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Environmental Regulations on Chlorofluorocarbons[1]

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In August 1988, the U.S. Environmental Protection Agency issued final regulations that implement the *Montreal Protocol on Substances that Deplete the Ozone Layer.* The regulations require a 50% reduction in consumption of fully halogenated chlorofluorocarbons (CFCs) within 10 years and a freeze on consumption of halons within 4 years. The Montreal Protocol provisions were designed in September 1987 based on the results of a 2-year international series of scientific, technical, and economic workshops. As would be expected, scientific investigations continued during this period. While these investigations suggested that significant global depletion had already occurred, these preliminary findings were not taken into account during negotiations or rulemaking. In March 1988, however, the international Ozone Trends Panel confirmed the findings. Depletion greater than that projected under the Montreal Protocol has already occurred. An early reassessment of the Protocol provisions appears to be inevitable. Restrictions on CFCs will affect the refrigeration and air-conditioning industries. Emerging alternatives to CFCs include newly developed refrigerants, innovative designs, and engineering controls. Key issues in evaluating these alternatives include energy efficiency, capital costs, service to consumers, and compatibility with existing designs.

KEY WORDS: chlorofluorocarbons; freons; ozone layer; refrigerants.

1. SCIENCE BEFORE THE MONTREAL PROTOCOL

In August 1988, the U.S. Environmental Protection Agency (EPA) issued final regulations that implement the *Montreal Protocol on Substances that Deplete the Ozone Layer.* The regulations require a 50% reduction in consumption of fully halogenated chlorofluorocarbons (CFCs) within 10 years and a freeze on consumption of halons within 4 years.

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During the protocol negotiations, the scientific basis for evaluating different control strategies was a major scientific assessment prepared by the World Meteorological Organization (WMO) [1]. The WMO assessment stated that no statistically significant global change had occurred in total column ozone. In addition, it reviewed the current generation of atmospheric models and found that they replicated many atmospheric conditions and could serve as a useful tool in projecting effects of atmospheric trace gases.

EPA's methodology for evaluating the risks of stratospheric ozone depletion used a parameterized one-dimensional atmospheric model developed by the Lawrence Livermore National Laboratory. An international modeling workshop convened by the United Nations Environment Programme in Wurzburg, FRG, in April 1987 found that this parameterized model produced outputs that were slightly lower than, but within the range of, those of major one-dimensional models [2] (Fig. 1).

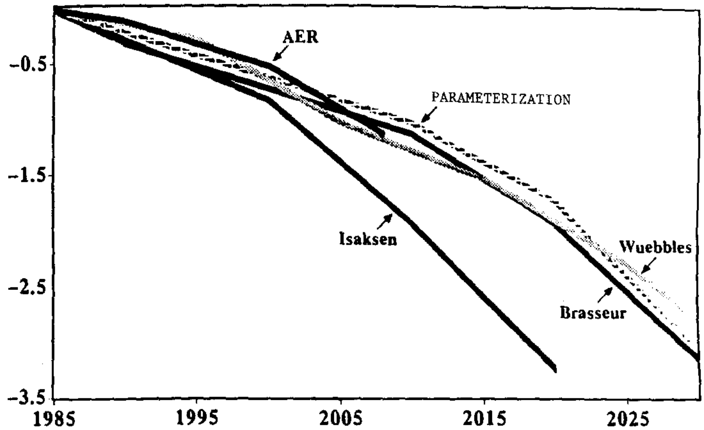

Fig. 1. EPA's parameterized one-dimensional (1-D) model. Global average change in total column ozone is shown as calculated by several modeling groups for a common scenario as follows.

Compound	Growth rate (%/year)
CFCs	3.0 (emissions)
CH_4	1.0 (concentrations)
N_2O	0.25 (concentrations)
CO_2	~0.60 (concentrations)

Results are shown for two-dimensional models of Isaksen and Sze (AER), one-dimensional models of Brasseur and Wuebbles, and EPA's parameterized one-dimensional model (Connell). Sources: Chemical Manufacturers Association [8]; WMO [1], Connell [9], Brasseur and DeRudder [10], and Isaksen and Stordal [11].

In addition, EPA used an integrated set of economic, technical, and effects models that were based on the results of a 2-year international series of scientific, technical, and economic workshops. The EPA approach was reviewed by its independent Science Advisory Board (SAB) [3].

EPA's *Regulatory Impact Analysis* used the models reviewed by SAB to project the effects of uncontrolled use of CFCs and halons [4]. Projections of future use in the absence of controls were developed based on the economic workshops that had been sponsored by UNEP. EPA's baseline scenario projected growth in CFC use of approximately 2.5% per year, with higher growth rates in the Soviet Union and developing nations and higher growth for CFCs used in electronics cleaning. Growths of methane, carbon dioxide, and nitrous oxide were taken at historical rates. The baseline growth scenario was projected to result in ozone depletion of 40% by 2075 (Fig. 2).

To evaluate the health and environmental effects of ozone depletion, EPA used dose–response models developed in its risk assessment. For populations alive today and born before 2075, EPA found that significant health effects would result—154.5 million additional skin cancer cases and 3.2 million additional skin cancer deaths (Fig. 2). In addition, 18.2 million additional cataract cases were projected. Significant damage would occur to commercial crops and fish harvests, tropospheric oxidant problems would be exacerbated, and outdoor materials would be degraded (Fig. 3).

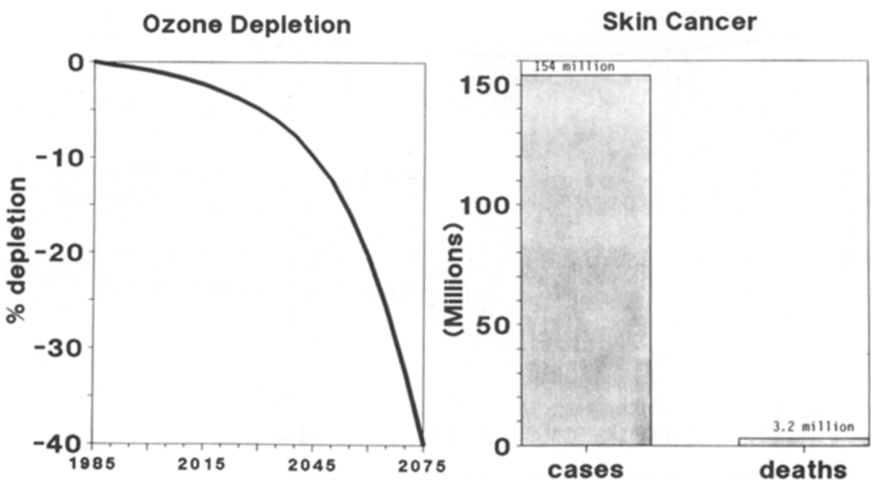

Fig. 2. Projected depletion and skin cancers if no controls are taken. Assumptions: Ozone depletion computed with parameterized 1-D atmospheric model, with baseline growth in CFCs of ~2.7%/year. Other trace gases are assumed to grow at historical rates. Skin cancer estimates shown for populations born before 2075, based on dose–response models developed in EPA's risk assessment [4].

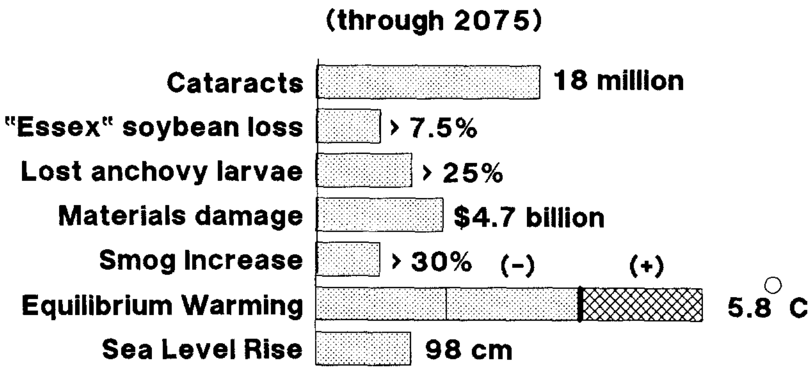

Fig. 3. Other projected effects of atmospheric change if no controls are taken. Assumptions: Effects computed for ozone depletion as shown in Fig. 2, based on dose–response models developed in EPA's risk assessment [4]. Global warming estimate assumes 3°C for doubled CO_2; equilibrium warming could be 50% higher or lower.

2. PROJECTED BENEFITS OF THE MONTREAL PROTOCOL

By reducing the future use and emissions of CFCs and halons, the *Montreal Protocol* will reduce projected ozone depletion. Figure 4 shows the projected depletion for the protocol and the resulting health and environmental benefits.

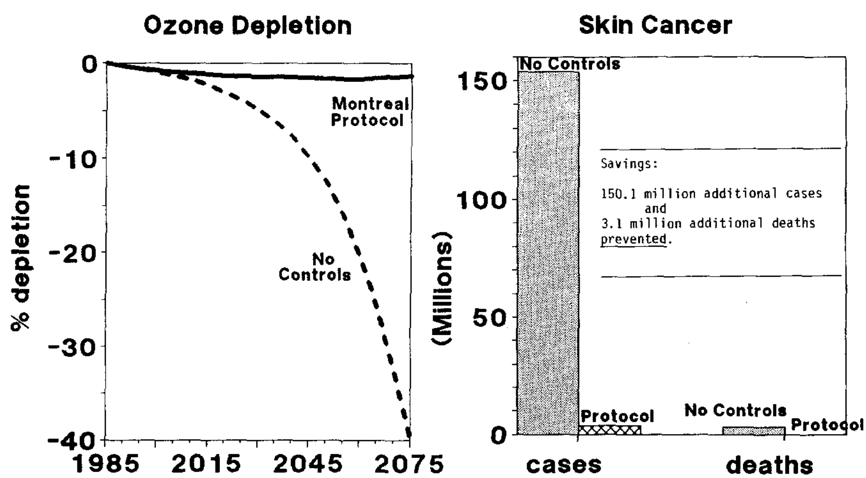

Fig. 4. Projected benefits of the Montreal Protocol. Assumptions: Ozone depletion computed with parameterized 1-D atmospheric model, with baseline growth in CFCs of ~2.7%/year. Other trace gases are assumed to grow at historical rates. Montreal Protocol case assumes that 94% of developed nations and 65% of developing nations join the protocol. Skin cancer estimates shown for populations born before 2075, based on dose–response models developed in EPA's risk assessment [4].

3. SCIENCE AFTER THE MONTREAL PROTOCOL

At the time the protocol restrictions were being negotiated, they appeared to be stringent enough to limit depletion to relatively low levels. As would be expected, scientific investigations continued during this period. While they suggested that significant global ozone depletion had already occurred, these preliminary findings were not taken into account during negotiations.

In March 1988, the international Ozone Trends Panel confirmed that significant global ozone depletion had occurred since 1970 (Fig. 5) and could be attributed to atmospheric chlorine [5]. Depletion greater than that projected under the Montreal Protocol has already occurred.

The Ozone Trends Panel also announced that the seasonal losses of over 40% observed in Antarctica were conclusively linked to atmospheric chlorine [5].

4. EMERGING ALTERNATIVES TO CHLOROFLUOROCARBON REFRIGERANTS

As of today, EPA has implemented a cap on production and consumption of fully halogenated CFCs, with a 50% phasedown to occur in step with the Montreal Protocol [6]. In August 1988, EPA issued its final rule.

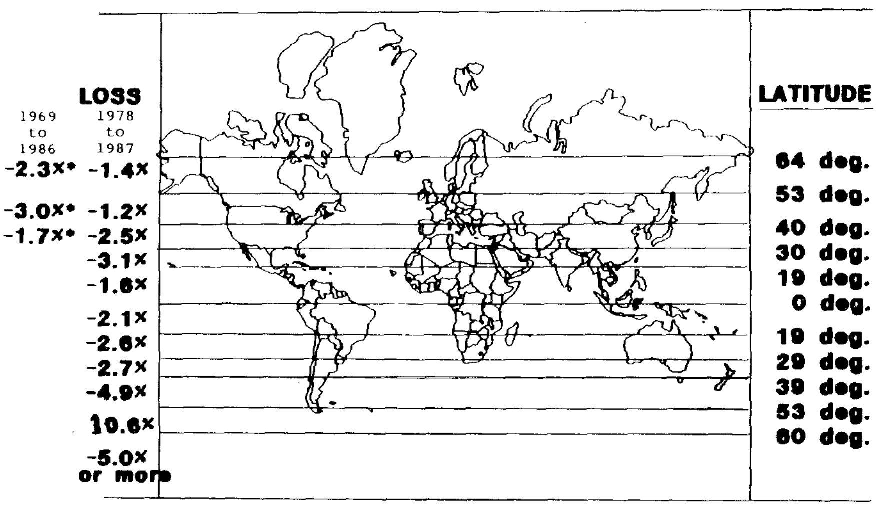

Fig. 5. Observed global depletion. Observed depletion shown for each latitude band as reported by the international Ozone Trends Panel in March 1988 [5].

The refrigeration and air-conditioning industries (retail refrigeration, chillers, cold storage, residential refrigerators and freezers, and mobile air-conditioning) are important sectors of the economy. As CFCs become more scarce and their prices increase, companies that use the chemicals are expected to reduce their CFC use.

Emerging alternatives to CFCs include newly developed refrigerants, innovative designs such as vacuum panel units, and engineering controls such as recovery and recycling. Key issues in evaluating these alternatives include energy efficiency, capital costs, and compatibility with existing designs.

HCFC-22 is a commercially available refrigerant that has 5% of the ozone depletion potential of CFC-11 and CFC-12. HCFC-22 could be used in retail food refrigeration, chillers, and mobile air-conditioning. Using this chemical would require substantial system redesign in some applications.

Blends of currently available refrigerants can be used in some applications including mobile air conditioning. Although not in use currently, some CFC blends (e.g., CFC-12/DME) may be considered promising interim solutions that can be used safely with minor design modifications.

New refrigerants such as HCFC-134a are being developed and tested. In March 1988, an international consortium of 14 companies was formed to pool information on toxicity testing of these new chemicals. A committee of internationally recognized chemists recently released its findings that if regulations sufficiently increased the price of existing CFCs, alternative chemicals could be marketed within 5 years [7].

In addition, a mixture of HCFC-22 and HCFC-142b is now commercially available and is claimed by its manufacturer to yield better energy efficiency while being compatible with current equipment.

An innovative refrigeration unit is currently being developed that uses helium. The manufacturer claims that discussions are under way with the Peoples Republic of China jointly to develop and market the unit.

Refrigerators could also be designed to achieve higher levels of insulation. Promising alternatives, including the use of thicker insulating foams and a newly developed vacuum panel design, are also being considered.

5. KEY ISSUES IN EVALUATING ALTERNATIVES

Successful introduction of alternative refrigerants and technologies must consider four issues: energy efficiency, capital costs, consumer service, and compatibility with existing designs.

New designs must be able to meet the energy efficiency goals established by the Federal Government. The National Appliance Energy Conservation Act of 1987 (Pub. L. 100-12) established energy efficiency standards for major household appliances, including room air-conditioners, refrigerators, refrigerator-freezers, and freezers. Furthermore, the act requires the Department of Energy to consider tightening the stringency of these standards.

To be successful in the marketplace, alternative units must be priced competitively. Manufacturers must weigh the capital costs of a new unit against its long-term operating costs.

Compatibility with existing designs will constrain the introduction of some alternatives. It is likely, for example, that owners of large commercial chillers with high capital costs would prefer a drop-in chemical substitute to a new unit that would lead to early retirement of the existing capital equipment.

It is critical to examine the tradeoff between keeping existing designs and moving toward new designs that better meet energy efficiency standards or consumer service goals. For example, HCFC-22 used in a two-stage refrigeration cycle might be more energy efficient and provide consumers with better control of temperatures in freezers and the refrigeration portion of their boxes but would clearly require retooling and new designs.

Manufacturers should be careful to evaluate the range of options so as to be certain that they can compete with international competition. We can expect foreign competitors to retool quickly. If U.S. industry is to remain competitive, it must consider energy efficiency and the likely impact of competition from abroad that markets "ozone layer-safe products."

6. POTENTIAL FOR FUTURE REGULATION

The initial CFC reductions made by the refrigeration industry will be required by the Montreal Protocol. Due to recent advances in our scientific knowledge, however, further CFC reductions may prove necessary, and the refrigeration industry should be prepared to make cuts beyond the 50% currently required by the protocol.

The likelihood of further CFC reductions was reinforced by DuPont's announcement that it will cease production of CFCs. Pennwalt Corporation has also announced such a goal. These statements occurred soon after the Ozone Trends Panel released its findings.

The scientific basis for determining the stringency of CFC reductions required to reduce the risks of ozone depletion was undercut by the Ozone Trends Panel report. As shown in Fig. 6, the ozone depletion that has already been observed is greater than that projected ever to occur under the Montreal Protocol. The current generation of atmospheric models is not capable of replicating observed depletion.

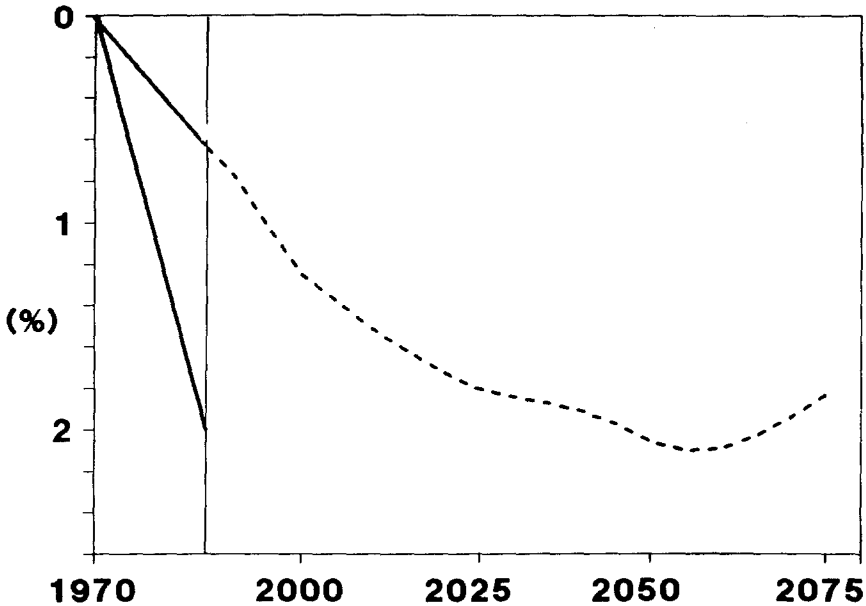

Fig. 6. Observed depletion exceeds protocol projections. Assumes average ozone loss computed by models to be ~0.5% from 1970 to 1986; observed global loss is ~2% [5].

An alternative approach to analyzing stringency is to evaluate future concentrations of chlorine (and bromine) in the atmosphere. The merit for examining the potential for future ozone depletion in this manner stems from the fact that chlorine (and bromine) abundances ultimately determine the risk of ozone depletion. Consequently, information about their abundances can be of use to decision makers without making final and certain conclusions about the quantitative relationship between their abundances and ozone depletion.

Because CFCs have long lifetimes, they accumulate in the atmosphere and their concentrations will grow even if their emissions are held constant. Figure 7 shows the increases in emissions and atmospheric chlorine projected for no controls and the Montreal Protocol. The protocol would reduce the chlorine levels that would occur if no controls were taken, but chlorine levels will still increase by at least a factor of three [12].

The protocol was crafted to allow revision of its coverage and stringency based on advances in our scientific understanding of the global atmosphere. The first reassessment called for by the protocol was scheduled to begin in 1990. Already, many have asked the protocol's governing body to accelerate this timetable so that the reassessment can be completed

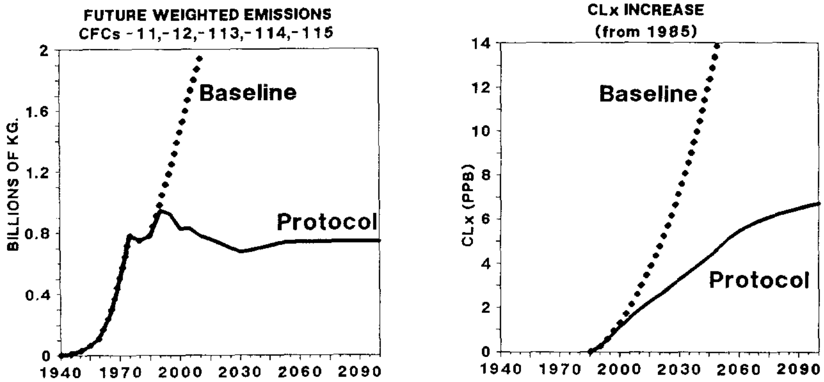

Fig. 7. Atmospheric chlorine is projected to increase. Increase in Cl_x computed by EPA's parameterized 1-D atmospheric model. No-controls case assumes 2.75% average annual rate of growth from 1985 to 2050 and no growth thereafter for CFC-11, -12, -113, -114, and -115; HCFC-22; CCl_4; CH_3CCl_3; and Halon 1211 and 1301. Protocol case simulates the scheduled 50% phasedown for CFC-11, -12, -113, -114, and -115 and freeze on halons, with the United States, 94% of other developed nations, and 65% of developing nations joining the protocol (other compounds grow at baseline rates). Source: Hoffman and Gibbs [12].

earlier. The heads of State of several nations, including the United States and United Kingdom, have announced their goal of eliminating CFC use by the turn of the century. Major CFC producers have also adopted this goal. Consequently, the refrigeration industry and scientists should expedite their examination of alternatives.

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