ARTICLES

Science, Policy, and Environment in the 21st Century

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Humanity in the twenty-first century faces a new generation of environmental challenges. These differ significantly from past environmental problems that were familiar local accompaniments to the industrialization process. In the mid-1970s, the first truly global threat to the planet – depletion of the stratospheric protective ozone layer – was theorized, derided, hotly debated, and ultimately proven true, later earning for its discoverers the Nobel Prize. In the years following, scientists across a broad range of disciplines began to sound alarms about other portentous environmental changes caused by human activities: the greenhouse effect and climate change, the mass extinction of species and loss of biological diversity, the worldwide destruction of forests and habitat, the diffusion of persistent organic pollutants, the spread of desertification and land erosion, the pollution of oceans and coastal waters, and the growing pressures on fresh water.

These new environmental issues share several common features. They are global in scope, transcending national boundaries and affecting all, or substantial portions of, the world's population. They are slow in developing and long-term in their consequences; they may be irreversible over generations, or even forever, once their impacts become entrenched. Addressing these threats requires an unprecedented degree of international cooperation, involving governments, intergovernmental bodies, the private sector, and, indeed, all of society. And, significantly, the problems are characterized by considerable scientific uncertainties concerning their causes, impacts, feedbacks, and the interrelationships among complex natural and social parameters.

It is, therefore, fair to say that the scientific community bears, in this new century, a special responsibility both to identify and assess risks, and to devise solutions to complex and often interrelated threats to the planet's natural cycles – a responsibility upon which the future of human welfare may well depend. At the same time, political and economic decision makers have a concomitant responsibility to take heed of the messages of science, as well as to encourage scientific curiosity and provide adequate research funding.

From this perspective of the indispensable future interaction between science and policy, I would like to analyze the experience of the most successful global environmental agreement to date, the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer -- a treaty that has been characterized by the heads of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) "as one of the great international achievements of the century." [1]

Given the threats to life on Earth that have been averted through this landmark treaty, few would challenge their statement as hyperbole. Ozone, whose existence was unknown until 1839, has been characterized as "the single most important chemically active trace gas in the earth's atmosphere." [2] Absent the protection of the thin and constantly varying stratospheric ozone layer, life as it currently exists could not have evolved on this planet.

The Montreal Protocol, by phasing out certain chemicals, preserved the integrity of the stratospheric ozone layer that absorbs harmful ultraviolet radiation from the sun. Depletion of this thin gaseous shield – which, if compressed to the planet's surface, would be no thicker than gauze -- would have incalculable impacts on human, animal, and plant cells, as well as on climate and ecological systems. Research has indicated that if anthropogenic ozone-depleting substances had continued their rapid accumulation in the upper atmosphere, there would have been a "runaway increase" in skin cancer within decades. [3]

And yet, even while the Montreal Protocol was being negotiated during 1986 and 1987, few observers believed that it would be possible for governments to agree on any strong international controls over the production and consumption of the suspected ozone depleting chemicals. The scientific, economic, technological and political factors underlying the negotiations were staggeringly complex.

The science itself remained speculative, relying upon projections from evolving computer models of imperfectly understood atmospheric processes – models that had yielded differing, often contradictory predictions each time that they were refined. Moreover, actual measurements revealed neither the theorized mid-latitude depletion of ozone nor any of the predicted harmful effects. [4]

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[1] P. Obasi and E. Dowdeswell, Foreword to R. Bojkow, *The Changing Ozone Layer* (Geneva: WMO/UNEP, 1995).

[2] D. Albritton et. al., *Stratospheric Ozone: The State of the Science and NOAA's Current and Future Research* (Washington, D.C.: National Oceanic and Atmospheric Administration, 1987), p.1.

[3] H. Slaper et. al., "Estimates of Ozone Depletion and Skin Cancer Incidence to Examine the Vienna Convention Achievements," *Nature* 384 (November 21, 1996):256.

[4] At the time, the Antarctic "ozone hole" was considered by most scientists as an anomaly, since it did not conform to theoretical ozone depletion models and could possibly have had other than anthropogenic causes.

Chlorofluorocarbons (CFCs) and related substances were virtually synonymous with modern standards of living. Indeed, they had seemed to be the perfect chemicals: nonflammable, nontoxic, and noncorrosive – and easy and inexpensive to manufacture. During the 1980's, entrepreneurs found new applications for CFCs in thousands of products and processes across dozens of industries, from electronics, refrigeration, insulation, and plastics, to telecommunications, aerospace, pharmaceuticals, and transportation. Powerful political and economic interests thus became aligned to oppose meaningful controls.

Nevertheless, the Montreal Protocol was signed in September 1987 and entered into force in January 1989. Within three years it had been ratified by more than 100 countries and had undergone two major revisions. Unexpectedly, the "smoking gun" of CFC complicity in the Antarctic ozone hole was proven in March 1988, and governments then moved rapidly to strengthen the treaty. The list of controlled substances was increased from 8 to over 90, and the timetables for reduction and phase-out of the dangerous chemicals were significantly strengthened.

Within a few more years, a total of nearly 170 nations had joined the protocol. [5] A veritable technological revolution was unleashed that transformed entire industries. The protocol created the first-ever global environmental fund to assist developing nations, and promoted an unprecedented North-South cooperation in research and diffusion of innovative technologies that have now made ozone-depleting substances obsolete.

Even so, it was not inevitable. For decades after their discovery in the 1930's, no one suspected that these "wonder-chemicals" could cause any harm – much less to the critical ozone layer. And, because the CFCs and their cousins have such long atmospheric lifetimes, their deleterious impacts will still be felt for decades, even after new emissions cease.

Unquestionably, science and scientists were the indispensable element in the success of the Montreal Protocol. Without the courage of a handful of curious researchers in the mid-1970's, the world would have learned too late of the deadly, hidden dangers associated with rapidly expanding use of CFCs. The now legendary hypotheses of Sherwood Rowland and Mario Molina at the University of California-Irvine in 1973 initially unleashed a firestorm of criticism and controversy. Together with Paul Crutzen of the Netherlands, they were vindicated by the 1995 Nobel Prize in Chemistry, but it is worth noting that the first popular book on this subject, published in 1978, was entitled *The Ozone War.* [6]

The complexity of the research effort was noteworthy. Ozone amounts to considerably less than one part per million of the total atmosphere, and 90 percent of it is found above six miles in altitude. The intrinsically unstable ozone molecules were continually being created and destroyed by dimly understood natural forces involving solar radiation and interactions with even more minute quantities of trace gases. To complicate matters, stratospheric ozone concentrations fluctuate considerably on a daily, seasonal, and solar-cyclical basis; there are also sizeable geographical and altitudinal variations.

Amidst all these fluxes, scientists faced a formidable challenge in predicting, and then detecting, the minuscule "signal" of a downturn in stratospheric ozone concentrations, not to mention linking such a development to CFCs. This necessitated the development of ever more sophisticated computer models to simulate the stratospheric interplay among radiative, chemical, and dynamic processes such as wind and temperature -- and projecting this for decades or centuries into the future. Intricate miniaturized measuring devices were created and fitted onto aircraft, satellites, and rockets in order to monitor remote gases in quantities as minute as parts per trillion.

To understand the implications of a fading ozone layer, scientists had to venture far beyond atmospheric chemistry: they had to examine our planet as a system of interrelated physical, chemical and biological processes on land, in water, and in the atmosphere – processes that are themselves influenced by economic, political, and social forces. The Montreal Protocol became a truly multi- and interdisciplinary effort. Over the years, researching the dangers and solutions involved, not just chemists and physicists, but also meteorologists, oceanographers, biologists, oncologists, economists, soil scientists, toxicologists, agronomists, pharmacologists, electrical, chemical, automotive and materials engineers, botanists, entomologists, and more.

It was not sufficient, moreover, for scientists merely to publish their findings. In order for the theories to be taken seriously and lead to concrete countermeasures, scientists had to interact with diplomatic negotiators and government policy makers. This meant that they occasionally had to leave the familiar atmosphere of their laboratories and assume an unaccustomed shared responsibility for the policy implications of their research. The history of the Montreal Protocol is replete with instances of scientists being called upon to analyze and report on the implications of alternative remedial strategies and policy measures.

International scientific consensus was also a crucial element. The development of an accepted common body of data and analysis was the prerequisite for a political solution among nations whose opening negotiating positions were essentially incompatible. In 1984, a remarkable international research cooperation was spearheaded by the National Aeronautics and Space Administration

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See e.g., Albritton et. al., S*tratospheric Ozone*, p. 9; WMO, *Atmospheric Ozone 1985: Assessment of Our Understanding of the Processes Controlling Its Present Distribution and Change* (Geneva, 1986), chap. 14.

[5] R. Benedick, *Ozone Diplomacy: New Directions in Safeguarding the Planet* (Cambridge, MA. and London: Harvard University Press, rev. ed. 1998), provides a history and analysis of the ozone issue and the Montreal Protocol negotiations.

[6] L. Dotto and H. Schiff, *The Ozone War* (Garden City, NY: Doubleday, 1978).

(NASA) and the National Oceanic and Atmospheric Administration (NOAA), together with the WMO, UNEP, the Federal Aviation Administration, the German Ministry for Research and Technology, and the Commission of the European Communities.

The Montreal Protocol later institutionalized this concept by establishing international expert panels to periodically assess scientific, technological, economic, and environmental knowledge, and thereby guide the negotiators in the further evolution of the treaty. Over the years hundreds of scientific experts from dozens of countries participated in the drive to learn more about the risks as well as the possible technological solutions. This proved to be a central element in the protocol's success, facilitating agreement by negotiators on additional, ever stronger measures to protect the ozone layer. In effect, the Montreal Protocol was deliberately designed as a dynamic process of narrowing the ranges of uncertainties, rather than a static solution based on the status quo.

The role of scientists in the ozone history provided some important lessons for climate change. During the 1980's, a few assessments on climate change had been issued under the aegis of WMO and UNEP, developed by a small group of mainly self-selected scientists called the Advisory Group on Greenhouse Gases. While preparing for the final ozone negotiation in Montreal, I recommended in the summer of 1987 that the US government take an initiative to establish a formal international assessment body on climate change, similar to what we were doing on the ozone issue. My belief was that findings would be more credible if they came from a larger and more diverse group of scientists under intergovernmental auspices.

This proposal attracted some unexpected allies and opponents. Anti-environmentalist officials within the Reagan Administration – who only a few short months earlier had tried to replace me as chief US negotiator on ozone -- endorsed the idea, hoping that it would give governments more control over the science. In contrast, some environmentalists feared that the process would become distorted by politics. My own feeling, grounded in the ozone experience, was that the vast majority of scientists would be unlikely to allow themselves to be diverted by political or commercial interests, and that governments would sooner be co-opted by the science than vice versa.

The subsequent experience of the Intergovernmental Panel on Climate Change, founded in 1988, confirmed my expectation concerning the independence of the participating scientists. However, it should be noted that there is at present a critical difference between the science underlying the negotiations on the ozone layer and the science of climate change. In both cases, the theory was robust. In the case of climate change, there is no dispute that an indefinite accumulation of greenhouse gas concentrations would lead to potentially calamitous alterations in the climate system. But it is not yet possible to predict how far into the future serious effects would occur. There is still considerable uncertainty about the probability, timing, location, and severity of the potential harmful impacts of climate change, which include flood, drought, rising sea levels, the spread of tropical diseases, extinction of species, and increased extreme weather events. In contrast, the probable consequences of ozone layer depletion were strikingly clear for the negotiators: the impacts would be global and fatal, and within a time-span of decades.

Another useful lesson from the Montreal Protocol's success is the importance of public education: interpreting the continually evolving and sometimes confusing data, and communicating the science intelligibly, yet without exaggeration, to the general public and the media. This information flow mobilized public opinion on the potential dangers of a diminishing ozone layer, and thereby fostered political consensus for both policy measures and for funding research. The proponents of strong actions to protect the ozone layer generally did not sensationalize their conclusions merely in order to capture media and public attention. In this way, they maintained their credibility and, importantly, they did not inadvertently provide gratuitous ammunition to those interests that sought to downplay the danger of ozone layer depletion.

Here again, the currently ongoing climate negotiations present a contrast to the Montreal Protocol. Perhaps frustrated by initial public indifference to the indefinite and future dangers of climate change, some advocate organizations, especially in Europe, became tempted to exaggerate the threats and immediacy of climate catastrophe ("Klimakatastrophe"). The particularly hot summer of 1988 encouraged some groups to foment a sense of panic; popular publications (also in the US) featured cover stories with the Empire State Building or Eiffel Tower partially submerged by raging tides. When the following summers were more normal, public interest waned, even though some activists (not scientists) continued to label every serious hurricane or flood as evidence of climate change. Damage had been done, and not only to credibility. The exaggerations tended to polarize the debate and to harden the position of industries and others who were reluctant to admit the legitimacy of the problem.

Information, and particularly sober and accurate information, is thus a critical factor in the linkage between science and policy. The power of the media – and the consumer – should never be underestimated. Between 1976 and 1978, US media interest in the fate of the ozone layer, promoted and nurtured by scientists, legislators, and environmental organizations, stimulated decisions made by millions of individual consumers that led to the collapse of the domestic market for CFC aerosol sprays -- even before there was any government regulation. Later, UNEP and WMO played prominent roles, using workshops, publications, and electronic media, in disseminating relevant information, including the availability of new technologies, to officials, businesses, and the general public throughout the world.

The success of the Montreal Protocol also underscored the necessity of providing adequate funding for all levels of science, from curiosity-driven basic research to applied engineering solutions. While most ozone research funding originally came from governments, for example NASA and NOAA in connection with their space-related research, this was not always the case. In 1985, at a time when the U.K. Government was still opposed to strong controls over CFCs, it ceased financing British scientists in Antarctica who were coming up with disturbing evidence of stratospheric ozone losses. Interestingly, the gap was filled by the

US Chemical Manufacturers Association, which, although also not in favor of controls, was nevertheless even more concerned that the uncertainties finally be resolved -- one way or the other – so that they could plan for the future.

Research investments by the private sector later proved crucial in developing substitutes for the ubiquitous CFC family of chemicals. Unusual public-private partnerships found ozone-friendly solutions for products and processes where it had never been thought possible. In one case, Greenpeace teamed up with a former East German company to develop CFC-free refrigerators, which subsequently were adopted in European markets and then promoted in China and India by the German and Swiss aid programs. The technological revolution had many novel aspects, ranging from cooperation by AT&T and a Florida citrus grower in developing new solvents for electronic circuit boards, to China's indigenous approach to replacing styrofoam with a biodegradable product of grass and straw. Scientists and engineers again played a central role in solving the problems of replacing the harmful chemicals.

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"Politics," stated Lord Kennet during ozone debates in the House of Lords, "is the art of taking good decisions on insufficient evidence." [7] The memorable success of the Montreal Protocol stands as a beacon for how science can guide decision makers to overcome conflicting political and commercial interests and reach desirable outcomes. The ozone history demonstrates that, even in the real world of ambiguity and imperfect knowledge, the international community -- with the strong assistance of science -- is capable of undertaking difficult and foresighted actions for the common good.

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[7] U.K. House of Lords, *Hansard* 500 (October 20, 1988): col. 1308.