Advances in

# ENVIRONMENTAL SCIENCE AND TECHNOLOGY

Edited by

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# INTRODUCTION TO THE SERIES

Advances in Environmental Science and Technology is a series of multiauthored books devoted to the study of the quality of the environment and to the technology of its conservation. Environmental sciences relate, therefore, to the chemical, physical, and biological changes in the environment through contamination or modification; to the physical nature and biological behavior of air, water, soil, food, and waste as they are affected by man's agricultural, industrial, and social activities; and to the application of science and technology to the control and improvement of environmental quality.

The deterioration of environmental quality, which began when man first assembled into villages and utilized fire, has existed as a serious problem since the industrial revolution. In the second half of the twentieth century, under the ever-increasing impacts of exponentially growing population and of industrializing society, environmental contamination of air, water, soil, and food has become a threat to the continued existence of many plant and animal communities of the ecosytem and may ultimately threaten the very survival of the human race.

It seems clear that if we are to preserve for future generations some semblance of the existing biological order and if we hope to improve on the deteriorating standards of urban public health, environmental sciences and technology must quickly come to play a dominant role in designing our social and industrial structure for tomorrow. Scientifically rigorous criteria of environmental quality must be developed and, based in part on these, realistic standards must be established, so that our technological progress can be tailored to meet such standards. Civilization will continue to require increasing amounts of fuels, transportation, industrial chemicals, fertilizers, pesticides, and countless other products, as well as to produce waste products of all descriptions. What is urgently needed is a total systems approach to modern civilization through which the pooled talents of scientists and engineers, in cooperation with social scientists and the medical profession, can be focused on the development of order and equilibrium among the presently disparate segments of the human environment. Most of the skills and tools that are needed already exist. Surely a technology that has created manifold environmental problems is also capable of solving them. It is our hope that the series in Environmental Sciences and Technology will not only serve to make this challenge more explicit to the established professional but will also help to stimulate the student toward the career opportunities in this vital area.

Finally, the chapters in this series of Advances are written by experts in their respective disciplines, who also are involved with the broad scope of environmental science. As editors, we asked the authors to give their "points of view" on key questions; we were not concerned simply with literature surveys. They have responded in a gratifying manner with thoughtful and challenging statements on critical environmental problems.

James N. Pitts, Jr.
Robert L. Metcalf

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# Air Pollution: Present and Future Threat to Man and His Environment

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Man has been subject to air pollution since his primordial ancestor lit the first fire. It was not, however, until people became crowded together in cities that pollution was more than a family problem associated with smoke from the hearth. With the coming of the use of coal for heating and the Industrial Revolution, the problem became intensified. Today, with the phenomenal growth of both the population and the use of power in the technologically advanced countries, pollution has reached such magnitude that it not only threatens the health and well-being of the population in a particular locality, but also produces effects on a global scale. It can now truly be said that man not only pollutes his own house but also has the ability to foul the atmosphere of the entire world.

The root cause of air pollution and, in fact, water pollution, land pollution, and other forms of deterioration of the environment is "more." In terms of air quality deterioration, there are three "mores" of particular significance: (*1*) more people, (*2*) more urbanization, and (*3*) more technology.

It has been predicted that by the year 2000 the United States will contain 320 million people, 85% of whom will be in cities concentrated on 10% of the total land area. As we all know, the increase of the human population has been almost incredible. On a global basis, the population doubles each 30 years. Furthermore, worldwide, people tend to concentrate in cities. Obviously the greater the concentration of people in a given area, the greater the problems created locally by the by-products of their living.

Such a concentration of people through urbanization (see Fig. 1) is also proceeding at an accelerated rate even in the less technologically advanced countries where sociological trends and agricultural practices appear to make it inevitable. In our own country the development of huge industrial-urban complexes encompassing several states is so well known that it scarcely needs mentioning. From the standpoint of air pollution, such complexes compound the situation because in these areas numerous local pollutant sources contribute to a continuum of

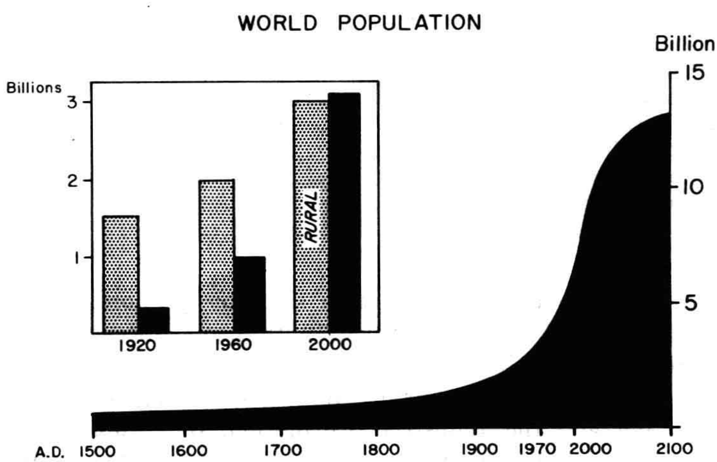


**Fig. 1. Population growth curve for world human population with concomitant trend for urbanization indicated. Courtesy of *Natural History Mag.*, American Museum of Natural History, New York, January 1970, p. 62.**

discharge of noxious material into the atmosphere. Thus pollutants accumulate despite considerable movement by wind and by diffusion into the upper air.

By and large, the major pollutants are products of combustion, including domestic fires and combustion for various technological processes, such as smelting, roasting, desalting, and ignition of fuels for the production of power. Classically, the coal-fired domestic heating unit has been very important and still contributes much to air pollution in coal-producing areas of the world. However, the change to central heating and

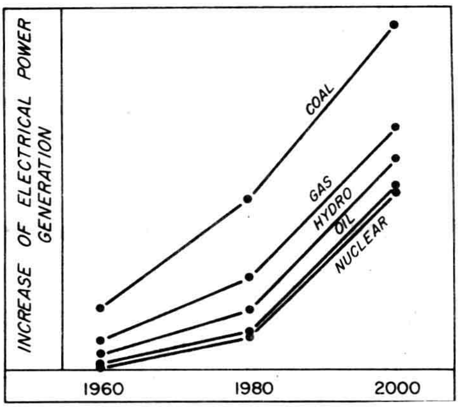


Fig. 2. The amount of electricity used in the United States is higher than in any other country, and is increasing each year. By 1980 estimations are that three times as much electricity will be used as in 1960; by the end of the century, five and six times as much. In 1960 nuclear and water energy, neither of which contributes significantly to air pollution, supplied a small fraction of our needs; nuclear energy undoubtedly will be used increasingly in the future. However, the greatest source of energy is now and will continue to be the burning of coal and oil. The combustion of these fuels is already a major contributor to the pollution of our atmosphere. From *U.S. Public Health Serv. Publ.* No. 1555.

the use of other fuels has reduced to some extent the relative importance of this contribution to air pollution. Strangely enough, the switch to electric power (Fig. 2) has not eliminated the consumption of fuel for power since, despite the large output of hydroelectric power, the majority of electricity is still generated by the combustion of fuel; coal and oil presently generate 95%. Although nuclear power will be used increasingly in the future, fossil fuel generation of power will continue to rise for several decades.

The development and application of atomic reactors for the generation of electric power offer hope that ultimately much of our power will be produced by this source, which is low in conventional air pollution emissions. Even atomic power, however is not innocent in the production of environmental pollution. Large amounts of coal are presently used in the preparation of reagents for reaction. Of much greater significance in the long run is the pollution potential of the reactors themselves in the form of radioactive wastes and of heat discharged into the water of seas, streams, and lakes. Since an enormous proliferation of such reactors would be necessary to replace fossil fuels for power production to any significant extent, the possible ecological implications of these two by-products of atomic reactors are now the subject of intense private and public debate (1). This problem must be solved before any real consensus can be reached. However, even if concern over pollution by radioactive wastes or heat does not inhibit the development of atomic reactors, it would appear that by the year 2000 considerably more power will still be generated by the conventional sources of coal and oil than today.

## THE AUTOMOBILE AS A SOURCE OF POLLUTION

The internal combustion motor has rightly been incriminated as a major source of air pollution in American cities, where the growth of the number of automobiles and the amount of automobile travel has been astronomical. It is generally agreed that automobiles proliferate

| Source | Carbon monoxide | Particulates | Hydrocarbons | Nitrogen oxides | Sulfur oxides | Total |
|---|---|---|---|---|---|---|
| Transportation | 64.5 | 1.2 | 17.6 | 7.6 | 0.4 | 91.3 |
| Fuel Combustion in Stationary Sources | 1.9 | 9.2 | 0.7 | 6.7 | 22.9 | 41.4 |
| Industrial Processes | 10.7 | 7.6 | 3.5 | 0.2 | 7.2 | 29.2 |
| Solid Waste Disposal | 7.6 | 1.0 | 1.5 | 0.5 | 0.1 | 10.7 |
| Miscellaneous | 9.7 | 2.9 | 6.0 | 0.5 | 0.6 | 19.7 |
| Total | 94.4 | 21.9 | 29.3 | 15.5 | 31.2 | 192.3 |
| Forest Fires | 7.2 | 6.7 | 2.2 | 1.2 | N | 17.3 |
| Total | 101.6 | 28.6 | 31.5 | 16.7 | 31.2 | 209.6 |

Fig. 3. There is no "worse source" of air pollution. In this country automobiles are the major contributor to carbon monoxide and hydrocarbon pollution. Stationary sources account for most of the sulfur oxides and formed particles, whereas the nitrogen oxides are evenly divided. From the Third Report of the Secretary of Health, Education, and Welfare to Congress in compliance with Public Law 90-148, Department of Health, Education, and Welfare, Air Pollution Control Office, March 1970.

approximately at the rate of twice the population growth. In the face of such burgeoning pollution sources, it seems rather hopeless to expect any real results from partially effective pollution controls. While certain cities have become notorious for auto smog, an examination of air pollution data shows that this form of pollution is probably of some importance in most American cities. From the standpoint of air pollution, the internal combustion engine can be considered a pollution machine for the production of pollutants and a pump to put them into the atmosphere. (See Fig. 3)

## II. FACTORS AFFECTING LOCAL CONCENTRATION OF POLLUTANTS

If factors affecting pollution from stacks and tail pipes are assumed to be equal, a number of meteorologic and geographic conditions alter the pollution in a local area: concentrations of emission sources, topography, wind velocity, wind direction, and the frequency of temperature inversions. The concentration of emission sources is a result of the urbanization mentioned earlier. Pollutants tend to accumulate more when wind speed is low and in bowls in the hills in the face of the prevailing wind and in valleys or other depressions (Figs. 4 and

Fig. 4. Typical smog in New York City with only the top of the Empire State Building emerging above the temperature inversion. Courtesy of Fairchild Aerial Surveys.

5). Temperature inversions (when cool air next to the earth is overlaid by warmer air) are especially important since they serve as a "lid" or ceiling (Fig. 6) that prevents the dissipation of pollutants into the upper air by means of convection currents.

Inversions occur nightly when land cools as a result of heat irradiation to the sky and air cools next to the earth. This phenomenon is more prevalent and long lasting in valleys or other depressions. Inversions may also occur, however, over large areas or plains when a warm front overrides cooler air. Such inversions may persist for a considerable time and, invariably, are associated with the extreme buildup and persistence of pollutants in the atmosphere. Another meteorological factor of great importance to air pollution is the formation of anticyclonic

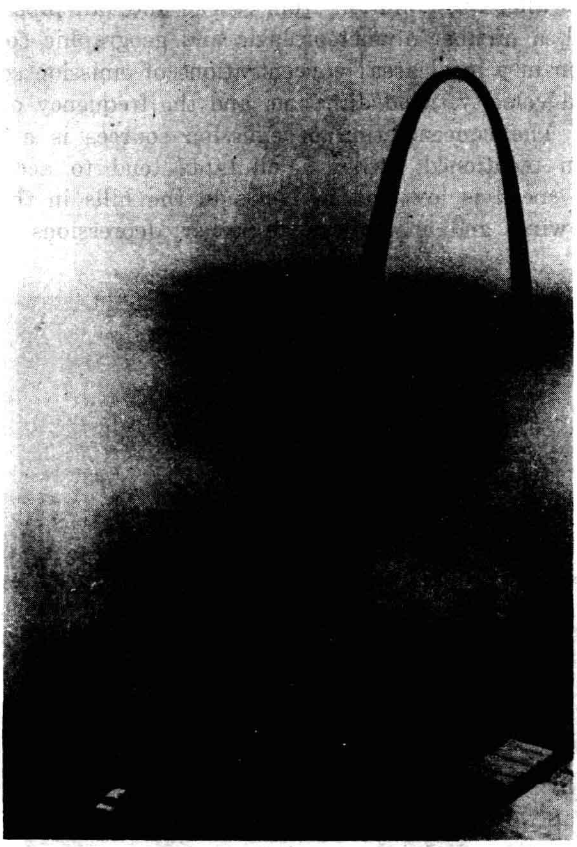

Fig. 5. Midmorning smog in St. Louis obscuring the base of the Memorial Arch. Courtesy of World-Wide Photo.

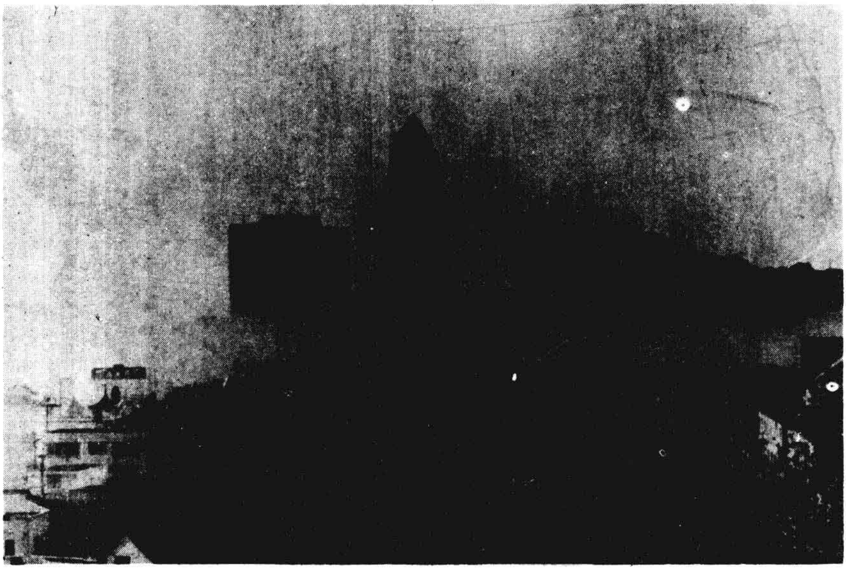

Fig. 6. Typical smoggy day in Los Angeles, showing the smog accumulating below the temperature inversion that serves as a lid above which the auto exhaust constituents do not disperse. Courtesy of Los Angeles County Air Pollution Control District.

centers associated with large areas of atmospheric stagnation and intense accumulations of air pollutants (2). Most of the so-called episodes occur during such stagnation periods. Although these factors are especially important in the production of local air pollution problems, they do not aggravate the global problem (see ecological effects in Section III).

## III. SPECIFIC POLLUTANTS

Air pollution atmospheres tend to fall into two main categories: (*1*) those derived from the combustion of fossil fuels for heat and stationary power sources, which we might term the classical form of air pollution and which are characteristic of the great urban and industrial complexes (Fig. 7) of Europe and Eastern and Central North America; and (*2*) those derived from automobile traffic which are most characteristic of Western North American cities. The latter are termed photochemical pollution or auto smog. Auto smog tends to be more concentrated and to occur more frequently in the presence of an irradiative climate such as that of the Southwestern United States. Almost no American city,

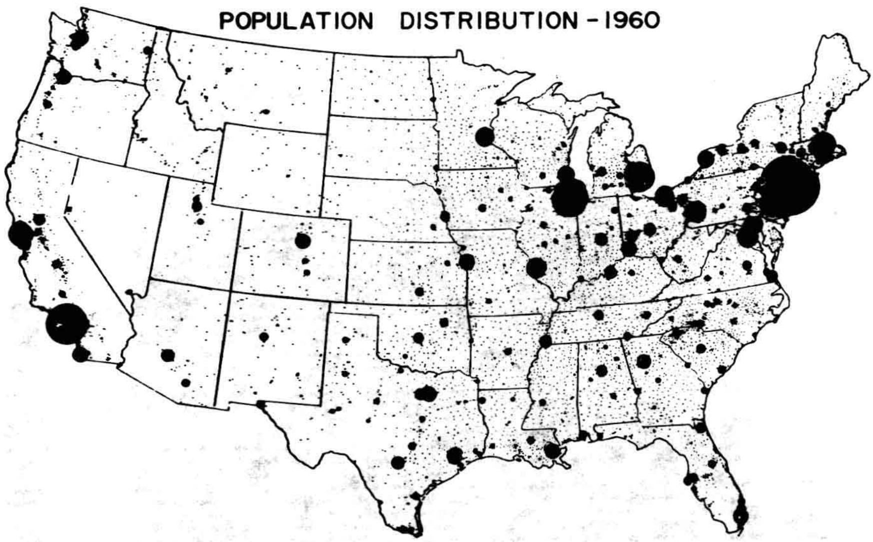


Fig. 7. In 1960 population distribution of the United States shows that major air pollution problems coincide with the urban industrial complexes. From the Department of Commerce, Bureau of the Census, *U.S. Public Health Serv. Publ.* No. 975.

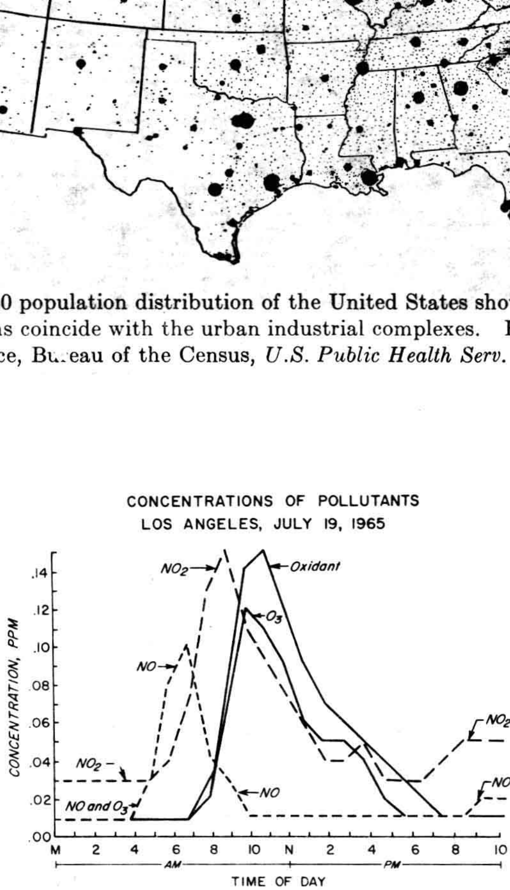


Fig. 8. Primary exhaust pollutants are usually bimodel with morning and evening peaks reflecting traffic patterns. The secondary pollutants shown here, however, peak at midday, since they result from the interaction of sunlight on emissions produced in the morning. From J. N. Pitts, "Environmental Appraisal: Oxidants, Hydrocarbons, and Oxides of Nitrogen," *J. Air Pollution Control Assoc.*, **19,** 658–667 (1969).

however, is free of days in which strong sunlight reacts with auto exhaust to produce significant photochemical smog. As is mentioned later, problems with other constituents of auto exhaust, such as carbon monoxide, lead, and particulates, are not dependent on photochemical reactions. They may occur anywhere and at any time that there is a sufficient amount of automobile traffic, since their development is not dependent on radiant energy derived from sunlight (Fig. 8). Furthermore, constituents of auto exhaust (both irradiated smog and nonirradiated exhaust) are added to the list of classical pollutants, intensifying the noxious mixture in the air of many cities.

## IV. CLASSICAL POLLUTION

Many gases and solid particles are the product of the combustion of fossil fuels (coal and oil) in stationary units for the production of heat mainly for warming space and the production of power. The proportions of the various constituents vary according to the quality of the fuel, size of the firebox, temperature of the fire, and other factors. For instance, it has been the experience of certain cities that their atmospheric sulfur dioxide and nitrogen oxide levels rose even though more efficient firing practices reduced their smoke. In addition, the presence of particles from other sources such as fog and dust appears to accentuate the effects on health of these atmospheres. The major constituents of this class of pollution generally are gases—sulfur oxides, nitrogen oxides—and particulates—sulfur trioxide, sulfates, sulfuric acid mists, hydrocarbons, and constituents of fly ash (silica, alumina, iron oxides, carbon).

## V. AUTOMOBILE EXHAUST

As emitted from the tail pipe of a car, exhaust has the following major constituents: gases—carbon monoxide, nitric oxides, unburned hydrocarbons, partial oxidation products (formaldehyde, acetaldehyde, acrolein, etc.); and particulates—including lead compounds, carbon, and various other inorganic and organic materials in particulate form. Furthermore, additional hydrocarbons and fuel additives are contributed by the evaporation of gasoline from automobile fuel tanks and carburetors. In the absence of bright sunlight no great alteration of automobile effluent occurs, which is thus mixed with whatever other pollutants are present. Therefore, oxides of nitrogen, carbon monoxide, and lead oxide particles are thrown into atmospheres already polluted by sulfur oxides,

oxides of nitrogen, hydrocarbons, and other particulates derived from smokestacks.

In the presence of bright sunlight, however, a complex chemical interaction occurs between various constituents in the exhaust and the oxygen of the air. This results in photochemical smog, which produces intense eye irritation in human beings and damage to plants and forms haze, oxidant, and a characteristic odor. The haze is light, slightly brownish, and foglike. This is not to be confused with heavy smog, such as that occurring typically in Eastern American and European cities, caused by a physical and chemical interaction between smoke, sulfur oxides, and fog. A number of highly irritating compounds are formed as secondary pollutants in photochemical auto smog. Among these compounds are ozone, peroxyacetyl nitrates, formaldehyde, and acrolein, which develop in a chain reaction involving the constituents of auto exhaust and oxygen as reactants and sunlight as the energy source. Hydrocarbons are essential in this reaction, serving as multipliers of photoenergy. In the process, nitrogen dioxide absorbs ultraviolet light from the sun and is broken down to nitric oxide and atomic oxygen. The atomic oxygen unites with molecular oxygen to form ozone, which then reacts with nitric oxide to form nitrogen dioxide and molecular oxygen. Atomic oxygen also is thought to react with hydrocarbons to form special complexes called free radicals which undergo complex interactions that give rise to secondary pollutants. The whole process is a complex phenomenon still not completely understood. An important component of this atmosphere is termed oxidant, which is actually a chemical activity rather than a chemical entity. Its presence in smog is usually measured by its propensity for oxidizing potassium iodide. The bulk of this oxidizing property during peak daylight hours can be identified as ozone. Several thousand tons of ozone are formed on a smoggy day in Los Angeles, and as much as 500 tons are present over the city at any given moment (3). Because of the importance of ozone in photochemical smog and its extreme toxicity for plants and animals, it has been the subject of intensive research.

## VI. SPECIAL POLLUTANTS

Effluents from various classes of industries contain specific pollutants which may be peculiar to the industry or the particular process of manufacture. Raw acids may be emitted by chemical plants, aliphatic compounds are derived from soap factories, iron oxide from steel mills, and so on. Although these contribute to the overall pollution problem, they usually are more important locally. An effluent of great veterinary interest is, of course, fluoride in dust and gases from rock crushing, fertilizer manufacture, and smelting processes (see Section XV).

## VII. SPECIFIC EFFECTS OF AIR POLLUTANTS ON MAN AND HIS ENVIRONMENT

Pollution of the air affects man by aesthetically degrading his environment, interfering with his visibility, soiling and corroding his property, blighting his crops, affecting his animals, and, finally, interfering with his health and well-being. Aesthetic degradation of the environment is conspicuous in many of our communities. Foul odors from specific sources bring remarks of distaste generally whenever they are experienced. Often the odor of various sulfur compounds may pervade large communities where fossil fuels are consumed in large amounts in stationary sources. What traveler in a forested area is not shocked by the stench emanating from a paper mill or by the pall of smoke from a waste burner at a sawmill in areas of otherwise great air purity and scenic beauty?

The significant reduction of visibility by the various kinds of air pollution has become aesthetically objectionable in many communities on many days of the year. Often the populace of a community have become so inured to air pollution, industrial haze, and smog that they are scarcely aware of it until they have had an opportunity to view it in perspective from a distant high point or from an airplane. Citizens of communities in a mountainous environment seem more aware of decreased visibility since it ruins their view. Reduction of visibility has more than an aesthetic effect, however, since days of smogged-in airports and hazardous freeway driving are markedly increased by air pollution's contribution to reduced visibility. The haze, smoke, and smog from community air pollution are highly visible from the air where one can observe the haze over a city or industrial area sharply contrasting with the comparative clarity of the air of the surrounding countryside. It is also believed that air pollution haze may have regional and even global implications (see Section XVII).

The corrosive effects of acid products of pollution on metals and their destructive action on paint have long been recognized, since pollution by sulfur oxides is an old phenomenon present wherever fossil fuels are burned. Furthermore, the oxidants derived from auto smog and other sources are responsible for the cracking of rubber in tires and the deterioration of insulation on electric wires. Sulfur oxides cause weakening of natural and synthetic fiber in clothing. It has been estimated that the cost of air pollution damage to materials and the various attempts to prevent it, may amount from $2 to 12 billion yearly in the United States alone (4).

## VIII. AIR POLLUTION DAMAGE TO PLANTS

The deleterious effects of various air pollutants on plants are extremely well documented. Whole communities have in the past been completely devastated by fumes emanating from smelters (Fig. 9), for example.

Plants are generally more susceptible to damage from air pollutants than are mammals, since they have no effective means of protecting their respiratory surface from the ingress of pollutants and no adequate excretory apparatus for eliminating absorbed materials from their tissues. Sulfur oxides, oxidants, ozone, fluoride, peroxyacetyl nitrates, and many other pollutants in very low concentrations produce specific recognizable lesions on plants. Economic loss occurs to field crops, ornamental plants, and forest trees (Fig. 10). Citrus fruits, leafy row

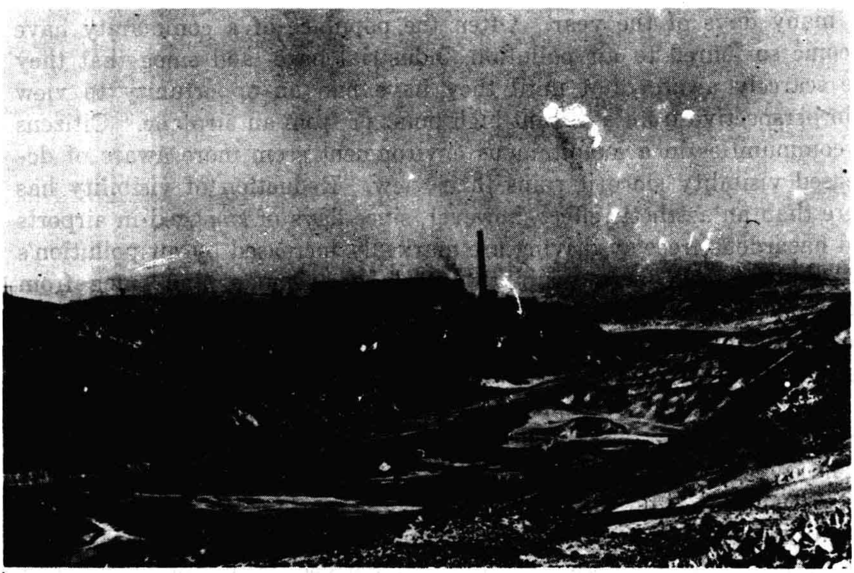

Fig. 9. Devastation of a once-forested countryside by sulfur dioxide from a smelter, Copper Hill, Tenn. While such ravages from localized emissions have occurred in many places, more subtle damage results from auto smog that may selectively kill certain species over widespread areas, often by increasing their susceptibility to intercurrent natural disease. Courtesy of U.S. Forest Service.