

# Science and Diplomacy: Montreal Protocol on Substances that Deplete the Ozone Layer

*K. Madhava Sarma and Stephen O. Andersen*

---

**ABSTRACT.** The ozone layer forms a thin shield in the stratosphere, protecting life on Earth from harmful ultraviolet radiation. Emissions of ozone-depleting substances (ODS) used in many sectors (such as refrigeration, air-conditioning, foams, and firefighting) destroy stratospheric ozone. Increased ultraviolet radiation from major depletion of stratospheric ozone can cause increases in skin cancer and cataracts, weaken the human immune systems, damage some agricultural crops, impact natural ecosystems, and degrade materials such as plastic. The Montreal Protocol on Substances that Deplete the Ozone Layer seeks worldwide phaseout of the production and consumption of ODS. Scientists confirmed that the protocol is working and that the ozone layer is on its way to recovery around the year 2050. Science and technology, including research at Antarctic stations proving that manufactured chemicals destroy stratospheric ozone and cause the Antarctic ozone hole, played important roles in the evolution and success of the protocol. Scientists provided early warning about the issue, discovered the Antarctic ozone hole, and linked it to CFC emissions and, along with nongovernmental organizations and the media, informed the public. The United Nations Environment Programme facilitated negotiations by governments. Science and technology panels of the protocol verified the performance of and facilitated periodical strengthening of the protocol. The scientific findings stimulated and motivated industry to innovation of alternatives to ODS. The protocol promoted universal participation, early action, continuous learning, and progressively tougher action. The protocol's Multilateral Fund and its implementing agencies assisted developing countries through technology transfer, creation of national focal points and networks, training, and introduction of regulations and policies.

## INTRODUCTION

The Antarctic Treaty of 1959, one of the first treaties to protect global commons, formalized scientific cooperation, set aside Antarctica as a scientific preserve, established freedom of scientific investigation, and banned military activity on the Antarctic continent.

The Vienna Convention for the Protection of the Ozone Layer, 1985, and its Montreal Protocol on Substances that Deplete the Ozone Layer, 1987, promote global cooperation to meet the global threat of stratospheric ozone depletion. The Antarctic Treaty was a research platform for the science that later proved essential for the protection of the ozone layer. The Antarctic is (1) the

---

*K. Madhava Sarma (deceased), United Nations Environment Programme and Montreal Protocol Technology and Economic Assessment Panel, Chennai, India. Stephen O. Andersen, Montreal Protocol Technology and Economic Assessment Panel, 2317 North Road, Barnard, Vermont 05031-0257, USA. Correspondence: Anderson, soliverandersen@aol.com.*

first place on Earth where ozone depletion was observed to be depleted at alarming rates, (2) the location of an alarming “ozone hole” that inspired the global action, (3) the place where scientists established the link between CFCs and ozone depletion, and (4) the place from where important data will continue to be generated on the expected recovery of the ozone layer.

The ozone layer forms a thin shield in the stratosphere, protecting life on Earth from the harmful effects of excessive ultraviolet radiation (UV). Emissions of human-made ozone-depleting substances (ODS) transported by the wind to the stratosphere release chlorine and bromine atoms that destroy ozone. Excessive UV radiation increases the risk of skin cancer, weakens human immune systems, damages crops and natural ecosystems, and degrades paint and plastic.<sup>1</sup> Most of these ODS are also greenhouse gases that contribute to climate change, causing glacier melting and sea level rise, and changes in precipitation and temperature.<sup>2</sup>

Ozone-depleting CFCs were invented in 1928 by a technologist working for General Motors and were marketed by DuPont to replace ammonia, sulphur dioxide, and other flammable and toxic refrigerants. CFCs are non-reactive and nonflammable, have low toxicity, and have a long atmospheric life. They were considered wonder gases and quickly became favored as in many applications.

By the late 1980s, more than 250 separate product categories were made with, or contained, ODS. Many of these products had become vital to society.

The more critical uses of ODSs included medical applications (metered-dose medicine inhalers and sterilisation); refrigeration; air-conditioning; foam; solvents for cleaning of electronic and mechanical components; soil, building, and commodity fumigation; and fire protection.

The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) of 1987, as amended from time to time, has been hailed as the most successful environmental agreement ever. This is the only international agreement with participation of all 196 countries of the world. A pattern of fruitful collaboration has been established between scientists, governments, nongovernmental organizations (NGOs), media, and UN organizations: science leading to understanding, understanding leading to policy, policy leading to implementation, and implementation leading to global environmental protection.

If there were no Montreal Protocol, the chlorine and bromine in the atmosphere would be, by the year 2065, 40 times higher than its natural level. Total ozone would have decreased by two-thirds, which would have ultimately

resulted in many more millions of cases of skin cancer and cataracts and would have irreparably damaged agriculture and ecosystems. The reasons for the success of the protocol may be summarized as

- the strong role played by scientists and technologists in the foundation and evolution of the protocol,
- the development and deployment of ozone-safe technologies by industry, and
- the protocol regime facilitating universal participation and transferring ozone-safe technologies expeditiously to developing countries on fair terms.

### SCIENCE AS A SOURCE OF EARLY WARNING

Scientists have known the importance of the ozone layer from 1930, and some countries regularly monitored the atmospheric ozone. In preparation for the International Geophysical Year in 1957–1958, a worldwide network of scientific stations was developed to measure ozone profiles and the total column abundance of ozone using a scientific instrument and procedure pioneered by Gordon M. B. Dobson. The World Meteorological Organization (WMO) established the framework for ozone-observing projects, related research, and publications; this network eventually became the Global Ozone Observing System, with approximately 140 monitoring stations. The British, Japanese, and North American scientific stations in Antarctica in 1957 installed ozone monitors, which eventually recorded the high depletion of the stratospheric ozone that is called the Antarctic ozone hole.

In 1970, Paul Crutzen of the Netherlands demonstrated the importance of catalytic loss of ozone by the reaction of nitrogen oxides and theorized that chemical processes that affect atmospheric ozone can begin on the surface of the Earth.<sup>3</sup> Nitrogen oxide emissions result from industrial and medical processes and, to a small extent, from use of NO<sub>2</sub>-propelled aerosol products. They are also formed in the atmosphere through chemical reactions involving nitrous oxide (N<sub>2</sub>O), which originates from microbiological transformations on the ground. Therefore, Crutzen theorized increasing atmospheric concentration of nitrous oxide from the use of agricultural fertilizers might lead to reduced ozone levels. At the same time, James Lovelock of the United Kingdom measured air samples in the North and South Atlantic and reported in 1973 that CFCs had been detected in every one of his samples, wherever and whenever they were sought.<sup>4</sup>

In 1971, Harold Johnston of the United States showed that the nitrogen oxides produced in the high-temperature exhaust of the proposed fleet of SSTs could contribute significantly to ozone loss by releasing the nitrogen oxides directly into the stratospheric ozone layer.<sup>5</sup> In 1972, Crutzen elaborated on this theory with a paper that explained the process by which ozone is destroyed in the stratosphere, and presented estimates of the ozone reduction that could result from the operation of supersonic aircraft.<sup>6</sup>

Another American, James McDonald, theorized in 1971 that even a small change in the abundance of stratospheric ozone could have significant effects in transmitting more ultraviolet radiation to the surface of the Earth, affecting the incidence of skin cancer. In March 1971, the U.S. House of Representatives voted not to continue funding development of the American SST. Subsequently, in 1974, the U.S. Department of Transportation completed the first comprehensive scientific assessment of stratospheric ozone depletion called the “Climatic Impact Assessment Program—CIAP.” In 1973, Pan Am and TWA cancelled their orders for Concorde SSTs. Only British Airways and Air France purchased Concorde aircraft for routes across the Atlantic Ocean. Recently, for reasons of safety, all Concorde flights have been discontinued.

Mario J. Molina and F. Sherwood Rowland, two chemists at the University of California at Irvine, were the first to study CFCs as a possible source of chlorine in the stratosphere. CFCs refer to all fully halogenated compounds containing chlorine, fluorine, and carbon. In a paper published in the 28 June 1974 issue of *Nature*, Molina and Rowland hypothesized that when CFCs reach the stratosphere, ultraviolet radiation causes them to decompose and release chlorine atoms, which, in turn, become part of a chain reaction; as a result of the chain reaction, a single chlorine atom would destroy as many as 100,000 molecules of ozone.<sup>7</sup> Rowland and Molina estimated that “if industry continued to release a million tons of CFCs into the atmosphere each year, atmospheric ozone would eventually drop by 7 to 13 percent.”

### SCIENCE AS A FORCE FOR CHANGE

Rowland and Molina did not rest with their theoretical discoveries. They foresaw the danger to the planet and, with the encouragement of the Natural Resources Defense Council (NRDC), an NGO, presented their findings and held a press conference at a meeting of the American Chemical Society in 1974. Rowland reported that if CFC production rose at the then-current rate of 10 percent a

year until 1990, and then levelled off, up to 50 percent of the ozone layer would be destroyed by the year 2050. Even a 10 percent depletion, he said, could cause as many as 80,000 additional cases of skin cancer each year in the United States alone, along with genetic mutations, crop damage, and possibly even drastic changes in the world’s climate.

In January 1975, a report of the U.S. National Academy of Sciences and Department of Transportation confirmed similar findings. These reports laid the foundation for widespread public concern and forced the governments to consider regulatory action.

The significant media coverage of Molina and Rowland’s press conference at the meeting of the American Chemical Society in 1974 resulted in headlines in the U.S. media such as “Aerosol Spray Cans May Hold Doomsday Threat.” The U.S. environmentalists were galvanized. Many consumer groups demanded a ban on the use of CFCs in aerosols, a “frivolous use.” The NRDC petitioned the U.S. Consumer Product Safety Commission to ban the use of CFCs in aerosols. The media exposure motivated several governments, including Canada, Sweden, and the United States, to take measures to reduce the ODS consumption wherever alternatives were readily available.

### SCIENCE AS A SOURCE OF ISSUES ON THE POLICY AGENDA

The U.S. National Academy of Science, in a 1976 report, confirmed the earlier findings and further noted that CFCs were produced and used around the world, advising, “Clearly, although any action taken by the United States to regulate the production and use of CFMs [CFCs] would have a proportionate effect on the reduction in stratospheric ozone, such action must become worldwide to be effective in the long run.” Thus, was born the concept of a global stratospheric ozone depletion problem that needs action by the entire world for it to be solved.

### SCIENCE AS A CONFIDENCE-BUILDING ACTIVITY

Since individual scientists of a few countries came up with ozone depletion discoveries, the challenge was convincing the governments of the world of the threat to the ozone layer. Hence, many countries felt it was necessary for the UN to organize scientists from many countries in a collaborative effort.

The UN organized the Conference on Human Environment in Stockholm, Sweden, in June 1972, the first of such global environment conferences. The institutional arrangements set out in the conference report led to the establishment of the UN Environment Programme (UNEP). The “Pollutants” paper of the conference called for research on how human activities influenced the stratospheric transport and distribution of ozone.

In April 1975, the UNEP Governing Council backed the Outer Limits Programme to protect stratospheric ozone and other vulnerable global commons.<sup>8</sup> At its meeting in April 1976,<sup>9</sup> the council requested the executive director to convene a meeting to review all aspects of the ozone layer, identify related ongoing activities and future plans, and agree on a division of labor and a coordinating mechanism for the compilation of research activities and future plans and the collection of related industrial and commercial information.

In March 1977 a meeting convened by UNEP in Washington, D.C., in accordance with this mandate agreed a World Plan of Action on the Ozone Layer and established the UNEP Coordinating Committee on the Ozone Layer. The basic components of the action plan were

- coordinate atmospheric research (WMO);
- study the impact of changes in the ozone layer/biosphere (World Health Organization [WHO], WMO/UNEP, and Food and Agriculture Organization [FAO]);
- assess the impacts on human health (WHO);
- investigate other biological effects (FAO);
- develop computational climate models (WMO) and study regional climate effects (FAO);
- research socioeconomic aspects (UNEP, International Chamber of Commerce [ICC], Organization for Economic Cooperation and Development [OECD], and International Civil Aviation Organization);
- evaluate aircraft emissions, nitrogen fertilizers, and other potential modifiers of the stratosphere (UN Department of Economic and Social Affairs and OECD); and
- identify institutions to implement the action plan: UN bodies, specialized agencies, international, national, intergovernmental, and nongovernmental organizations, and scientific institutions.

The many reports of the UNEP Coordinating Committee on the Ozone Layer and National Academy of Sciences convinced many governments of the danger to the ozone layer. However, some countries of Europe and the companies that manufactured the CFCs were not convinced that CFC emissions were the primary cause of

ozone depletion. They wanted more studies. To develop a world consensus, UNEP initiated diplomatic negotiations in 1982. The negotiations went on for three years, resulting in the Vienna Convention for the Protection of the Ozone Layer, 1985 (Vienna Convention), which agreed on further research but no steps for curbing the emissions of CFCs, in view of the scepticism of some countries. The labors of the scientists continued, and governments agreed to continue negotiations.

Seven international agencies teamed up to write a three-volume assessment of the state of the ozone layer in 1985. The report calculated the predicted magnitude of ozone perturbations for a variety of emission scenarios involving a number of substances. As early as October 1981, Dobson instrument measurements from Japanese, British, and other research stations recorded reductions in ozone levels above Antarctica. In 1984, Shigeru Chubachi of the Japanese Meteorological Research Institute reported his findings on declining ozone amounts over Antarctica but did not suggest that there was anything unusual about these data.<sup>10</sup> By May 1985, Farman, Gardiner, and Shanklin of the British Antarctic Survey had realized the scientific significance of the widespread measurements that ozone levels above Antarctica were significantly depleted every Antarctic spring. Unlike Chubachi, they chose to publish their findings in *Nature*, where the policy significance would be appreciated, and to suggest a connection between ozone depletion and chlorofluorocarbons.<sup>11</sup> The phenomenon of ozone depletion over Antarctica became known as the “ozone hole.” Another International Ozone Trends Panel in 1988 confirmed and expanded these findings.

### SCIENCE AS A BEACON TO INDUSTRY

In early 1986, representatives of the companies DuPont, Allied, and ICI separately reported that between 1975 and 1980, they had identified compounds meeting environmental, safety, and performance criteria for some CFC applications but had terminated research and development when they concluded that none were as inexpensive as CFCs and there would be no market for the alternatives.<sup>12</sup> The U.S. Environmental Protection Agency quickly organized a team of international experts, who confirmed, by consensus, that a wide range of chemical alternatives with no or low ozone depletion potential (ODP) could be commercialized at just three to five times the price of the ODSs they would replace. Since ODSs are typically a very small part of total cost of products, the higher ODS price was considered insignificant and well worth the benefits of ozone layer protection.

Industry attitudes had changed considerably by December 1986. Previously, producers and users of CFCs argued that further regulations were uncalled for until science proved the ozone depletion theory. The industry coalition Alliance for a Responsible CFC Policy changed its position in 1986 and said that it would support a reasonable global limit on the future rate of growth of fully halogenated CFC production capacity.

Warnings by scientists that large unrestrained growth in CFC usage would lead to future ozone depletion caused industry to fear that the growth in demand of CFCs was bound to concern governments. Further, the Vienna Convention had served notice that the ozone depletion issue was being taken seriously. The negotiations under the auspices of UNEP on a protocol under the Vienna Convention further confirmed this feeling. The U.S. producers, from that point, added to the pressure for an international protocol, wanting to avoid a situation in which the United States regulated CFCs domestically while the rest of the world did not. Thus, after a decade of industry opposition to regulation, industry claimed that it was the lack of regulation that prevented it from introducing products to protect the ozone layer.

In 1986, scientists provided the first evidence that chlorine chemistry was, indeed, the cause of the ozone hole on the basis of ground-based experiments.<sup>13</sup> In 1987, the internationally sponsored Airborne Antarctic Ozone Experiment confirmed the key role of chlorine in chemical reactions associated with ozone hole formation.<sup>14</sup> The experiment's "smoking gun" data showed an inverse correlation between ozone and chlorine monoxide from CFCs.

On 16 September 1987 the UNEP conference of the governments agreed on the Montreal Protocol on Substances that Deplete the Ozone Layer. Only mild control measures were agreed upon to ensure that all countries could come aboard. In Article 6 of the protocol, the governments agreed that there will be periodic scientific, technological, and economic assessment of the issues concerning the CFCs and that the protocol will be revised on the basis of the results of the assessment. In October 1988, in compliance with Article 6 of the Montreal Protocol, the scientific, environmental, technology, and economic assessment processes were initiated.

### SCIENCE AS A TOOL OF DIPLOMACY

In November 1989, four Montreal Protocol assessment panels reported their findings: The Scientific Assessment Panel (SAP) reported that "Even if the control measures of the Montreal Protocol (of 1987) were to be

implemented by all nations, today's atmospheric abundance of chlorine (about 3 parts per billion by volume) will at least double to triple during the next century. If the atmospheric abundance of chlorine reaches about 9 parts per billion by volume by about 2050, ozone depletions of 0–4 percent in the tropics and 4–12 percent at high latitudes would be predicted. To return the Antarctic ozone layer to levels of the pre-1970s, and hence to avoid the possible ozone dilution effect that the Antarctic ozone hole could have at other latitudes, one of a limited number of approaches to reduce the atmospheric abundance of chlorine and bromine is a complete elimination of emissions of all fully halogenated CFCs, halons, carbon tetrachloride, and methyl chloroform, as well as careful considerations of the HCFC substitutes." The Environmental Effects Assessment Panel (EEAP) confirmed the adverse impacts of ozone depletion on human health and environment. The Technology Assessment Panel (TAP) concluded that it was technically feasible to phase down the production and consumption of the five controlled CFCs by at least 95%, phase out production and consumption of carbon tetrachloride, and phase down the production and consumption of methyl chloroform by at least 90 percent. The Economic Assessment Panel (EAP) noted that many companies already started phasing out the CFCs and the costs were much less than was originally feared.

The synthesis of the four assessment panels' reports provided many policy options to governments for phasing out CFCs. It also concluded that

Protection of the ozone layer will require a full partnership between developed countries that have caused the problem and those in developing countries who would now like to improve their standard of living by using these chemicals for uses such as refrigeration. The lack of technical knowledge and financial resources of developing countries inhibits the adoption of certain CFC/halon replacement technologies and the definition and implementation of the best national options for the transition to CFC-free technologies. Funding is needed to assist the transfer of technology to developing countries during the transition period because currently available resources are already strained as a result of the world debt problem and the dire economic situation of many countries.

It is this report that led to more negotiations and an agreement in the second Meeting of the Parties in London in 1990 to completely phase out CFCs by the year 2000, with a 10-year grace period for developing countries, and to assist the developing countries with technologies and financial assistance through a Multilateral Fund (MLF) contributed by the developed countries. At the second

meeting, the parties merged the TAP and EAP into the Technology and Economics Panel (TEAP) and asked the all the assessment panels to submit another comprehensive assessment in November 1991. The 1991 TEAP report found that

It is technically feasible to eliminate virtually all consumption of controlled substances in developed countries by 1995–1997, if commercial quantities of transitional substances are available . . . As a result of rapid development of technology, the costs of eliminating controlled substances are lower than estimated in 1989 and will decline further.

The parties to the protocol approved the Copenhagen Adjustment and Amendment of 1992. They brought into the protocol HCFCs, HBFCs, and methyl bromide as controlled substances, each with a specific control schedule. The phaseout of CFCs, carbon tetrachloride, and methyl chloroform by the developed countries was advanced from the year 2000 to 1996, and the phaseout of halons was advanced to 1994.

The assessment panels' 1994 report put forward further options to strengthen the protocol.<sup>15</sup> As a result of this assessment, the 1995 meeting of the parties further strengthened the protocol, and in 1997 and 1998 the protocol was further strengthened. In 2007, the protocol was further adjusted to advance the phaseout of the HCFCs, the low-ODP substances used to replace the ODS.

### **SCIENCE FOR MONITORING, REPORTING, AND VERIFICATION**

Since 1957, the WMO has provided the backbone of the global ozone monitoring network. In 1960, it established the World Ozone Data Centre in Toronto, Canada. Many countries measure ozone and abundance of ODS in the atmosphere through satellites, aircraft, balloons, and ground measurements. The scientific assessment panel of the protocol collates this information and studies the consistency of the scientific observations with the data on production and consumption of ODS reported by the parties to the protocol annually to the secretariat of the protocol. Any anomalies are investigated and causes found. Science thus provides a check on the reports of governments to the protocol secretariat. Following the measurements of the Antarctic ozone hole in 1984–1985, WMO initiated the public release of Antarctic ozone bulletins, which are issued every 10–14 days, beginning in mid-August. Spring-time bulletins are issued for northern midlatitudes and the Arctic regions when conditions warrant.

### **SCIENCE TO MEASURE REGULATORY PERFORMANCE**

The 2006 UNEP/WMO SAP report synthesized all the scientific observations of the ozone layer and concluded that the Montreal Protocol was a success:<sup>16</sup>

The total combined abundances of anthropogenic ozone-depleting gases in the troposphere continue to decline from the peak values reached in the 1992–1994 time period.

The combined stratospheric abundances of the ozone-depleting gases show a downward trend from their peak values of the late 1990s, which is consistent with surface observations of these gases and a time lag for transport to the stratosphere.

The Montreal Protocol is working: There is clear evidence of a decrease in the atmospheric burden of ozone-depleting substances and some early signs of stratospheric ozone recovery.

Economic analyses of the Montreal Protocol's control measures have found that the speed of the phaseout has been faster, the costs have been lower, and the alternatives and substitutes have been more environmentally acceptable than the parties anticipated at the protocol's initial and ongoing negotiations.<sup>17</sup>

The HFCs that replaced CFCs were zero ODP and had generally much lower global warming potentials (GWP), and the HCFCs that replace CFCs were generally low ODP and had equal or lower GWP. However, in some cases alternatives to ODSs had comparable GWPs that were too high to be environmentally sustainable. Overall, national regulations, voluntary actions, and compliance with the Montreal Protocol have protected the climate in the past and can add to climate protection in the future. Over the Kyoto Protocol to the United Nations Framework Convention on Climate Change (Kyoto Protocol) period (1990–2010), the reduction in GWP-weighted ODS emissions from compliance to control measures of the Montreal Protocol was about 8 Gt CO<sub>2</sub> equivalents per year. This reduction is substantially greater than the first Kyoto reduction target (2 Gt CO<sub>2</sub> equivalents per year), even after accounting for the climate impact of ozone depletion and HFC emissions. And now, there are proposals before the parties to the Montreal Protocol to control the HFCs that were once necessary to replace the ODSs.

### **DEVELOPMENT OF OZONE-SAFE TECHNOLOGIES**

From 1988, many companies proactively innovated and introduced many ozone-safe technologies. Industry

leadership was an important ingredient in the accelerated and cost-effective phaseout of ODSs. The industry had many sources of motivation: respect for science, social motivation, desire for reputation and good will, motivation to avoid excessive regulation by governments, economic and strategic motivation, public relations, and employee motivation.

## GLOBAL INDUSTRY COOPERATION

To accelerate the pace of toxicity testing and reduce costs, in 1988, 14 global chemical manufacturers with an interest in commercialising new substitutes to the most damaging ozone-depleting substances formed the Program for Alternative Fluorocarbon Toxicity Testing (PAFT). Another significant response was the creation of the Alternative Fluorocarbon Environmental Acceptability Study (AFEAS) consortium formed in 1989 to determine the environmental fate and investigate any potential impacts of alternatives in cooperation with government agencies and academic scientists. This unprecedented scientific cooperation shortened the time to commercialisation of new HCFC and HFC chemical substitutes by three to five years.

At least six industry associations based on science and engineering were started with the express goals of speeding the elimination of ODSs: AFEAS, the Halon Alternatives Research Corporation (HARC), Halon Users National Consortium (HUNC), the Industry Cooperative for Ozone Layer Protection (ICOLP), the Japan Industrial Conference for Ozone Layer Protection (JICOP), and PAFT. At least two other industry organizations, the U.S. Alliance for Responsible Atmosphere Policy (ARAP) and the Australian Association of Fluorocarbon Consumers and Manufacturers (AFCAM), transformed themselves from questioning to supporting regulations to protect the ozone layer. Several dozen other existing organizations created substantial internal subcommittees on ozone layer protection.

## TECHNOLOGY AND ECONOMIC ASSESSMENT

The parties to the Montreal Protocol benefit from annual, up-to-date technical assessments from its TEAP and its Technical Options Committees (TOCs) for the six sectors of ODS use. The TOC reports are consolidated by the TEAP, and the results are synthesized with findings of the SAP and the EEAP.

The TEAP consists of the cochairs of the TOCs and a few other experts. Each TOC has cochairs from both developing and developed countries and 20–35 members from all parts of the world. Members of the TEAP are appointed by Meetings of the Parties (MOPs). Governments may propose members to TOCs. The cochairs of the TOCs have the full freedom to choose whom they want in consultation with the TEAP, depending on the expertise needed, which may vary from time to time. The membership is from government environment ministries, industries, academia, and a few professional consultants.

The presence of industry on the TOCs and the TEAP provides access to cutting-edge data that are often not yet published in scientific or technical journals since industry rarely publishes about emerging technologies it has developed for commercial purposes. As a result, reports from the TOCs and the TEAP often provide the parties with the first public disclosure of the latest developments. A code of conduct for TEAP and TOCs ensures that membership does not lead to taking undue advantage by the members.

Whereas the TEAP and TOCs were originally constituted to advise the parties at least once in four years on strengthening the protocol, the MOPs have actually used the TEAP and TOCs to spearhead more aggressive phase-out and to solve the many problems faced by the parties. For example, every three years the TEAP and the TOCs are asked to recommend the replenishment requirements of the MLF.

The reports of the TEAP or TOCs are presented to the parties as they are written, without any editing by policy makers. Parties are free to disagree with the reports but cannot amend them. The panels can present information that is relevant for policy making but do not recommend specific policies.

## ROLE OF THE PROTOCOL REGIME

### REGIME ENCOURAGING INVOLVEMENT OF ALL THE STAKEHOLDERS

All developing countries became parties to the protocol because of the concessions given to them, including a grace period for implementation of the control measures and a fund to meet their incremental costs. Every party to the Montreal Protocol has engaged in stakeholder dialogue and collaboration, and most operate national steering committees comprised of representatives from government ministries (e.g., agriculture, defence, environment, finance, and industry), industry associations, technical

experts, NGOs, and others, such as from international implementing organizations or bilateral donor agencies.

#### MULTILATERAL FUND AND IMPLEMENTING AGENCIES

The financial mechanism of the Montreal Protocol, the MLF, is based on the recognition that many developing countries lack the capacity to comply with treaty obligations and that developed countries that are often disproportionately responsible for causing the ozone depletion, should provide technologies and financial assistance to developing countries to ensure compliance. The developing and developed parties are equally represented in the executive committee of the fund. The contributions of the MLF have been critical to the success of the Montreal Protocol. The Global Environment Facility (GEF), though not a financial mechanism of the protocol, provided financial assistance to countries with economies in transition, which were not eligible to receive financial assistance from the MLF.

The MLF is also the focus of all the activities to assist the developing countries. Donor countries can have their own bilateral Montreal Protocol programmes (up to 20% of their contribution due to the MLF) in developing countries, but such programmes have to be approved by the executive committee. This requirement avoids confusion and duplication of activities.

Another reason for the success of the MLF is the replenishment process, which occurs every three years. The TEAP estimates the funding required for each replenishment period, taking into account the obligations of the developing countries, the projects already approved, and the lead time for completion of projects. The TEAP report is reviewed and decided upon by the parties at the MOP.

#### NATIONAL FOCAL POINTS AND NETWORKS

The MLF financed creation of an office, or “focal point,” within each developing country’s government with financial assistance. This office coordinates the country activities for the phaseout, consults with industry and other interested organizations on the steps to be taken for the phaseout, prepares a country programme, designs and implements the national law and the financial measures to facilitate phaseout, organizes awareness and training programmes for the industry and public, and creates a system for monitoring and reporting on national production and consumption of ODSs.

The focal points of each country, along with interested developed countries, are organized into nine regional networks to facilitate the exchange of information, best

practices, and technology transfer. These networks facilitate feedback to the MLF and to other parties, allowing parties to learn from each other and transfer expertise and technology from one country to another.

#### NATIONAL REGULATIONS AND POLICIES

All the parties to the Montreal Protocol established regulations that included outright bans on production and imports. Many countries have taxes or fees on ODSs to discourage use and raise revenue. Other mechanisms included auctioning the right to the permitted ODSs. Labelling programmes help inform consumers which products and processes are ozone safe. The labelling programmes encourage product manufacturers to halt ODS use to satisfy customers and avoid administrative expenses and penalties.

### CONCLUSION

The Montreal Protocol on Substances that Deplete the Ozone Layer is the most successful environmental agreement ever, and the Antarctic Treaty was a research platform for the science that was instrumental in protecting the ozone layer. The Montreal Protocol is the only international agreement with participation of all 196 countries of the world, and it is the only environmental agreement to be on track to achieve all of its goals. The foundation of its success is science and technology, including the science discovered in Antarctica. Collaboration has been established between scientists, governments, NGOs, media, and UN organizations: science leading to understanding, understanding leading to policy, policy leading to implementation, and implementation leading to global environmental protection. If there were no Montreal Protocol, stratospheric ozone would have decreased by two-thirds, ultimately resulting in death and disability from tens of millions of cases of skin cancer, cataracts, and suppression of the human immune system, and would have irreparably damaged agriculture and ecosystems, which would have resulted in even more misery.

### NOTES

1. Ultraviolet radiation can reach components of the immune system present in the skin. Experiments on animals show that UV exposure decreases the immune response to skin cancers, infectious agents, and other antigens and can lead to unresponsiveness upon repeated challenges, and studies of human subjects also indicate that UVB exposure can suppress some immune system functions. The risk of these immune

effects for humans is uncertain but may be significant where infectious diseases already challenge human health and in persons with impaired immune function. See A. Jeevan and M. L. Kripke, "Impact of Ozone Depletion on Immune Function," *World Resource Review* 5 (2001): 2; and Janice D. Longstreth, Frank R. de Gruijl, and Margaret L. Kripke, "Effects of Increased Solar Ultraviolet Radiation on Human Health" *Ambio* 24, no. 3 (1995): 153–165. See also the Columbia University Center for International Earth Science Information Network (CIESIN) thematic guide to the impact of stratospheric ozone depletion on suppression of the human immune system, <http://www.ciesin.org/TG/HH/ozimmun.html> (accessed 7 December 2010).

2. Because ozone-depleting substances were already scheduled for phaseout under the Montreal Protocol, they are not included in the Kyoto Protocol. However, SF<sub>6</sub>, PFCs, and, particularly, HFCs that are substitutes for ozone-depleting substances in some applications are controlled by the Kyoto Protocol. The HFCs controlled under the Kyoto Protocol have global warming potentials (GWPs) that are generally lower than the CFCs they replaced. For example, the GWP of HFC-134a is about one-sixth the GWP of the CFC-12 it replaces as a refrigerant. See UNEP Ozone Secretariat, "The Implications to the Montreal Protocol of the Inclusion of HFCs and PFCs in the Kyoto Protocol," report of the HFC and PFC Task Force of the Technology and Economic Assessment Panel, 1999, [http://www.ozone.unep.org/Assessment\\_Panels/TEAP](http://www.ozone.unep.org/Assessment_Panels/TEAP) (accessed 7 December 2010).

3. P. Crutzen, "The Influence of Nitrogen Oxides on the Atmospheric Ozone Content," *Quarterly Journal of the Royal Meteorological Society*, 96, no. 408 (1970): 320–325.

4. J. E. Lovelock, R. J. Maggi, and R. J. Wade, "Halogenated Hydrocarbons in and over the Atlantic," *Nature*, 241 (1973): 195, as discussed in M. Kowalok, "Common Threads: Research Lessons from Acid Rain, Ozone Depletion, and Global Warming," *Environment* 35, no. 6 (1993): 12–20, 35–38, <http://www.ciesin.org/docs/011-464/011-464.html> (accessed 7 December 2010).

5. H. S. Johnston, "Reduction of Stratospheric Ozone by Nitrogen Oxide Catalysts from Supersonic Transport Exhaust," *Science* 173 (1971): 517–522.

6. P. Crutzen, "SST's: A Threat to the Earth's Ozone Shield," *Ambio* 1, no. 2 (1972): 41–51.

7. M. Molina and F. S. Rowland, "Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom-Catalyzed Destruction of Ozone," *Nature* 249, no. 5460 (1974): 810–812.

8. UN Environment Programme Governing Council, Decision 29(III), April 1975.

9. UN Environment Programme Governing Council, Decision 65(IV), April 1976.

10. S. Chubachi, "Preliminary Result of Ozone Observations at Syoma Station from February 1982 to January 1983," *Memoirs of National Institute of Polar Research* 34 (1984): 13–19.

11. J. S. Farman, B. G. Gardiner, and J. D. Shanklin, "Large Losses of Total Ozone in Antarctica Reveal Seasonal ClO<sub>x</sub>/NO<sub>x</sub> Interaction," *Nature*, 315 (1985): 207–210.

12. See Robert S. Orfeo, "Response to questions to the panel from Senator John H. Chafee," *Ozone Depletion, the Greenhouse Effect, and Climate Change, Hearings before the Senate Subcommittee on Environmental Pollution of the Committee on Environment and Public Works* (Washington, D.C.: GPO, 1986), pp. 189–192; and Donald Strobach, "A Search for Alternatives to the Current Commercial Chlorofluorocarbons," in *Protecting the Ozone Layer: Workshop on Demand and Control Technologies* (U.S. Environmental Protection Agency: Washington, D.C., 1986).

13. S. Solomon, G. H. Mount, R. W. Sanders, and A. L. Schemltekopf, "Visible Spectroscopy at McMurdo Station, Antarctica: 2. Observation of OCIO," *Journal of Geophysical Research* 92 (1987): 8329–8338.

14. NASA, "Airborne Antarctic Ozone Experiment," [http://geo.arc.nasa.gov/sge/jkskiles/fliers/all\\_flier\\_prose/antarcticO3\\_condon/antarcticO3\\_condon.html](http://geo.arc.nasa.gov/sge/jkskiles/fliers/all_flier_prose/antarcticO3_condon/antarcticO3_condon.html) (accessed 7 December 2010).

15. World Meteorological Organization, *Scientific Assessment of Ozone Depletion: 1994; Executive Summary*, World Meteorological Organization Global Ozone Research and Monitoring Project Report 37, World Meteorological Organization, Geneva, 1995.

16. World Meteorological Organization, *Scientific Assessment of Ozone Depletion: 2006; Executive Summary*, World Meteorological Organization Global Ozone Research and Monitoring Project Report 50, World Meteorological Organization, Geneva, 2007, [http://ozone.unep.org/Assessment\\_Panels/SAP/Scientific\\_Assessment\\_2006\\_Exec\\_Summary.pdf](http://ozone.unep.org/Assessment_Panels/SAP/Scientific_Assessment_2006_Exec_Summary.pdf) (accessed 7 December 2010).

17. Economic Options Committee, 1991, 1994, 1998; and Stephen O. Andersen and K. Madhava Sarma, *Protecting the Ozone Layer: The United Nations History* (London: Earthscan, 2002), pp. 187–233.