ADVANCES IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY

VOLUME SEVEN

Edited by James N. Pitts, Jr.
and Robert L. Metcalf

Alan C. Lloyd, Associate Editor

Advances in ENVIRONMENTAL SCIENCE AND TECHNOLOGY

Edited by

JAMES N. PITTS, JR.
University of California
Riverside, California

and

ROBERT L. METCALF
University of Illinois
Urbana, Illinois

Associate Editor

ALAN C. LLOYD
University of California
Riverside, California

Volume 7

A Wiley-Interscience Publication

JOHN WILEY & SONS

New York/London/Sydney/Toronto

ERNEST S. STARKMAN

This volume is dedicated to the memory of Ernest S. Starkman, who, with his colleague Fred W. Bowditch, made a significant contribution to this book—a contribution that reflects his wisdom and experience in engineering research and its applications to the control of air pollution. Ernie, as his former students, friends, and colleagues knew him, had a distinguished career as Professor of Mechanical Engineering at the University of California, Berkeley, and then went on to become Vice President of General Motors Corporation Environmental Activities staff, a position he held at the time of his sudden death on January 13, 1976. He had a rare combination of talents and will be remembered by all of us as a gentleman and a scholar who dealt equally well with challenges in the "ivory tower of academe" and those in the "real world."

Acknowledgment

The editors are deeply indebted to Mrs. Dolores V. Tanno for her painstaking effort in final typing this volume of the Series.

Library of Congress Catalog Card Number 74-644364

ISBN: 0-471-01365-X

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

Contributors

Gerald G. Akland
Environmental Sciences Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina

Delbert S. Barth
U. S. Environmental Protection Agency
Environmental Monitoring and Support Laboratory
Las Vegas, Nevada

Fred W. Bowditch
Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan

George E. Brown, Jr.
Member of Congress
U. S. House of Representatives
Washington, D. C.

Paul B. Downing
Department of Economics
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Barbara J. Finlayson-Pitts
Department of Chemistry
California State University
Fullerton, California

John F. Finklea
National Institute of Occupational Safety and Health
5600 Fishers Lane
Rockville, Maryland

Ralph I. Larsen
Environmental Sciences Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina

John B. Moran
Environmental Sciences Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina

George B. Morgan
Environmental Monitoring and Support Laboratory
U. S. Environmental Protection Agency
Las Vegas, Nevada

Leik N. Myrabo
Department of Chemistry and Energy Center
University of California, San Diego
La Jolla, California

William C. Nelson
Environmental Sciences Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina

James N. Pitts, Jr.
Statewide Air Pollution Research Center and
Department of Chemistry
University of California
Riverside, California

Edward A. Schuck
Environmental Monitoring and Support Laboratory
U. S. Environmental Protection Agency
Las Vegas, Nevada

Carl M. Shy
Institute for Environmental Studies
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina

Chester W. Spicer
Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio

Jeremy L. Sprung
Sandia Laboratories
Albuquerque, New Mexico

Ernest S. Starkman (deceased)
Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan

Eric O. Stork
Office of Air and Waste Management
U. S. Environmental Protection Agency
Washington, D. C.

John C. Trijonis
Technology Service Corporation
Santa Monica, California

William D. Watson, Jr.
Resources for the Future
Washington, D. C.

Kent R. Wilson
Department of Chemistry and Energy Center
University of California, San Diego
La Jolla, California

ROBERT L. METCALF, Editor
Environmental Studies Institute
Departments of Biology and Entomology
University of Illinois
Urbana-Champaign, IL 61801
Telephone: (217) 333-3649

DANIEL GROSJEAN, Associate Editor
Statewide Air Pollution Research Center
University of California
Riverside, CA 92502
Telephone: (714) 787-3629

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 ecosystem 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 fuel, 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 Science 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.

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.

From time to time volumes of the Advances series will emphasize particular fields in the environmental sciences. In this edition we have focused upon air pollution—with chapters by experts covering the entire range from federal policy through areas of emission standards and controls, atmospheric reactions and monitoring to health effects and statistical models, concluding with economic considerations in enforcing environmental controls. Indeed, this volume might serve, at least in part, as a text for courses involving the various elements of the air pollution system.

This is the last volume for which Dr. Alan C. Lloyd serves as Associate Editor. We wish to acknowledge with thanks his many and valuable contributions to the series for a number of years.

We should also like to introduce the new Associate Editor, Dr. Daniel Grosjean. Dr. Grosjean is an expert in atmospheric chemistry with special emphasis on the gas-to-particle conversion processes occurring in the polluted troposphere. After completing his Ph.D. at the University of Paris, France, Dr. Grosjean worked with Professor Sheldon Friedlander's group at the California Institute of Technology as a Research Fellow in Environmental Health Engineering and Environmental Engineering Sciences. He joined the University of California Statewide Air Pollution Research Center as Assistant Research Chemist in 1975. Dr. Grosjean is currently serving on the National Academy of Sciences-National Research Council MBEEP Panels on Ammonia and on Ozone and Other Photochemical Oxidants.

JAMES N. PITTS, JR., Editor
Statewide Air Pollution Research Center
and Department of Chemistry
University of California
Riverside, CA 92502
Telephone: (714) 787-4584

Contents

Beyond Technology: New Perspectives on Pollution Control

GEORGE E. BROWN, JR.
Congressman

I. INTRODUCTION

Modern industrial societies have serious and fundamental flaws. This chapter's premise is that pollution control efforts have failed to recognize these weaknesses. Efforts to control pollution have been directed at symptoms of the larger problems, and although they have frequently been successful in alleviating the immediate symptoms, they will eventually fail unless the larger problems are simultaneously addressed.

Pollution is an inextricable part of our population growth and of our energy and material use; it flows from our land use patterns; it is encouraged by the dynamics of our economic system and by our traditional social, philosophical, and even religious values.

Modern society's trend toward reductionism and specialization has caused us to become shortsighted and unaware of this phenomenon. The environmental movement, however, has finally brought the question to the surface, and the study of environmental sciences and ecology is an admission that we need a more integrated and holistic view. I am skeptical, however, that a multidisciplinary scientific approach will be sufficient in solving the basic problems. The difficulties of modern, industiral societies cannot be solved merely by science and technology. Those who believe otherwise are practicing an act of faith. This faith in science and technology defines products of that technology almost uniformly as "progress," and identifies all such progress as "good." This is a philosophical, or metaphysical, judgment that I do not share.

II. DEFINITIONS

The definition of some commonly used environmental terms often vary among disciplines, although they may be readily understood within a particular one. The following definitions should clarify my interpretation of these terms.

A. Technology

Technology has a narrow definition that is implied by the term "pollution control technology." In this context it is generally considered to be the application of science, by the use of hardware, to control a pollution source. There is also a broader definition used by policymakers involved with technology assessments. Harvey Brooks, a leader in the technology assessment movement, defines technology as "a specifiable and reproducible way of doing things. It is not hardware but knowledge, including the knowledge not only of how to fabricate hardware to predetermined specifications and functions, but also how to design administrative processes and organizations to carry out specified functions, and to influence human behavior toward specified ends" (1). Within this broader context every law and policy that has a specified end is applied technology. This chapter examines the need to go beyond the reliance on "hardware" technology to an attempt to control pollution. To go beyond "hardware" technology requires the use of the "software" technology implied by Brooks, and further leads into analysis of the most basic value system used to choose among pathways for social development.

B. Environmental Science

The editors of this series gave a comprehensive definition of "environmental science" in the first volume of the Advances Series. They stated that

> Environmental Science therefore relates to (a) the chemical, physical, and biological changes in the environment through contamination or modification; (b) the chemical nature and biological behavior of air, water, soil, food, and waste as they are affected by man's agricultural, industrial, and social activities; and (c) the application of the natural sciences and technology as well as social sciences, including political science and administration, to the control and improvement of environmental quality (2).

This is an adequate definition, although it does not specify any particular mix of backgrounds for the working environmental scientist. A positive statement about the necessary mix was made by the National Science Board.

> As environmental science advances, there will be an increasing need for 'natural resource administrators' to serve in local, state, or federal governments. The education of these public administrators involves two types of interdisciplinary training. On the one hand, scientists and engineers must gain a better understanding of the social, economic, legal, and political environment within which practical action must be sought. On the other hand, students of public administration must gain a better perception of the scientific process and a better understanding of how scientists can contribute effectively to the practical solution of environmental problems (3).

This discussion of the evolution of environmental science puts my contribution to the field in the proper perspective.

C. Pollution Control

It should now be obvious that I consider any means to reduce pollution, be it through the application of hardware, software, or philosophical value judgments, to be a valid approach to control pollution. Pollution is mainly those by-products of technology that are harmful to the well-being of that society, and, therefore, necessary for society to control. Pollution is therefore an unwanted negative product. The determination of what is a "pollutant" can be done by measurements of physical harm to some object or living organism, or it can be done in an arbitrary manner. However precise the definition of what a particular pollutant may be, there is still a considerable amount of value judgment to be made in arriving at a legal definition.

There are various types of pollution that must be controlled. One author broke pollutants into four categories:

> (1) Direct assaults on human health (for example, lead poisoning or aggravation of lung disease by air pollution). (2) Damage to goods and services that society provides for itself (e.g., the corrosive effects of air pollution on buildings and crops). (3) Other direct effects on what people perceive as their 'quality of life' (e.g., congestion and litter). (4) Indirect effects on society through interference with services that are provided for society by natural ecosystems such as ocean fish production and control of erosion by vegetation. Examples of such indirect efforts are destruction of vegetation by overgrazing and logging, and poisoning of coastal waters with oil and heavy metals (4).

This chapter will concentrate specifically on the first, second, and fourth types of pollutants, or those which cause the greatest harm to living systems. There is concern, however, for the third type as an underlying theme and as a focus for a new kind of growth goal for society.

III. LEGISLATION TO CONTROL POLLUTION

Pollution has been primarily attacked by society through the passage of legislation against particular pollutants. The specifics of the legislation have varied with each type of pollutant, but in each case a sequence of events has evolved that has continually imposed stricter controls. Every level of government has been involved. This chapter deals primarily with federal legislation, with air pollution as the main case in point, but the generalizations derived from this analysis do have broader applications.

A. Historical Trends

A huge literature has been written about various types of pollution. The main conclusion that can be derived from these writings is that pollution is a matter of serious concern. Some forms of pollution are still on the increase, whereas others are on the decline. But there is a growing general concern about the long-term adverse effects of existing levels of pollution on humans and the ecosystem.

The reasons for this interest are fairly obvious. We are generating new, more toxic forms of pollution; we are learning more about the health effects of particular pollutants; and we are learning that we cannot easily control a pollutant, even when we make a serious attempt to do so. The complexity of interactions between pollutants, and between pollutants and the natural ecosystem, have made it obvious that simple, local views of pollution problems and remedies will not suffice. Overwhelming all these factors is the simple increase in scale of our perturbations on the environment. The best defense against pollutants has always been dilution, but man's activities have grown so large that he has overwhelmed the planet's capacity to absorb his waste. Even relatively innocuous by-products of technology like phosphorus become dangerous to the life system of the earth in sufficient quantity. The amount of phosphorus reaching the sea from the rivers, more than 12 billion pounds per year, is over 30 times what would be the natural runoff in the absence of man's detergent and fertilizer production. Input of lead, a much more intrinsically toxic material, similarly overwhelms natural sources at an annual rate of 2-1/2 billion pounds or 13 times the natural leaching rate.

In the past, legislative approaches to pollution control have been fought by special interest groups. This is understandable in part because pollution control laws are almost always retroactive. The problems are usually not recognized, and regulatory legislation is not written, until after industry has made very large capital investments in the offending technology. The costs of "retrofitting" to meet the new awareness of pollution problems can seem extremely unfair to a producer, especially if neither the government nor the public is willing to share the costs of an orderly economic transition. The almost inevitable resulting conflict between industry and environmental standards must then be confronted by those who wish to control pollution.

In the past, citing the economic consequences of pollution controls has often enabled interest groups adversely affected to prevent stringent regulation. In recent years, perhaps because of the mass media's impact on educating people to the dangers of pollution, and certainly because the old laws were often shown to be ineffective, new legislation directly confronting the economics of entrenched industries has been passed. In many cases these laws are yet to be fully implemented, however, and the effectiveness of recent legislation is still in doubt.

Air pollution is an interesting case in point. Although air pollution has been a matter of scientific and social concern for several hundred years and laws regulating the location and type of fuel burners have been in effect for decades, serious, systematic air pollution control technologies have been applied only very recently. The early air pollution control laws were not based on any rigorous scientific criteria of emission limitations or ambient air quality standards. Nor were they applied equally throughout the industry or the country. The most stringent controls were, naturally enough, required in the areas that had the most active citizen interest, such as Los Angeles County. In most cases these areas also had the most severe cases of air pollution. Public involvement spread, the areas of control spread, and the basis for those controls became more firmly established in science, law, and administrative practice. Every step of this process was a long and difficult struggle.

An often unspoken underlying difference of viewpoint in this struggle has been the question of who was responsible for the burden of proof in establishing pollution control standards. Those with an economic stake in on-going practices naturally assume that new regulations should apply only when levels of pollutants are unequivocably demonstrated to have serious harmful effects. Those focusing on the health of the ecosystem, however, believe laws should be based on the premise that no man-made contaminants should be permitted unless positively proven to be truly harmless.

Much of the legislation in this field has been written with the relatively narrow view that our technological, market-oriented society would, given the proper stimulus, develop the technology to control pollution without any major change in values. The specific legislative approaches to accomplish this end have varied. The federal law has undergone several major revisions, beginning with the Clean Air Act of 1963 (P.L. 88-206), which mandated a federal but nonspecific role in this field. This law was amended in succeeding Congresses by the "Motor Vehicle Air Pollution Control Act" (P.L. 89-272; Oct. 20, 1965), the "Clean Air Act Amendments of 1966" (P.L. 89-675; Oct. 15, 1966), the "Air Quality Act of 1967" (P.L. 90-148; Nov. 21, 1967), and finally, the primary law in the field of air pollution control, the "Clean Air Act Amendments of 1970" (P. L. 91-604; Dec. 31, 1970). There have been several amendments since the passage of this act, but they do not mark a significant departure from the Clean Air Act (42 U.S.C. 1857 et seq.), as amended in 1970.*

The changes in the Clean Air Act paralleled overall changes in public attitudes. People began to recognize that air pollution was not merely a local problem. This was not only because air pollution crossed state lines, but because the products of our industrialized society were part of a national economy, and pollution was, therefore, a national product. In addition to this acknowledgment, it was recognized that if nationwide standards were not effective, polluting industries in unregulated areas would be at an economic advantage over industries that had to curtail pollution. Thus a major industry could refuce to control pollution on economic grounds, and even threaten to move to a more hospitable location if the local authorities did not stop enforcing strict controls. Nationwide emission standards were designed to eliminate this economic blackmail as much as they were designed to control air pollution.

Another key development in the 1970 amendments was the resolution of the argument over whether controls should be based on health standards or on economic and technological feasibility. The legislative history is instructive here. The report that accompanied the bill, when it was sent to the United States Senate floor, stated:

> In the Committee discussions, considerable concern was expressed regarding the use of the concept of technical feasibility as the basis of ambient air standards. The Committee determined that (1) the health of people is more important than the question of whether the early achievement of ambient air quality standards protective of health is technically feasible; and (2) the growth of pollution load in many areas, even with applications of available technology, would still be deleterious to public health. Therefore, the Committee determined that existing sources of pollutants either should meet the standard of the law or be closed down, and in addition that new sources should be controlled to the maximum extent possible to prevent atmospheric emissions (5).

This statement of legislative intent provides no room for ambiguity.

---

*A footnote on the date this was written (before the 1976 amendments) may be necessary—if these pass in 1976.

We are now at the stage in air pollution control in the United States where the laws are strict enough to accomplish the goal, but because the enforcement of these laws may force drastic changes, and conflict with other social values, enforcement agencies are resisting this effort.

B. Limitations

Despite that brave language of the Clean Air Act, we have not eliminated air pollution, nor have we even reduced air pollution to the level required to protect the public health. The deadline for attaining the ambient air quality standards is 1977; but few, if any, regions of the country appear likely to meet them for all pollutants. In fact the trend may be reversed, and we may have a distinct deterioration in air quality. The U.S. Environmental Protection Agency points out that the greatest reduction in air pollution emissions has come not through the application of a control technology, but through the shift from coal and high-sulfur fuel oil to natural gas and low-sulfur fuel oil. The supplies of the latter two are diminishing and the shift is now back to the original fuels. In addition, the background levels of ozone and sulfates, and the incidence of "acid rain" have all increased, which indicates that even with stricter controls being continually applied, pollution may not be uniformly reduced.

Many limitations of the existing law may appear obvious to the environmentally sympathetic reader, but efforts are nonetheless being mounted to further weaken regulations.

The easiest form of attack on the implementation of the Clean Air Act is to criticize the ambient air quality standards as being "too stringent." This approach does not attack the existence of goals, but instead attempts to "correct" those goals. This attack is usually based on the first of the underlying assumptions mentioned earlier, that the burden of scientific proof in enforcing environmental law, especially in the face of economic dislocation, is to show that a given level of a pollutant is definitely harmful to health or property. Because much of society agrees that the burden does rest with those who want to regulate pollution, as opposed to those who wish to pollute, this has been a relatively effective line of criticism. The resulting controversy has caused the Senate Public Works Committee, which authored the original Act, to commission a National Academy of Sciences study on the federal ambient air quality standards. Despite the implicit acceptance of the heavy burden of proof, the Executive Summary of that report stated