Q14 Are there controls on the production of ozone-depleting substances?

Yes, the production and consumption of ozone-depleting substances (ODSs) are controlled under a 1987 international agreement known as the "Montreal Protocol on Substances that Deplete the Ozone Layer" and its subsequent amendments and adjustments. The Protocol, now ratified by 198 parties, establishes legally binding controls on the global production and consumption of ODSs. Production and consumption of controlled ODSs by developed and developing nations will be almost completely phased out by 2030.

The Vienna Convention and the Montreal Protocol. In 1985, a treaty called the Vienna Convention for the Protection of the Ozone Layer was signed by 26 nations. The signing nations agreed to take appropriate measures to protect the ozone layer from human activities. The Vienna Convention was a framework agreement that supported research, exchange of information, and future protocols. In response to growing concern, the Montreal Protocol on Substances that Deplete the Ozone Layer was signed in 1987 and, following ratification, entered into force in 1989. The Protocol has been successful in establishing and enforcing legally binding controls for developed and developing nations on the production and consumption of halogen source gases known to cause ozone depletion. Halogen source gases containing chlorine and bromine that are emitted by human activities and are controlled under the Montreal Protocol are referred to as ozone-depleting substances (ODSs). National consumption of an ODS is defined as production plus imports of the controlled substance, minus exports of the substance. Inadvertent emissions of ODSs used as feedstock (raw material used to synthesize other substances through a process of chemical transformation) are not controlled by the Montreal Protocol. Nations are, however, required to report imports, exports, and production of ODSs used as feedstocks. The Protocol provisions are structured for developed countries to act first and for developing countries to follow with financial assistance, technology transfer, and the sharing of knowledge for mitigation of emissions of ODSs as well as the destruction of ODSs within equipment or products. In 2009, the Montreal Protocol became the first multilateral environmental agreement to achieve universal ratification.

Amendments and Adjustments. As the scientific basis of ozone depletion became more certain after 1987 and substitutes and alternatives became available to replace ODSs, the Montreal Protocol was strengthened with amendments and adjustments. Each amendment is named after the city in which the Meeting of the Parties to the Montreal Protocol took place and by the year of the meeting. The timeline in Figure Q0-1 shows some of the major decisions that have been adopted. These decisions brought additional ODSs under control, accelerated the timing of existing control measures, or prescribed phaseout dates for the production and consumption of certain gases. The initial Protocol measures were a 50% reduction in chlorofluorocarbon (CFC) production and consumption by 1998 and a freeze on halon production and consumption. The 1990 London Amendment called for a phaseout of the production and consumption of the most damaging ODSs in developed nations by 2000 and in developing nations by 2010. The 1992 Copenhagen Amendment accelerated the phaseout date for CFCs, halons, carbon tetrachloride, and methyl chloroform to 1996 in developed nations and also initiated controls on future production and consumption of hydrochlorofluorocarbons (HCFCs) in developed nations. Further controls on ODSs were agreed upon in later meetings in Vienna (1995), Montreal (1997, 2007), and Beijing (1999). The latest development is the 2016 Kigali Amendment (see Q19), which expanded the Montreal Protocol to control production and consumption of hydrofluorocarbons (HFCs) with high global warming potentials (GWPs) (see Table Q6-1). As explained below, HFCs are greenhouses gases (GHGs) which warm climate in the lower atmosphere and do not cause ozone depletion.

Influence of the Montreal Protocol. Montreal Protocol phase down schedules for each group of ODSs are based on several factors including (1) the effectiveness in depleting stratospheric ozone in comparison with other substances (see Ozone Depletion Potential, ODP, in Q17), (2) the availability of suitable substitutes, and (3) the potential impact of controls on developing nations. The influence of Montreal Protocol provisions on stratospheric ODS abundances can be demonstrated with long-term changes in equivalent effective stratospheric chlorine (EESC).

Calculations of EESC combine the amounts of chlorine and bromine present in air near Earth's surface to form an estimate of the potential for ozone destruction in a particular stratospheric region on an annual basis (see definition in Q15). EESC values in the coming decades will be influenced by (1) the slow natural removal of ODSs present in the atmosphere, (2) emissions from continued production and use of ODSs, and (3) emissions from existing ODS banks. The phrase ***ODS banks*** refers to long-term containment of ODSs in various applications. Examples are CFCs in refrigeration and air-conditioning equipment as well as insulating foams, and halons in fire-extinguishing equipment. Annual emissions are projected based on release from existing banks and any new production and consumption of ODSs. The long-term changes in EESC at midlatitudes are shown in **Figure Q14-1**, based upon estimates of future emissions of ODSs that were published in year 2007 for the following cases:

- **No Protocol.** In a world-avoided scenario without the Montreal Protocol, the production, use, and emissions of CFCs and other ODSs continue to increase unabated after 1987. This No Protocol scenario is illustrated using an annual growth rate of 3% for the emissions of all ODSs. As a result, EESC increases nearly 10-fold by the mid-2050s compared with the 1980 value. Computer models of the atmosphere show that EESC under the No Protocol scenario dramatically increases global total ozone depletion between 1990 and 2020 relative to what actually occurred, and increases ozone depletion much more by midcentury. As a result, harmful UV-B radiation would have roughly doubled at Earth's surface by the middle of the 21st century, causing damage to ecosystem health, and a global rise in skin cancer and cataract cases (see Q16). Since ODSs are powerful GHGs, the climate forcing from ODSs increases substantially without the Montreal Protocol (see Q18).
- **Montreal Protocol provisions.** International compliance with only the 1987 provisions of the Montreal Protocol and the later 1990 London Amendment substantially slowed the projected growth of EESC relative to the world-avoided (No Protocol) scenario. The projections show a decrease in future EESC values for the first time with the 1992 Copenhagen Amendments and Adjustments. The provisions became more stringent with the amendments and adjustments adopted in Beijing in 1999 and Montreal in 1997 and 2007. Now, with full compliance to the Protocol, ODSs will ultimately be phased out, with some exemptions for critical uses (see Q15). Global EESC is slowly decaying from its peak value in 1998 and is expected to reach 1980 values around 2066. The success of the Montreal Protocol to date is demonstrated by the decline in ODP-weighted emissions of ODSs shown in Figure Q0-1. Total emissions peaked in 1987 at values about 10-fold higher than natural emissions

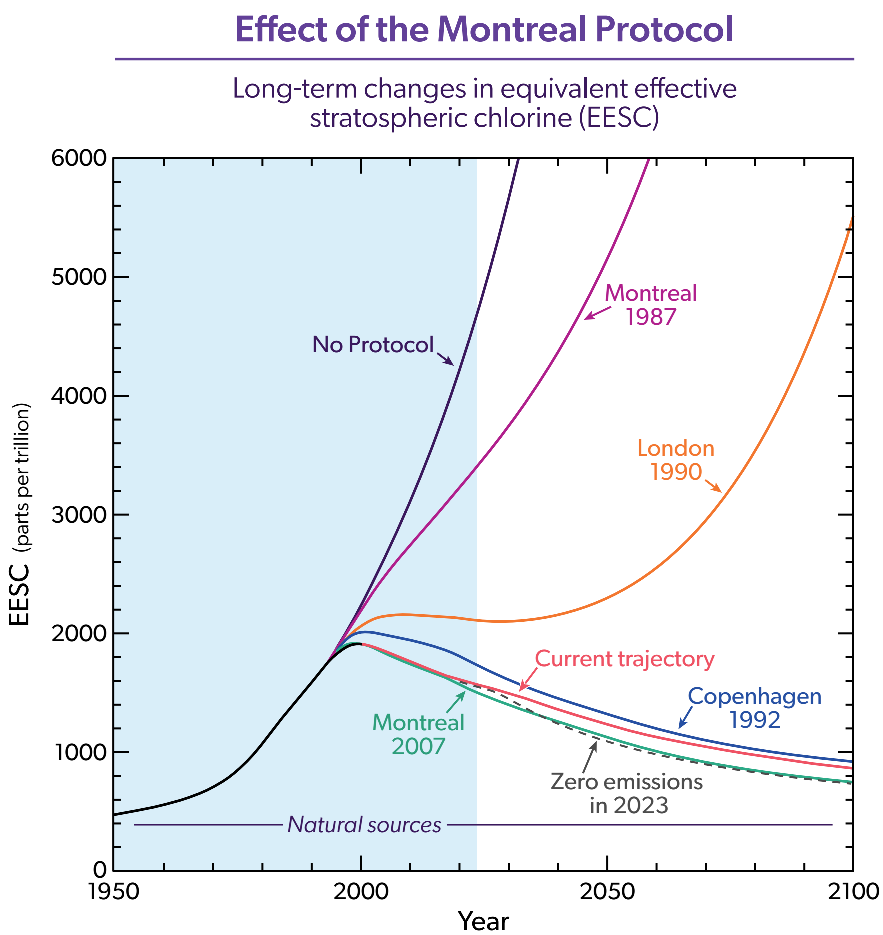

Figure Q14-1. Effect of the Montreal Protocol. The Montreal Protocol protects the ozone layer through control of the production and consumption of ozone-depleting substances (ODSs) by the world's nations. Equivalent effective stratospheric chlorine (EESC) is a quantity that represents the abundance of halogens available for ozone depletion in the stratosphere. Values of EESC are based upon either analysis of surface observations of ODSs (see Q15) or projections of future abundances of ODSs. Projections of EESC for the midlatitude lower stratosphere (about 19 km altitude) are shown separately for: no Protocol provisions; the provisions of the original 1987 Montreal Protocol and some of its subsequent amendments and adjustments as projected in in 2007; the current trajectory for EESC (red solid curve); and for future EESC assuming zero emissions of ODSs starting in 2023 (black dashed curve). The city names and years indicate where and when changes to the original 1987 Protocol provisions were agreed upon (see Figure Q0-1). Without the Protocol, EESC values would have increased significantly in the 21st century, leading to large amounts of ozone depletion throughout the world, including over highly populated regions. Only with the Copenhagen (1992) and subsequent Amendments and Adjustments do projected EESC values show a long-term decrease. The EESC values from observations shown in Figure Q15-1 lie above the Montreal 2007 projection due mainly to the use of larger emissions of ODSs from banks as well as increased emissions of ODSs from feedstocks used to manufacture various other chemicals than was considered in the original Montreal 2007 projection. Upward revision of the lifetime of CFC-11 and a few other ODSs since 2007, as well as unreported emissions of CFC-11, make small contributions to the slower decline in EESC than projected in 2007. If future emissions of ODSs from feedstocks, banks, and quarantine and pre-shipment applications of CH_3Br currently allowed under the Montreal Protocol could all be eliminated starting in 2023 (black dashed line), EESC would fall below the trajectory of full compliance following the Montreal 2007 Adjustment, as had been projected in 2007 (green line). The contributions from very short-lived gases (see Figure Q6-1), which have been minor to this point, are not included in any of these EESC time series.

(The unit "parts per trillion" is defined in the caption of Figure Q6-1.)

from methyl chloride and methyl bromide (see Q15). Between 1987 and 2022, the emissions of ODSs from human activities decreased by almost 80%.

Figure Q14-1 also shows long-term changes in EESC for two additional cases from the 2022 Scientific Assessment of Ozone Depletion report:

- **Current trajectory.** The current trajectory of EESC shown in Figure Q14-1 is based on observed abundances of ODSs from 2007 to 2021 and projected future abundances, assuming compliance with the Montreal Protocol. The current trajectory for EESC lies above the Montreal 2007 curve for two reasons: increased emissions of ODSs from banks as well as from feedstocks used for production of other chemicals, both relative to the assumptions of the original Montreal 2007 projection. The upward revision of the lifetime of CFC-11 and a few other ODSs since 2007, as well as unreported emissions of CFC-11, make small contributions to the slower decline of EESC than was projected in 2007.
- **Zero emissions.** The zero emissions scenario demonstrates the reduction in EESC that occurs if emissions of all ODSs are set to zero beginning in 2023. This assumption eliminates the emissions from new production, feedstocks, and banks. Significant differences from the current trajectory are evident in the first decades following 2023 because the phaseout of all ODS production under the Protocol will not be complete in 2023 and continued bank emissions are substantial. In the zero-emissions scenario, EESC returns to the 1980 value about a decade earlier than currently projected (solid red and dashed black lines, Figure Q14-1).

HCFC substitute gases. The Montreal Protocol provides for the use of hydrochlorofluorocarbons (HCFCs) as transitional, short-term substitute compounds for ODSs with higher ODPs, such as CFC-12. HCFCs are used for refrigeration, in making insulating foams, and as solvents, all of which were primary uses of CFCs. HCFCs are generally more reactive in the troposphere than other ODSs because they contain hydrogen (H) in addition to chlorine, fluorine, and carbon. Per amount emitted to the atmosphere, HCFCs are 88 to 98% less effective than CFC-11 in depleting stratospheric ozone because their chemical removal occurs primarily in the troposphere (see ODPs in Table Q6-1). The dominance of tropospheric removal for HCFCs prevents most of the halogen content this group of ODSs from reaching the stratosphere. In contrast, CFCs and some other ODSs release all their halogen content in the stratosphere because they are chemically inert in the troposphere (see Q5).

Under the provisions of the Montreal Protocol, developed and developing countries may continue to produce and import HCFCs over the rest of this decade before they are ultimately phased out. In the 2007 Adjustment to the Protocol, the phaseout of HCFCs was accelerated so that nearly all production ceased by 2020 for developed countries and ceases by 2030 for developing countries, about a decade earlier than in previous provisions. In making this decision, the Parties reduced the contribution of HCFC emissions to both long-term ozone depletion and future climate forcing (see Q17 and Q18).

HFC substitute gases. Hydrofluorocarbons (HFCs) are transitional substitute compounds for CFCs, HCFCs, and other ODSs. HFCs contain hydrogen, fluorine, and carbon. HFCs do not contribute to ozone depletion because they contain no chlorine or bromine. However, most HFCs and ODSs are also GHGs with long atmosphere lifetimes, so they contribute to human-induced climate change (see Q18 and Q19). Under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), HFCs are included in the basket of GHGs for which regular reporting of national annual emissions are required. The Paris Agreement of the UNFCCC is an international accord designed to reduce the emissions of GHGs in order to limit global warming to well below 2.0°C relative to the start of the Industrial Era and pursue efforts to limit global warming to 1.5°C warming. Future growth in the production and consumption of HFCs with high GWPs is now limited by the 2016 Kigali Amendment to the Montreal Protocol (see Q19).

Very short-lived (VSL) chlorine source gases. VSL halogenated source gases, defined as compounds with atmospheric lifetimes typically shorter than 0.5 years, are primarily converted to reactive halogen gases in the lower atmosphere (troposphere). Atmospheric release of most very short-lived chlorine source gases, such as dichloromethane (CH_2Cl_2, which is also known as methylene chloride) and chloroform ($CHCl_3$), results primarily from human activities. This class of compounds is not controlled by the Montreal Protocol and therefore they are not included in the estimates of EESC shown in Figure Q14-1. The atmospheric abundance of VSL chlorine source gases has increased substantially since the early 1990s and these gases presently contribute about 4% (130 ppt) to the total chlorine entering the stratosphere (see Figure Q6-1). Furthermore, the fraction of VSL gases that reach the stratosphere varies as a function of the location where the gases are emitted into the atmosphere. Should this class of compounds ever come under the control of the Montreal Protocol, future actions would be effective at lowering atmospheric abundances rather quickly, because these compounds are removed from the atmosphere within a few years.