ATMOSPHERIC POLLUTION

Atmospheric Pollution: History, Science, and Regulation provides a comprehensive introduction to the history and science of major air pollution issues. It begins with an introduction to the basic atmospheric chemistry and the history of discovery of chemicals in the atmosphere, then moves on to a discussion of the evolution of the earth's atmosphere and the structure and composition of the present-day atmosphere. Subsequently, a comprehensive and accessible discussion of the five major atmospheric pollution topics – urban outdoor air pollution, indoor air pollution, acid deposition, stratospheric ozone reduction, and global climate change – is provided. Each chapter discusses the history and science behind these problems, their consequences, and the effort made through government intervention and regulation to mitigate them. The book contains numerous student examples and problems, more than 200 color illustrations, and is international in scope.

Atmospheric Pollution: History, Science, and Regulation forms an ideal introductory textbook on atmospheric pollution for undergraduate and graduate students taking courses in atmospheric chemistry and physics, meteorology, environmental science, earth science, civil and environmental engineering, chemistry, environmental law and politics, and city planning and regulation. It also forms a valuable reference text for researchers and an introduction to the subject for general audiences.

Mark Z. Jacobson is an Associate Professor of Civil and Environmental Engineering at Stanford University. He has published over 40 peer-reviewed papers and another textbook, *Fundamentals of Atmospheric Modeling* (1998, Cambridge University Press), that has been rated by students in the top 5% of textbooks in the School of Engineering at Stanford for nine consecutive quarters. Professor Jacobson is a recipient of the National Science Foundation Career Award, the Powell Foundation Award, a Frederick Terman Fellowship, and a NASA New Investigator Award. In addition to these awards and scholarships, in 1985, 1986, and 1987, he received an NCAA–ITCA scholar–athlete of the year award at Stanford University.

To Yvonne and William

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HISTORY, SCIENCE, AND REGULATION

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PREFACE

Natural air pollution problems on the Earth are as old as the Earth itself. Volcanoes, fumaroles, natural fires, and desert dust have all contributed to natural air pollution. Humans first emitted air pollutants when they burned wood and cleared land (increasing windblown dust). More recently, the burning of coal; chemicals; oil, gasoline, kerosene, diesel, jet and alcohol fuels; natural gas; and waste and the release of chemicals have contributed to several major air pollution problems on a range of spatial scales. These problems include outdoor urban smog, indoor air pollution, acid deposition, Antarctic ozone depletion, global ozone reduction, and global warming.

Urban smog is characterized by the outdoor buildup of gases and particles emitted from vehicles, smokestacks, and other human sources, or formed chemically in the air from emitted precursors. Smog affects human and animal health, structures, and vegetation. Urban smog occurs over scales of tens to hundreds of kilometers.

Indoor air pollution results from the emission of pollutant gases and particles in enclosed buildings and the transport of pollutants from outdoors into buildings. Indoor air pollutants cause a variety of human health effects. Indoor air pollution occurs over scales of meters to tens of meters.

Acid deposition occurs when sulfuric acid, nitric acid, or hydrochloric acid in the air deposits to the ground as a gas or dissolved in rainwater, fogwater, or particles. Acids harm soils, lakes, forests, and structures. In high concentrations, they can harm humans. Acid deposition occurs over scales of meters to thousands of kilometers.

Antarctic ozone depletion and **global ozone reduction** are caused, to a large extent, by human-produced chlorine and bromine compounds that are emitted into the air and break down only after they have traveled to the upper atmosphere. Ozone reduction increases the intensity of ultraviolet (UV) radiation from the sun reaching the ground. Intense UV radiation destroys microorganisms on the surface of the Earth and causes skin cancer in humans and animals. Antarctic ozone depletion occurs over a region the size of North America. Global ozone reduction occurs globally.

Global warming is the increase in global temperatures, rainfall patterns, and sea level due to human emission of carbon dioxide, methane, nitrous oxide, other gases,

and particulate black carbon. Global warming is a global problem with regional impact.

Air is not owned privately; instead, it is common property (accessible to all individuals). As a result, air has historically been polluted without limit. This is the classic **tragedy of the commons**. The only known mechanism of limiting air pollution, aside from volunteerism, is government intervention. Intervention can take the form of setting up economic markets for the rights to emit pollution, limiting emissions from specific sources, requiring certain emission control technologies, or setting limits on pollutant concentrations and allowing the use of any emission reduction method to meet those limits.

Because government action usually requires consensus that a problem exists, the problem is severe enough to warrant action, and action taken will not have its own set of adverse consequences (usually economic), national governments did not act aggressively to control global air pollution problems until the 1970s and 1980s. For the most part, action was not taken earlier because lawmakers were not always convinced of the severity of air pollution problems. Even when problems were recognized, action was often delayed because industries used their political strength to oppose government intervention. Even today, government intervention is opposed by many industries and politicians out of often-misplaced concern that intervention will cause adverse economic consequences. In many developing countries, intervention is sometimes opposed because of the concern that developed countries are trying to inhibit economic expansion of the less-developed countries. In other cases, pollution is not regulated strictly due to the perceived cost of emission-control technologies and enforcement.

Despite the opposition to government intervention and although work still needs to be done, government intervention has proved effective in mitigating several of the major air pollution problems facing humanity. The problems mitigated but not eliminated include urban air pollution (in some countries), acid deposition (in some countries), and stratospheric ozone reduction. The problem of global climate change has not been controlled to date, and only recently has it been addressed on a global scale.

The purpose of this book is to discuss the history and science of major air pollution problems, the consequences of these problems, and efforts to control these problems through government intervention. Such a study involves the synthesis of chemistry, meteorology, radiative processes, particle processes, cloud physics, soil sciences, microbiology, epidemiology, economics, and law. The field of air pollution is a true interdisciplinary field.

This book is directed at students in the environmental, Earth, and atmospheric sciences. It was designed to be detailed enough to be used as a reference text as well. Chemical symbols and chemical equations are used, but all chemistry required is introduced in Chapter 1 – no previous knowledge of chemistry is needed. The text also describes a handful of physical laws; however, no calculus, geometry, or high math is needed.

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