CLIMATE CHANGE

Preserving Montreal Protocol Climate Benefits by Limiting HFCs

With no impending global controls on HFCs, the Montreal Protocol offers a near-term path to preserve its climate benefits.

Guus J. M. Velders,[1]* A. R. Ravishankara,[2] Melanie K. Miller,[3] Mario J. Molina,[4] Joseph Alcamo,[5] John S. Daniel,[2] David W. Fahey,[2] Stephen A. Montzka,[2] Stefan Reimann[6]

The Montreal Protocol is perhaps the most successful international environmental treaty, responsible for global phaseout of the consumption and production of ozone-depleting substances (ODSs), e.g., chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Hydrofluorocarbons (HFCs), which do not destroy stratospheric ozone, were considered long-term substitutes for ODSs and are not controlled by the Montreal Protocol. Because most HFCs are potent greenhouse gases (GHGs), they are included in the Kyoto Protocol. But climate benefits provided by this protocol are limited as they apply only to developed countries and over a short time (2008–2012). As we describe below, with no impending global controls on HFCs, inclusion of HFCs under the Montreal Protocol offers a path, starting in the short term, to preserve the climate benefits already achieved by this protocol.

Climate considerations are not new to the Montreal Protocol. Signatory nations acknowledged in the preamble that they are "Conscious of the potential climatic effects of emissions of these substances [ODSs]." The climate contribution of future HCFC emissions was an important consideration for the accelerated phaseout agreed to by the parties in 2007.

Since 2010, 108 nations have signed a declaration stating their "intent to pursue further action under the Montreal Protocol aimed at transitioning the world to environmentally sound alternatives to HCFCs and CFCs" (*1*). Canada, Mexico, and the United States, as well as the Federated States of Micronesia, submitted proposals in 2010 and 2011 to control HFC use by amending the Montreal Protocol. The proposals and declaration were motivated by the interest in limiting climate change from future emissions of HFCs with high global warming potentials (GWPs) (*2*). These proposals were discussed but not adopted at the last two meetings of the Parties to the Montreal Protocol. Negotiations are expected to continue in future meetings as details of the proposals are refined.

At the 2011 Durban climate negotiations, it was decided that new climate commitments will come into effect only from 2020 onward, leaving the coming 8 years or more without any legally binding global measures under a climate agreement to reduce potential climate effects of HFCs and other GHGs. This delay heightens policy and scientific interest in examining the possibilities and consequences of regulating HFCs under the Montreal Protocol.

Climate Benefits of Montreal Protocol

Most ODSs are also potent GHGs (*3*). Thus, reductions in atmospheric ODS concentrations to protect the ozone layer have had the added benefit of providing some climate protection. The radiative forcing (*4*) from ODSs reached 0.32 W/m^2 around 2000 (compared with about 1.5 W/m^2 for CO_2) and has remained nearly constant since. Without the Montreal Protocol, radiative forcing from ODSs could have reached 0.60 to 0.65 W/m^2, or about 35% of that of CO_2, in 2010 (see the graph) (*5*). This direct climate benefit is offset in part (about 30%) by other factors, including indirect radiative forcing from reductions in stratospheric ozone and climate forcing by increased use of ODS substitutes (*5*). Total avoided net annual ODS emissions are estimated to be equivalent to about 10 Gt CO_2/year in 2010, which is about five times the annual reduction target of the Kyoto Protocol for 2008–2012 (*5*). This climate benefit of the Montreal Protocol may be reduced or lost completely in the future if emissions of ODS substitutes with high GWPs, such as long-lived HFCs, continue to increase.

Growth in HFCs as ODS Substitutes

With CFC phaseout completed in 2010 and the scheduled phaseout of most HCFCs by 2030, HFCs are being used more in applications that traditionally used ODSs, e.g., refrigeration and air-conditioning equipment, blowing agents for foams, aerosol sprays, fire protection systems, and solvents (*6*, *7*). The atmospheric abundances of major HFCs used as ODS substitutes (*8*) are increasing 10 to 15% per year in recent years (*9*). Rising use of HFCs is directly attributable to intent and actions of the Montreal Protocol (*7*), hence, the HFC contribution to climate change can be viewed as an unintended negative side effect of these actions.

The current contribution to climate forcing of HFCs used as ODS substitutes is about 0.012 W/m^2 [excluding HFC-23 (*8*)], less than 1% of the total forcing from long-lived GHGs, but it is increasing rapidly (*9*, *10*). Growth rates and projections indicate potential for substantial future increases in emissions and atmospheric abundances of HFCs in the absence of new controls (*9*). These business-as-usual projections are based on increasing demand for ODS substitutes, particularly in developing countries (*11*).

In an upper-range scenario, global radiative forcing from HFCs increases from about 0.012 W/m^2 in 2010 to 0.25 to 0.40 W/m^2 in 2050 (*11*) (see the graph). This corresponds to 14 to 27% of the increase in CO_2 forcing under the range of Intergovernmental Panel on Climate Change (IPCC) business-as-usual scenarios from 2010 to 2050 (*12*). In these scenarios, developing countries replace HCFCs with HFCs by using the same substances and use patterns as adopted by developed countries (*11*).

Wide Range of HFC Lifetimes and GWPs

In recent proposals to amend the Montreal Protocol, production and consumption of HFCs would be reduced in phases from baseline levels. This would encourage the use of alternative substances with low GWPs. The extent to which HFCs or other ODS substitutes will influence climate depends on past and future emissions, atmospheric lifetimes, and the efficiency of these molecules in absorbing infrared radiation. Most fluorocarbons (e.g., CFCs, HCFCs, and HFCs) have a similar ability (within about a factor of three) to trap infrared radiation, on a per-molecule

[1]National Institute for Public Health and the Environment (RIVM), 3720 BA Bilthoven, Netherlands. [2]Earth System Research Laboratory, National Oceanic and Atmospheric Administration (NOAA), Boulder, CO 80305, USA. [3]Touchdown Consulting, 1310 La Hulpe, Belgium. [4]University of California, San Diego, La Jolla, CA 92093, USA. [5]United Nations Environment Programme (UNEP), Nairobi, Kenya. [6]Swiss Federal Laboratories for Materials Science and Technology (Empa), CH-8600 Duebendorf, Switzerland.

*To whom correspondence should be addressed. E-mail: guus.velders@rivm.nl

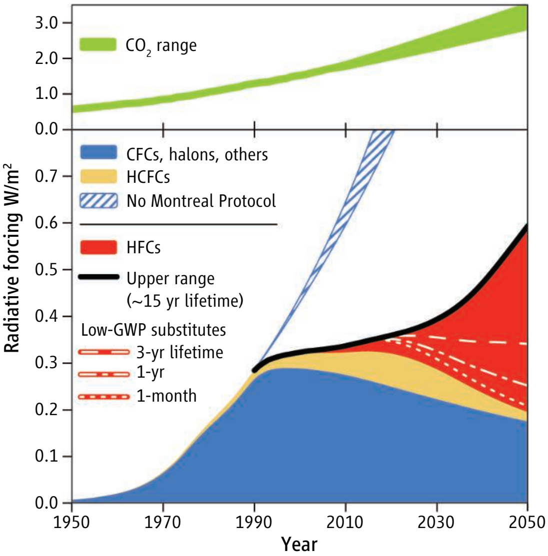
Published by AAAS

basis, in Earth's atmosphere. Therefore, differences in their relative impact on climate arise primarily from differences in atmospheric lifetimes. The longer the lifetime of a molecule, the larger its potential contribution to climate forcing.

Fully saturated HFCs (molecules with only single bonds), used in significant quantities commercially (e.g., HFC-32, -125, -134a, -143a, and -152a), have atmospheric lifetimes that range from 1 to 50 years (*9*). Their 100-yr GWPs range from 100 to about 4000. Unsaturated HFCs (also referred to as hydrofluoro-olefins, HFOs) have much shorter atmospheric lifetimes, on the order of days to weeks, with correspondingly smaller GWPs (~20 or less). If the current mix of HFCs with an average lifetime of 15 years (average GWP of 1600) were replaced by HFCs with lifetimes less than 1 month (GWP less than ~20), the total HFC radiative-forcing contribution in 2050, even under the high-emission scenario, would be less than the current forcing from HFCs (see the graph). Such choices are currently available.

Choosing Appropriate Alternatives

Approaches to reduce climate forcing from future HFC use and to preserve climate benefits provided by the Montreal Protocol include (*6*, *13*, *14*) these: (i) replacing high-GWP HFCs with substances that have low impact on climate (e.g., hydrocarbons, CO_2 or certain HFCs) and alternative technologies (e.g., fiber insulation materials) and (ii) reducing HFC emissions (e.g., by changing the design of equipment and capturing and destroying HFCs when equipment reaches the end of its useful life). Given the orders-of-magnitude differences in GWPs, it is expected that transitioning to low-climate-impact substitutes with similar life-cycle energy efficiencies as high-GWP HFCs has the potential to provide larger climate benefits than attempts to reduce emissions of HFCs in applications. Low-climate-impact substitutes are already in commercial use in several sectors. These include fiber insulation materials; dry powder asthma inhalers; and non-HFC substances with low or zero GWPs, such as hydrocarbons, ammonia, and CO_2 in some refrigeration systems. Several HFCs with very short atmospheric lifetimes (hence, low GWPs) are now being introduced for foams and aerosols (HFC-1234ze) and mobile air conditioners (HFC-1234yf) (*15*). Also, the Multilateral Fund (MLF) of the Montreal Protocol is funding many projects in developing countries for the transition from ODSs to alternative substances or methods with lower impact on climate. The primary decisions about whether to use high-GWP HFCs or alternatives are currently made by companies and are subject to normal commercial considerations, such as performance; viability; affordability; availability; and health, safety, and environmental factors (*13*). A global framework for regulating future HFC use would provide a clear signal for the commercial sector, guiding the selection of substances for long-term use, as done under the Montreal Protocol for ODSs.



Projected radiative forcing by ODSs, HFCs, low-GWP substitutes, and CO_2 (*12*). The blue hatched region indicates what would have occurred in the absence of the Montreal Protocol, with 2 to 3% annual production increases in ODSs [data taken from (*5*)]. Added to the radiative forcing from ODSs [data from (*9*)] are the contributions from HFCs from the upper-range scenario [data from (*11*)]. Also shown are the radiative forcing from alternative scenarios in which substitution is made with chemicals having shorter lifetimes (lower GWPs); their contribution is calculated using methods described in (*11*) with the parameters from (*16*). Under the Montreal Protocol, use reductions started in 1989 for CFCs and in 1996 for HCFCs.

In addition to the direct contribution to climate forcing, indirect climate effects arise from the energy used or saved during the application or product's full life cycle. Ideally, alternative systems would have overall energy efficiencies at least as high as the systems they replace. This is already feasible in a number of sectors, such as domestic, commercial, and industrial refrigeration and some types of air-conditioning systems (*6*, *13*, *15*).

Future Challenge for Policy-Makers

A large number of countries have formally stated their intention to preserve climate benefits of the Montreal Protocol (*1*). A challenge for policy-makers is to identify how this might be accomplished. Given that climate impacts of HFC use can be viewed as unintended side effects of the Montreal Protocol, an option is to expand provisions of this protocol while drawing from parties' experience in formulating successful ODS controls that took scientific, economic, and technical aspects into account. The Montreal Protocol has relevant infrastructure for accomplishing this, including the MLF, expert panels, regional networks, and administrative procedures. This infrastructure and experience suggest that such an approach could effectively and quickly limit continued growth of high-GWP HFCs and preserve the substantial climate benefits that were gained by the Montreal Protocol in phasing out ODSs.

References and Notes

1. UNEP, *Report of the 22nd Meeting of the Parties to the Montreal Protocol, Annex III, Declaration on the Global Transition Away from HCFCs and CFCs* (UNEP, Nairobi, Kenya, 2010).
2. The GWP is an index that enables comparison of climate forcing integrated over a specified time horizon (usually 100 years) of the emissions of GHGs relative to CO_2.
3. V. Ramanathan, *Science* **190**, 50 (1975).
4. Radiative forcing is a measure of how a climate-forcing agent influences the energy balance of Earth.
5. G. J. M. Velders *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **104**, 4814 (2007).
6. IPCC and Technology and Economic Assessment Panel (TEAP), *Special Report: Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons*, B. Metz *et al.*, Eds. (Cambridge Univ Press, New York, 2005).
7. TEAP, *2010 Assessment Report of the Technology and Economic Assessment Panel* (UNEP, Nairobi, Kenya, 2011).
8. The presence of HFCs in the atmosphere arises almost completely from their use as substitutes for ODSs. HFC-23 is an exception. It results primarily from unintentional production and release during the production of HCFC-22.
9. World Meteorological Organization (WMO), *Scientific Assessment of Ozone Depletion: 2010* (Global Ozone Research and Monitoring Project Report no. 52, WMO, Geneva, 2011).
10. S. A. Montzka *et al.*, *Nature* **476**, 43 (2011).
11. G. J. M. Velders *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 10949 (2009).
12. IPCC, *Climate Change 2001: The Scientific Basis*, J. T. Houghton *et al.*, eds. (Cambridge Univ. Press, New York, 2001).
13. TEAP, Progress Report of the Technology and Economic Assessment Panel (UNEP, Nairobi, Kenya, 2010), vol. 1.
14. W. Schwarz *et al.*, Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases (Öko-Institute, Freiburg, Germany, 2011).
15. UNEP, *HFCs: A Critical Link In Protecting Climate and the Ozone Layer* (UNEP, Nairobi, Kenya, 2011).
16. For the substitutes, a molecular mass of 100 g/mol is used and a radiative efficiency of 0.2 W/m² per ppb; typical values for commercially used HCFCs and HFCs. An annual release from the bank of 13% is assumed, typical for refrigeration and air conditioning (*9*). The low-GWP scenarios are based on the assumption that from 2015 onward all demand for HFCs [taken from (*11*)] is met by substitutes with shorter lifetimes.
17. The opinions expressed here are those of the authors and not of their institutions.

10.1126/science.1216414