

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 national production and consumption of ODSs. Production and consumption of all principal 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 28 nations in Vienna. 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 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 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. The Protocol provisions are structured for developed countries to act first and for developing countries to follow with some financial assistance. 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 in the last three decades. These decisions listed additional ODSs under control, accelerated the timing of existing control measures, and prescribed phaseout dates for the production and consumption of certain gases. The initial Protocol measures were a 50% reduction in chlorofluorocarbon (CFC) production and a freeze on halon production. 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 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 certain hydrofluorocarbons (HFCs). As explained below, HFCs are greenhouse gases (GHGs) which warm climate and do not cause ozone depletion.

Influence of the Montreal Protocol. Montreal Protocol controls are based on several factors that are considered separately for each ODS. The factors include (1) the effectiveness in depleting ozone in comparison with other substances (see Ozone Depletion Potential, ODP, in Q17), (2) the availability of suitable substitutes for domestic and industrial use, 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 surface air to form a measure 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 still present in the atmosphere, (2) emissions from continued production and use of ODSs, and (3) emissions from existing ODS banks containing a variety of compounds. The phrase ODS banks refers to long-term containment of ODSs in various applications. Examples are CFCs in refrigeration equipment and 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 allowed under the Montreal Protocol. The long-term changes in EESC at midlatitudes are shown in **Figure Q14-1** for several cases:

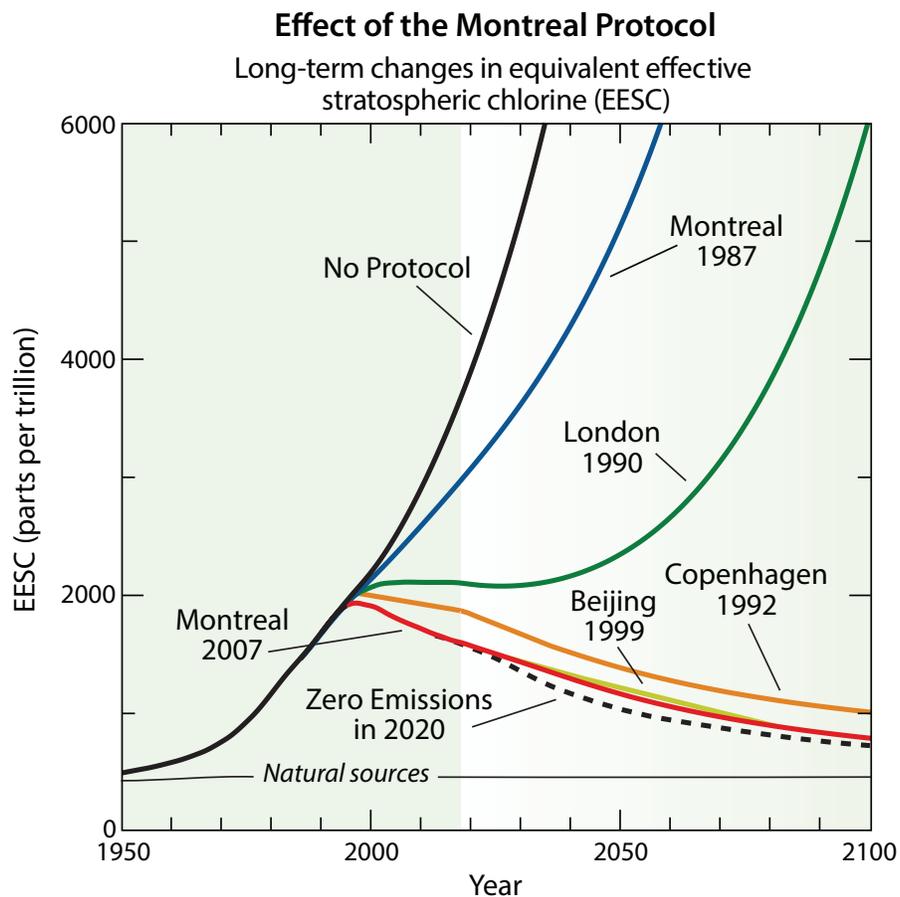


Figure Q14-1. Effect of the Montreal Protocol. The Montreal Protocol protects the ozone layer through control of the global production and consumption of ozone-depleting substances (ODSs). Equivalent effective stratospheric chlorine (EESC) is a quantity that represents the abundance of halogens available 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; and zero emissions of ODSs starting in 2020. 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 did projected EESC values show a long-term decrease. The EESC values from observations shown in Figure Q15-1 agree well with the Montreal 2007 curve shown in this figure. 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.

- No Protocol.** In a scenario without the Montreal Protocol, the production, use and emissions of CFCs and other ODSs continue to increase after 1987 at a rate faster than what actually occurred. 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 doubles global total ozone depletion between 1990 and 2010 relative to what actually occurred, and increases ozone depletion much more by midcentury. As a result, harmful UV-B radiation increases substantially 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 would have increased 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 would have substantially slowed the projected growth of EESC. The projections showed 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 the late 1990s and is expected to reach 1980 values in the mid-21st century. 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. Between 1987 and 2018, ODS emissions from human activities have decreased by almost 80%.

- **Zero emissions.** The zero emissions scenario demonstrates the reduction in EESC that occurs if emissions of all ODSs are set to zero beginning in 2020. This assumption eliminates the emissions from new production as well as banks. Significant differences from the Montreal 2007 projections are evident in the first decades following 2020 because the phaseout of all ODS production under the Protocol will not be complete in 2020 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. 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). This removal protects stratospheric ozone from most of the halogen content of HCFC emissions. In contrast, CFCs and some other ODSs release all of 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 use HCFCs as ODS substitutes in the coming decades before they are ultimately phased out. In the 2007 Adjustment to the Protocol, the phaseout of HCFCs was accelerated so that production ceases by 2020 for

developed countries and by 2030 for developing countries, about a decade earlier than in previous provisions. In adopting 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 used as transitional, short-term 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, HFCs and all 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 controlled GHGs. 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 emissions of HFCs with high Global Warming Potentials (GWPs) is limited by the 2016 Kigali Amendment to the Montreal Protocol (see Q19).

Very short-lived chlorine source gases. Very short-lived halogenated source gases, defined as compounds with atmospheric lifetimes 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), result primarily from human activities. This class of compounds is not regulated by the Montreal Protocol. The atmospheric abundance of very short lived chlorine source gases has increased substantially since the early 1990s and these gases presently contribute about 3.5% (115 ppt) to the total chlorine entering the stratosphere (see Figure Q6-1). Nonetheless, the estimates of EESC shown in Figure Q14-1 do not include contributions from very short-lived chlorine source gases because prior abundances of key gases such as CH_2Cl_2 exhibit large variability with respect to time and place of observation. Furthermore, projection of future abundances of very short-lived chlorine source gases are highly uncertain due to the lack of information on industrial sources. Should this class of compounds ever pose a threat to the ozone layer, future controls would be effective almost immediately because these compounds are removed from the stratosphere within a few years.