence from causing material damage to the surface. This may be accomplished by leaving adequate coal in place, backfilling or other measures to support the surface, or by mining in a manner that provides for planned and controlled subsidence. Underground mining is prohibited beneath or adjacent to streams or beneath impoundments of 20 acre-feet or more, beneath aquifers that serve as municipal water supplies, and beneath or in proximity to public buildings, unless the permitting agency determines that subsidence will not cause material damage to any of these factors. In addition, the mine operator is required to consult with the surface owner prior to conducting any underground mining activities, and the surface owner may request a comprehensive premining survey of dwellings, structures, and other physical factors that may be affected by subsidence. However, these measures primarily are designed to preserve the surface owner's rights under insurance and tort law; under SMCRA the mine operator is not directly responsible for subsidence damage and gives no warrantee to the surface owner.

The requirements of SMCRA are enforced through performance bonds that are condi-

tioned on compliance with the terms of the Act. In general, liability under the bond continues for 5 years after reclamation is complete in areas with more than 26 inches of rain per year and for 10 years in areas with less than 26 inches. However, no long-term bonds are required for problems such as subsidence that may not occur until many years after mining is terminated.

As discussed in chapter VII, the success of SMCRA in correcting the abuses that have prevailed in the past will depend largely on the adequacy of enforcement under State programs. However, the history of compliance with previous State regulatory programs is not promising. A survey of 16 sites in Appalachia shows that only 9 of the sites are in complete compliance with the minimal grading requirements in effect during the period the sites were mined; 1 site is in partial compliance, while on 6 of the sites no grading at all has taken place. A similar study of 9 sites in the Eastern Interior region shows 5 had complied fully with the applicable grading requirements, while 3 sites are in partial compliance, and 1 in noncompliance. Of 13 additional sites mined before any regulations were in effect, 6 show voluntary compliance with subsequent grading requirements while 7 show no grading at all.[105]

The storage and disposal of mine wastes is regulated under SMCRA and under RCRA. In general, mine operators must maintain approved disposal sites within the mine permit area for coal processing wastes and for spoil not required to achieve the original contour. The waste disposal areas must be designed, constructed, and maintained in order to prevent combustion, adverse water quality impacts, and erosion. Mandated provisions in-

clude grading and compaction, then covering the waste with a minimum of 4 feet of the best available nontoxic material. Wastes may not be used in the construction of dams and embankments unless the mine operator demonstrates through appropriate engineering analyses that the waste will have no adverse effect on stability, and that the dam or embankment will be constructed, designed, and maintained in accordance with proper engineering principles.

RCRA seeks to prevent adverse effects on health or the environment from disposal of all types of solid wastes. The requirements of RCRA are primarily intended to prevent leaching into ground and surface waters, and are discussed in the section on impacts to water systems.

Finally, a number of Federal laws regulate transportation and transmission facilities. The construction of coal haul roads is regulated under SMCRA, which requires that erosion and siltation, air and water pollution, and damage to public or private property be minimized. In addition, roads must be removed and the land regraded and revegetated unless they are part of the approved postmining land use, in which case they must be maintained adequately. Permanent roads built with Federal funds are subject to extensive environmental protection and routing requirements under Department of Transportation regulations.

Rights-of-way for roads, transmission, and waterways across public lands must be permitted by the Federal agency having jurisdiction over the land. Federal right-of-way laws usually limit the width of the path. Dredging for waterways, or construction of any structure in the navigable waters must be permitted by the Army Corps of Engineers. Finally, most federally permitted activities that will have significant environmental effects will require an environmental impact statement under the National Environmental Policy Act.

---

[105]D Willard, et al "Land Use Changes Resulting from Strip Mining in the Ohio River Basin Energy Study Region" (Draft Report, unpublished) October 1978