Insights on the Global Environment. Mending the Ozone Hole: Science, Technology, and Policy by Arjun Makhijani and Kevin R. Gurney, 1995, MIT Press, 360 pp.

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The *Montreal Protocol on Substances that Deplete the Ozone Layer* marks the first major effort by the nations of the world to join forces to resolve a global environmental issue and protect the Earth for future generations. Developed initially in 1987, with several amendments since, the Montreal Protocol was also eventful in its successful collaborations between scientists and policy makers. At the time, significant scientific uncertainties remained about detailed aspects of the processes affecting the observed ozone depletion. There also was no clear evidence of impacts from the existing ozone decrease on ecosystems or human health. However, the future risks of such impacts were substantial enough to get nations to subordinate their economic self-interests to achieve a common goal for the good of the planet.

The major concerns about ozone had first surfaced in the early 1970s with the recognition that chlorine and bromine could react catalytically with the naturally produced ozone layer in the stratosphere, in a manner such that one atom could destroy thousands of ozone molecules. The importance of the ozone layer in protecting humanity and ecosystems from potentially harmful levels of ultraviolet radiation was also becoming increasingly evident. It was soon realized that long-lived compounds called chlorofluorocarbons (CFCs, containing chlorine) and halons (containing bromine), gases at atmospheric pressures, would release their chlorine and bromine in the stratosphere and could be affecting ozone. The industrially produced CFCs and halons had become valuable chemicals for a broad range of applications throughout the world, as primary refrigerants and in many other important uses. By the mid-1980s, measurements of ozone from satellite- and ground-based instruments had shown stratospheric ozone levels were decreasing. The data also implicated CFCs and halons as the primary sources of the ozone loss. By this time, the search for replacement compounds was well underway. With the discovery of a major ozone decrease over Antarctica in the spring time of 1985, far exceeding losses over the rest of the world, the pressure increased to negotiate a global agreement to eliminate the use of CFCs and halons. The pressure also increased yo search for replacements.

Several books have previously focused on the struggles of the scientific community to determine the factors affecting ozone and to evaluate the validity of the hypothesis of ozone destruction by chlorine and bromine from CFCs and halons. Other books have given more weight to the policy considerations and the resulting negotiations leading to the Montreal Protocol. Where Makhijani and Gurney's book, *Mending the Ozone Hole: Science, Technology, and Policy* distinguishes itself is in its consideration of the technological developments spurred by the search for replacements for CFCs and halons.

At the same time, it provides a generally well-written overview of the scientific findings and policy actions.

Mending the Ozone Hole is divided into three sections. The first (Chapters 1 and 2) focuses on the causes and consequences of stratospheric ozone depletion, the essential science underlying the environmental issue. The second section (chapters 3 through 10) primarily discusses the technological approaches being used to find replacement compounds, using defined goals for protecting the ozone layer as a basis for emphasizing the types of replacements desired (i.e., especially those compounds with no known destructive effects on ozone). The third section (Chapters 11 through 15) reports on existing policies to protect the ozone layer and the authors= recommendations for further reducing the impact of human activities on ozone.

The book gives a good overview of the scientific understanding of ozone change over recent decades and the evidence connecting ozone change with emissions and resulting atmospheric buildup of CFCs and halons. The measured trends in stratospheric ozone are discussed along with the evidence implicating chlorine and bromine in the observed ozone change. Naturally induced variations occurring in ozone are given their due. Implications of the direct radiative importance on climate from growing atmospheric concentrations of CFCs and the resulting changes in ozone are also discussed.

The discussion of the effects of decreasing amounts of stratospheric ozone on increasing the ultraviolet radiation reaching the Earth=s surface and the resulting impacts on humans and other biological systems is particularly well done. The presentation of these impacts is balanced, with appropriate recognition of the extent of remaining uncertainties.

The real strength of this book lies in its discussion of the technological development involved in the search for replacements for CFCs, halons, and other major ozone-destroying substances used as refrigerants, plastic foam-blowing agents, solvents, aerosol propellants and fire-extinguishing agents. The many factors affecting the suitability of a replacement compound or, as appropriate, new technological development are discussed. The existing choices for replacements and the possible directions for the future are well covered. In some cases, however, it appears that the authors were overly optimistic about the ability to put some of the new technological developments rapidly into the marketplace. Too quickly they dismiss remaining hurdles to wide-spread implementation.

First published in 1995, the book is already somewhat outdated. For example, it does not account for findings in the last few years relating on the trends in the amount of ozone depletion, the changes occurring in the emissions and atmospheric concentrations of the chemicals affecting ozone, the changes in chemical uses affecting future projections of emissions, or ongoing discussions about further development of new replacement compounds. None of these, however, take away from the overall value of the book.

Of more concern is the discussion on policy, particularly as the authors call for major changes to existing policy. Their discussion on the pathway taken by the U.S. and other world governments in getting to the current policy is generally well stated and accurate. The existing policy, primarily based on the meeting of the world governments in Copenhagen in 1992, has greatly limited production and use of CFCs and halons, plus several other compounds affecting ozone depletion. A new meeting of the parties to the *Montreal Protocol* in 1997 has led to some further modifications to the Protocol. However, the changes to international policy from this latest meeting were minor, with the exception of further strengthening the call for elimination of methyl bromide. This book does not

stop at explaining existing policy and its impact though, and proceeds to lobby for stronger controls to eliminate fully all of the compounds containing chlorine and bromine.

The arguments made by the authors for total elimination of compounds containing chlorine and bromine are overly simplistic. They also are not realistic. Some of these compounds are unlikely ever to have a significant effect on ozone, primarily because of their naturally rapid removal from the atmosphere. The vast majority of the chlorine or bromine in these compounds never reaches the stratosphere and therefore does not affect stratospheric ozone. For example, some compounds like hydrochloric acid are water soluble and will be rapidly removed by rainout processes. Some compounds will be difficult to replace for particular uses, like HCFC-123 in large commercial chillers, and if sufficiently controlled would have insignificant effects on ozone. The current Protocol calls for elimination of all HCFCs in the next 30 years, however the authors would have this occur much sooner.

Another shortcoming of the book is the discussion in Chapter 4 on policy approaches and goals to protect the ozone layer. This chapter is not current in its consideration of the policy tools used in ozone analyses. In particular, the discussion on Ozone Depletion Potentials (ODPs) does not adequately represent the use of this concept in ozone policy. For instance, the authors primarily discuss ODPs in terms of the change in ozone at steady-state (or at equilibrium) for a mass emission of a compound, relative to the change in ozone from the same mass emission of CFC-11, one of the gases of most concern to ozone. However, one of the most important factors in the use of steady-state ODPs results from their being equivalent to the effects on ozone from the impulse response of a unit mass emission of a compound relative to a similar impulse emission of CFC-11. This negates several arguments by the authors about the limitations of steady-state ODPs. It also helps explain why this concept has gained such wide use in essentially all policy relating to effects of chlorine and bromine compounds on ozone.

As we approach the dawning of new international policy relating to concerns about climate change, it is worthwhile to examine the lessons learned from the concerns about ozone. Whereas in general, a much smaller problem in extent and in policy implications than the concerns about global warming, the ozone issue is a microcosm of this larger issue. The pathway being taken so far in public acceptance of the concerns scientists have about climate change parallels that of concerns about ozone in the late 1970s. Similarly, the steps towards policy also appear to be following the path of ozone policy considerations in the early 1980s. There is no question that the potential concerns about climate are much farther reaching than the implications of ozone change. *Mending the Ozone Hole* provides a useful historical perspective on a major environmental issue, and it also can offer many insights into the pathways being taken at achieving policy in the much more complex climate issue. The rapid rate at which new technology was and is being developed to protect atmospheric ozone can also provide some sense of optimism as humanity proceeds towards developing the technology required to control the impact of climate change on the global environment. As long as the reader recognizes the overstated agenda the authors have for eliminating chlorine and bromine, I can recommend this book for its insights into the ozone issues.