

# The Montreal Protocol Protection of Ozone and Climate

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*The Montreal Protocol is an international treaty that has reduced the atmospheric abundances of ozone-depleting substances (ODSs) through regulations on national production and consumption of these substances. The regulations have succeeded in protecting the ozone layer from unchecked future emissions of ODSs. As such, the Protocol is perhaps the most successful example of international cooperation on the environment. ODSs are also greenhouse gases that have the potential to change global climate when they accumulate in the atmosphere. Thus, the actions of the Montreal Protocol to protect ozone have also protected future climate and, hence, have provided a dual benefit to society. As for the long-term substitutes for ODSs, hydrofluorocarbons (HFCs) do not destroy ozone — but they are greenhouse gases. The increases in HFC emissions that occur in response to Montreal Protocol regulations could be substantial by the mid twenty-first century, offsetting the climate protection already achieved by the Protocol. Avoiding these projected HFC emissions stands as a significant opportunity for international cooperation on protecting future climate.*

## INTRODUCTION

Ozone (O<sub>3</sub>) is a key chemical constituent of the atmosphere, one that protects living organisms by shielding the earth from harmful ultraviolet (UV) radiation from the sun. Significant depletion of the stratospheric ozone layer has occurred over the last several decades as a consequence of anthropogenic emissions of certain long-lived gases. These gases, known as ozone-depleting substances

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(ODSs), contain chlorine and bromine atoms, which chemically destroy ozone in the stratosphere. The most severe depletion has occurred in the polar regions and has been widely recognized by the public in the form of the Antarctic *ozone hole*, first reported in 1985. This regular, seasonal loss of ozone has increased surface UV in the Antarctic and surrounding areas and caused changes in surface winds and temperatures at high southern latitudes.<sup>1</sup>

The threat to the ozone layer from continued ODS emissions led to the *Vienna Convention for the Protection of the Ozone Layer* in 1985 and ultimately to its *Montreal Protocol on Substances that Deplete the Ozone Layer* in 1987.<sup>2</sup> The Montreal Protocol is perhaps the most successful example of international cooperation to protect the environment. Since 1987, the Protocol has provided legally binding regulations that have been adopted in 197 nations with the ultimate objective of protecting the ozone layer by reducing ODS amounts in earth's atmosphere. In addition, the Protocol made provisions for using other compounds as substitutes in applications requiring ODSs. ODSs also contribute to climate change because they are potent greenhouse gases (GHGs). As a consequence, the actions under the Protocol have also protected the future climate while protecting the ozone layer.

In Parts I and II, this *dual benefit* will be examined in more detail. The contributions of ODSs to ozone depletion and climate change are described and contrasted by considering the emissions of ODSs and other long-lived GHGs both in past decades and in projections of future emissions in the twenty-first century. Part III provides a view of the milestones in the Montreal Protocol process, which highlights international cooperation on this global issue. Parts IV and V address the potential role of the Montreal Protocol and international cooperation in regulating the future emissions of long-term ODS substitute compounds to protect climate. The last Part concludes.

## I. THE MONTREAL PROTOCOL PROTECTION OF THE OZONE LAYER

The emissions of a wide variety of ODSs have been accumulating in the atmosphere for many decades.<sup>3</sup> The principal gases are the chlorofluorocarbons (CFCs), carbon tetrachloride (CCl<sub>4</sub>), hydrochlorofluorocarbons (HCFCs), methyl chloroform (CH<sub>3</sub>CCl<sub>3</sub>), methyl bromide (CH<sub>3</sub>Br), and the halons (bromine-containing gases). These and other minor gases have been released in a wide

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1 WORLD METEOROLOGICAL ORGANIZATION (WMO), SCIENTIFIC ASSESSMENT OF OZONE DEPLETION: 2010 (2011).

2 Montreal Protocol on Substances that Deplete the Ozone Layer, Sept. 16, 1987, 1522 U.N.T.S. 3.

3 WMO, *supra* note 1.

variety of human-based activities or applications, such as air conditioning, refrigeration, fire protection, insulating foam, agricultural and pre-shipment fumigation, aerosol propellants, and metal and electronic parts cleaning.

Global total ozone values began declining in response to ODS emissions in the late 1970s. Depletion maximized near four percent in the early 1990s, with the largest losses in both hemispheres occurring outside of the tropics.<sup>4</sup> The Antarctic ozone hole represents the largest recurring loss with approximately sixty percent of stratospheric ozone destroyed each year, primarily during late September and early October, over a geographical area of 25,000,000 km<sup>2</sup>. In the months following October minimum values, ozone is restored to the Antarctic region with the poleward transport of ozone-rich air that is produced at lower latitudes. The Antarctic losses have been sustained at these levels since the early 1990s. These large annual losses will continue for several decades until ODSs are substantially removed from the atmosphere by natural processes. New emissions of the principal ODSs have ceased around the globe in response to the Montreal Protocol regulations.

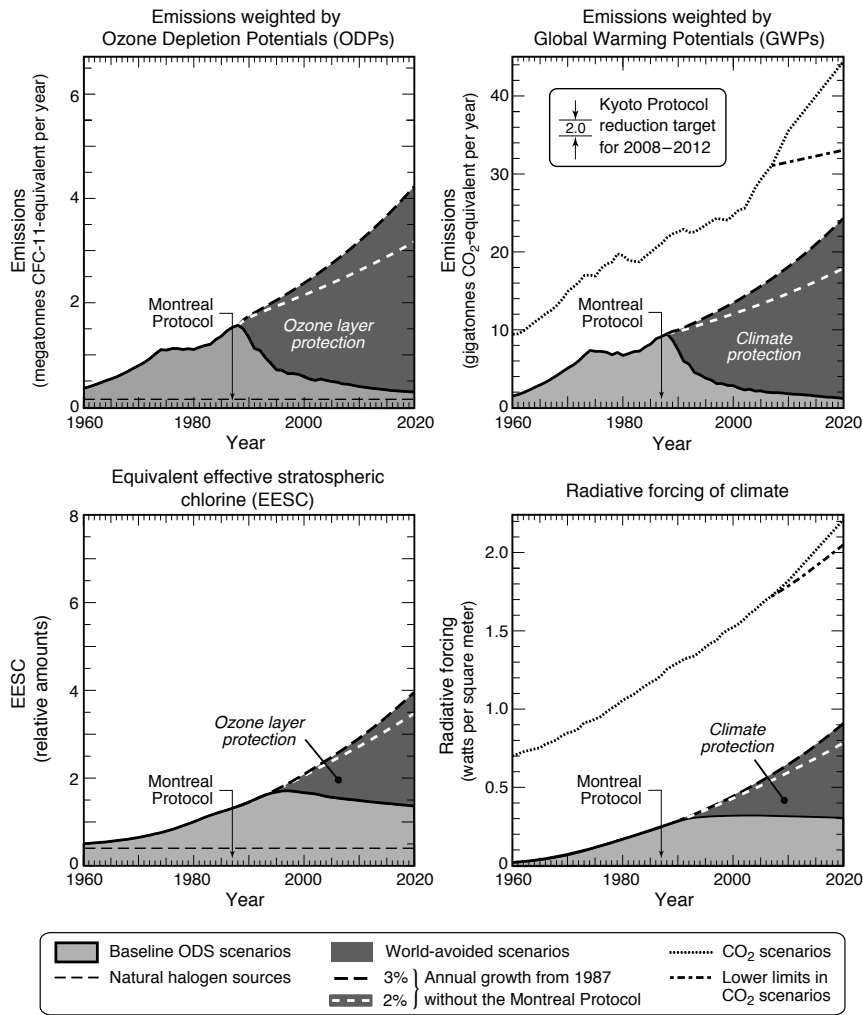
Due to their prior widespread and prolonged use, CFC-11 and CFC-12 are the most abundant chlorine-containing gases in the stratosphere and will remain so for many decades. Policymakers and scientists have chosen CFC-11 to serve as the reference point for evaluating the full suite of chlorine- and bromine-containing gases released by human activities. The emissions of all gases can be expressed as *CFC-equivalent* amounts using the ozone-depletion potential (ODP) of each gas as the scaling factor. A gas with a larger ODP destroys more ozone over its atmospheric lifetime. The ODP is calculated relative to CFC-11, which is defined as having a reference ODP value of 1, using computer models of the atmosphere that include the transport of air in and out of the stratosphere and the key chemical processes that destroy stratospheric ozone.

Atmospheric lifetime is a key factor in setting the ODP value; a longer lifetime increases the effectiveness of a gas in destroying ozone. Halons have ODPs significantly larger than CFC-11 and most other emitted gases because bromine atoms are much (about sixty times) more effective overall on a per-atom basis than chlorine in chemical reactions that destroy ozone. By summing over the historical and projected amounts of ODSs in the atmosphere and weighting these amounts by the respective ODP values, a total ODS burden in the atmosphere can be expressed in *CFC-11-equivalent amounts*. The timeline of these annual amounts defines the *baseline scenario* of ODS emissions.

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4 *Id.*

**Figure 1: The Montreal Protocol Protection of Ozone and Climate  
(From Global Emissions of All Ozone-Depleting Substances  
(ODSs) and CO<sub>2</sub>)<sup>5</sup>**



5 The scenarios and comparisons shown here demonstrate the dual benefit of the Montreal Protocol in protecting ozone (left panels) and climate (right panels). Baseline scenarios in each panel include all ODS emissions as observed in the past and projected to 2020. The ODS emissions in the top panels are weighted by ozone depletion potentials (ODPs) or global warming potentials (GWPs). With these weightings, emissions are expressed as CFC-11-equivalent or CO<sub>2</sub>-equivalent mass per year, respectively. The lower panels show EESC and radiative forcing

The baseline ODS scenario is shown in several forms in Figure 1. With the metric of CFC-11-equivalent emissions, substantial growth in ODS emissions can be seen in Figure 1A in the latter half of the twentieth century in response to increased consumer application demand. For example, as the number of air conditioners and refrigerators in use increases, the overall leakage of ODSs to the atmosphere from these units also increases. Total ODS emissions peaked in the late 1980s. Natural sources of ODSs account for only a small fraction of the peak emissions (see dashed line in Figures 1A and 1B).

In the years immediately following the signing of the Montreal Protocol in 1987, total ODS emissions, in CFC-11-equivalent amounts, began to notably decrease. Montreal Protocol regulatory actions reduced global ODS production and consumption, increased the use of substitute gases that are less effective in destroying ozone, and increased the use of not-in-kind alternative technologies that reduced the need for using ODSs. An example of a not-in-kind solution is the replacement of ODSs used in degreasing and cleaning operations in manufacturing with non-ODS compounds. The reduction in CFC-11-equivalent ODS emissions is the most appropriate quantitative measure to describe the success of the Montreal Protocol in protecting the ozone layer. By 2010, CFC-11-equivalent emissions of total ODSs were twenty-six percent of the 1988 peak values; by 2020 the emissions are projected to be only nineteen percent of the peak.

Another measure of the success of the Montreal Protocol is a comparison of actual CFC-11-equivalent emissions with those that might have occurred in the absence of the Montreal Protocol. The latter, termed *world-avoided* emissions, are calculated by assuming a growth in ODS emissions of two or three percent per year beyond 1987 (see heavy dashed lines in Figure 1A). With two and three percent growth, emissions would have doubled by 2020 and 2010, respectively. The projections with a two to three percent annual growth rate are considered highly plausible given the large number of ODS applications and world-population growth rates in 1990 and subsequent decades. By contrast, actual CFC-11-equivalent emissions are projected to be only seven to ten percent of these world-avoided emissions in 2020 (see Figure 1A). The large difference between the world-avoided and baseline-

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of climate as derived from the respective ODP- and GWP-weighted scenarios. The world-avoided emission scenarios assume ODS emission growth of two or three percent per year beyond 1987 abundances. Shown for reference are the emissions and radiative forcing of CO<sub>2</sub>, and the emissions reduction target of the first commitment period of the Kyoto Protocol (inset). (A megatonne = 1 billion (10<sup>9</sup>) kilograms. A gigatonne = one trillion (10<sup>12</sup>) kilograms.). See WMO, *supra* note 1.

scenario emissions in 2011 is an optional measure to describe the current and future success of the Montreal Protocol in protecting the ozone layer.

Another important metric in the depletion of ozone by ODSs is that of *equivalent effective stratospheric chlorine* (EESC). EESC is an annualized sum over chlorine and bromine amounts in the stratosphere that are available to destroy ozone. When the EESC sum is calculated, available bromine amounts are scaled upward by a large factor (about sixty) to account for the greater effectiveness of bromine in ozone destruction reactions. Annual EESC values calculated from observed and projected ODSs amounts are shown in Figure 1B for baseline and world-avoided scenarios. Unlike emissions, EESC values did not decline strongly after the Montreal Protocol came into effect. Instead, they declined slowly in proportion to the average lifetime of ODSs in the atmosphere. The principal ODS contributions to EESC come from CFC-11 and CFC-12, which have lifetimes of forty-five and one hundred years, respectively. In this case, it will require decades for EESC values to decline to those prevalent before the Montreal Protocol. In the world-avoided scenario in Figure 1B, EESC doubles between 2015 and 2020. The consequences of such an increase would be more global depletion in all latitude zones and more intense losses in the polar regions.<sup>6</sup> Instead, actual EESC values are projected to be thirty-four to thirty-nine percent of world-avoided values in 2020.

## II. THE MONTREAL PROTOCOL PROTECTION OF CLIMATE

Earth's atmosphere is a complex part of our climate system. The atmosphere's chemical composition and physical processes create conditions that support the abundance of life. Key chemical compounds in the atmosphere include naturally occurring greenhouse gases (GHGs). These gases act to enhance the warming by the sun by trapping terrestrial, outgoing radiation in the lower atmosphere. Without natural abundances of GHGs, temperatures on earth would not support life as we know it. GHGs now have both natural and anthropogenic origins. Human activities since the preindustrial era have led to substantial increases in the atmospheric abundances of a number of GHGs, including tropospheric ozone, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and all ODSs. For example, tropospheric ozone is produced near earth's surface from other pollutant gases; carbon dioxide is emitted in fossil fuel combustion; methane is released from livestock and agricultural activities; and nitrous oxide is emitted in response to fertilizer use.

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6 Paul A. Newman & Richard McKenzie, *UV Impacts Avoided by the Montreal Protocol*, 10 PHOTOCHEMICAL & PHOTOBIOLOGICAL SCI. 1152 (2011).

When human activities cause an increase in GHG abundances, more outgoing radiation is absorbed by the atmosphere, which further warms the surface and leads to changes in other climate parameters, such as precipitation. This change in earth's radiative balance caused by human activities is called a *radiative forcing of climate* and is generally evaluated at or near the top of the atmosphere using units of *Watts per square meter* ( $\text{W/m}^2$ ). Positive forcings generally lead to *warming* and negative forcings lead to *cooling* of earth's surface. The potential for climate change from human activities increases as the magnitude of radiative forcing increases. International assessments by the Intergovernmental Panel on Climate Change (IPCC) have concluded that it is very likely that much of the observed increase in global average temperatures documented in the last decades is attributable to GHG emissions from human activities.<sup>7</sup>

The increases in ODS emissions in the baseline scenario (Figure 1A) lead to a positive climate forcing because ODSs are GHGs.<sup>8</sup> Atmospheric GHGs cause a positive climate forcing by retaining heat that otherwise would escape to space, thereby increasing surface temperatures. In order to quantify the forcing contributions and compare them to the contribution from increases in  $\text{CO}_2$ , the principal anthropogenic GHG, we use the metric of the global warming potential (GWP). The GWP is generally evaluated as the radiative forcing integrated over one hundred years. It is derived from the radiative properties of each gas and its atmospheric lifetime in a manner similar to the ODP derivation described above. The GWP of an ODS is referenced to the radiative forcing from  $\text{CO}_2$  over the same time period. The GWP of  $\text{CO}_2$  is always defined as one. ODSs are generally far more effective GHGs than  $\text{CO}_2$  for equal mass amounts and therefore have GWPs far larger than one. For example, the GWPs of CFC-11 and CFC-12 are 5000 and 11,000, respectively. As a consequence, the emission of a kilogram of CFC-12 to the atmosphere causes 11,000 times more warming over the following one-hundred years than emitting a kilogram of  $\text{CO}_2$ . However, the total contribution to climate forcing from CFC-11 and CFC-12 is far less than  $\text{CO}_2$  because the mass emissions and atmospheric abundances of  $\text{CO}_2$  are far greater than all ODSs.

With the GWP metric used for weighting individual substance emissions, the baseline scenario of all ODS emissions is expressed as  *$\text{CO}_2$ -equivalent*

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7 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), *Summary for Policymakers*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS: CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (Susan Solomon et al. eds., 2007).

8 Guus J.M. Velders et al., *The Importance of the Montreal Protocol in Protecting Climate*, 104 PROCEEDINGS NAT'L ACAD. SCI. 4814 (2007).

*emissions* in Figure 1C. The scenario looks very similar to that of CFC-11-equivalent emissions in Figure 1A, with peak values occurring in 1989 followed by a steady decline. The similarity derives from the large, predominant contributions from CFC-11 and CFC-12 in both scenarios. By 2010, CO<sub>2</sub>-equivalent emissions were nineteen percent of 1988 peak values; by 2020 the emissions are projected to be thirty-percent of the peak. A comparison to the world-avoided scenarios in Figure 1C shows that actual emissions under the Montreal Protocol are five to seven percent of world-avoided emissions in 2020. As in the case of ozone depletion discussed above, the decrease from the 1988 peak emissions and the difference from the world-avoided scenario are the most appropriate quantitative measures to describe the success of the Montreal Protocol in protecting the climate system.

Using the GWP metric, annual ODS emissions can be compared directly to CO<sub>2</sub> emissions that are included in Figure 1C. The comparison shows that in the upper world-avoided scenario, ODS emissions are fifty-five to seventy-four percent of CO<sub>2</sub> emissions in 2020. In contrast, the emissions in the baseline scenario are projected to be only 2.7% to 3.6% of CO<sub>2</sub> emissions in 2020.

The accumulation of ODSs in the atmosphere leads to increases in radiative forcing of climate in the baseline scenario, which is shown in Figure 1D. The baseline EESC and radiative forcing scenarios look very similar because they both derive from atmospheric abundances rather than annual emissions. Between 1988 and 2020, radiative forcing decreases only slightly because of the long atmospheric lifetimes of the ODSs that are most abundant in the atmosphere (i.e., CFC-11 and CFC-12). In these cases, the gases remain in the atmosphere for many decades, with the consequence that year-to-year reductions in abundances are small after emissions cease. A comparison to the world-avoided scenarios in Figure 1D shows that actual ODS forcing under the Montreal Protocol is thirty-five to forty-one percent of world-avoided forcing in 2020 and is fourteen to fifteen percent of that from accumulated CO<sub>2</sub> in 2020. With the substantially greater radiative forcing in the world-avoided scenario in 2010, climate change in that scenario is expected to be enhanced beyond what has already been observed, with, for example, further increases in global average surface temperatures and changes in precipitation patterns and amounts.

The panels in Figure 1 taken together illustrate the dual benefit of Montreal Protocol regulations since 1987. CFC-11-equivalent and CO<sub>2</sub>-equivalent emissions (Panels A and C) have declined substantially from peak values in the late 1980s, and EESC and radiative forcing values (Panels B and D) are no longer increasing. For each parameter, the world-avoided values that are projected with two to three percent annual growth of ODS emissions are far larger than those in the present day. The differences between present-day and



world-avoided values quantify the dual benefits provided by the Montreal Protocol.

The accomplishments of the Montreal Protocol in protecting climate by reducing ODSs can be compared to the goals set by the Kyoto Protocol.<sup>9</sup> The Kyoto Protocol is an international treaty of the United Nations Framework Convention on Climate Change (UNFCCC) that serves to regulate the emissions from a *basket* of long-lived GHGs in participating countries. The basket includes carbon dioxide, methane, nitrous oxide, HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>), and excludes ODSs since they are gases regulated by the Montreal Protocol. In the first commitment period of the Kyoto Protocol (2008 to 2012), the target for global emission reductions from the basket of gases is two gigatonnes CO<sub>2</sub>-equivalent per year. The magnitude of this target reduction is illustrated by the inset in Figure 1C. By contrast, the effective reduction from Montreal Protocol regulation in 2010 shown in the same panel is about 9.7 to 12.5 gigatonnes CO<sub>2</sub>-equivalent per year.<sup>10</sup> As a consequence, the Montreal Protocol in 2010 has achieved a reduction that is *five to six times larger* than the Kyoto Protocol target. This reduction will be sustained in coming years with continuing adherence to the Montreal Protocol regulations. Any further reductions under the Montreal Protocol necessarily will be smaller and occur more gradually (see Figure 1A) since the principal ODSs have already been completely phased out from national production and consumption.

Changes in stratospheric ozone represent a climate forcing since ozone is also a GHG. In the last several decades, emissions of ODSs have led to measureable depletion of global stratospheric ozone, which represents a negative climate forcing (cooling). This cooling serves to partially offset the warming from the ODSs that caused the depletion. By contrast, anthropogenic emissions at the surface, primarily from fossil-fuel burning, have led to increases in tropospheric ozone, which represents a positive radiative forcing (warming). A summary of the principal contributions to radiative forcing from changes in long-lived GHGs is shown for 2005 in Figure 2. ODSs represent about ninety-four percent of the halocarbon term, with the balance from Kyoto Protocol gases. The halocarbon term is third in magnitude (0.34 W/m<sup>2</sup>) following carbon dioxide (1.66 W/m<sup>2</sup>) and methane. The ozone terms are of opposite sign, with the tropospheric forcing (warming) greater than the stratospheric

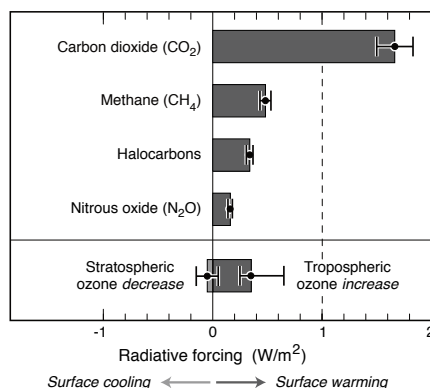
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9 Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 11, 1997, 2303 U.N.T.S. 162, *available at* <http://unfccc.int/resource/docs/convkp/kpeng.pdf> [hereinafter Kyoto Protocol].

10 These values include offsets from associated ozone depletion and HFC use as described in Velders et al., *supra* note 8.

forcing (cooling). Figure 2 shows unequivocally that stratospheric ozone depletion is not the principal cause of climate change since it represents only a limited fraction of all forcings due to other GHGs in 2005.

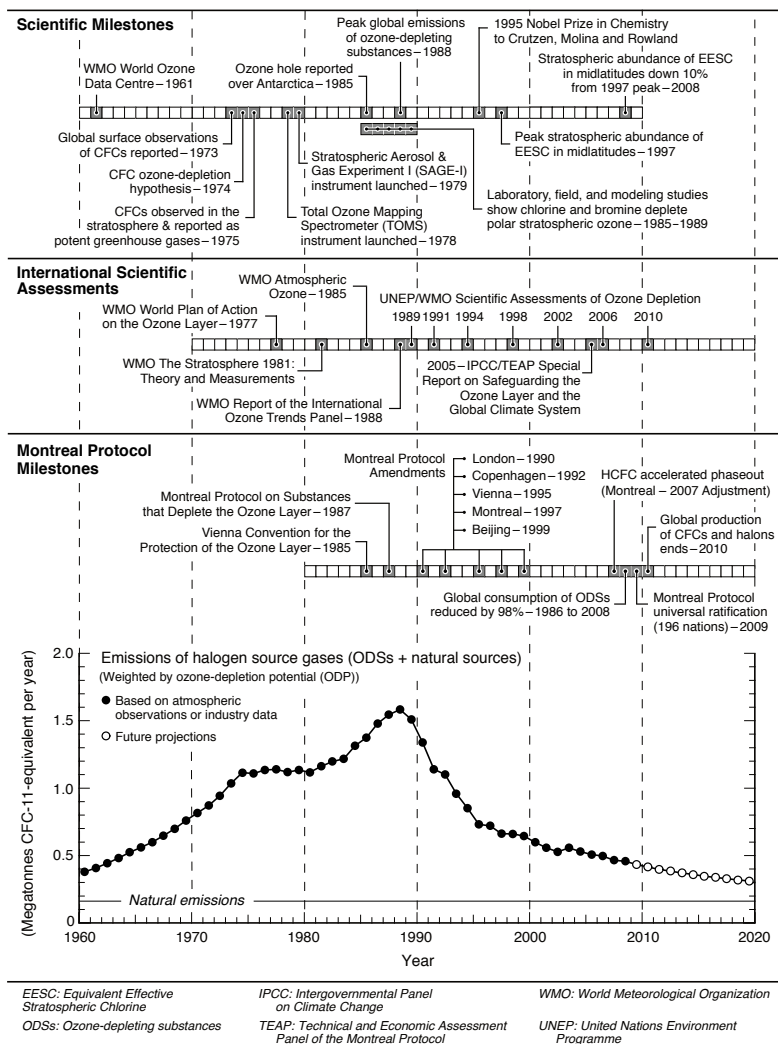
**Figure 2: Radiative Forcing of Climate Change (From Changes in Greenhouse Gases Caused by Human Activities Between 1750 and 2005)<sup>11</sup>**



### III. THE MONTREAL PROTOCOL PROCESS AND INTERNATIONAL COOPERATION

The Montreal Protocol is a leading example of international cooperation on an environmental issue and of successful interactions between scientists and policymakers. Figure 3 shows a timeline of Montreal Protocol milestones juxtaposed with the timeline of ODS emissions. As discussed above, the regulation of ODS production and consumption began after the signing of the Protocol in 1987, as reflected in the occurrence of peak emissions in 1988. The initial Protocol regulations provided for only small reductions in ODSs and would not have served to protect the ozone layer from significant depletion in the coming decades.

<sup>11</sup> Radiative forcing of greenhouse gases in 2005 resulting from human activities since the start of the Industrial Era (around 1750). The largest forcing is from carbon dioxide (CO<sub>2</sub>), followed by methane (CH<sub>4</sub>), tropospheric ozone, halocarbon gases, and nitrous oxide (N<sub>2</sub>O). Uncertainties are indicated by the length of the whiskers on each bar. The halocarbon contribution derives primarily from the atmospheric abundances of ODSs and their substitute gases. See WMO, *supra* note 1; IPCC, *supra* note 7.

**Figure 3: Milestones in the History of Stratospheric Ozone Depletion<sup>12</sup>**

Since 1987, the Protocol has revisited its regulations on a recurring basis to consider how new scientific results and other information might lead to amendments and adjustments to further strengthen or relax its regulations. The

- 12 Timeline of milestones related to (top to bottom) scientific accomplishments, the completion of international scientific assessments, highlights of progress related to the Montreal Protocol, and the history and near future of annual total emissions of ODSs. The same emissions data are used to produce the baseline scenarios shown in Figure 1. *See WMO, supra* note 1.

timeline in Figure 3 shows the city and year of Montreal Protocol meetings that led to amendments that strengthened protocol regulations and resulted in reduced emissions. The Copenhagen amendments were the first to provide for a future decrease of ODS amounts in the stratosphere. The amendments represent a high level of international cooperation on the technical, economic, and social aspects of protocol regulations that has been widely documented.<sup>13</sup> Important milestones reside on the far right of the timeline documenting the success of the Protocol. First, 2009 marked the universal ratification of the Montreal Protocol with the signatures of 196 nations.<sup>14</sup> Second, in 2010, all global production of CFCs and halons ended following the protocol provisions.<sup>15</sup>

Scientists played a strong and leading role in the initiation of the Protocol and its subsequent amendments and adjustments. Before 1987, several scientific assessments of stratospheric ozone were undertaken by the World Meteorological Association (WMO), as noted in the timeline. After the Protocol was signed, the vehicle of information exchange between scientists and Protocol parties was the more formal *Scientific Assessment of Ozone Depletion* completed in regular intervals by the Scientific Assessment Panel under the joint auspices of the WMO and the United Nations Environment Programme (UNEP).<sup>16</sup> These recurring assessments were mandated under the Protocol provisions and each was undertaken with requests for specific scientific input from the Montreal Protocol parties.

Participating scientists, usually numbering near a hundred, were drawn from the international atmospheric sciences community. There was wide participation in the assessments by leading stratospheric scientists, who came to anticipate the assessment process as extremely valuable for defining progress and outlining new challenges in stratospheric ozone science. The assessment results were invaluable to the parties, as they evaluated the need for amendments and adjustments to the protocol provisions. The assessments provided comprehensive information, key aspects of which were (i) changes in ODS and ozone abundances in the atmosphere based on observations and projections, and (ii) calculations of ODPs for current and proposed ODSs and their substitutes. The latter served as an *early warning* system by means

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13 STEPHEN O. ANDERSEN & K. MADHAVA SARMA, PROTECTING THE OZONE LAYER: THE UNITED NATIONS HISTORY (2002).

14 *The Montreal Protocol on Substances that Deplete the Ozone Layer*, UNEP OZONE SECRETARIAT, [http://ozone.unep.org/new\\_site/en/montreal\\_protocol.php](http://ozone.unep.org/new_site/en/montreal_protocol.php) (last visited Oct. 1, 2012).

15 UNEP OZONE SECRETARIAT, HANDBOOK FOR THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEplete THE OZONE LAYER (9th ed. 2012).

16 *Assessment Panels*, UNEP OZONE SECRETARIAT, [http://ozone.unep.org/Assessment\\_Panels/](http://ozone.unep.org/Assessment_Panels/) (last visited Oct. 1, 2012).

of which policymakers and chemical companies could learn about the threat to ozone posed by the use and emission of new chemical compounds to the atmosphere.

The unqualified success of the Montreal Protocol derives from the sustained cooperation amongst all nations and their high level of commitment to protect the ozone layer. This cooperation marks its twenty-fifth anniversary this year.<sup>17</sup> The role of scientists in informing the protocol of the current and future state of the atmosphere was an invaluable contribution to the successful strategies undertaken by the protocol. The future looms against this backdrop of success and brings with it the challenging issue of future emissions of the HFC substitute compounds and their role in climate change. As explained in the next Parts, this issue offers a specific opportunity to continue the international and scientific cooperation of the past decades.

#### **IV. THE FUTURE CONTRIBUTION OF HFCs TO GLOBAL CLIMATE CHANGE**

The success of the Montreal Protocol has relied on guiding the transition away from the use of CFCs and halons and towards substitute compounds and not-in-kind technologies. In the first phase, HCFCs were the designated class of transitional, substitute compounds. HCFCs were chosen because they could be used directly in — or adapted to — many applications that used CFCs and had very low ODP values. HCFC-22, currently one of the most widely used compounds, has an ODP of 0.05, only five to six percent of CFC-11 and CFC-12 values. As a consequence, if the same mass of HCFC-22 and CFC-11 were emitted to the atmosphere, the HCFC-22 release would cause about twenty times less ozone destruction than the CFC-11 release over their respective atmospheric lifetimes. HCFCs are currently being used in both developed and developing countries. Under Montreal Protocol regulations, a complete phaseout will occur by 2030, with the phaseout year occurring earlier for developed countries.

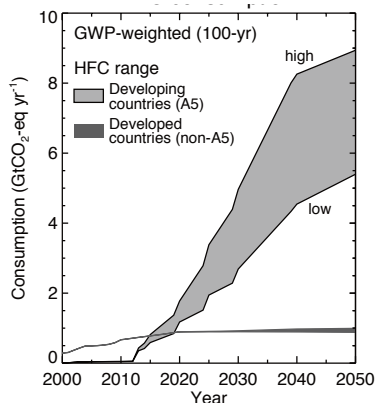
HFCs were chosen to be long-term ODS substitute compounds because they have ODPs of zero and could be used directly or adapted for use in many ODS applications, similar to the situation for HCFCs. The world has already begun to use HFCs in anticipation of the HCFC phaseout. The Montreal Protocol currently has no existing regulations to regulate HFCs because HFCs

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17 *The 2012 Ozone Day — Protecting Our Atmosphere for Generations to Come*, UNEP OZONE SECRETARIAT, [http://ozone.unep.org/new\\_site/en/ozone\\_day\\_details.php?year=2012](http://ozone.unep.org/new_site/en/ozone_day_details.php?year=2012) (last visited Oct. 1, 2012).

do not destroy ozone. Instead, HFCs and other principal GHGs are regulated under the Kyoto Protocol.<sup>18</sup>

**Figure 4: Global HFC Consumption<sup>19</sup>**



There is expected to be significant growth in HFC global production and consumption in the coming decades in response to the HCFC phaseout and to the growth in application demand in developing nations. The growth in global production can be derived using scenarios from IPCC that are based on gross domestic product (GDP) and population. The scenarios include all current regulations and use the pattern of HCFC-to-HFC replacements that is underway in developed countries in order to project use in developing countries. The results for global consumption (production minus imports) are shown in Figure 4 for the developed and developing world in the coming decades using units of CO<sub>2</sub>-equivalent emissions.<sup>20</sup> The high and low ranges in the scenario follow IPCC ranges. Consumption in the developing world exceeds that in the developed world before 2020 and by 800% in 2050. The scenarios reflect that per-capita HFC demand saturates in this decade in developed countries and grows only modestly following population increases in the subsequent decades. In the developing world, saturation of demand begins to influence growth only several decades later around 2040.

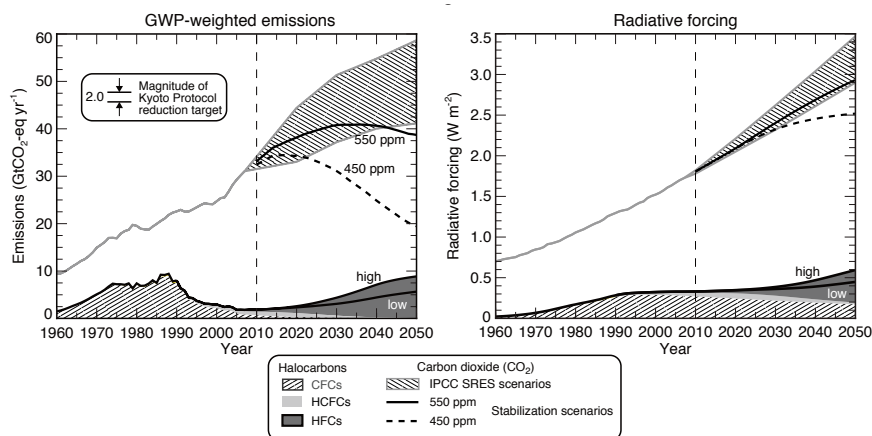
<sup>18</sup> Kyoto Protocol, *supra* note 9.

<sup>19</sup> Consumption in kilotons per year of HFCs in the developed and developing world based on emissions data and future projections. The shaded regions are bounded by high and low limits, as defined by the upper and lower ranges of the baseline IPCC scenarios in both developed and developing countries. *See id.*

<sup>20</sup> Guus J.M. Velders et al., *The Large Contribution of Projected HFC Emissions to Future Climate Forcing*, 106 PROCEEDINGS NAT'L ACAD. SCI. 10949 (2009).

The climate forcing contributions of future HFC use to 2050 are shown in Figure 5, using the metrics of CO<sub>2</sub>-equivalent emissions and radiative forcing as used in Figure 1 for all ODSs. Annual HFC emissions are assumed to be equal to HFC consumption with a few years lag time. HFC emissions are projected to reach 5.5 to 8.8 Gt CO<sub>2</sub>-eq yr<sup>-1</sup> in 2050 and continue increasing. By comparison, ODS emissions peaked at 9.4 Gt CO<sub>2</sub>-eq yr<sup>-1</sup> in 1988. Thus, the climate protection achieved by the Montreal Protocol, expressed as an annual reduction in CO<sub>2</sub>-equivalent emissions, is essentially lost by 2050 in this scenario due to growth in HFC emissions. By contrast, radiative forcing from accumulated HFCs increases to 0.25 to 0.40 W m<sup>-2</sup> in 2050, well above the peak from ODSs alone. Thus, the slow decline anticipated for ODS radiative forcing in the coming decades in this scenario is overshadowed by the increase in HFC radiative forcing.

**Figure 5: Emissions and Climate Forcing from Halocarbons and CO<sub>2</sub><sup>21</sup>**



- 21 GWP-weighted emissions (left) and radiative forcing (right) of ODSs (CFCs and HCFCs), HFCs, and CO<sub>2</sub>. Halocarbons are a class of substances that includes all ODSs and HFCs. CFCs show continued declines in emissions from the present to 2050. By contrast, values of CO<sub>2</sub> and HFCs show steady increases in business-as-usual scenarios. By 2050, global GWP-weighted HFC emissions are comparable to the peak in global ODS emissions in the late 1980s. The radiative forcing from HFCs in 2050 is comparable or exceeds that at the peak due to ODSs. The curves labeled high and low represent the upper and lower limits in the global baseline IPCC scenarios. Shown for additional reference are emissions and radiative forcing for the 450- and 550-ppm CO<sub>2</sub> stabilization scenarios from IPCC. See Velders et al., *supra* note 20.

The HFC scenarios for emissions and radiative forcing are compared to those from CO<sub>2</sub> in Figure 5. Global CO<sub>2</sub> emissions are expected to increase monotonically in the business-as-usual IPCC scenarios. In this case, HFC emissions reach nine to nineteen percent of CO<sub>2</sub> annual emissions in 2050, depending on the high/low scenario choice. By contrast, if the world has chosen to limit CO<sub>2</sub> emissions to achieve stabilization targets of 450 or 550 ppm, annual emissions would need to follow the dashed lines labeled in Figure 5. (Current CO<sub>2</sub> abundances are near 390 ppm.) In these stabilization cases, the respective 2050 HFC emissions would be twenty-eight to forty-five percent and fourteen to twenty-three percent of CO<sub>2</sub> emissions. In radiative forcing, HFCs contribute seven to twelve percent of the CO<sub>2</sub> values in 2050, which represents six to thirteen years of CO<sub>2</sub> emission growth in the 2050 timeframe. These percentages indicate that HFC emissions would significantly offset the stabilization emission rates and radiative forcings from other GHGs in 2050 and, hence, would likely alter the climate state anticipated in the stabilization emission scenarios.

One of the HFC substitute gases, HFC-23, is a particularly potent GHG with a GWP of 14,800. Thus, the release of a kilogram of HFC-23 produces a climate forcing over one-hundred years that is the same as that produced by a 14,800-kilogram release of CO<sub>2</sub>. In contrast to other HFCs used in commercial and consumer applications, HFC-23 is an unavoidable byproduct of large-scale HCFC-22 production. HCFC-22, which is used extensively in refrigeration and air conditioning equipment, is also used as a chemical feedstock in the manufacturing of fluoropolymers. Generally, HFC-23 is treated as a waste gas, which is often vented to the atmosphere.

Based on the large HFC-23 GWP value, global efforts have been undertaken to reduce HFC-23 emissions through destruction (incineration) of quantities that otherwise would be vented to the atmosphere or through reduction by process optimization in HCFC-22 production plants. Destruction in facilities in developing countries has been subsidized under the UNFCCC Clean Development Mechanism (CDM).<sup>22</sup> In this case, developed countries fund projects in developing countries, where large HCFC-22 plants exist, to destroy HFC-23 as an alternative to venting. The destroyed gas is quantified as Certified Emission Reductions (CERs), which represent carbon credits for the funding country. For example, approved projects in developing countries destroyed 5.7 and 6.5 Gg of HFC-23 in 2007 and 2008, respectively.<sup>23</sup> Based

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22 *Clean Development Mechanism (CDM)*, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, <http://cdm.unfccc.int/> (last visited Aug. 21, 2012).

23 B.R. Miller et al., *HFC-23 (CHF<sub>3</sub>) Emission Trend Reponse to HCFC-22 (CHClF<sub>2</sub>) Production and Recent HFC-23 Emission Abatement Measures*, 10 *ATMOSPHERIC CHEMISTRY & PHYSICS* 7875 (2010); S.A. Montzka et al., *Recent*



on a carbon value of thirteen dollars per ton CO<sub>2</sub>-equivalent, these projects had a value of nearly one billion dollars annually.

In the decade after the Montreal Protocol signing, HFC-23 emissions from developed countries were the principal atmospheric source.<sup>24</sup> Beginning in the early 2000s, growth of emissions in developing countries became the dominant factor in controlling HFC-23 atmospheric abundances, as production of HCFC-22 increased. In the 2007 to 2009 period, the destruction of HFC-23 in CDM projects limited HFC-23 emissions and was sufficiently large that atmospheric abundances began to decline thereafter, despite continued increases in HCFC-22 production.

The subsidized CDM cost of destroying HFC-23 is substantially higher than the estimated industry cost of this HFC-23 emission abatement alone.<sup>25</sup> This has led to a situation in which developing countries have an incentive to expand HCFC-22 production to increase their participation in CDM projects.<sup>26</sup> With reasonable cost assumptions, HCFC-22 manufacturers can earn nearly twice as much from CDM payments for HFC-23 destruction than from selling the associated HCFC-22 product. The European Union, for example, has brought pressure on the CDM Executive Board to reduce this incentive. Recent action by the CDM Executive Board indicates that future CDM approval of HFC-23 projects may be more limited than in the past.<sup>27</sup>

## V. HFCs AND FUTURE INTERNATIONAL COOPERATION IN THE MONTREAL PROTOCOL

The HFC climate contribution as projected to 2050 in Figure 5 is not an assured outcome. The projection assumes that the transition in the developing world will follow the technical choices made in developed countries. However, technical and market choices regarding HFC use were made at a time when the climate contribution of substances used in air conditioning, refrigeration, and foaming blowing equipment was not one of the primary selection criteria. With the growing awareness of climate forcing from synthetic gas emissions, other

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*Increases in Global HFC-23 Emissions*, 37 GEOPHYSICAL RES. LETTERS L02808 (2010).

24 Miller et al., *supra* note 23; Montzka et al., *supra* note 23.

25 Michael Wara, *Is the Global Carbon Market Working?*, 445 NATURE 595, 595-96 (2007).

26 Michael Wara, *Measuring the Clean Development Mechanism's Performance and Potential*, 55 UCLA L. REV. 1759 (2008).

27 *Newsletter #20 — July 2012*, CDM WATCH: SCRUTINIZING CARBON OFFSETS (July 2012), <http://www.cdm-watch.org/?p=3971>.

transition options are being evaluated that would avoid the business-as-usual scenario. In addition, equipment is being redesigned to use lower quantities of synthetic gases and to reduce gas leakage during equipment lifetime. An opportunity exists for developed and developing countries to work cooperatively to identify the best substance to meet growth in application demand while minimizing climate forcing from substance leakage and energy usage.

A case in point is the use of HFCs in automobile air conditioning systems. These systems, which use HFC-134a, account for about sixty percent of current HFC refrigerant emissions.<sup>28</sup> HFC-134 has a GWP of 1370, which is much smaller than CFC-11 and CFC-12, substances that were widely used in previous air conditioning systems (GWP (100-yr) = 4750 and 10,900, respectively). In a U.S. industry collaboration (Dupont/Honeywell), a new refrigerant, HFO-1234yf, has been developed for automobile air conditioning systems. HFO-1234yf has a GWP of four, which is 340 times smaller than HFC-134a, while delivering comparable fuel efficiency. Initiatives by vehicle manufacturers have been directed towards reducing the GWP of synthetic gases used in automobile systems while maintaining energy efficiency. HFO-1234yf has been approved as an acceptable alternative to ODSs in automobile systems by the U.S. Environmental Protection Agency.<sup>29</sup> In the European Union, a directive bans the use of refrigerants with GWPs above 150 in new vehicles beginning in 2017.<sup>30</sup> The use of HFO-1234yf or other lower GWP substances in the balance of the global automobile fleet in the coming decades would substantially reduce HFC CO<sub>2</sub>-equivalent emissions in the developing country scenario in Figure 5.

In November 2010, ninety nations signed a declaration that stated interest in guiding the world away from using high-GWP substitutes for ODSs.<sup>31</sup> The declaration at once recognizes the business-as-usual scenario in Figures 4 and

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28 *E.g.*, U.N. ENV'T PROGRAMME (UNEP), HFCs: A CRITICAL LINK IN PROTECTING CLIMATE AND THE OZONE LAYER (2011), *available at* [http://www.unep.org/dewa/Portals/67/pdf/HFC\\_report.pdf](http://www.unep.org/dewa/Portals/67/pdf/HFC_report.pdf).

29 EPA, PROTECTION OF STRATOSPHERIC OZONE: NEW SUBSTITUTE IN THE MOTOR VEHICLE AIR CONDITIONING SECTOR UNDER THE SIGNIFICANT NEW ALTERNATIVES POLICY (SNAP) PROGRAM (2011), *available at* [http://www.epa.gov/ozone/downloads/HFO-1234yf\\_prepublication\\_version.pdf](http://www.epa.gov/ozone/downloads/HFO-1234yf_prepublication_version.pdf).

30 Directive 2006/40/EC, of the European Parliament and of the Council of 17 May 2006 Relating to Emissions from Air Conditioning Systems in Motor Vehicles and Amending Council Directive 70/156/EEC, 2006 O.J. (L 161) 12.

31 U.N. Env't Programme (UNEP), Declaration of the Twenty-Second Meeting of the Parties to the Montreal Protocol on the Global Transition Away from Hydrochlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs), *Decision XXII/Annex III* (2010), *available at* [http://ozone.unep.org/new\\_site/en/Treaties/](http://ozone.unep.org/new_site/en/Treaties/)

5; the value in protecting climate by reducing climate forcing from synthetic gas emissions; and the potential role of the Montreal Protocol in regulating HFCs based on its success in ODS regulation.<sup>32</sup> The declaration was meant to gather support for formal consideration of new regulatory action within the Montreal Protocol process.

As an initial step towards accomplishing this goal, Canada, Mexico and the United States, as well as the Federated States of Micronesia, have submitted proposals to amend the Montreal Protocol to include controls on HFC consumption and production.<sup>33</sup> The proposed amendments would establish a phasedown rather than a phaseout of HFCs, thereby allowing a reduced baseline of emissions for certain uses. The regulations would account for the special situations in developing countries with regard to capacity and funding and would not require changes in the Kyoto Protocol.

Negotiations continued at the November 2011 Montreal Protocol meeting in Bali, Indonesia.<sup>34</sup> An amendment to regulate HFCs under the Montreal Protocol would be a complex undertaking, not unlike that required to develop ODS regulations. The cooperation between countries would be extraordinary, encompassing technical, legal, procedural, social, economic, and scientific dimensions.

## CONCLUSION

The Montreal Protocol has been highly successful in regulating the use of ODSs and achieving a phaseout of the substances most damaging to the ozone layer, and stands as an outstanding example of international cooperation sustained over more than two decades. Concurrently, the Protocol regulations and initiatives have facilitated the use of substitute and transitional compounds and not-in-kind technologies to mitigate ODS use. These alternatives have

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decisions\_text.php?dec\_id=1070. For a summary of the Declaration's, see *infra* Appendix A.

32 Guus J.M. Velders et al., *Preserving Montreal Protocol Climate Benefits by Limiting HFCs*, 335 SCI. 922, 922-23 (2012).

33 *North American Amendment Proposal to Phase Down Use of HFCs Under the Montreal Protocol*, U.S. DEP'T OF STATE (May 9, 2011), <http://www.state.gov/r/pa/prs/ps/2011/05/162930.htm>. For summary points, see *infra* Appendix B.

34 For summary highlights of the meeting, see *Ninth Meeting of the Conference of the Parties to the Vienna Convention for the Protection of the Ozone Layer and Twenty-Third Meeting of the Parties to the Montreal Protocol on Substances That Deplete the Ozone Layer*, IISD REPORTING SERVICES, <http://www.iisd.ca/ozone/mop23/> (last visited May 5, 2012).

allowed substantial growth in industrial and consumer ODS applications in the developed and developing world in the decades since 1987 when the Montreal Protocol was signed.

Since ODSs are potent GHGs, Montreal Protocol regulations have served to protect climate by reducing total radiative forcing from human activities and, hence, to delay surface warming and other changes from anthropogenic emissions. The protection of ozone and climate by the Montreal Protocol represents a dual benefit to society. HFCs, which were selected to be long-term substitute gases for ODSs, are projected to grow substantially in the coming decades from growth in the developing world. The projections show the fractional contribution of HFCs to total anthropogenic climate forcing to be substantial in 2050, particularly if CO<sub>2</sub> emissions are by then on a course to achieve stabilization. These projections, based on business-as-usual assumptions, would be altered substantially if low-GWP substances are introduced as well as other mitigating measures. Proposals have been submitted to amend the Montreal Protocol to regulate HFCs and, thereby, avoid the substantial projected values in the business-as-usual scenario. These proposals stand as an opportunity for the international community to continue cooperation in support of the environment.

#### **APPENDIX A. SUMMARY DECLARATION ON THE GLOBAL TRANSITION AWAY FROM HYDROCHLOROFLUOROCARBONS (HCFCs) AND CHLOROFLUOROCARBONS (CFCs)**

*Recognizing that hydrofluorocarbons (HFCs) are replacements for ozone depleting substances (ODS) being phased out under the Montreal Protocol, and that the projected increase in their use is a major challenge for the world's climate system that must be addressed through concerted international action,*

*Recognizing also that the Montreal Protocol is well-suited to making progress in replacing hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) with low-GWP alternatives,*

*Mindful that certain high-GWP alternatives to HCFCs and other ODS are covered by the UNFCCC and its Kyoto Protocol and that action under the Montreal Protocol should not have the effect of exempting them from the scope of the commitments contained thereunder,*

*Interested in harmonizing appropriate policies toward a global transition from HCFCs to environmentally sound alternatives,*

*Encourage all Parties to promote policies and measures aimed at selecting low-GWP alternatives to HCFCs and other ODS,*

*Declare our intent to pursue further action under the Montreal Protocol aimed at transitioning the world to environmentally sound alternatives to HCFCs and CFCs.*

*Afghanistan, Antigua and Barbuda, Armenia, Austria, Australia, Bahamas, Bangladesh, Belgium, Belize, Benin, Bosnia and Herzegovina, Bulgaria, Burkina Faso, Cambodia, Cameroon, Canada, Columbia, Comoros, Congo, Cook Islands, Costa Rica, Cyprus, Czech Republic, Democratic Republic of the Congo, Denmark, Dominican Republic, Egypt, Estonia, European Union, Federated States of Micronesia, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Haiti, Hungary, Indonesia, Iraq, Ireland, Italy, Japan, Kazakhstan, Kyrgyzstan, Latvia, Liechtenstein, Lithuania, Luxembourg, Madagascar, Mali, Mauritius, Macedonia, Malta, Mexico, Micronesia, Montenegro, Mozambique, Myanmar, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Palau, Philippines, Poland, Portugal, Republic of Moldova, Romania, Saint Lucia, Sao Tome and Principe, Senegal, Serbia, Slovakia, Slovenia, Spain, Somalia, Sri Lanka, Sweden, Switzerland, Timor-Leste, Togo, Tuvalu, Uganda, United Kingdom, United States of America, Vietnam*

## **APPENDIX B. SUMMARY POINTS AS PROVIDED WITH THE NORTH AMERICAN HFC SUBMISSION TO THE MONTREAL PROTOCOL (MAY 2010)**

The North American proposal is a clarification or supplement to the Mauritius and Micronesia proposal, which is formally under consideration under the Protocol this year, having been submitted prior to the May 4 deadline for amendments. The following are key elements of the proposal:

- Lists twenty specified HFCs as a new Annex F to the Protocol (including two substances sometimes referred to as HFOs).
- Recognizes that there are not alternatives for all HFC applications and therefore utilizes a phasedown mechanism, as opposed to a phaseout.
- Establishes provisions for developed country (non-Article 5) phasedown of production and consumption:
  - Uses a baseline of the average of 2004-2006 annual production and consumption of HCFCs and HFCs.
  - Initiates the phasedown in 2013.
  - Achieves a final phasedown plateau of fifteen percent of baseline in 2033.
- Establishes provisions for developing country (Article 5) phasedown of production and consumption:

- Uses a baseline of the average of 2004-2006 annual production and consumption of HCFCs and HFCs
- Initiates the phasedown in 2016
- Achieves a final phasedown plateau of fifteen percent of baseline in 2043.
- Both developed and developing country phasedowns include interim steps between initiation and the final plateau step.
- Introduces weighting using Global Warming Potential for HFCs as compared to typical Montreal Protocol practice of Ozone Depleting Potential
- Includes provisions to strictly limit HFC-23 byproduct emissions resulting from the production of HCFCs (e.g., HCFC 22).
- Requires licensing of HFC imports and exports, and bans imports and exports to non-Parties.
- Finally, requires reporting on production and consumption of HFCs, as well as on HFC-23 byproduct emissions.
- Relationship with the UNFCCC:
  - The proposal envisions an amendment to the Montreal Protocol, and a related decision by the UNFCCC confirming the Montreal Protocol approach.
  - It would leave unchanged the provisions of the UNFCCC / Kyoto Protocol that govern HFCs.
  - The Montreal Protocol obligations would be consistent with, and additional to, UNFCCC and/or Kyoto Protocol obligations. Parties could follow Montreal Protocol obligations as a way to meet some of their UNFCCC obligations with regard to HFCs.