CHAPTER ELEVEN

Stratospheric Ozone

The ozone layer is vital to life as we know it. Ozone shields living things from the most biologically damaging wavelengths of solar ultraviolet radiation, known as UV-B and UV-C, which can alter the structure of genetic material and lead to harmful mutations. Scientists believe that land-based life could not have evolved on Earth without the ozone layer's protection.

Ninety percent of the Earth's ozone resides in the stratosphere, forming a layer that begins 6 miles above the planet's surface and extends to a height of 25 miles.

This layer absorbs all UV-C radiation and most UV-B, while allowing the longer, largely beneficial wavelengths (UV-A) of sunlight to penetrate to the land and ocean below.

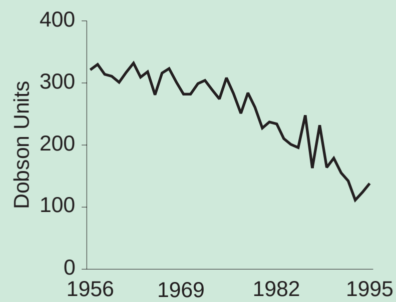
The ozone layer normally exists in a state of dynamic balance, with the gas continually being formed and destroyed at equal rates. Except for seasonal variations, this balance maintains ozone concentrations at relatively constant levels over time. (Short-term natural fluctuations occur in response to changes in solar activity, volcanic eruptions, shifts in wind patterns, and other phenomena.)

THE PROBLEM AND ITS CONSEQUENCES

In the past several decades, however, increasing amounts of chlorine- and bromine-containing compounds, used by society for a wide range of applications, have drifted up to the stratosphere. Increasing concentrations of chlorine and bromine from these chemicals have upset the ozone layer's balance, causing more of the chemical to be destroyed than is produced. The cumulative decline in stratospheric ozone over the Northern Hemisphere since 1979 has been roughly 5 percent, with record lows measured in late 1994 and early 1995. The seasonal Antarctic ozone "hole," first detected in 1985, has covered an area of roughly 9.5 million square miles—larger than North America—each austral spring since 1990. The 1995 ozone hole was the longest lasting on record (Figure 11.1).

United Nations projections indicate that as ozone depletion reaches its peak before the year 2000, mid-latitudes in the Northern Hemisphere may experience a 15 percent increase in UV-B exposure during winter and spring and an 8 percent increase in summer, compared with levels of the late 1960s. (These projections assume that other factors affecting the

Figure 11.1 Ozone Thickness over Antarctica, 1956-1995



Source: J.D. Shanklin, British Antarctic Survey (BAS). Note: Mean October ozone column thickness is measured at the BAS station, Halley Bay, Antarctica.

amount of UV-B that reaches the surface, such as cloud cover and atmospheric pollution, remain unchanged.)

For humans, the potential consequences of such increases in UV-B exposure include a higher risk of skin cancers and cataracts and lower resistance to infectious diseases. Agricultural, ecological, climatological, and biogeochemical impacts are also possible, including reductions in crop productivity, changes in plant communities, disruption of aquatic food webs, reductions in fish and amphibian populations, changes in stratospheric circulation, and changes in the atmospheric concentrations of greenhouse gases such as methane and carbon dioxide.

THE INTERNATIONAL RESPONSE

December 31, 1995, the date on which the industrialized nations of the world officially ended their production of ozone-depleting chlorofluorocarbons (CFCs), stands as the defining milestone of an extraordinary 22-year endeavor that has united scientists, policymakers, diplomats, corporate officials, and engineers in service to the global environment.

The process began in 1974, when Nobel Prize-winning chemists Mario Molina and F. Sherwood Rowland published their seminal paper linking CFCs to the destruction of stratospheric ozone. At the time, over 5 million metric tons of CFCs were being produced worldwide each year, for use in refrigeration, air-conditioning, insulating foams, and aerosol cans.

Political leaders were initially reluctant to ban such valuable chemicals on the strength of an uncertain scientific hypothesis. But, over time, further research began to confirm that CFCs indeed posed a serious threat.

In 1976, the National Academy of Sciences upheld Molina and Rowland's conclusions, and 2 years later the United States and several other countries banned the sale of nonessential aerosol cans containing CFCs. Although the ban had a significant impact on CFC emissions and temporarily reduced demand for the chemicals, global production began climbing again as new applications were developed.

By 1985, concern about the continued increase in global CFC production, along with additional scientific evidence, prompted 22 nations to negotiate and subsequently sign the Vienna Convention for the Protection of the Ozone Layer, an agreement that established mechanisms for international scientific cooperation and committed the parties to take action to protect stratospheric ozone.

Although the Convention did not alter the production or use of CFCs, it created the legal framework for a binding protocol to be negotiated in the future.

While significant uncertainties remained, growing scientific evidence led international negotiators to discuss specific limits on the production and use of CFCs and halons (related chemicals that also adversely affect stratospheric ozone). These talks culminated in the signing, in September 1987, of the Montreal Protocol on Substances That Deplete the Ozone Layer.

The Protocol initially required its parties to freeze CFC production at 1986 levels by 1989, phasing down to a 50 percent reduction by 1998. It also froze, but did not reduce, halon production. The agreement provided a 10-year delayed compliance schedule to developing countries with CFC and halon consumption below 0.3 kilograms per capita.

In addition, the Protocol established a process for periodic international assessments of ozone depletion science, the environmental effects of ozone depletion, and technological and economic options. These assessments, performed by expert panels under the auspices of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), have played a key role in the subsequent negotiation of amendments to strengthen the Protocol's provisions.

In March 1988, just 6 months after the Montreal Protocol was signed, the WMO's Ozone Trends Panel reported that statistically significant levels of ozone depletion were occurring over middle latitudes as well as the poles, and it provided the strongest evidence yet that CFCs and halons were the cause. These findings prompted a reassessment of the Protocol and its effectiveness. Meeting in London in 1990, the parties negotiated the first schedule for a total phaseout of CFCs and other ozone-depleting compounds.

The London amendments banned production and importation of CFCs and halons in industrialized nations by the year 2000 and added two new ozone-depleting compounds—the industrial solvents carbon tetrachloride and methyl chloroform—to the list of controlled chemicals. The London meeting also established a fund to assist developing countries, which must complete their CFC phaseout by 2010, in fulfilling their obligations under the agreement.

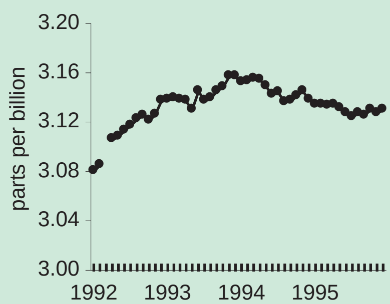
In February 1992, the United States, responding to new scientific information about ozone losses, announced that it would accelerate its phaseout of CFCs to December 31, 1995. This decision, coupled with the conclusions of UNEP/WMO assessments published since the London amendments, helped lead the Montreal Protocol parties to negotiate an accelerated and expanded phaseout later that year.

These amendments, adopted at a meeting in Copenhagen, phased out halons in 1994, and CFCs, carbon tetrachloride, and methyl chloroform by January 1, 1996. The new agreement also set restrictions on hydrochlorofluorocarbons (HCFCs)—CFC substitutes that have a relatively small but not insignificant ozone-depleting potential—and froze the production of methyl bromide, an agricultural fumigant that new research had shown to be an important contributor to ozone depletion.

Meeting again in December 1995, the parties—now numbering more than 150 countries—agreed to phase out the production of methyl bromide in industrialized countries by 2010. Developing countries agreed to new restrictions on methyl bromide and HCFCs.

As a direct result of the Montreal Protocol and its amendments, chlorine concentrations in the troposphere peaked in early 1994 and began declining in 1995 (Figure 11.2). Stratospheric chlorine concentrations are expected to peak before the year 2000. Assuming continued global compliance with the amended Protocol, the ozone layer is projected to gradually recover over the coming decades, returning to pre-ozone-hole levels by around 2050 (Figure 11.3).

Figure 11.2 Tropospheric Abundance of Ozone-Depleting Chemicals from Humans, 1992-1995



Source: Montzka et al., *Science* (May 31, 1996).
Note: Data refer to chlorine and bromine as "equivalent chlorine" in the troposphere.

THE U.S. APPROACH TO OZONE LAYER PROTECTION

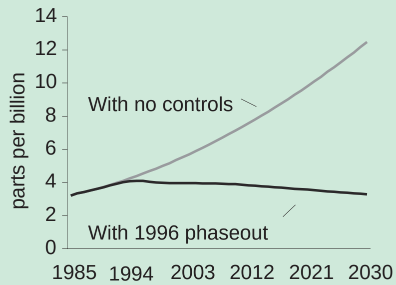
In implementing its commitments under the Montreal Protocol and the Vienna Convention, the United States has aimed to achieve an orderly phaseout of ozone-depleting substances (ODSs) and a smooth transition to alternatives, minimizing costs to producers, manufacturers, and consumers.

The government's approach has emphasized flexibility, facilitation, and close cooperation with affected parties, while attempting to send clear and unambiguous signals that ODS production and imports will be eliminated on schedule.

The phaseout of ODS production and importation has been, and continues to be, implemented through an array of general and sector-specific measures, including:

- a progressively increasing excise tax on controlled substances;
- tradable production and importation allowances;
- a halon banking system;
- monitoring and reporting requirements;
- mandatory recovery and recycling of refrigerants during service and disposal;
- product labeling requirements;

Figure 11.3 Adjusted Atmospheric Chlorine Loading, 1985-2030



Source: U.S. Environmental Protection Agency.

- a program to review the health effects, safety, and availability of alternatives;
- federal procurement regulations;
- bans on nonessential products (such as party streamers);
- interdiction of illegal imports; and
- training of law enforcement officers in the U.S. and abroad.

Narrow exemptions for health- and safety-related applications are allowed, as are small levels of CFC production for export to developing countries. Recycled or surplus ODSs produced or imported prior to the 1996 phaseout may be used to service existing equipment.

Many agencies play a role in these programs, including EPA, the Internal Revenue Service, the Federal Trade Commission, the Customs Service, the State Department, the Commerce Department, the Justice Department and the Department of Agriculture. Individual states and municipalities have also passed legislation or launched programs to reduce emissions of ODSs.

The effective use of market instruments, such as the CFC excise tax and tradable permits, has been a hallmark of the government's phaseout strategy. The excise tax, which took effect in 1990, established a base level (initially $1.37 per pound), with adjustments according to each chemical's ozone-depleting potential. The base tax rose incrementally as the phaseout deadline approached—reaching $5.35 per pound in 1995— providing a clear price signal and an incentive for users to switch to alternatives. The tax applies to floor stocks as well as sales, thus discouraging excessive hoarding of virgin ozone-depleting chemicals for use after the production phaseout. An exemption for recycled and reprocessed CFCs, used primarily to service refrigeration and air-conditioning equipment, is making the transition more affordable for building and automobile owners.

The tradable permit system ensured an orderly phaseout of production and consumption of ODSs by allocating steadily diminishing allowances to producers and importers. To provide flexibility, unused allowances could be sold, with certain restrictions, to companies that were still manufacturing or importing the chemicals. Allowances could also be used, with restrictions, to make or import larger quantities of other chemicals with a lower ozone-depleting potential.

The federal government has combined regulatory controls with a collaborative and flexible approach, working closely with producers, manufacturers, and users to ensure a smooth transition away from ozone-depleting substances. For example, when it first became apparent that supplies of CFC-12—a refrigerant used in car air conditioners and some chillers (air-conditioning units for commercial buildings)—might not be adequate to service existing equipment after the phaseout, EPA encouraged affected industries to establish banks of virgin and recycled CFC-12 while the chemical was still readily available. The agency provided information on alternatives to CFC-12 and encouraged industry to extensively evaluate low-cost alternatives for use in existing car air conditioners.

EPA currently operates a nationwide CFC-12 clearinghouse on the Internet to improve public access to information about price and availability of the refrigerant. The U.S. government has played an important facilitative role in the development of alternative chemicals and technologies. The Significant New Alternatives Policy (SNAP) program, officially established in early 1994, has evaluated the safety and environmental acceptability of a wide range of ODS substitutes in nearly 100 specific end uses. SNAP has listed viable alternatives for virtually every ODS application (with the exception of methyl bromide), and it has helped users direct investments appropriately.

EPA also serves as a clearinghouse for practical information on ODS alternatives. In 1994, the agency began publishing case histories documenting the ways in which individual companies eliminated their use of CFCs, and it has sponsored an international conference on CFC and halon alternatives each year since 1988. EPA operates a toll-free Stratospheric Ozone Hotline to answer queries from businesses, organizations, and the general public.

Key policy developments at the federal level in 1994 and 1995 include publication of the final SNAP rule and subsequent updates, mobilization of a multiagency effort to crack down on illegal imports of CFCs, and continued support for development of alternatives to methyl bromide. EPA also revised controls for imports of used and recycled ODSs, modified requirements for exporting ODSs to developing countries, and implemented a number of other administrative changes in the program. EPA, the National Weather Service and the Centers for Disease Control and Prevention launched the UV index, a public health information program aimed at preventing dangerous exposures to ultraviolet radiation.

INDUSTRY'S ROLE

In the 1980s, U.S. companies were using hundreds of thousands of tons of CFCs to manufacture more than $100 billion in products each year.

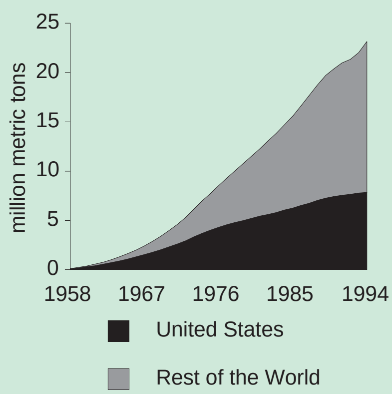
By the end of 1995, the production and importation of CFCs was banned in the United States and the rest of the industrialized world. The fact that such a rapid transition to alternatives occurred without massive economic disruption owes much to the creative and proactive initiatives undertaken by industry.

Industry groups and individual companies, large and small, dedicated substantial resources toward meeting this challenge. Many set stringent, self-imposed deadlines that went well beyond those required by law. For example, in 1988, food-service packaging manufacturers voluntarily phased out their use of CFCs in foam products. In 1991, in response to new scientific evidence, DuPont announced that it would halt its production of CFCs by 1997, three years ahead of the schedule then imposed by the Montreal Protocol. In early 1993, DuPont announced it would stop producing CFCs by the end of 1994. Many other companies eliminated their use of ODSs ahead of schedule, or voluntarily improved their products to reduce emissions, and found that their actions gave them a competitive advantage.

Industry groups such as the International Cooperative for Environmental Leadership (launched in 1989 as ICOLP, the International Cooperative for Ozone Layer Protection) have been valuable allies in the effort to eliminate ODSs. Member companies credit ICOLP with helping them achieve their phaseouts ahead of schedule; in some cases up to 4 years ahead of Montreal Protocol deadlines. In partnership with EPA, ICOLP has published and distributed seven technical manuals on ODS alternative technologies and practices, and many developing countries have profited from ICOLP technical assistance projects.

EPA has provided public recognition for these dedicated companies and organizations through its annual Stratospheric Ozone Protection Awards program.

Figure 11.4 Cumulative Production of CFCs,1958-1994



Source: See Part III, Table 71.
Note: Data refer to production of CFC-11 and CFC-12.

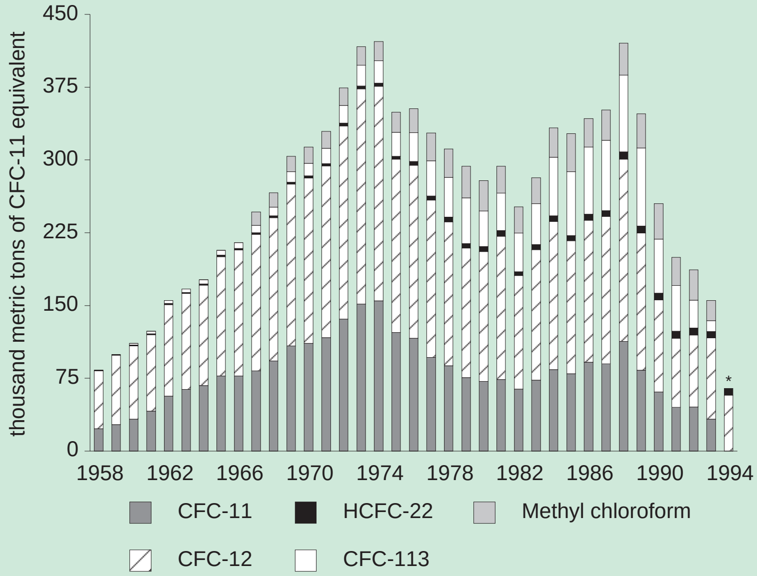
RESULTS OF THE U.S. PHASEOUT

Before 1970, the United States was the world's leading producer of CFCs. But after the aerosol ban and subsequent Clean Air Act controls, the U.S. share of global production rapidly declined. However, by the mid-1990s, the United States still accounted for about one third of world production (Figure 11.4).

Production of CFCs in the United States peaked in 1987 at nearly 400,000 metric tons, dropping to approximately 180,000 metric tons by 1995 before ending in 1996 (Figure 11.5). Without controls, the production of CFCs was estimated to reach almost 3 million metric tons by 2005.

In some cases, the phaseout has had economic as well as environmental benefits. For example, some ozone-benign technologies and practices have proved more cost-effective than those employing

Figure 11.5 U.S. Production of Selected Ozone-Depleting Chemicals, 1958-1994



Source: See Part III, Table 71.
Note: *1994 data for CFC-11, CFC-113, and methyl chloroform not available.

ODSs. For example, when solvent users began researching alternative cleaning methods, many found that they could reduce or eliminate the use of chemicals without sacrificing product quality. Water- and citrus-based solvents have replaced CFCs in many applications, and some manufacturers have managed to eliminate the cleaning process altogether.

Significant improvements in energy efficiency are expected to result from the conversion of existing refrigeration equipment to CFC alternatives. By 1998, according to the Air Conditioning and Refrigeration Institute, 44 percent of existing chillers will be converted or replaced with equipment that uses non-CFC refrigerants. For new equipment owners, the resulting efficiency improvements are expected to reduce energy use by almost 7 billion kilowatt-hours per year, saving them $480 million annually. These estimated energy savings would avoid some 4 million metric tons of carbon dioxide and 34,000 metric tons of sulfur dioxide emissions from fossil fuel power plants.

FUTURE CHALLENGES

The successful phaseout of CFCs, halons, methyl chloroform, and carbon tetrachloride is not the end of the ozone protection story. Many issues remain to be addressed, on both the domestic and the international level.

Stockpiles of virgin and recycled CFCs will be used to service existing air-conditioning and refrigeration equipment for some time to come. Mobile air-conditioning (in cars and trucks) is the largest source of ODS emissions in the United States, and some 90 million older vehicles on the road in 1995 still use CFC-based air conditioners. Mandatory recovery and recycling of refrigerants have greatly reduced emissions, but leaky systems still pose a problem.

Fortunately, in many cases the cost to convert these vehicles to alternative refrigerants is far less than some engineers originally thought. For some vehicles and some refrigerants, the cost to convert is only slightly more than that of recharging the system with CFC-12.

Emissions of two leading classes of ODS alternatives, the HCFCs and hydrofluorocarbons (HFCs), must be controlled to reduce their environmental impacts. Both HCFCs and HFCs contribute to global climate change; HCFCs, while contributing much less to ozone depletion than CFCs, still contribute some chlorine to the stratosphere. EPA now requires that both be recycled during servicing of air-conditioning and refrigeration equipment.

The Montreal Protocol eliminates HCFCs by 2030, allowing them to serve as interim substitutes. The U.N. Framework Convention on Climate Change and its future protocols, if any, may eventually require countries to control emissions of HFCs. EPA intends to continue working with industry to identify alternatives to HCFCs and HFCs and to mitigate their effects through containment and recycling. EPA is also rejecting (through the SNAP program) those alternatives that exhibit very high global warming potential unless there is no other feasible substitute available.

Non-ozone-depleting alternatives for halons are still needed for about 10 percent of total halon use. These include military applications (e.g., fire protection in personnel carriers and command centers), industrial processing of flammable liquids and gases, and aviation. Several U.S. and international groups, including the U.S. military, EPA, the British Ministry of Defense, and U.S. industry, are seeking alternatives for these applications.

Public awareness and concern about the health impacts of ozone depletion may be waning. A number of recent media reports on scientific findings have given the impression that ozone depletion is a “solved problem” and that there is little to worry about. In fact, the ozone layer is expected to continue thinning until around the year 2000, and will recover only gradually after that. It is not expected to return to pre-ozone-hole conditions until the middle of the next century.

The phaseout of methyl bromide poses challenges in the United States and internationally. Under the Montreal Protocol, production and consumption of methyl bromide must be phased out in industrialized countries by 2010. The United States, which accounts for 41 percent of global consumption, froze methyl bromide production at 1991 levels in 1994 and will phase out its production and importation by 2001. Many alternatives to methyl bromide have been identified, but their effectiveness depends on the specific crop and target pest being addressed. The U.S. Department of Agriculture is taking the lead on research and development of additional alternatives.

The control of illegal imports of CFCs into the United States will require continued vigilance. Illegal importers have established a black market for new CFCs that are claimed as recycled (and therefore not subject to an import ban), disguised as other substances, or listed as intended for export to other countries. Estimates of CFCs that illegally entered the United States during 1994 and 1995 range from 10 million to 30 million pounds.

EPA and the Justice Department will continue to work with the Customs Service, the Internal Revenue Service, the Commerce Department and the State Department to crack down on this problem.

Over 1 million pounds of CFCs that were illegally imported into the United States were seized by Customs officials in 1995, and numerous convictions have resulted from these seizures. Illegal imports have been significantly curtailed in 1996.

EPA has also instituted a petition process, by which importers intending to bring in used CFCs must submit extensive information to EPA that indicates the material's former use and handlers. The agency must then approve that petition before the substance can be imported as a legitimately recycled compound.

CONCLUSIONS

The global response to the ozone crisis stands as a model for policy-science dialogue, international cooperation, and regulatory and industrial innovation. As a world leader in this process, the United States has demonstrated that flexible, market-based policies, developed in cooperation with affected parties, along with effective enforcement, can help achieve ambitious environmental goals without significant economic disruption. While the job of protecting the ozone layer is not yet complete, the successful phaseout of CFCs less than 10 years after controls were first negotiated remains a remarkable achievement, a powerful testimony to the effort, ingenuity, and cooperation of thousands of dedicated individuals worldwide.

REFERENCES

Benedick, R.E., *Ozone Diplomacy: New Directions in Safeguarding the Planet* (Harvard University Press, Cambridge, MA, 1991).

Cagin, Seth, and Philip Dray, *Between Earth and Sky* (Pantheon Books, New York, 1993).

Cook, Elizabeth, *Marking a Milestone in Ozone Protection: Learning from the CFC Phase-Out* (World Resources Institute, Washington, DC, 1996).

Makhijani, Arjun, and Kevin Gurney, *Mending the Ozone Hole* (MIT Press, Cambridge, MA, 1995).

Montzka, Stephen, et al., "Decline in the Tropospheric Abundance of Halogen from Halocarbons: Implications for Stratospheric Ozone Depletion," *Science*, Vol. 272 (May 31, 1996), pp. 1318–1322.

U.S. Environmental Protection Agency, EPA Fact Sheets: "Ozone Depletion: The Facts Behind the Phaseout"; "Benefits of the CFC Phaseout"; "Fact Sheet on the Accelerated Phaseout of Ozone-Depleting Substances" (EPA, Washington, DC, 1993–1996).

World Meteorological Organization, *Scientific Assessment of Ozone Depletion: 1994, WMO Global Ozone Research and Monitoring Project*, Report No. 37 (WMO, Geneva, 1995).