ENVIRONMENTAL POLLUTION:

A LONG-TERM PERSPECTIVE

James Gustave Speth

WORLD RESOURCES INSTITUTE

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Environmental Pollution

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Today, pollution is occurring on a vast and unprecedented scale around the globe. Trends point in two ominous directions: first, toward large and growing releases of certain chemicals—principally from burning fossil fuels—that are now significantly altering the natural systems on a global scale; and second, toward steady increases in the use and release to the environment of innumerable biocidal products and toxic substances. These shifts from the "sewage and soot" concerns of the pre-World War II periods to vastly more serious concerns pose formidable challenges for societies, both industrial and developing—challenges that modern pollution control laws address only partially. To address the serious pollution challenges of decades ahead, several large-scale social and technological transitions are needed. Today's pollution is integrally related to economic production, modern technology, life-styles, the sizes of human and animal populations, and a host of other factors. It is unlikely to yield except to broad macrotransitions that have multiple social benefits. These transitions include shifting away from fossil fuels and waste-intensive technologies, bringing our most sophisticated science to bear, altering prices and other economic incentives, perceiving pollution as transboundary and global, and progressing to a stable world population.

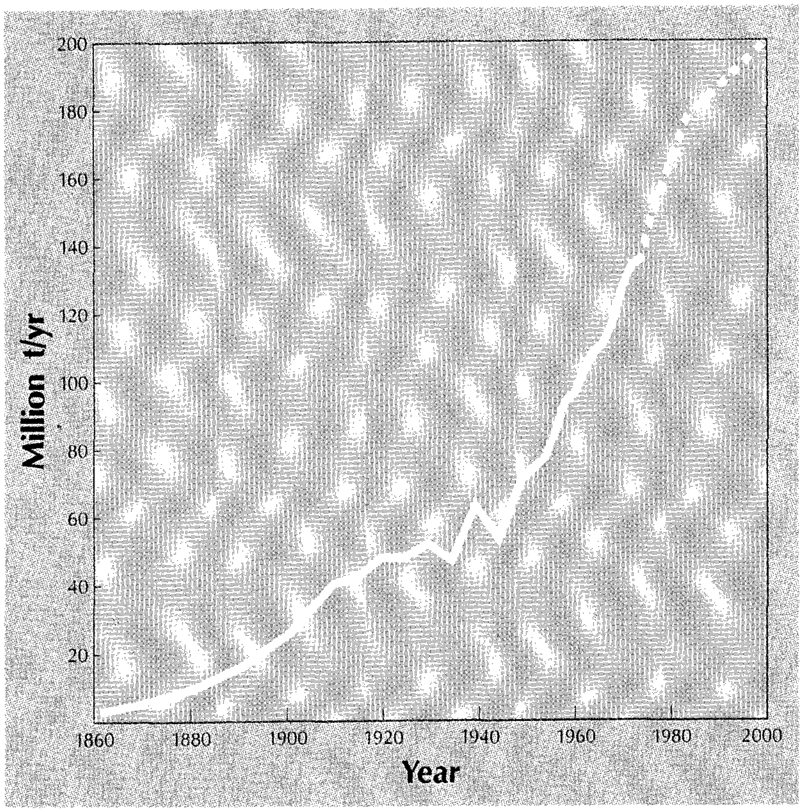
Pollution has been around as long as humans have organized societies and carried out economic activity, though it has varied enormously in time, type, and seriousness. In an amusing scene in a recent popular movie, Captain Kirk awakes from an early attempt at time-travel and, gazing out, sees that his starship is, as hoped, orbiting Earth. "Earth," he says, "but when?" To which Mr. Spock, checking his instrument panel, replies, "Judging from the pollution content of the atmosphere, I believe we have arrived at the latter half of the 20th century." And indeed they had. In fact, if good records were available, it should be possible to use Earth's pollutant mix and atmospheric condition to gauge the date with far greater accuracy than did Mr. Spock.

By definition, pollution is harmful—too much of something in the wrong place. In appropriate quantities, some erstwhile pollutants are beneficial. Phosphates and other plant nutrients are essential to aquatic life; too much of these nutrients, however, and eutrophication results. Carbon dioxide in the atmosphere helps keep Earth warm enough to be habitable, but the buildup of vast quantities of excess carbon dioxide from fossil fuel use and other sources now threatens to alter the planet's climate. Other pollutants, like dioxin and P.C.B.s, are so toxic that even the most minute amounts pose health hazards, such as cancer and reproductive impairment.

Releases of pollutants to the environment are most often the casual by-product of some useful activity, such as generating electricity or raising cows. Pollution of this type is a form of waste disposal. It occurs when the economic costs of eliminating the pollution exceed the economic benefits, at least the benefits to the polluter—a calculation historically skewed in favor of pollution since the atmosphere and waterways have been treated as free disposal sites. But releases of pollutants can also be purposeful, as with pesticides, where biocidal substances are released into the environment to reap economic rewards, or accidental, as in oil spills, where the polluters themselves suffer loss.

Pollution is traditionally categorized in several ways—by receiving media, sources, types of pollutants, and effects. Perhaps the most customary pollution categories are those that focus on the receiving media: air (emissions), water (effluents), and land (dumps and disposals). A slightly more sophisticated breakdown would distinguish between inland and marine waters, surface and groundwater, troposphere and stratosphere, and perhaps we should now add outer space as well, given the satellite and other debris accumulating out there. Most discussion and regulation of pollution is built around these categories, but concern is shifting increasingly to inter-media effects, such as the acidification of lakes and streams caused by air pollution or the disposal on land or in the ocean of sludges and other residuals from air- and water-pollution control measures.

While public attention most often focuses on industry, virtually all sectors of modern life are producers of pollution: households, agriculture and forestry, and government, as well as industry and commerce. Our affluent households generate huge volumes of garbage and other solid waste, liquid sewage, and exhausts from our cars and trucks. In recent years, pollution from agriculture has attracted increased attention. By some measures, agriculture is now the largest source of pollutant loadings to U. S. streams and lakes. Soil particles, fertilizers, pesticides, animal wastes, salts, and other substances that wash into U. S. streams from agriculture cost Americans billions of dollars annually (Conservation Foundation 1987).

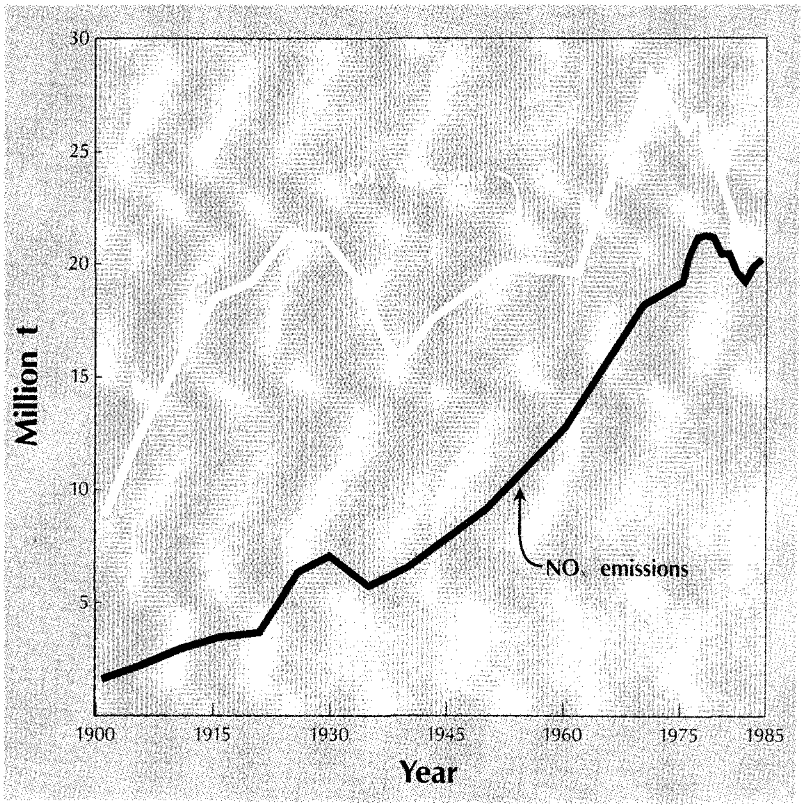


GLOBAL SULFUR DIOXIDE EMISSIONS

Figure 1. **In 1975, 92 per cent of sulfur emissions were from fossil fuel combustion, 51 per cent from coal alone. [source: Moller, D. 1984. Estimation of the global man-made sulfur emission. *Atmospheric Environment* 18(1):19–27]**

While responsibility for pollution is widespread, two human activities deserve special note: our reliance on fossil fuels, the combustion of which gives rise to carbon monoxide and carbon dioxide, oxides of nitrogen and sulfur (Figure 1), heavy metals, and particulates; and our reliance on the chemical and metals industries, which are linked directly and indirectly to pollution from pesticides, synthetic organic chemicals, fertilizers, heavy metals, and the generation of hazardous wastes.

Most pollutants are of concern because of their chemical activity, whether it be toxic effects on living organisms or damage to buildings and corrosion of



EMISSIONS OF SULFUR AND NITROGEN OXIDES, U. S.

Figure 2. **In the United States sulfur dioxide emissions increased by about 160 per cent during this century, while nitrogen oxide emissions increased by about 900 per cent. [source: 1900–1935—Gschwandtner, G., Gschwandtner, K. C., & Eldridge, K. 1985. *Historic Emissions of Sulfur and Nitrogen Oxides in the United States from 1900 to 1980.* 1940–1985—Environmental Protection Agency. 1987. *National Air Pollutant Emission Estimates* 1940–1985]**

metal. But there are many varieties of non-chemical pollution—notable principally because of their physical effects—including radiation, both ionizing and nonionizing; thermal pollution; infrared trapping; noise; waterborne and other pathogens; silt, trash, and various solid wastes; and aesthetic pollution, including odors and visibility impairment.

It is customary to think of pollutants as having negative effects on human health and "welfare," where welfare is meant to include everything other than health effects. The serious health problems pollution causes—cancer, respiratory diseases, infections, and a host of others—are well known. Fortunately, after some years of neglect, the welfare consequences of pollution are beginning to receive serious attention as well. Indeed, it is becoming clear that "welfare" is an inadequate label to put on a variety of adverse pollution impacts, including:

- economic damage caused by pollution, such as the damage to crops, forests, and fisheries;
- harm to recreational and aesthetic enjoyment of the environment—for example, loss of visibility and of hunting and fishing opportunities;
- ecological degradation of natural areas, including the impoverishment of ecosystems and changes in habitat and species distribution due to pollution stresses; and
- disruption of services provided by natural systems, such as the regulation of climate and hydrologic systems.

Some sense of the economic damage caused by pollution can be seen in the benefits that air pollution control has achieved. One recent study estimated the annual gross benefits (not benefits net of pollution control expenditures) to the U. S. population in 1981 from air pollution control to be between $20 billion and $54 billion (Freeman 1979, Leighton *et al.* 1984).

Yesterday, Today, and Tomorrow

Today, pollution is occurring on a vast and unprecedented scale worldwide. It is pervasive, affecting in some way virtually everyone and everything. Trends, particularly since World War II, have been in two directions: first, toward large and growing releases of certain chemicals (principally from burning fossil fuels) that are now significantly altering natural systems on a global scale; and, second, toward steady increases in the use and release to the environment of innumerable biocidal products and toxic substances. These shifts from the "sewage and soot" concerns of the pre-war period to vastly more serious concerns pose formidable challenges for societies, both industrial and developing—challenges that modern pollution control laws address only partially. The dramatic changes in pollution in this century are best described in terms of four long-term trends.

From Modest Quantities to Huge Quantities

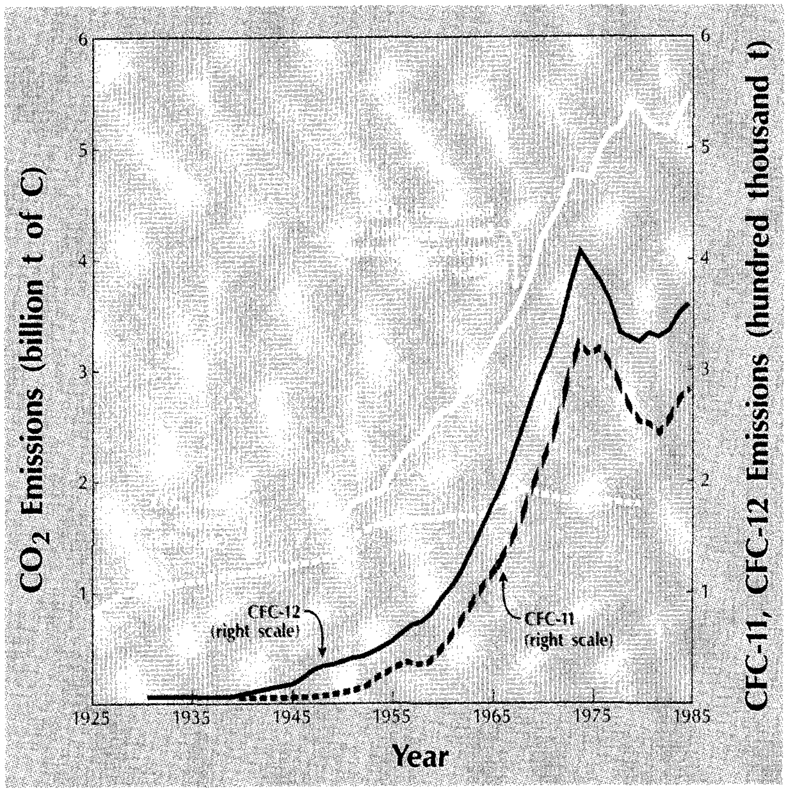
The 20th century has witnessed unprecedented growth in human population and economic activity. World population has increased more than threefold; gross world product by perhaps twentyfold;

and fossil fuel use by more than tenfold (Brown *et al.* 1987). In the United States, gross national product (G.N.P.) has grown by a factor of nine in this century, and fossil fuel use has more than doubled since 1950 (D.O.E. 1987).

With these huge increases in population and economic activity have come huge changes in the quantities of pollutants released. Consider how increased use of fossil fuel influences sulfur dioxide and nitrogen oxide emissions. These products of fossil fuel combustion are among the principal sources of smog and other urban air pollution; they are also the pollutants that give rise to acid rain. Between 1900 and 1980, annual sulfur dioxide emissions grew by an estimated 470 per cent globally (to about 160 million metric tons) and by about 160 per cent in the United States (to about 23 million metric tons). Nitrogen oxide emissions in the United States increased by about 900 per cent during this period (to about 20 million metric tons annually) (Figure 2).

Another gas formed by burning fossil fuels is carbon dioxide (CO_2), one of the greenhouse gases implicated in global warming and climate change. One recent estimate is that, as a result of human activity, annual global emissions of CO_2 have increased about tenfold in this century (MacDonald 1985) (Figure 3). One result of this upsurge has been the dramatic increase in the CO_2 content of Earth's atmosphere. The buildup of greenhouse gases such as CO_2 can lead to global climate change, which has far-reaching implications for agricultural production, coastal flooding, and human well-being.

These examples of sharp increases in pollution in this century could be multiplied by many others—in the United States alone, mountains of garbage and other solid waste, the quantity of which has roughly doubled over the past three decades; hundreds of millions of tons of hazardous wastes generated annually; about 500 million pounds of insecticides produced annually, only half of which reaches a crop and less than 1 per cent of which reaches an insect (C.E.Q. 1981). In these and other ways, the 20th century has been a century of vast increases in the quantity of pollutants imposed on a finite environment.



EMISSIONS OF MAJOR CONTRIBUTORS OF GLOBAL WARMING AND OZONE DEPLETION

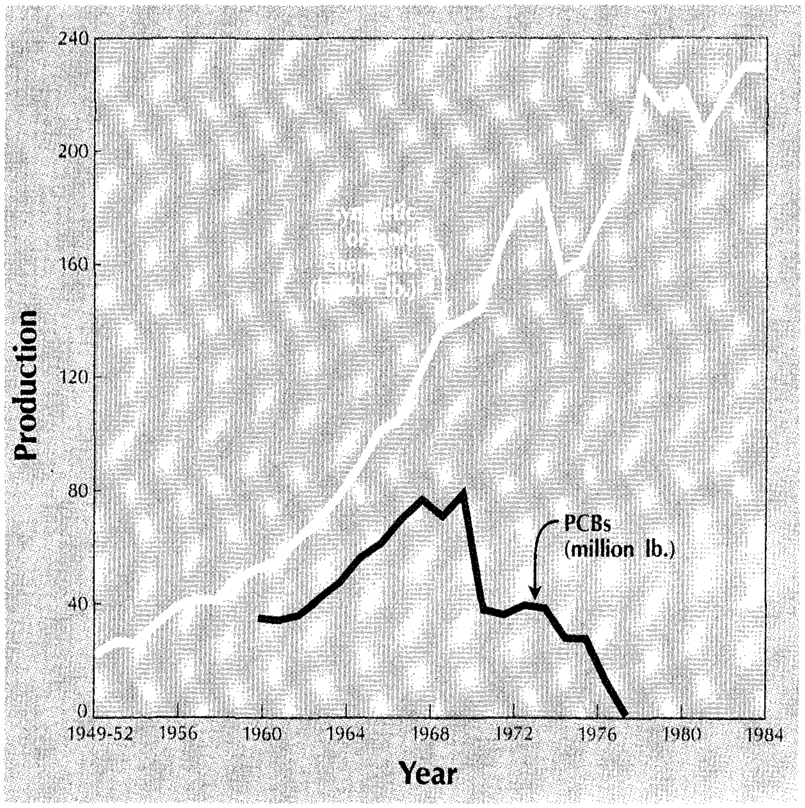
Figure 3. **The steady and large increase in global carbon dioxide emissions in recent decades comes from fossil fuel combustion, industrial processes, and biotic sources such as deforestation and the destruction of soil humus. [source: biotic emissions—Houghton, R. *et al.* Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: a net release of CO_2 to the atmosphere. *Ecological Monographs* 53(3):235–236, and unpublished data; CO_2 emissions from fossil fuel combustion—Rotty, R.M., University of New Orleans, November 1986; C.F.C. emissions—Chemical Manufacturers Association. 1986. *Production, Sales, and Calculated Release of CFC-11 and CFC-12 Through 1985.* Washington, D. C.]**

From Gross Insults to Microtoxicity

Before World War II, concern with air and water pollution focused primarily on smoke and sewers, problems with which people have grappled since the dawn of cities. The traditional public health threats—killer fogs like the one that sickened thousands and killed 20 in Donora, Pennsylvania, in 1948; and sanitary water supplies for urban areas—were serious concerns. Buildings coated with soot and grime, and streams thick with algae were typical non-health issues (*e.g.*, Kapp 1971, Melosi 1980).

The emergence of the chemical and nuclear industries fundamentally changed this focus on gross insults. Paralleling the dramatic growth in the volume of older pollutants, such as sulfur dioxide, has been the introduction in the post-World War II period of new chemicals and radioactive substances, many of which are highly toxic in even minute quantities and some of which persist and accumulate in biological systems or in the atmosphere.

The synthetic organic chemicals industry is



PRODUCTION OF SYNTHETIC ORGANIC CHEMICALS AND P.C.B.s, UNITED STATES

Figure 4. **This industry hardly existed before World War II, and between 1950 and 1985, annual production grew from about 24 billion to 225 billion pounds. [source: synthetic organic chemicals—Department of Commerce, International Trade Commission 1954, '56, '58, '60, '62, '63, '65, '67, '69, '71, '73, '75, '77, '79, '81, '83, '85. *Synthetic Organic Chemicals.* P.C.B. production—Council on Environmental Quality. 1979. *Environmental Statistics 1978.* Washington, D. C., p. 129]**

largely a product of the last half century. The industry hardly existed before World War II, and between 1950 and 1985 its annual U. S. production grew from about 24 billion to 225 billion pounds (Figure 4). Organic compounds (those that contain carbon) occurring in nature are the basis of life, but over the past 50 years, tens of thousands of synthetic organic compounds have been introduced into the environment as pesticides, plastics, industrial chemicals, medical products, detergents, food additives, and other commercially valuable products. Life as we know it would hardly be the same without these products, but the development of the chemical industry has also given rise to a vast and, to many, a frightening armada of new products that are harmful to people or nature. More than 90 per cent of the substances listed as potential human carcinogens by the U. S. National Toxicology Program are organic chemicals, as are 110 of the 126 toxic compounds listed as priorities under the Federal Clean Water Act (Conservation Federation 1987).

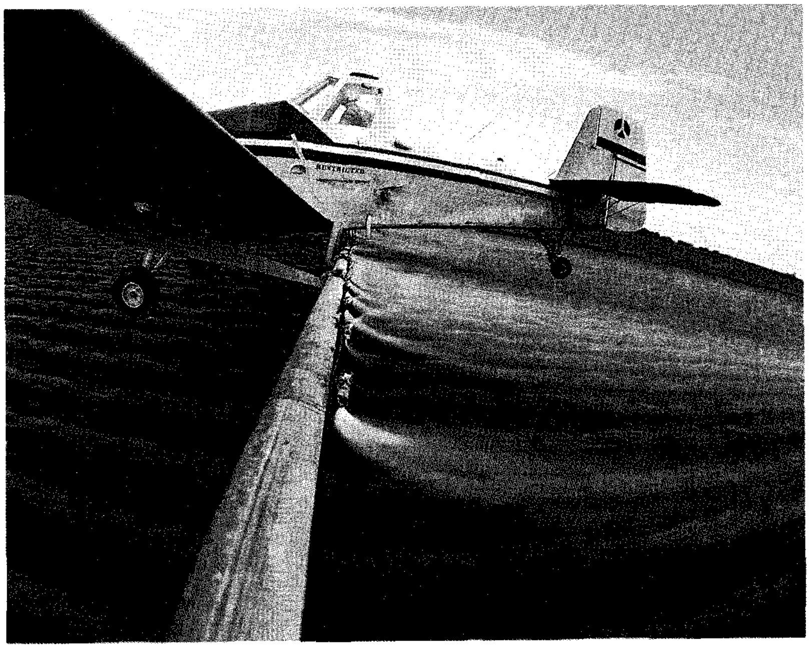
These substances are but a few of the bewildering number of chemicals that confront environmental regulators. The U. S. Toxic Substances Control Act Inventory lists more than 63,000 chemical substances that have been used commercially since 1975, and today new chemicals are introduced in the United States at a rate of about 1,500 per year (Conservation Foundation 1987). Of roughly 70,000 chemicals in trade today, as many as 35,000 are classed by the U. S. Environmental Protection Agency (E.P.A.) and the Organization for Economic Cooperation and Development (O.E.C.D.) as definitely or potentially harmful to human health (I.I.E.D. & W.R.I. 1987).

Pesticides, a major product of the modern chemicals industry, are released to the environment precisely because they are toxic (Figure 5). Globally, pesticide sales have skyrocketed from about $5 billion in 1975 to $28 billion in 1985 (1977 dollars). Projected sales for 1990 are $50 billion, a tenfold increase since 1975 (U.N.E.P. 1987a). About 90 per cent of all pesticides are used to increase agricultural production (primarily of corn, cotton, soybeans, wheat, and rice), and most of the rest are used in the health protection field (U.N.E.P. 1987a). The benefits of pesticides for increasing world food supply and controlling diseases are undeniably great, but the success of pesticides has extracted a price in terms of side effects, including adverse effects on human health. Perhaps a million cases of acute pesticide poisoning occur annually worldwide, and there are many other negative consequences as well (U.N.E.P. 1987a).

One important example of regulatory response to pesticide risks occurred in 1979, when the E.P.A. issued emergency orders to suspend the registration of two of the most widely used herbicides in the United States, Silvex and 2,4,5-T. The action was based on human evidence and animal tests that indicated that these herbicides and their common contaminant, dioxin, can cause miscarriages, birth defects, and other adverse reproductive effects. Studies of dioxin show that it has fetotoxic effects in rats and monkeys at levels as low as 10 parts per trillion; dioxin appears to be carcinogenic in test animals at doses as low as 2.2 parts per billion. Furthermore, no one doubts that dioxin is highly carcinogenic, but the debate on just how carcinogenic continues (C.E.Q. 1979, *New York Times* December 9, 1987).

Two of the most widely acknowledged problems associated with pollution's evolution toward increasingly dangerous substances are the accumulation of nuclear and hazardous waste. The United States leads the world in hazardous waste generation with an annual total of about 264 million metric tons, including heavy metal residues and volatile organic and other chemical wastes (Figure 6). About 1 per cent of this amount is toxic; the rest is water and other nontoxic chemicals (I.I.E.D. & W.R.I. 1987). The legacy of past mismanagement of these wastes is staggering. Estimates of the number of hazardous waste dump-sites in the United States that now require cleanup varies from 2,000 to 10,000, and the cost of cleanup from about $20 billion to $100 billion (I.I.E.D. & W.R.I. 1987).

The great quantities of radioactive materials generated by the nuclear weapons and nuclear power industries have always been much more tightly controlled than chemical waste. Nevertheless, in many countries numerous incidents of unpermitted radiation releases have occurred, the most important of these being the Chernobyl nuclear power reactor accident in 1986. Contamination from Chernobyl spread over much of Europe. The long-term health effects remain uncertain, with estimates of from 5,000 to 50,000 additional deaths from cancer over the next 30 to 60 years (I.I.E.D. & W.R.I. 1987).



SPRAYING INSECTICIDE

Figure 5. **This plane is spraying insecticide above a Texas cotton field. Billions of gallons of pesticide solutions are applied yearly to U. S. crops, rangeland, and forests. [photo: ©Fred Ward]**

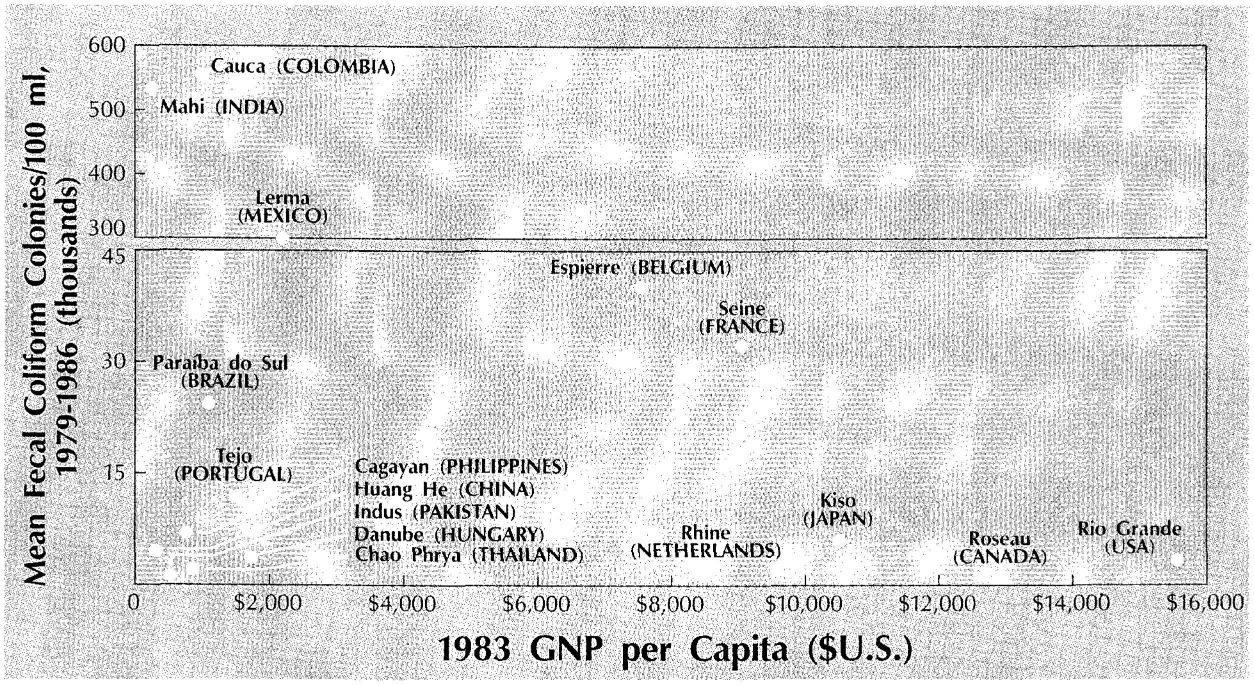
From First World to Third World

A myth easily exploded by a visit to many developing countries is that pollution is predominately a problem of the highly industrialized countries. While it is true that the industrial countries account for the bulk of the pollutants produced today, pollution is a serious problem in developing countries, and many of the most dramatic and alarming examples of its consequences can be found there. This is true whether we focus on older problems such as sewage, or more modern problems such as pesticides, heavy metals, and other toxic chemicals.

Given the population explosion in developing countries and their estimated sixfold increase in economic output (to more than $2 trillion annually) between 1965 and 1985 (World Bank 1987), it is hardly surprising that pollution is a growing problem. India is a good example. An estimated 70 per cent of its total surface waters are polluted. Of India's 3,119 towns and cities, only 217 have even partial sewage-treatment facilities. A 48-kilometer stretch of the Yamuna River, which flows through New Delhi, contains 7,500 coliform bacteria per 100 milliliters of water before entering the capital, but after receiving an estimated 50 million gallons of untreated sewage every day, it leaves New Delhi carrying an incredible

DISPOSING OF CHEMICAL WASTE

Figure 6. **About 400 companies dumped some 50,000 drums of chemical waste—including cyanide, arsenic, P.C.B.s, toxic metals, solvents, naphthalene, and explosives—at a 13-acre disposal site near Seymour, Indiana. [photo: ©Fred Ward]**



RIVER POLLUTION AS A FUNCTION OF G.N.P. PER CAPITA

Figure 7. **River pollution, measured by fecal coliform bacteria content, for a sample of the world's rivers is charted against income per capita for the countries where these rivers occur. Rivers are being polluted in both industrial and developing countries, but the rivers most severely polluted by bacterial contamination (mostly urban sewage) are in developing countries. [source: U.N. Environment Programme. 1986. Global Environmental Monitoring System, unpublished, November]**

24 million coliform organisms per 100 milliliters. That same stretch of the Yamuna River picks up 5 million gallons of industrial effluents, including about 125,000 gallons of "D.D.T. wastes," every day (W.R.I. & I.I.E.D. 1986) (Figure 7). The four-year drought in India, which reached crisis proportions in 1987, has forced larger portions of the population to consume unsafe water, and, as of late 1987, more than 1,700 people had died and 684,000 were ill from severe diarrhea and other waterborne diseases (*New York Times* December 6, 1987).

Data from the U.N.'s Global Environmental Monitoring System (G.E.M.S.) indicate that, by and large, cities in Eastern Europe and the Third World are consistently more polluted with sulfur dioxide and particulates than most (but not all) of the cities in O.E.C.D. countries (W.R.I. & I.I.E.D. 1986). A recent G.E.M.S. survey found that cities with the highest concentrations of suspended particulates tend to be in the developing countries, and that air pollution in developing regions tends to be worsening rather than improving (Figures 8 & 9). For Asian countries on which data are available, sulfur dioxide levels seem to have gone up about 10 per cent per year between 1973 and 1984 (*Los Angeles Times* February 26, 1987, U.N.E.P. & W.H.O. 1987) (Figure 10).

Another indication of the growing pollution potential in the developing countries is the rapid expansion of the chemical industry in these countries (Figure 11). Similarly, pesticide use in developing countries is accelerating rapidly: one recent study concluded that developing countries are consuming about 45 per cent of all insecticides and about 10 per cent of all fungicides and herbicides (*Christian Science Monitor* June 11, 1987, *Los Angeles Times* October 18, 1987, U.N.E.P. 1987a).

Third World populations now rank high in their exposure to toxic chemicals. In a sample of 10 industrial and developing countries, three of the four countries with the highest blood lead levels of their populations were Mexico, India, and Peru; for the same 10 countries, D.D.T. contamination of human milk was highest in China, India, and Mexico. In another comparison of the dietary intake of cadmium, lead, and aldrin–dieldrin, Guatemala (the only developing country in the sample) ranked at or near the

MEXICO CITY AIR: GOOD, BAD, AND UNHEALTHY

Figure 8. **A clear winter day in September 1985 when winds washed out the city's vast bowl-shaped valley. Even the peaks of the nearby volcanoes are visible.** ***Figure 9.*** **A haze of pollution chokes Mexico City on a winter morning in 1986. Vehicle exhaust, factory smoke, and smoldering refuse heaps befoul the air inhaled by 17 million people. Breathing this air has been compared with smoking two packs of cigarettes per day. [photos: ©Guillermo Aldana Espinosa]**

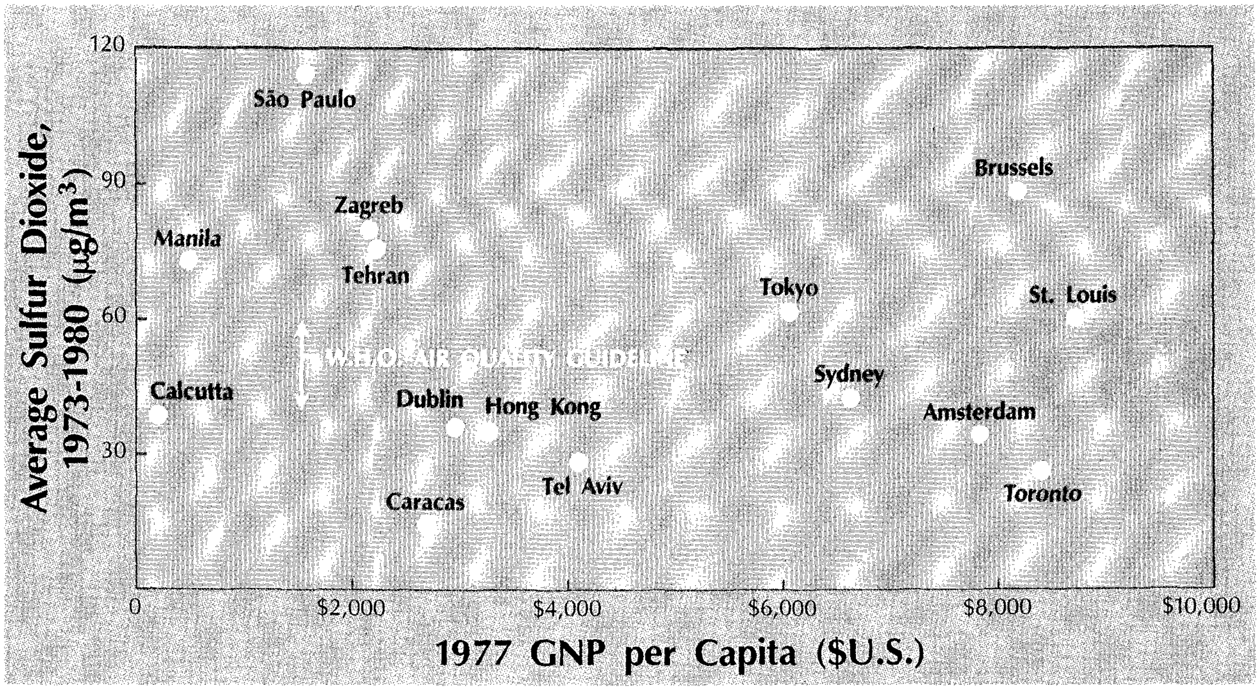
top for each of the three (U.N.E.P. & W.H.O. 1987).

What may be the worst industrial accident in history occurred in Bhopal, India, in 1984, when more than 2,000 people were killed. The accident occurred when a chemical used in the manufacture of pesticides, methyl isocyanate (M.I.C.), escaped and drifted into crowded, low-income settlements that adjoin the Union Carbide facility.

From Local Effects to Global Effects

When the volumes of pollution were much smaller and the pollutants were similar to natural substances, impacts tended to be confined to limited geographic areas near the sources. Indeed, as late as 1970 national air pollution legislation in the United States treated air pollution largely as a local phenomenon. Today, the scale and intensity of pollution make its consequences truly global. For the first time, "human impacts have grown to approximate those of the natural processes that control the global life-support system" (Malone & Roederer 1985, p. xiv).

Nothing better illustrates this broadening perspective of pollution from a local affair to a global one than the evolution of concern about air pollution. (Pollution of the world's oceans is also a serious issue demanding concerted responses [*Business Week* 1987a, I.I.E.D. & W.R.I. 1987].) In a 1984 essay, atmospheric scientist John Firor (1984, MacDonald 1985) referred to the "endangered species of the atmosphere." Firor's metaphor is apt. Local air pollution is improving in some cities, but it is worsening in others and is hardly solved anywhere. Meanwhile, overall global use of fossil fuels, and emissions of traditional pollutants such as sulfur and nitrogen oxides that result from it, continue to climb. Acid rain, ozone, and other consequences of these pollutants are affecting plant and animal life over vast areas of the globe. Depletion of the stratosphere's ozone layer is a matter of such concern that an international treaty has been negotiated to sharply reduce emissions of chlorofluorocarbons (C.F.C.s). And, probably most serious of all, the buildup of greenhouse gases in the atmosphere—largely a consequence of the use of fossil fuels and C.F.C.s and various agricultural activities—continues, threatening societies with far-reaching climatic changes, sea level rise, and other consequences. These interrelated atmospheric issues probably constitute the most serious pollution threat in history; they deserve our special attention.



SULFUR DIOXIDE POLLUTION AS A FUNCTION OF G.N.P. PER CAPITA

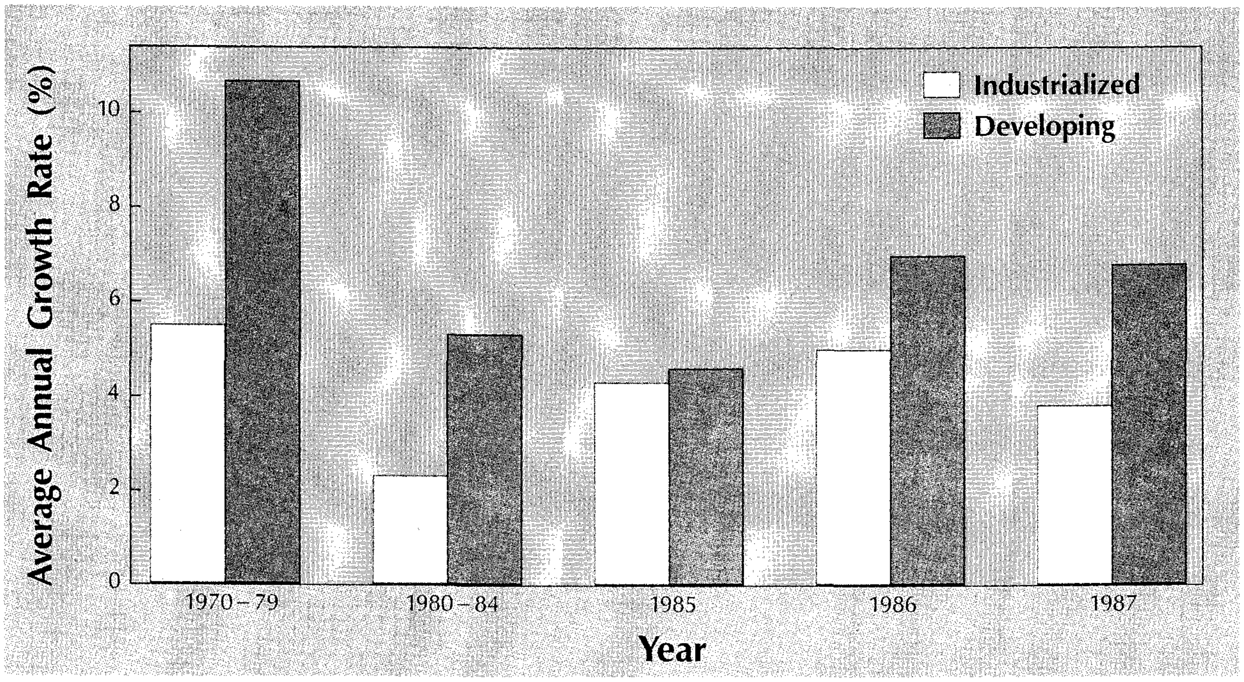
Figure 10. **Sulfur dioxide pollution is a serious problem for rich and poor alike. Here sulfur dioxide pollution of world cities is plotted against the per capita income levels of the countries in which those cities are located. Third World cities are prominent among those that substantially exceed World Health Organization air quality guidelines. [source: U. N. Environment Programme. 1987. *Environmental Data Report.* Basil, Blackwell, pp. 14–15]**

Acid Rain and Regional Air Pollution

The view of air pollution as primarily an urban problem was first challenged by acid rain and other regional or transboundary air pollution (I.I.E.D. & W.R.I. 1987, W.R.I. & I.I.E.D. 1986). The atmosphere transports many air pollutants hundreds of miles before returning them to the Earth's surface. During this long-distance transport, the atmosphere acts as a complex chemical reactor, transforming the pollutants as they interact with other substances, moisture, and solar energy. Under the right conditions, emissions of sulfur dioxide and nitrogen oxides from fossil fuel combustion are transformed chemically in the atmosphere into sulfuric and nitric acids. Other pollutants, notably carbon monoxide and volatile organic compounds, contribute to the reactions that make these strong acids.

Acid deposition is a major problem in Europe and North America, and it is emerging as a significant issue in parts of Asia and Latin America. Many adverse environmental effects have been attributed to acid rain, including damage to buildings and exposed metals. But recent attention has focused on damage to the natural environment, particularly the acidification of lakes and streams. Thousands of lakes have "gone acid" and, in effect, died as a result of widespread acid deposition in northern Europe and North America. In Sweden alone, 21,000 lakes have experienced at least some acidification as have some 60,000 miles of streams. In the United States, a recent government survey found that about 10 per cent of the lakes in the Adirondack region and the Upper Peninsula of Michigan were acidic (below pH 5) and about 5 per cent of the lakes in other sensitive regions were acidic. Sobering as these numbers are, some scientists have argued that use of pH 5 to define acidic surface waters grossly minimizes the problem (*e.g.*, Likens 1987, *Science* 1987).

Moreover, the dimensions of the problem have changed significantly in the past few years. Although acid deposition is still seen as the primary atmospheric agent damaging aquatic ecosystems, many other air pollutants are probably important in agricultural crop damage and in the widespread forest declines of Europe and North America observed over the past several years. Also, the geographic area now perceived as threatened by acid rain and the



GROWTH OF CHEMICAL MANUFACTURING, DEVELOPING VS. INDUSTRIAL COUNTRIES

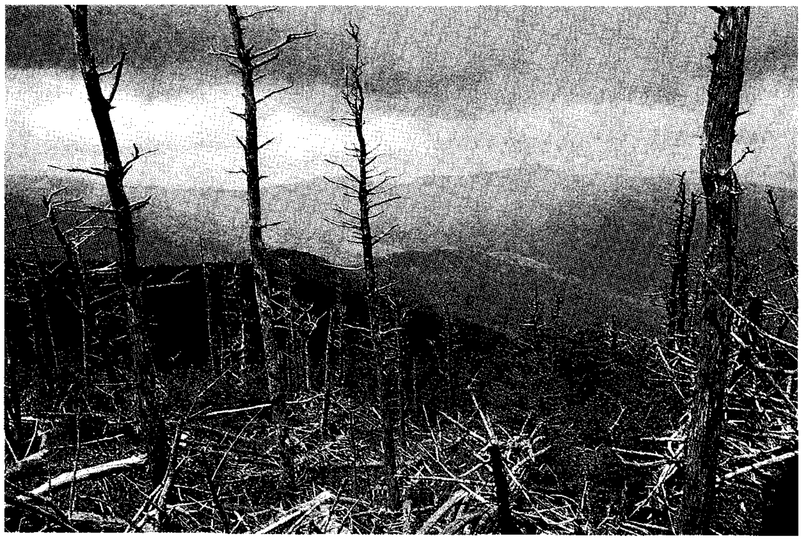
***Figure 11.* Chemical manufacturing grew about twice as fast in developing countries as it did in industrial countries during 1970–1984. [source: U. N. Industrial Development Organisation. 1986. *Industry and Development, Global Report, 1986.* Vienna]**

other airborne pollutants has expanded far beyond Scandinavia, central Europe, and eastern North America. It now encompasses nearly the whole of Europe (including the European part of the Soviet Union), parts of the western United States and Canada, and some industrialized areas of the Third World, including China, Brazil, and Nigeria.

The harmful effects of ozone and sulfur dioxide on crops and vegetation have been known for years, but more attention is now being given to the economic consequences of crop losses caused by air pollution. The U. S. National Crop Loss Assessment Network believes that ground-level ozone damage to U. S. crops amounts to $1 billion to $5 billion a year. A 25 per cent increase in ambient ozone concentrations throughout North America would cost society an estimated $1.9 billion to $2.3 billion a year in lost production (in 1980 dollars).

As of the end of 1985, at least 7 million hectares of forestlands in 15 European countries had been affected by *Waldsterben* (forest death). The massive forest decline observed in the Federal Republic of Germany over the past six years appears to be leveling off—at least in terms of its geographic distribution—but *Waldsterben* (Figure 12) is increasing in extent and severity in Switzerland, Austria, Czechoslovakia, Poland, the German Democratic Republic, France, Italy, Yugoslavia, and Sweden. North America's higher-elevation, eastern coniferous forests have experienced a rapid and severe decline in recent years. The damage appeared in the Appalachian Mountains from Georgia to New England, and has become increasingly serious and visible. A six-state study of the southern Appalachian region recently revealed that eastern white pine is suffering from pollution-related declines in 23 per cent of the stands surveyed. Pollution-related decline was most pronounced in Kentucky, where 77 per cent of all the white pine surveyed showed air pollution damage. The main pollutant known to damage white pine is ozone, along with other photochemical oxidants.

In North Carolina, the spruce–fir forest atop Mount Mitchell is undergoing rapid defoliation and decline. High levels of ozone, acidity, and even heavy metals have been detected, transported long distances in the atmosphere. While the exact cause-and-effect relationships remain unclear, the evidence is strong that chemical pollutants are important in the widespread forest destruction in Europe, now attacking the forests of North America.



WALDSTERBEN IN THE UNITED STATES

Figure 12. **Dead trees at the summit of Mt. Mitchell, in the Smokies of North Carolina, July 1985. Air pollution is believed to be an important contributor to forest decline. [photo: ©John M. Burnley]**

Chlorofluorocarbons and the Ozone Layer

Ozone (O_3), a variant of oxygen, is present throughout the atmosphere but concentrated in a belt around the Earth in the stratosphere (I.I.E.D. & W.R.I. 1987). Although ozone in the troposphere (nearest the Earth's surface) adversely affects human health and plant life, it is a valuable component of the upper atmosphere, where it acts as a filter, absorbing harmful wavelengths of ultraviolet radiation (U.V.). Without this radiation shield, more U.V. radiation would reach the surface of the Earth, and would damage plant and animal life and greatly increase the risk of skin cancers and eye disease.

In 1974, two University of California scientists, Mario Molina and F. S. Rowland, postulated that the widespread use of C.F.C.s—highly stable compounds used in aerosol propellants, refrigeration, foam-blowing, and industrial solvents—could damage the ozone shield. They hypothesized that C.F.C. gases could add chlorine to the stratosphere and, through complex chemical reactions, reduce the amount of stratospheric ozone, allowing more harmful U.V. radiation to reach the Earth's surface.

This hypothesis profoundly affected both the C.F.C. industry and national governments. The United States, Canada, and Sweden first banned inessential uses of C.F.C. propellants, and several other Nordic countries followed suit. As a result, world production of the two major chlorofluorocarbons—C.F.C.-11 and C.F.C.-12—decreased in the late 1970s. Reflecting these developments, global emissions of C.F.C.-11 and C.F.C.-12 peaked in the early 1970s. Although they declined during the late 1970s, they began climbing again in the early 1980s, renewing international concern (Figures 3 & 13).

Sophisticated atmospheric models relate emissions of C.F.C.s and other pollutants to long-term damage to the Earth's ozone layer. Increasing C.F.C. production at 1.5 per cent per year for 40 years, for example, would likely cause more than a 20 per cent reduction (at an altitude of 40 kilometers) in the ozone shield and much larger increases in incoming U.V. radiation (U.N.E.P. 1987b).

In 1985, when British scientists reported a dramatic seasonal thinning of the ozone shield over Antarctica—the now famous "hole" in the ozone layer (Figure 14)—the debate switched into high gear. The hole is now roughly the size of the continental United States, and it appears to be growing larger every year. In this hole, Antarctic springtime ozone levels have decreased by about 50 per cent since the mid-1970s. Recent evidence suggests that C.F.C.s bear ultimate responsibility for the ozone hole, although the stratospheric ice clouds over the polar region facilitate the chemical reaction that destroys the ozone (Molina *et al.* 1987, Zurer 1987).

The response to the ozone-depletion problem has been a precedent-setting and extremely important international agreement, the 1985 Convention for the Protection of the Ozone Layer. The first major step toward implementing this convention occurred with the 1987 adoption of the Montreal Protocol, in which officials from 23 countries agreed to a 50 per cent rollback in C.F.C. use by 1999. In light of the ozone hole and other results, the debate will now surely shift to whether the Montreal Protocol imposes sufficient restrictions on C.F.C.-11 and C.F.C.-12 and on other ozone-destroying pollutants.

The Greenhouse Effect and Global Climate Change

For the past several years, the international scientific community has been issuing unusual warnings (Mintzer 1987). Earth's climate, the climate that has sustained life throughout history, it says, is now seriously threatened by atmospheric pollution.

Perhaps the most notable warning came in October 1985, at a conference sponsored by the International Council of Scientific Unions (I.C.S.U.), the World Meteorological Organization (W.M.O.), and the U. N. Environment Programme (U.N.E.P.), in Villach, Austria. "As a result of the increasing concentrations of greenhouse gases," the conference statement began, "it is now believed that in the first half of the next century, a rise of global mean temperature could occur which is greater than any in Man's history" (U.N.E.P. *et al.* 1985).

Through such activities as burning fossil fuels, leveling forests, and producing certain synthetic chemicals, people are releasing large quantities of "greenhouse" gases into the atmosphere. These gases absorb Earth's infrared radiation and prevent it from escaping into space. This process traps heat close to the surface and raises global temperatures.

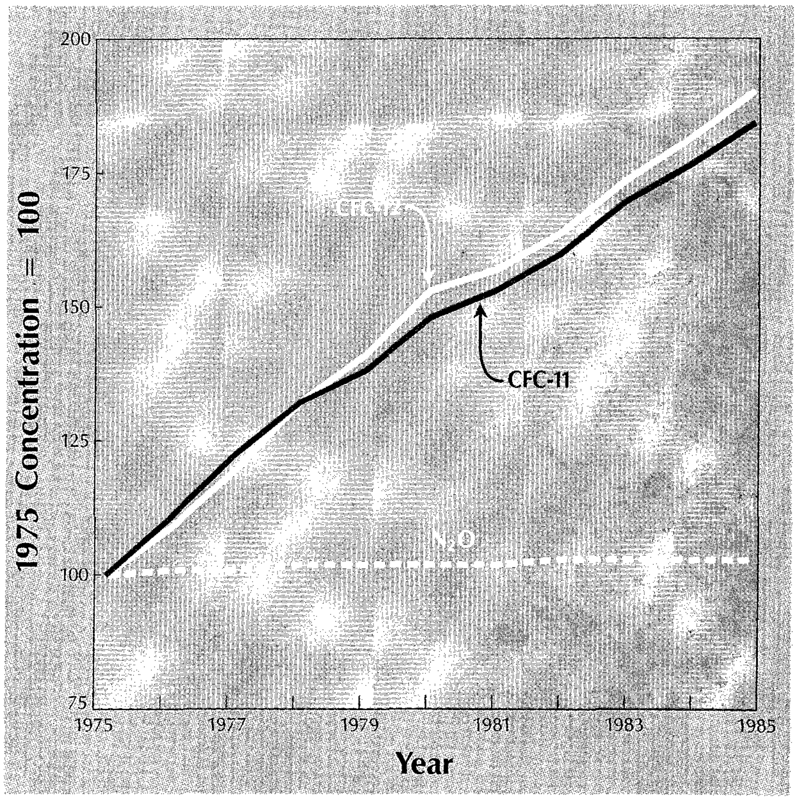
Excess carbon dioxide (CO_2) is the main offender. Prior to the Industrial Revolution, the concentration of CO_2 in the atmosphere was about 280 parts per million. At this concentration, CO_2 (and water vapor) warmed Earth's surface by about 33° Celsius and made Earth habitable. But, since then, especially since 1900 or so, the accelerating use of fossil fuels and vegetation loss over large areas of the planet have caused CO_2 in the atmosphere to increase by about 25 per cent, to 348 parts per million.

But CO_2 buildup is not the only problem. Much of the new urgency about the greenhouse effect stems from the realization that other gases released through human activity—including C.F.C.s, methane, nitrous oxide, and ozone—now contribute about as much to the greenhouse effect as CO_2 does (Figures 3, 13, & 15).

According to one estimate, past emissions of greenhouse gases have already committed Earth to an average warming of 1° to 2.5° Celsius over that of the pre-industrial era (Ramanathan 1987), though only a fraction of this warming has been felt to date because of the inertia of the oceans. Several models project that if current trends in greenhouse gas buildup continue, human activity will have committed Earth to a warming of 1.5° to 4.5° Celsius by around 2030, the upper end being the more probable.

To find conditions like those projected for the middle of next century, we must go back millions of years. If the greenhouse effect turns out to be as great as predicted by today's climate models, and if current emission trends continue, our world will soon differ radically from anything in human experience.

While the regional impacts of a global warming are uncertain and difficult to predict, many of the anticipated changes are both far-reaching and disturbing. Rainfall and soil moisture patterns could shift dramatically, upsetting agricultural activities worldwide. Sea level could rise from 1 to 4 feet, flooding coasts and allowing salt water to intrude into water supplies. Ocean currents could shift, altering the climate of many areas and disrupting fisheries. The ranges of plant and animal species could change regionally, endangering protected areas as well as species whose habitats are now few and confined. Record heat waves and other weather anomalies could harm susceptible people, crops, and forests.



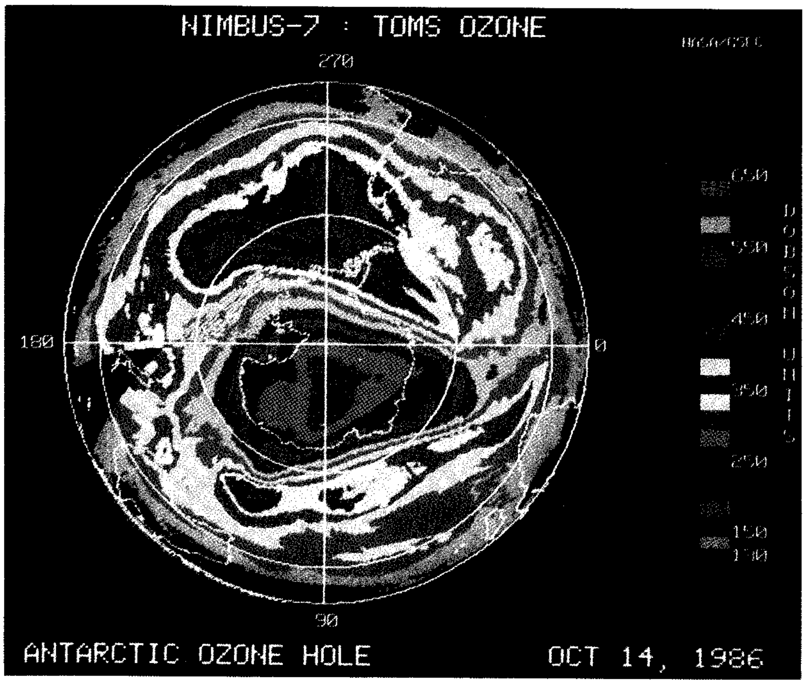
TRENDS IN GREENHOUSE GASES AND OZONE DEPLETERS

Figure 13. **The data indicate that atmospheric concentrations of C.F.C.-11 and C.F.C.-12 increased more than 85 per cent between 1975 and 1985. [source: Rasmussen, R. & Khalil, M. 1986. Atmospheric trace gases: trends and distrubutions over the last decade. *Science* June 27:1623–1624]**

In this context, it is not surprising that the scientists at Villach took the important step of urging that the greenhouse issue be moved into the policy arena. "Understanding of the greenhouse question is sufficiently developed," they concluded, "that scientists and policymakers should begin an active collaboration to explore the effectiveness of alternative policies and adjustments" (U.N.E.P. *et al.* 1985).

With the buildup of greenhouse gases proceeding apace, a planetary experiment is under way. Before the results are fully known, future generations may have been irrevocably committed to an altered world—one that may be better in some respects but that also involves truly unprecedented risks.

In light of these threats, two kinds of action seem justified: adaptive measures to prepare for



OZONE OVER ANTARCTICA

Figure 14. **Ozone in the upper atmosphere protects life on Earth by filtering the Sun's ultraviolet radiation. During the past nine years this protective layer has become thinner each spring over the South Pole. The "hole," shown as the purple area on the map, has deepened as ozone concentrations have fallen by 40 per cent. [source: National Aeronautics and Space Administration/Goddard Space Flight Center]**

aparently inevitable climate changes, and, more important, preventive measures to forestall changes that societies can still influence. Control of "greenhouse"-producing gas releases can both buy time and, ultimately, maintain Earth's climate as closely as possible to that of the past several thousand years.

Given what is now known, major national and international initiatives—grounded in the best available science and policy analysis—should become a top priority of governments and citizens. A deeper appreciation of the risks of "greenhouse"-producing gas buildup should spread to leaders of government and business and to the general public, investing the greenhouse issue with a sense of urgency absent today. If nations are to be spared a Hobson's choice between energy shortages and climate change, we must become committed to energy efficiency, to solar and other new and renewable energy sources (commercial prospects for new solar technologies, particularly photovoltaic solar cells, appear increasingly promising), and to economic incentives and other measures that discourage the use of high-carbon fuels. Additional steps should also be taken to halt deforestation now under way in the tropics and to regulate C.F.C.s and other greenhouse gases.

The years immediately ahead should be a period of intense scientific research, policy exploration, and adoption of appropriate measures. Innovative international responses should be discussed. Global and regional energy futures should be explored and we should especially emphasize their effects on the greenhouse problem. Preventive and adaptive strategies appropriate to the world's regions should be mapped and means found to build U. S.–Soviet cooperation on this issue since these two countries together have most of the world's coal reserves. (For discussions on the greenhouse effect and climate change, see: Mathews 1987, Mintzer 1987, U.N.E.P. 1987c.)

Progress in the United States: Is the Pollution Battle Being Won?

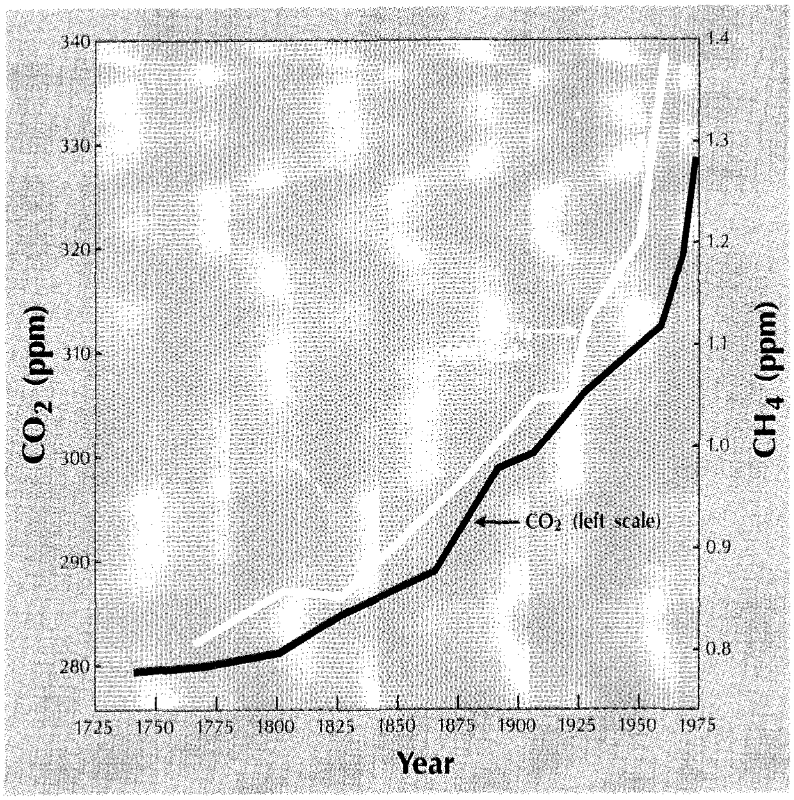
It has been a decade and a half since the United States and many other industrial countries spotlighted "traditional" pollutants and initiated major, expensive cleanup programs. Are these programs achieving their goals? When we examine the available information, the pattern that emerges is one of some success, some backsliding, and much "holding our own." Judged by the goals of the Federal Clean Air Act of 1970 and the Federal Water Pollution Control Act of 1972, progress has been disappointingly slow. Also, against the gains must be weighed "newer" problems such as hazardous waste sites and groundwater pollution (where correctional efforts have just begun) and the continuing outpouring of toxic chemicals old and new.

On the positive side, the emergence of environmental concern in the 1960s and the cleanup programs that followed in the 1970s have resulted in impressive pollution abatement efforts. The United States spent about $739 billion (1982 dollars) on pollution control between 1972 and 1984, with about 42 per cent of this going to clean the air, 42 per cent to water cleanup, and the rest primarily to solid waste. Private business spent about two thirds of this amount; government and individuals account for the rest (Conservation Foundation 1987).

Many corporations in manufacturing and elsewhere have made serious and responsible efforts to achieve and sometimes to exceed pollution control requirements. In the process, they have brought about major technological advances in pollution abatement, and a pollution control industry in the United States that created an estimated 167,000 jobs in 1985 (Management Information Services 1986). A majority of dischargers has come into compliance with their discharge permits and other requirements without the need for legal enforcement actions, but in many, many cases polluters have been recalcitrant, fighting every step of the way. Enforcement actions by state and federal authorities are commonplace. Each year E.P.A. issues thousands of administrative enforcement orders, and hundreds of lawsuits against polluters are referred to the Justice Department for civil or criminal action.

What are the results of all this activity? On water pollution, the results have been mixed. Discharges of certain key pollutants have been substantially reduced; for example, oxygen-demanding waste from industry and municipal sewage systems declined 71 per cent and 46 per cent, respectively, between 1972 and 1982 (Smith *et al.* 1987). The quality of many important waterways, such as the Potomac, has improved greatly. If we examine the national picture as a whole, however, progress does not seem terribly impressive. A recent Conservation Foundation (1987, p. 87) overview concluded that "in most cases little more has been done than to prevent further degradation." About two thirds of U. S. surface waters showed little overall change in water quality between 1972 and 1982. One important measure of water quality is the dissolved oxygen content of the water (Figure 16). Between 1974 and 1981, 17 per cent of U. S. monitoring sites reported improved oxygen levels, while 16 per cent reported deteriorating trends, and the remaining 72 per cent showed no significant change. Overall improvement was reported for bacterial and lead contamination, but nitrate, chloride, arsenic, and cadmium pollution increased significantly (Conservation Foundation 1987, Smith *et al.* 1987). However, a more recent E.P.A. study found that a fourth of U. S. lakes, rivers, and estuaries remain too polluted for fishing and swimming (*Washington Post* November 11, 1987). One problem is that thus far runoff and other "non-point" sources of pollution have escaped strict control. The disparity between large load restrictions in oxygen-demanding material from point sources, and the limited dissolved oxygen improvements may be due to non-point source contributions and to the location of monitoring sites, among other factors.

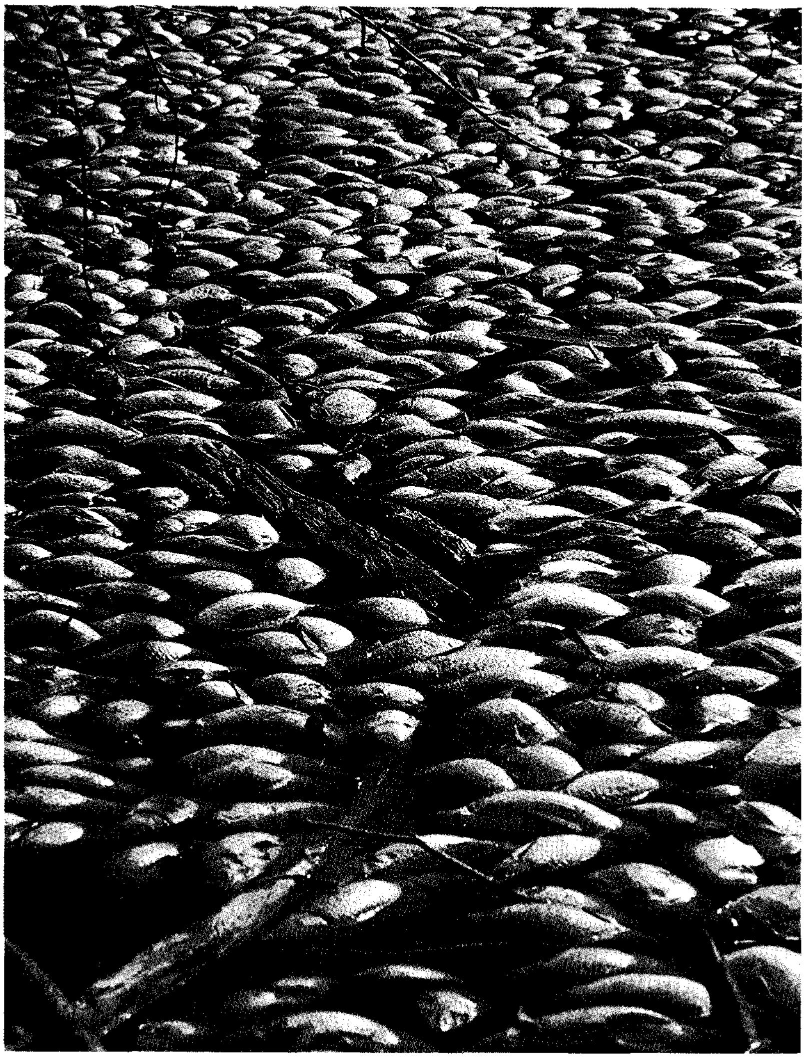
It is possible to be more positive about air pollution. Between 1975 and 1984, U. S. emissions of particulates fell 33 per cent, sulfur dioxide 16 per cent, and carbon monoxide 14 per cent. (The exception is nitrogen oxides, which showed little change between 1975 and 1984.) As a result of these gains, urban air quality in the United States, in general, has improved significantly (E.P.A. 1986).



ATMOSPHERIC CONCENTRATIONS OF CO_2 and CH_4

Figure 15. **Much of the new urgency about the greenhouse effect stems from the realization that other gases than CO_2 released through human activity contribute about as much to the greenhouse effect as CO_2 does. Methane (CH_4) is another important one. [source: CO_2 data—Neftel *et al.* 1985. Evidence from polar ice cores for the increase in atmospheric CO_2 in the past two centuries. *Nature* May 2:45; methane data—Stauffer, B. *et al.* 1985. Increase of atmospheric methane recorded in Antarctic ice core. *Science* 229:1386]**

These gains, while real enough, are modest when viewed against the environmental cleanup goals of the early 1970s. In every air pollutant category save one (particulates), total U.S. emissions today still exceed two thirds of the 1970 amounts. The bulk of the pollution that gave rise to the Clean Air Act of 1970 continues. For example, total emissions of volatile organic compounds, a key ingredient of urban smog and its principal component, ozone, were still 22 million metric tons in 1984, or 80 per cent of 1970 emissions (Conservation Foundation 1987). Many U. S. counties (and portions of counties) still fail to meet clean air standards. In 1985, 368 areas were not in compliance with the ozone standard (80 million



ORGANIC WASTES TOO MUCH FOR CARP

Figure 16. **Thousands of dead carp north of Chicago, 1969. Federal investigators found oxygen-consuming organic wastes and dangerous amounts of arsenic, zinc, copper, lead, and nickel in Skokie Lagoons north of Chicago. Carp need less oxygen than game fish; the game fish had long since disappeared. [photo: ©Joseph Sterling]**

people live in these noncomplying counties: 290 in noncompliance with particulate standards; 142 in noncompliance with carbon monoxide standards [Conservation Foundation 1987]). In short, then, air pollution, like water pollution, remains a serious problem on a national scale.

These modest gains in controlling "traditional" air and water pollutants look better when compared with what might have been. Between 1970 and 1985 U. S. G.N.P. grew by about 50 per cent in real terms, and population grew as well. Far from keeping pace with this growth, pollution actually declined. Overall, the U. S. economy today generates much less pollution per dollar of G.N.P. than it did two decades ago. For example, between 1975 and 1985 U. S. electrical utilities reduced sulfur dioxide emissions from coal burning by 44 per cent per unit of electricity generated, and spent some $62 billion on sulfur dioxide controls during this period (National Acid Precipitation Assessment Program 1987).

Environmental protection measures have had dramatic results in several areas. Lead emissions have taken a steep downturn as a result of federal regulations; these requirements resulted in a 78 per cent reduction of lead used in gasoline between 1970 and 1985 (Figure 17). Environmental releases of polychlorinated biphenyls (P.C.B.s) have dropped sharply as a result of a congressional ban on their manufacture, one of the provisions of the Toxic Substances Control Act of 1976 (Figure 4). Beginning with the bans on D.D.T. in 1972 and aldrin–dieldrin in 1974, E.P.A. has prohibited most uses of persistent organochloride pesticides. As a result of these decisive efforts, the presence of these toxic substances in the environment has improved impressively. Between 1976 and 1980, blood lead levels in the United States declined sharply, while D.D.T. concentrations in human tissue are only a fourth of what they were in 1972. The proportion of the U.S. population with P.C.B. levels above one part per million declined from about 70 per cent to about 10 per cent between 1972 and 1983 (Figures 18 & 19).

The presence of lead, D.D.T., P.C.B.s, and several other toxic substances has been greatly reduced because society has seen fit essentially to outlaw these substances and not merely to regulate their release. Industry has been required to innovate technologically and to find substitute products—for example, new means of providing high-octane gasoline—and not merely to use pollution control devices. There is a lesson here.

Paths to the Future

As we face the future, it is worth recalling what antipollution efforts are up against. The recent report of the World Commission on Environment and Development (W.C.E.D.), *Our Common Future,* stated the situation as follows:

The planet is passing through a period of dramatic growth and fundamental change. Our human world of 5 billion must make room in a finite environment for another human world. The population could stabilize at between 8 billion and 14 billion sometime next century, according to U.N. projections. More *than 90 per cent of the increase will occur in the poorest countries, and 90 per cent of that growth in already bursting cities.*

Economic activity has multiplied to create a $13 trillion world economy, and this could grow five- or tenfold in the coming half-century. Industrial production has grown more than fiftyfold over the past century, four fifths of this growth since 1950. Such figures reflect and presage profound impacts upon the biosphere as the world invests in houses, transport, farms, and industries.

(W.C.E.D. 1987, p. 4)

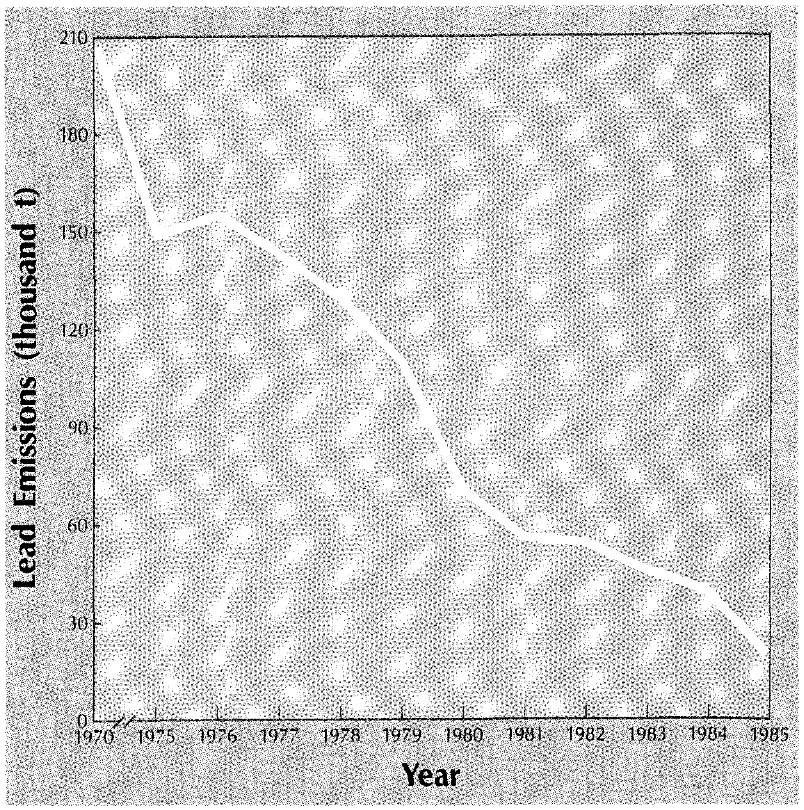
These challenges will require far-reaching responses. Certainly, a major component of future efforts to control pollutants must be to continue and strengthen the efforts already begun. The regulatory programs of the industrial countries have yielded definite results over the last two decades, particularly when judged against the economic expansion of this period, and continuing challenges will require that these programs be enhanced and improved. Monitoring and enforcement capabilities must be strengthened; new types and sources of pollution must be tackled; inter-media effects must be attended to; regional and global approaches to pollution control must become increasingly common; and the overall regulatory process must become more cost-effective, efficient, and streamlined as demands mount on both sides of the bargaining table.

The need for developing countries to face their escalating pollution problems is also acute. These countries can learn from the successes and the failures of the industrial countries—from the various regulatory approaches, the pollution control technologies, the research on health effects and other topics. They should also note the hard economic lessons the industrial countries have learned, including the large economic benefits of controlling pollution and the fact that it is typically cheaper to prevent pollution than to clean it up.

Yet, it is certain that more of the same, even if better, will not be enough to cope with the pollution challenges identified by the World Commission. More fundamental changes will be needed. If global economic activity does increase five- to tenfold over the next half-century, as the commission suggests, the cause of preserving our planetary environment seems lost if this vast growth merely duplicates over and over today's prevailing technologies. Such economic growth can be safely accommodated only if accompanied by a thoroughgoing transformation in the technologies of production, broadly conceived.

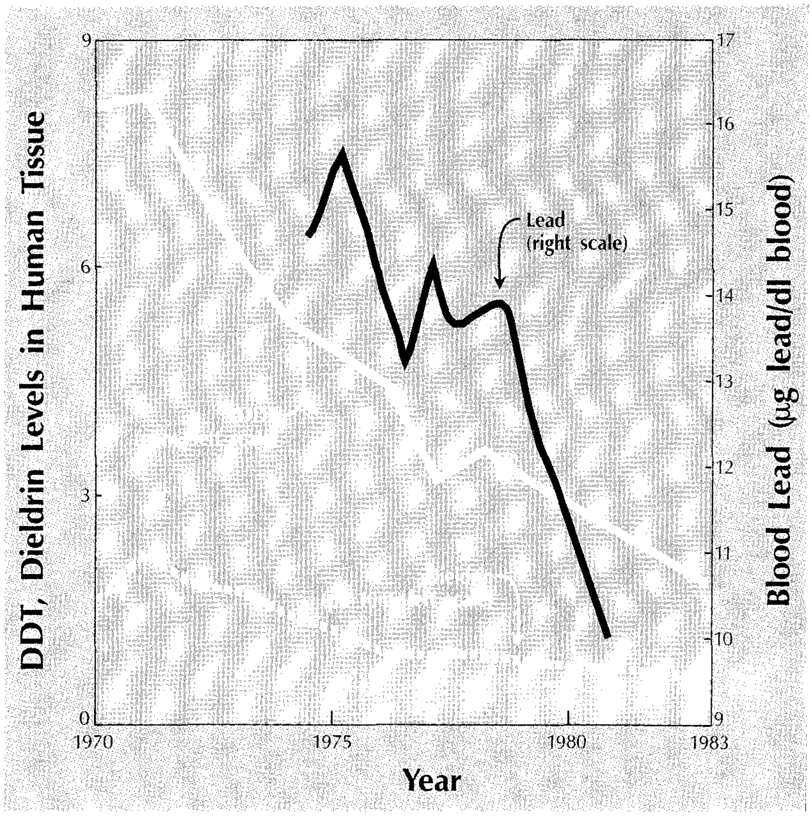
From its origins in the early 1970s, U. S. air- and water-pollution control legislation has recognized that tighter standards could be applied to "new sources" of pollution, in contrast to existing plants. This is because new sources present the opportunity to go beyond "end of pipe" removal of waste products and to build in "process changes" that reduce or eliminate the wastes that must otherwise be removed. The basic concept—source reduction instead of emissions control—writ large, is fundamental to solving world pollution problems. In the long run, the only affordable and effective way to control pollution of the scale and type societies confront today is to work "upstream" to change the products, technologies, policies, and pressures that generate waste and give rise to pollution.

To implement this requirement, and to deal with the pollution challenge in the decades ahead, several large-scale social and technological transitions are needed. The pollution today's societies confront is a huge, multifaceted phenomenon that cuts across economic sectors and regions. Everywhere it



RECENT TRENDS IN LEAD EMISSIONS, UNITED STATES

Figure 17. **Lead emissions have taken a steep downturn as a result of federal regulations, which resulted in a 78 per cent reduction of lead used in gasoline between 1970 and 1985. [source: Environmental Protection Agency. 1987. *National Air Pollutant Emission Estimates, 1940–1985*]**



HUMAN CONTAMINATION BY D.D.T., DIELDRIN, AND LEAD, UNITED STATES

Figure 18. **Between 1976 and 1980, blood lead levels in the United States declined sharply, while D.D.T. concentrations in human tissue are only a fourth of what they were in 1972. [source: lead data—Council on Environmental Quality. 1986. *Environmental Quality 1984*, p. 75; pesticide and P.C.B. data—Environmental Protection Agency. 1987. *National Human Adipose Tissue Survey*, unpublished]**

is integrally related to economic production, modern technology, life-style, the size of human and animal populations, and a host of other factors. Pollution is unlikely to yield except to broad macrotransitions of multiple social benefits. The key questions for policy-makers include: Are these transformations under way? If so, how can societies speed them along? If not, how can they be launched without delay?

Transition 1

Transition 1 is the shift away from the era of fossil fuels toward an era of energy efficiency and renewable energy. The extraction, transport, and, particularly, the combustion of fossil fuels create a huge portion of the world's environmental pollution and many of pollution's most disturbing consequences. Local air pollution problems (for example, smog), regional air pollution problems (for example, acid rain), and global air pollution problems (for example, climate change) are linked both through complex chemical reactions in the atmosphere and through the common origin of most of the pollutants involved: the combustion of fossil fuels.

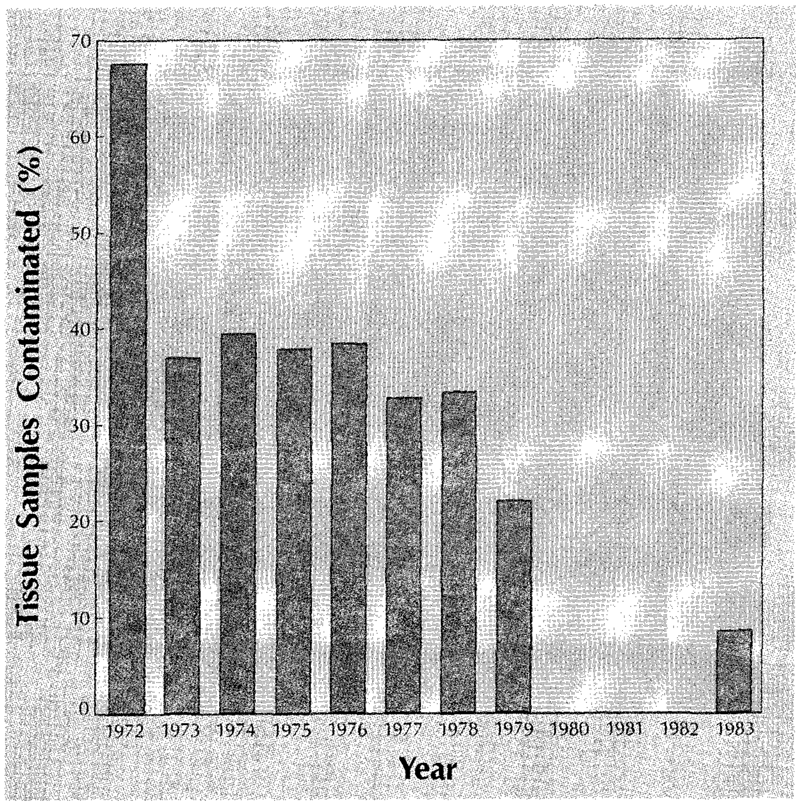
Fortunately, energy analysts are increasingly confident that the technologies and policy tools are at hand to increase energy efficiency greatly and to sharply curtail projected increases in fossil fuel use—if societies can muster the will to use them, and to do so without undermining economic growth. One recent global energy analysis, built up from careful studies of energy use in the United States, Sweden, India, and Brazil, concluded "that the global population could roughly double, that living standards could be improved far beyond satisfying basic needs in developing countries, and that economic growth in industrialized countries could continue, without increasing the level of global energy use in 2020 much above the present level" (Goldemberg *et al.* 1987, p. 12; see also Brown *et al.* 1985, Mintzer 1987, W.R.I. & I.I.E.D. 1986). In this technically and economically feasible future, total energy use goes up only 10 per cent between 1980 and 2020 and fossil fuel use grows even less.

These dramatic and hopeful projections are made possible by the rapid introduction of currently available, energy-efficient technologies in transportation, industry, buildings, and other areas. Recent experience has demonstrated that major improvements in the efficiency with which energy is used are possible. Between 1973 and 1985, per capita energy use in the United States fell 12 per cent while the per capita gross domestic product rose 17 per cent. The average fuel economy of new cars and light-duty trucks increased 66 per cent between 1975 and 1985 (Goldemberg *et al.* 1987). For the O.E.C.D. countries as a whole, the amount of energy needed to produce a dollar of G.N.P. declined by 19 per cent between 1973 and 1984 (Brown *et al.* 1986). Beyond efficiency improvements, commercial prospects for new solar technologies, particularly photovoltaic solar cells, appear increasingly promising. (*New York Times* April 29, 1986, February 11, 1987). These gains are the beginnings of what can be far more pronounced improvements in energy efficiency (Figure 20).

Transition 2

Transition 2 is the move from an era of capital- and materials-intensive, "high-throughput" technologies to an era of new technologies, soft and hard, that do not generate much pollution because they use raw materials very efficiently, rely on inputs that have low environmental costs, recover and recycle materials, and are hence more "closed." The beginnings of this transition can be seen in the current move toward "waste minimization," which one advocate describes as follows:

> *A large multinational corporation saves nearly $400 million over a 10-year period while cutting wastewater generation by 400 billion liters annually; . . . a chemical plant recycles and sells solvent wastes instead of simply discarding them. These are just a few examples that show that the global battle to keep toxic substances and hazardous wastes out of the environment without hampering the pace of industrial development is taking a promising turn . . . .*
>
> *Under the name of* waste minimization *(also called clean technology or low- and non-waste technology in some parts of the world), innovative technologies, management practices, and employee participation concepts are helping to produce the same or equivalent products through less polluting and less costly means . . . . It aims at preventing pollution before it starts. This front-end approach to industry resource management . . . results in less pollution and less production expenditures.*
>
> (Purcell 1987, p. 25)



HUMAN CONTAMINATION BY P.C.B.s, UNITED STATES

Figure 19. **During 1972 to 1983, those with P.C.B. levels above one part per million declined from about 70 per cent of the population to about 10 per cent of the population. [source: Environmental Protection Agency. 1987. *National Adipose Tissue Survey,* unpublished]**

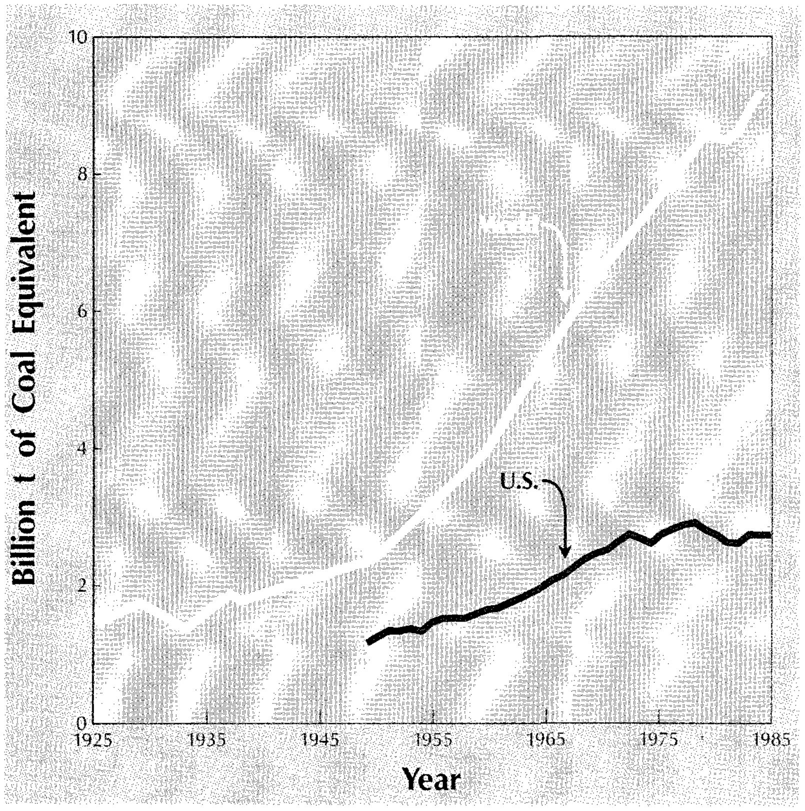
To further these trends, the "polluter pays" concept should be supplemented with another: "pollution prevention pays" (*e.g.,* 3M Company 1985, Royston 1979). Pollution prevention is encouraged by the rising costs of traditional pollution control, but policy-makers should encourage it in other ways as well, for example, by removing obstacles, increasing research and development, and establishing national waste-reduction policies and goals (see, *e.g., Washington Post* September 25, 1986).

Beyond reductions in raw material inputs and waste lie a panoply of other possibilities, from new, safer products that substitute for older, dangerous ones, to entirely new processes and even industries that can use sophisticated design and technology to minimize or eliminate pollution.

Transition 3

Transition 3 is the change to a future in which societies actually apply our most sophisticated technology-assessment capabilities and our best science to "design with nature." Much pollution regulation, for example, has been based on a "one pollutant/one effect" approach, often with the requirement that tight causal connections to environmental damage be identified for the particular pollutant. That, however, is not the way biological systems work. When we look at these systems, human or ecological, we see that they are subject to multiple and interacting stresses, chemical and physical, natural and man-made. New regulatory concepts are needed.

More broadly, new fields of science and technology offer great promise for understanding pollution, monitoring its sources, and reducing its presence. "Today we stand on the threshold of a renaissance in the sciences concerned with planet Earth," scientist Thomas F. Malone (1986, p. 6) recently wrote. This new field, Earth-systems science or biogeochemistry, offers a powerful new tool for understanding the planet's structure and metabolism. It is urgent that this new science be developed and applied, for the natural cycles of carbon, sulfur, nitrogen, and phosphorus that are among its primary subjects are now being affected on a global scale by pollution and other human activity. For example, human nitrogen fixation, in fertilizers and industry, is now estimated to be about half natural fixation of nitrogen. A major step toward realizing the potential



WORLD AND U. S. ENERGY CONSUMPTION

Figure 20. **U. S. consumption of energy has been leveling off, thanks to energy-efficient technologies in transportation, industry, buildings, and other areas. Meanwhile global energy use has continued to rise. [source: Darmstadter, J. 1971. *Energy and the World Economy.* Johns Hopkins; U. N. Statistical Office, 1984 and 1987. *Energy Statistics Yearbook 1982* and *1985.* New York; Department of Energy. 1987. *Annual Review of Energy 1986*]**

of the new Earth science has been taken with the 1986 launching of the International Geosphere–Biosphere Program (I.G.B.P.) under the leadership of the International Council of Scientific Unions.

Industrial agriculture is a leading source of pollution today, and here the new applied science of agro-ecology offers promise. The ecological approach to agricultural production stresses low inputs of commercial fertilizers, pesticides, and energy and, in the alternative, biological recycling of energy and nutrients and primary reliance on naturally occurring methods for crop protection (*e.g.,* Dover & Talbot 1987). Combined with rapid progress made in organic farming and in integrated pest management as an alternative to exclusive reliance on pesticides (Dover 1985, Reganold *et al.* 1987, *Washington Post* November 20 & 23, 1987), agro-ecology offers the prospect of an agriculture redesigned to be sustainable both economically and environmentally.

We live in an era of unprecedented technological change. Major new fields—biotechnology, computers and telecommunications, superconducting and other new materials, remote sensing, photovoltaics—offer solutions to some of our most severe pollution and other challenges (*e.g., Business Week* 1987b, Coulson *et al.* 1987, N.A.S. 1979). Yet much experience teaches that these and other emerging technologies can also give rise to serious problems of their own (Levin & Harwell 1986, Pimentel 1987). Governmentally sponsored technology assessments are an important part of the process of public influence on the direction of technological change. (See, for example, those carried out for the U. S. Congress by the Office of Technology Assessment and for the Executive Branch under the National Environmental Policy Act; also see *Scientists' Institute for Public Information v. Atomic Energy Commission,* 481 F.2d 1079 [D. C. Cir. 1973], requiring the application of N.E.P.A.'s environmental impact statement process to provide a technology assessment of the Atomic Energy Commission's fast breeder-reactor program.) A strong governmental role in technology assessment and choice is necessary if the full potential of emerging technologies is to be realized.

Transition 4

We should make a transition to an honest economics in which policies do not subsidize the use of raw materials or the generation of waste. Private companies and governments should "internalize the externalities" so that the prices of goods and services on the marketplace reflect the true social costs of production, including the costs of pollution to society. And national income accounts should treat the depreciation of natural assets just as rigorously as they do the depreciation of capital assets.

Creating effective economic incentives and disincentives is essential to long-term pollution control, and making the market mechanism work better by "getting the prices right" is an essential means to that end. Recent studies at the World Resources Institute have shown that many, perhaps most, countries are today subsidizing the use of water and chemicals in agriculture, energy, and other resources and thus encouraging overuse, waste, and pollution (Kosmo 1987; Repetto 1985, 1986a, b). Not only should we eliminate such subsidies (with appropriate measures to counter possible impacts on the poor), but we should seriously consider national or global taxes or fees on such important pollutants as carbon and sulfur.

The market is a powerful force, and market economies appear to be more successful at controlling pollution than are centrally planned ones (Brown *et al.* 1987). We must do much more to harness market forces for environmental objectives.

Transition 5

Fifth, we should move to more international approaches to reducing pollution. As we have seen, pollution problems are increasingly international and even global. The head of the O.E.C.D. Environmental Directorate recently made the case for international agreements as follows:

> *No state can escape from being influenced by developments elsewhere. The emergence of transfrontier pollution and the need for concerted action to reduce pollution have already modified concepts of national interest and international obligations. The realities of international interdependence, as we are facing them today, call for strengthened efforts to accelerate this progress.*
>
> (Lykke 1987, p.8)

Environmental cooperation at the international level is most advanced in countries of the European Community, where pollution control is increasingly a Community matter. Perhaps the most impressive international accords to date on pollution are the 1979 Geneva Convention on Transboundary Air Pollution (with its path-breaking 1984 protocol for a 30 per cent reduction in sulfur oxide emissions), and the Vienna Ozone Layer Convention (with its 1987 Montreal Protocol restricting chlorofluorocarbon emissions). Whether we like it or not, the diplomatic agendas of nations will increasingly feature pollution and other environmental issues.

Transition 6

And sixth is the evolution to a stable world population. Global population growth should be halted before it doubles again. Appropriate policies would be to promote economic advancement, education, and health; and to improve the status of women, infant care, and family planning services (Repetto 1985b). It will be difficult enough to cope with pollution in a world where population has grown from 5 billion to 8 billion people.

Conclusion

These six transitions, the reader will doubtless note, are the product of a deep appreciation of the importance of economic and technological forces in the modern world. But if solutions are found, they will come from another realm as well—from the hopes and fears of people, from their aspirations for their children and their wonder at the natural world, from their own self-respect and their dogged insistence that some things that appear to be very wrong are in fact very wrong. People everywhere are offended by pollution. They sense intuitively that we have pressed beyond limits we should not have exceeded. They want to clean up the world, make it a better place, be good trustees of the Earth for future generations. With Thoreau, they know that heaven is under our feet as well as over our heads. Politicians around the globe are increasingly hearing the demand that things be set right. And that, at least, is very good news indeed.

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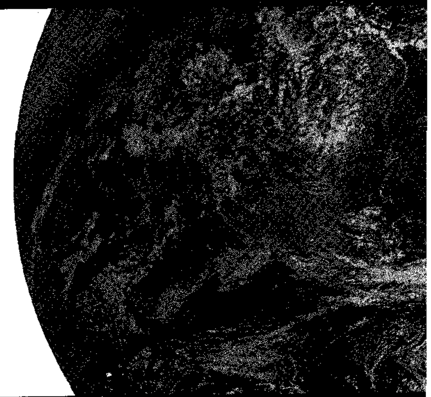

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