Benefits of Addressing HFCs under the Montreal Protocol

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Stratospheric Protection Division
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EXECUTIVE SUMMARY

The United States, Canada, and Mexico have proposed an amendment to the Montreal Protocol to phase down production and consumption of hydrofluorocarbons (HFCs) and control byproduct emissions. The proposal includes binding reduction targets for all countries, and provides access to financial support and extended phasedown time to developing countries.

HFC use and emissions are rapidly increasing as a result of the phaseout of ozone-depleting substances (ODS) and growing global demand for air conditioning and refrigeration. Although safe for the ozone layer, the continued emissions of HFCs – primarily as alternatives to ODS and also from the byproduct emissions of HFC-23 from the continued production of hydrochlorofluorocarbon (HCFC)-22 – will have an immediate and significant effect on the Earth's climate system. Without further controls, it is predicted that HFC emissions could partially negate the climate benefits achieved under the Montreal Protocol. The proposal calls for a gradual phasedown of HFCs to allow for early transition in sectors where we have alternatives, and gives more time and incentive for innovation to deploy alternatives in other areas. Some niche areas may never transition, which is why the phasedown ends at 15% of allowable use of HFCs relative to an established baseline.

Adoption of the HFC amendment would produce environmental benefits of more than 90 gigatons of carbon dioxide equivalent (CO_2eq) cumulatively by 2050. To provide some context, current global climate emissions from all sources are about 45 gigatons CO_2eq annually. The proposed Amendment builds on the success of the Montreal Protocol, relies on the strength of its institutions, and realizes climate benefits in both the near and long-term. Table ES-1 displays the projected benefits from the Amendment at various intervals to 2050.

TABLE ES-1: ESTIMATED BENEFITS OF THE AMENDMENT PROPOSAL, AT VARIOUS INTERVALS

Cumulative HFC Reductions ($MMTCO_2eq$)				
	2016 to 2020	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
HFC Phasedown – Consumption Reductions				
World	**800 – 1,300**	**13,500 –17,700**	**41,600 – 53,600**	**80,900 -- 102,100**
Byproduct Controls – Emissions Reductions				
World	**1,800**	**4,600**	**7,700**	**12,900**
World Total	**2,600 – 3,100**	**18,100 – 22,300**	**49,300 – 61,300**	**93,800 – 115,000**

The 40-year (i.e., through 2054) benefits from the amendment are between 100,100 – 125,400 $MMTCO_2eq$ of consumption reductions; combined with byproduct controls emissions reductions of 15,700 $MMTCO_2eq$, equate to a total of 115,800 – 141,100 $MMTCO_2eq$ cumulative HFC reductions.

1. INTRODUCTION

This paper presents analysis of potential benefits from globally reducing consumption of hydrofluorocarbons (HFCs) and reducing byproduct emissions of HFC-23. HFCs are a subset of fluorinated greenhouse gases that are intentionally-made and used in various applications, such as refrigeration, air conditioning, fire suppression, foam blowing, and solvents. HFCs are predominantly used as alternatives to ozone-depleting substances (ODS) being phased out under the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). Recent scientific papers, including a 2011 paper by Gschrey et al.,[1] a 2011 report from the United Nations Environment Programme (UNEP),[2] and a 2009 paper by Velders et al.,[3]suggest that HFC use will grow substantially over the next several decades, driven both by increased demand for refrigeration and air-conditioning (in particular but not exclusively in developing countries, hereinafter referred to as Article 5 or A5 countries), and because these substances were developed and are being used as alternatives to ODS.

HFCs are a small part of the global carbon dioxide (CO_2) emissions today. However, HFC emissions are increasing rapidly and many HFCs have global warming potentials (GWPs) much higher than CO_2. Left unabated, HFC emissions could rise to as much as 19% of carbon dioxide emissions by 2050. By acting now, we could stem the growth of HFC use and avoid an increase that in three decades could eclipse other climate protection efforts.

UNEP's report, *HFCs: A Critical Link in Protecting Climate and the Ozone Layer*, concludes HFCs have the potential to substantially influence climate. By 2050, the buildup of HFCs is projected to increase radiative forcing by as much as 0.4 W m^{-2} relative to 2000 and this increase would be as much as one-quarter of the expected increase in radiative forcing from CO_2 buildup since 2000. The abundances of HFCs in the atmosphere are also rapidly increasing. One example is HFC-134a, the most abundant HFC, which has increased by about 10% per year from 2006 to 2010.[4] Global HFC emissions (excluding emissions of HFC-23) increased 8% per year from 2004 to 2008. By acting now, UNEP concludes we can avoid an increase in high-GWP HFC emissions that would otherwise offset the climate benefits achieved by the ODS phaseout.[5]

HFC emissions also occur during the production of some fluorocarbons. This paper also presents analysis of potential benefits from globally reducing the byproduct emissions of HFC-23 during the production of hydrochlorofluorocarbon (HCFC)-22.

[1] Gschrey, B., Schwarz, W., Elsner, C., Engelhardt, R.: High increase of global F-gas emissions until 2050, Greenhouse Gas Measurement & Management 1, 85-92, 2011.
[2] UNEP, 2011. *HFCs: A Critical Link in Protecting Climate and the Ozone Layer*, United Nations Environment Programme (UNEP), 36 pp. Accessible at http://www.unep.org/dewa/Portals/67/pdf/HFC_report.pdf
[3] Velders, G. J. M., Fahey, D. W., Daniel, J. S., McFarland, M., and Andersen, S. O.: The large contribution of projected HFC emissions to future climate forcing, P. Natl. Acad. Sci. USA, 106, 10949–10954, doi:10.1073/pnas.0902817106, 2009. Accessible at: http://www.pnas.org/content/early/2009/06/19/0902817106.full.pdf+html
[4] Ibid.
[5] Ibid.

2. PROPOSED AMENDMENT TO PHASE DOWN HFC CONSUMPTION AND REDUCE HFC-23 BYPRODUCT EMISSIONS

The governments of Mexico, Canada, and the United States of America proposed an amendment to the Montreal Protocol to phase down the consumption and production of HFCs and reduce HFC-23 byproduct emissions. Key elements of this Amendment proposal include:

- Lists 19 HFCs as controlled substances under the Montreal Protocol.
- Recognizes that there may not be alternatives for all HFC applications at this time and therefore relies on a gradual phase down mechanism with a plateau as opposed to a complete phaseout.
- Establishes commitments for the developed country (non-Article 5) and developing country (Article 5) phasedown of HFC production and consumption while providing additional time for Article 5 countries.
    - The baseline for Article 5 countries is calculated as 100% of average HFC consumption and production and 40% of average HCFC consumption and production from 2011-2012.
    - For non-Article 5 countries, the baseline is calculated as 100% of average HFC consumption and production and 85% of average HCFC consumption and production from 2008-2010.
- The amendment uses GWP weighting for HFCs and HCFCs.
- Includes provisions to limit HFC-23 byproduct emissions resulting from the production of HCFCs and HFCs beginning in 2016.
- Requires reporting on HFC production, consumption, and byproduct emissions.
- Makes reductions in HFC production and consumption and byproduct emissions eligible for funding under the Multilateral Fund for the Implementation of the Montreal Protocol (MLF).
- Requires licensing of HFC imports and exports, and bans imports from and exports to non-Parties.

3. PROPOSED PHASEDOWN OF HFC CONSUMPTION

3.1. SUMMARY OF BENEFITS ANALYSIS

The U.S. Environmental Protection Agency's (U.S. EPA's) benefits analysis of the amendment proposal suggests it would reduce greenhouse gas (GHG) consumption and emissions by 93,800 – 115,000 million metric tonnes of carbon dioxide equivalent ($MMTCO_2eq$) through 2050 – of which 80,900 – 102,100 $MMTCO_2eq$ can be attributed to HFC Phasedown and 12,900 $MMTCO_2eq$ can be attributed to byproduct controls.

U.S. EPA's analysis assumes the HFC reduction obligations in the proposal by Mexico, Canada and the United States are met, and that all Parties (developed and developing countries) continue to comply with current HCFC phaseout obligations. Although both the HFC proposal and the HCFC controls would be effective simultaneously, individual countries would still have the ability to examine their specific conditions and obligations, and determine how to meet the obligations. Transitions from HCFCs could include interim steps using a range of HFCs in various end uses, transitioning to low-GWP HFCs and non-fluorinated alternatives (e.g., ammonia, hydrocarbons) and continuing to use some amount of HFCs for the foreseeable future for certain end-uses (e.g., metered dose inhalers for asthmatics). The estimated cumulative HFC

consumption reductions from the phasedown are 500 – 1,600 $MMTCO_2eq$ [6] through 2020, and 80,900 – 102,100 $MMTCO_2eq$ through 2050, assuming annual global compliance with the proposed HFC phasedown requirements. As explained in Section 4 below, the estimated cumulative HFC emission reductions from the control of byproduct emissions of HFC-23 are 1,800 $MMTCO_2eq$ through 2020, and 12,900 $MMTCO_2eq$ through 2050, assuming annual global compliance.

3.2. ASSUMPTIONS FOR ESTABLISHING THE BASELINE AND PROJECTED CONSUMPTION

3.2.1. BASELINE

Because HFCs have replaced HCFCs in many applications in some countries, the baseline used by Mexico, Canada and the United States is set using historical information while accounting for this transition. The baseline for non-Article 5 parties is calculated as the average, for the years 2008, 2009 and 2010, of 100% of the HFC consumption plus 85% of HCFC consumption. The baseline for Article 5 parties is calculated as 100% of the HFC consumption plus 40% of the average 2011 and 2012 HCFC consumption. The baseline equations are shown in Table 1.

TABLE 1: BASELINE EQUATIONS

Party	Method
Equation 1: Non-Article 5 Parties	$100\%\left(\frac{\left(\begin{array}{c}2008\ HFC\ Consumption\\ +2009\ HFC\ Consumption\\ +\ 2010\ HFC\ Consumption\end{array}\right)}{3}\right)+85\%\left(\frac{\left(\begin{array}{c}2008\ HCFC\ Consumption\\ +2009\ HCFC\ Consumption\\ +\ 2010\ HCFC\ Consumption\end{array}\right)}{3}\right)$
Equation 2: Article 5 Parties	$100\%\left(\frac{\left(\begin{array}{c}2011\ HFC\ Consumption\\ +2012\ HFC\ Consumption\end{array}\right)}{2}\right)+40\%\left(\frac{\left(\begin{array}{c}2011\ HCFC\ Consumption\\ +2012\ HCFC\ Consumption\end{array}\right)}{2}\right)$

3.2.2. ESTIMATED CONSUMPTION OF HCFCS AND HFCS

In addition to estimating historical HCFC and HFC consumption, U.S. EPA estimated business-as-usual (BAU) HFC consumption through 2050 to determine the benefits of the proposed phasedown. Such estimates are prepared regionally and aggregated below to reflect Article 5, non-Article 5, and world totals. The 2014 analysis differs from prior years' analysis by providing a range of projected benefits. The range is based on initial data and methodologies used in previous analysis as well as revised data that incorporates more actual reporting, thus, more accurately reflects the breakdown between chemicals. We continue to use our initial data for consistency when comparing benefits between proposals from different years.

[6] The benefit calculations assume participation from all parties to the Montreal Protocol (i.e., global participation), with consumption at the maximum level allowed under the proposed amendment. Other modeling techniques could calculate different benefits. For instance, a different method could be used to analyze what reduction options are available, what benefits they would achieve, and, assuming options are undertaken based solely on cost, the reductions that would be achieved.

Estimated Consumption in Other Countries: HCFCs

For the purpose of calculating baselines, aggregated developed and developing country HCFC-specific consumption data as reported under Article 7 of the Montreal Protocol are used to determine total GWP-weighted HCFC consumption. Reports from UNEP's Ozone Secretariat are in ozone depleting potential (ODP)-tonnes; therefore, assumptions regarding the mix of HCFCs for Article 5 countries are based on data gathered from HCFC Phaseout Management Plans which contain species-specific consumption data. Non-Article 5 countries' mix of HCFCs is based on U.S. consumption patterns as reported to the Ozone Secretariat. Once this breakdown is estimated, the ODP-weighted tonnes are converted into metric tonnes, which are then multiplied by the GWPs in the proposed Amendment, taken from the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4),[7] and used to develop total HCFC consumption in terms of $MMTCO_2eq$.

Projected Consumption in the United States: HFCs

For estimates of U.S. HFC consumption, U.S. EPA used its Vintaging Model,[8] which tracks and projects past and future use and emissions of chemicals (including HFCs) in products that previously relied on ODS. Although each type of product is modeled separately at its respective growth rate as determined through information relevant to the product type, U.S. EPA projected the U.S. growth of all products at an equal and steady amount beginning in 2030, the date at which ODS consumption in the United States will cease. For this period 2030–2050, U.S. EPA assumed an annual growth rate for each HFC-using product of 0.8%, which equals the approximate population growth rate expected in the United States at that time. Previous sensitivity studies using a 1.8% annual growth rate for 2030–2050 show an approximate 10% increase in cumulative benefits through 2050.

Projected Consumption in Other Countries: HFCs

HFC consumption was estimated on a country-by-country basis and then aggregated to Article 5 and non-Article 5 countries. To develop the global HFC consumption baseline through 2050, U.S. EPA relied on the approach used to develop two peer-reviewed reports released in 2006: *Global Anthropogenic Emissions of Non-CO_2 Greenhouse Gases: 1990–2020* (U.S. EPA Report #430-R-06-003)[9] and *Global Mitigation of Non-CO_2 Greenhouse Gases* (U.S. EPA Report #430-R-06-005).[10] This process, as outlined in those reports, generally follows these steps:

1. Gather ODS (i.e., chlorofluorocarbon (CFC), HCFC, halons, carbon tetrachloride, and methyl chloroform) consumption data as reported under the Montreal Protocol. Data from 1986, 1989 or 1990 are chosen because they pre-date most of the ODS phaseout.[11]
2. Split ODS consumption by ODS type into end-use sectors (i.e., refrigeration/air conditioning, aerosols, foams, solvents, and sterilization).

[7] International Panel on Climate Change (IPCC). 2007. "Climate Change 2007: The Physical Science Basis." Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. September 2007.

[8] Vintaging Model, 12/16/2009. (This version is used to maintain consistency with past analyses presented to the Montreal Protocol Parties.)

[9] http://www.epa.gov/climatechange/Downloads/EPAactivities/GlobalAnthroEmissionsReport.pdf

[10] http://www.epa.gov/climatechange/Downloads/EPAactivities/GlobalMitigationFullReport.pdf

[11] If available, 1989 data is used; where 1989 data is not available, the next closest available year's data is used.

3. Use ODS consumption to estimate HFC consumption by multiplying by the ratio of U.S. HFC consumption for the relevant year to U.S. 1990 ODS consumption. U.S. HFC consumption estimates are generated from U.S. EPA's Vintaging Model as described above.
4. Scale HFC consumption by the region's Gross Domestic Product (GDP) growth relative to U.S. historical and projected GDP. Data were obtained from the U.S. Energy Information Administration (2008).[12]
5. Apply several adjustment factors to account for country-specific differences in transition pathways:
   a. Apply the later phaseout of ODS for Article 5 countries.
   b. Account for a proportion of natural refrigerants (such as hydrocarbons) in lieu of HFCs in the baseline for all regions except North America.
   c. Account for lower levels of recovery and recycling of refrigerants from small equipment in Article 5 countries and certain eastern European countries.
   d. Account for regional transitions in the foams and fire protection sectors by using results from regional Vintaging Model runs that modeled sector-specific data from both the fire protection industry[13] and the foams industry.[14]
6. Multiply the consumption (i.e., tonnes) by an average GWP to derive GWP-weighted consumption (i.e., $MMTCO_2eq$). The average GWP, which varies by sector, is determined by examining the estimated baseline HFC consumption in the United States in 2012. This year is chosen because the U.S. HFC market is assumed to be relatively mature by this date and, under a BAU scenario, the mix of HFCs, and hence the average GWP, is not expected to change significantly thereafter. For instance, the year 2012 is beyond the recent (January 1, 2010) U.S. and Montreal Protocol HCFC phaseout step.

The procedure outlined above is summarized in Equation 3:

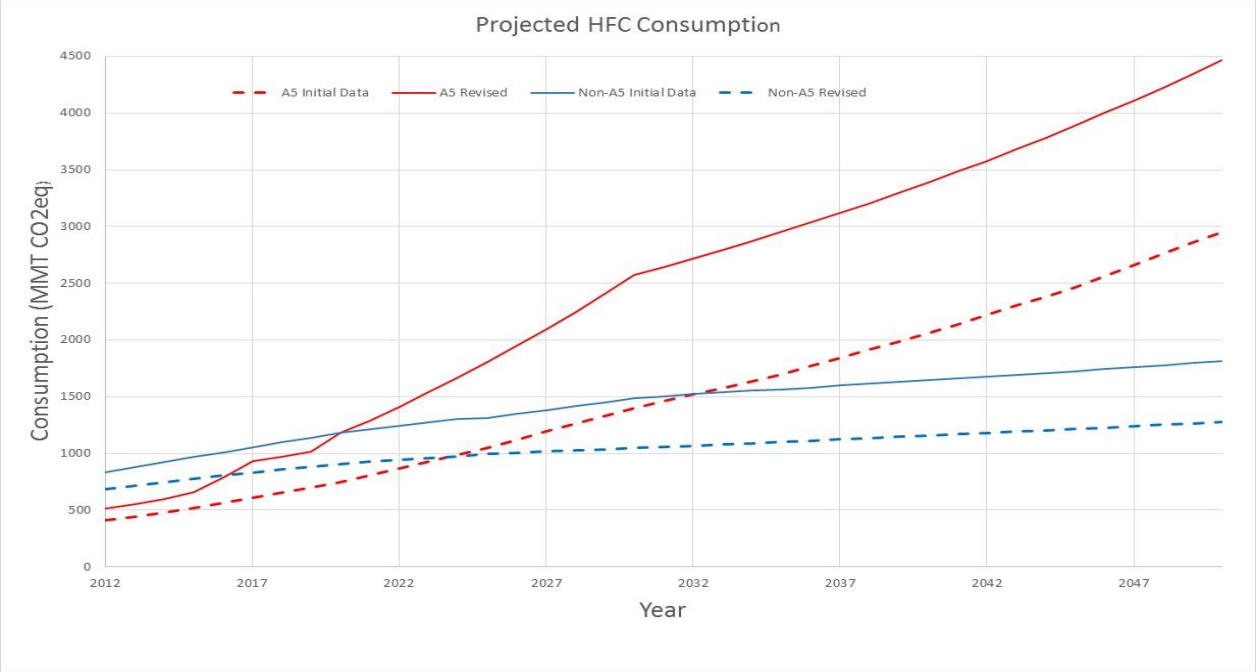
EQUATION 3: ESTIMATING HFC CONSUMPTION FROM ODS CONSUMPTION DATA

$$\text{ODS consumption (1989 or as available)} \times \text{End Use Percentage} \times \frac{\text{HFC consumption (U.S., year)}}{\text{ODS consumption (U.S., 1990)}} \times \text{Growth and other adjustments} \times \text{Average GWP of HFC consumption (U.S., 2012)} = \text{GWP-weighted HFC consumption (year)}$$

As part of the development of the revised data, U.S. EPA used the projected HFC consumption data from the "Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases: Final Report" prepared for the European Commission in September 2011[15]. This HFC consumption data is projected from 2010 through 2030. For the period 2030–2050, U.S. EPA assumed an annual growth rate for each HFC-using product of 2.8%, which represents an anticipated net growth rate based on end-uses. Projected consumption estimates for Article 5 and non-Article 5 are shown in Graph 1.

[12] EIA (2008) *International Energy Outlook 2008*. Washington, D.C. Release date: June 2008. Department of Energy/Energy Information Administration-084(2008). At: http://www.eia.doe.gov/oiaf/archive/ieo08/index.html
[13] 2001 Hughes Associates - International Market Share Data
[14] Data provided by Paul Ashford in personal communications with ICF in 2004.
[15] Available online at: http://ec.europa.eu/clima/policies/f-gas/docs/2011_study_en.pdf

GRAPH 1. PROJECTED HFC CONSUMPTION 2012 THROUGH 2050



3.3. REDUCTION SCENARIO AND RESULTS

The reduction schedule used for this analysis appears in Graph 2 and Table 2 below. Targets were set by considering the need to achieve significant reductions, the likely availability of alternatives, and other obligations under the Montreal Protocol (e.g., HCFC phaseout).

GRAPH 2. PROPOSED HFC REDUCTION SCHEDULES

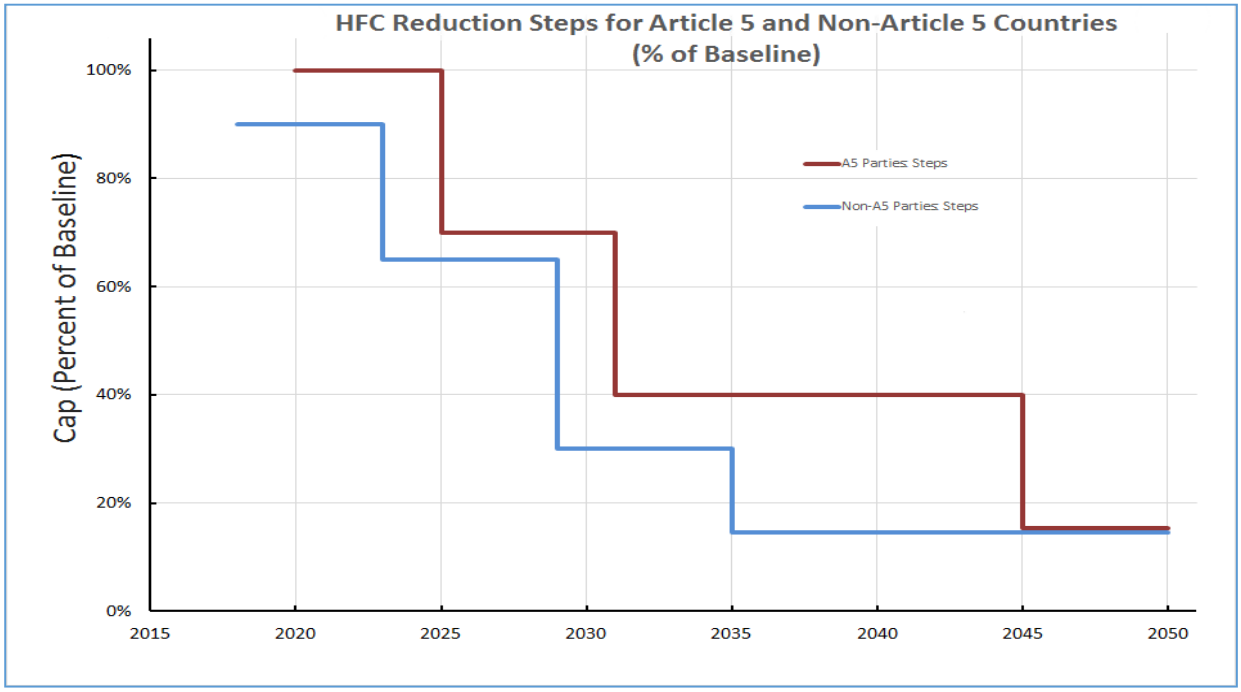


TABLE 2: PROPOSED HFC REDUCTION SCHEDULES

HFC Consumption Reduction Schedule			
Non-Article 5 Parties		**Article 5 Parties**	
Year	**Cap (% of Baseline)**	**Year**	**Cap (% of Baseline)**
2018	90%	2020	100%
2023	65%	2025	70%
2029	30%	2031	40%
2035	15%	2045	15%

Applying the reduction schedule and baselines to the projected consumption developed as described above yields HFC consumption reductions as shown in Table 3. Table 3 estimates the range of cumulative reductions of HFC consumption for four different time intervals: 2016 to 2020, 2016 to 2030, 2016 to 2040, and 2016 to 2050.

TABLE 3: ESTIMATED BENEFITS OF THE HFC PHASEDOWN, AT VARIOUS INTERVALS

Cumulative HFC Phasedown Consumption Reductions ($MMTCO_2eq$)				
	2016 to 2020	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
World	**800 – 1,300**	**13,500 – 17,700**	**41,600 – 53,600**	**80,900 – 102,100**

U.S. EPA also estimated the range of cumulative benefits over a 40-year time horizon to be consistent with the original time horizon of the 2010 amendment proposal. The results of the 40-year benefits horizon are shown in Table 4.

TABLE 4: ESTIMATED BENEFITS OF THE HFC PHASEDOWN, 40- YEAR TIME HORIZON

Cumulative HFC Phasedown Consumption Reductions ($MMTCO_2eq$) – 40-Year Time Horizon	
	40-Year Time Horizon
World	**100,100 - 125,400**

A recent study by Velders et al.[16] indicates that if HFC production were phased out in 2020 instead of 2050, for example, up to 146 $GtCO_2eq$ (or 146,000 $MMTCO_2eq$) of cumulative emissions could be avoided from 2020-2050, and an additional bank of up to 64 $GtCO_2eq$ (or 64,000 $MMTCO_2eq$) could also be avoided in 2050.

3.4. NATIONAL, REGIONAL, GLOBAL, AND CORPORATE INITIATIVES ON HFCS

Over the past several years, we have seen a proliferation of projects and activities designed to demonstrate and optimize transitions away from high-GWP HFCs, and to translate the form of those transitions into government and private-sector initiatives. These actions can be expected to expand the pool of experience and facilitate a smoother transition away from HFCs in developed and developing countries alike.

United States of America

Last June, President Obama announced the Climate Action Plan (CAP), and a broad set of initial steps designed to slow the effects of climate change. Among the many actions called for in the plan, the CAP outlined a set of measures to address HFCs. In the United States, emissions of HFCs are expected to double from current levels of 1.5 percent of greenhouse gas emissions to 3

[16] Velders et al. (2014) Growth of climate change commitments from HFC banks and emissions. Atmos. Chem. Phys., 14, 4563-4572.

percent by 2020 and nearly triple by 2030. HFCs are rapidly accumulating in the atmosphere. For example, the atmospheric concentration of HFC-134a, the most abundant HFC, has increased by about 10% per year from 2006 to 2012, and the concentrations of HFC-143a and HFC-125 have risen over 13% and 16% per year from 2007-2011, respectively.

The President directed the United States to lead through both international diplomacy and domestic action. In particular, he directed the EPA to use its authority through the Significant New Alternatives Policy (SNAP) Program to encourage private sector investment in low-emissions technology by identifying and approving climate-friendly chemicals while prohibiting certain uses of the most harmful chemical alternatives. In addition, the President directed his Administration to purchase cleaner alternatives to HFCs whenever feasible and to transition over time to equipment that uses safer and more sustainable alternatives.

U.S. EPA is proposing two initial rules – the first expanding the list of low-GWP alternatives and the second that will change the status to unacceptable for certain HFCs for specific uses in the aerosols, refrigeration and air conditioning, and foam blowing sectors.

European Fluorinated Gas Regulation

The European Commission recently revised and strengthened their existing revision on fluorinated gases as part of its policy to combat climate change. The previous F-gas regulation was adopted in 2006 and was aimed at stabilizing European Union (EU) F-gas emissions at 2010 levels. The new regulation goes into effect January 1, 2015. The intent is to cut the EU's F-gas emissions by two-thirds compared with 2014 levels. Requirements include a European phasedown and quota system for the supply of HFCs beginning in 2015, along with bans on certain HFC-containing equipment, and a requirement to destroy or recycle HFC-23 (a production byproduct). Existing regulation on labeling, refrigerant management and reporting requirements, and training programs have also been expanded to cover HFCs. The expected cumulative emission savings are 1.5 gigatons of CO_2-equivalent by 2030 and 5 gigatons by 2050.

Japanese Fluorinated Gas Regulation

In April 2013, Japan enacted a law updating their existing fluorocarbon regulation. The objective of the new legislation is to reduce HFC emissions through measures that cover the total life cycle of fluorocarbons from manufacture through disposal, as well as equipment using these gases. Among other requirements, the law requires that entities manufacturing and importing air conditioning and refrigeration units transition to either non-fluorinated gases or low-GWP fluorocarbons by certain years.

Consumer Goods Forum Resolution

The Consumer Goods Forum (CGF), a group of over 400 private sector companies from 70 countries, has pledged to phase out HFC refrigerants in new point-of-sale units and large refrigeration systems starting in 2015. CGF also urges companies to practice effective maintenance to minimize, detect, and promptly repair leaks in existing refrigeration systems. CGF members include The Coca Cola Company, 3M, Procter & Gamble, and Unilever. Given the reach of many CGF companies, and the impact on national equipment production that similar CFC-related pledges had, the global community can expect to see very significant changes in the production and use of related equipment in developed and developing countries alike.

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants

The Climate and Clean Air Coalition (CCAC) to Reduce Short-Lived Climate Pollutants is a voluntary initiative launched in 2012 aimed at achieving progress in addressing near-term contributions to global warming. The CCAC is focusing on HFCs as well as black carbon and methane, and has sponsored several capacity building activities such as workshops and conferences focusing on enabling the use of climate-friendly alternatives to high-GWP HFCs and removing barriers to their adoption. The CCAC is also helping countries inventory their HFC sectors, and has produced case studies to share information about successful transitions to climate-friendly alternatives in commercial refrigeration, and is sponsoring several technology demonstration projects, HFC inventories in developing countries, as well as additional capacity building efforts.

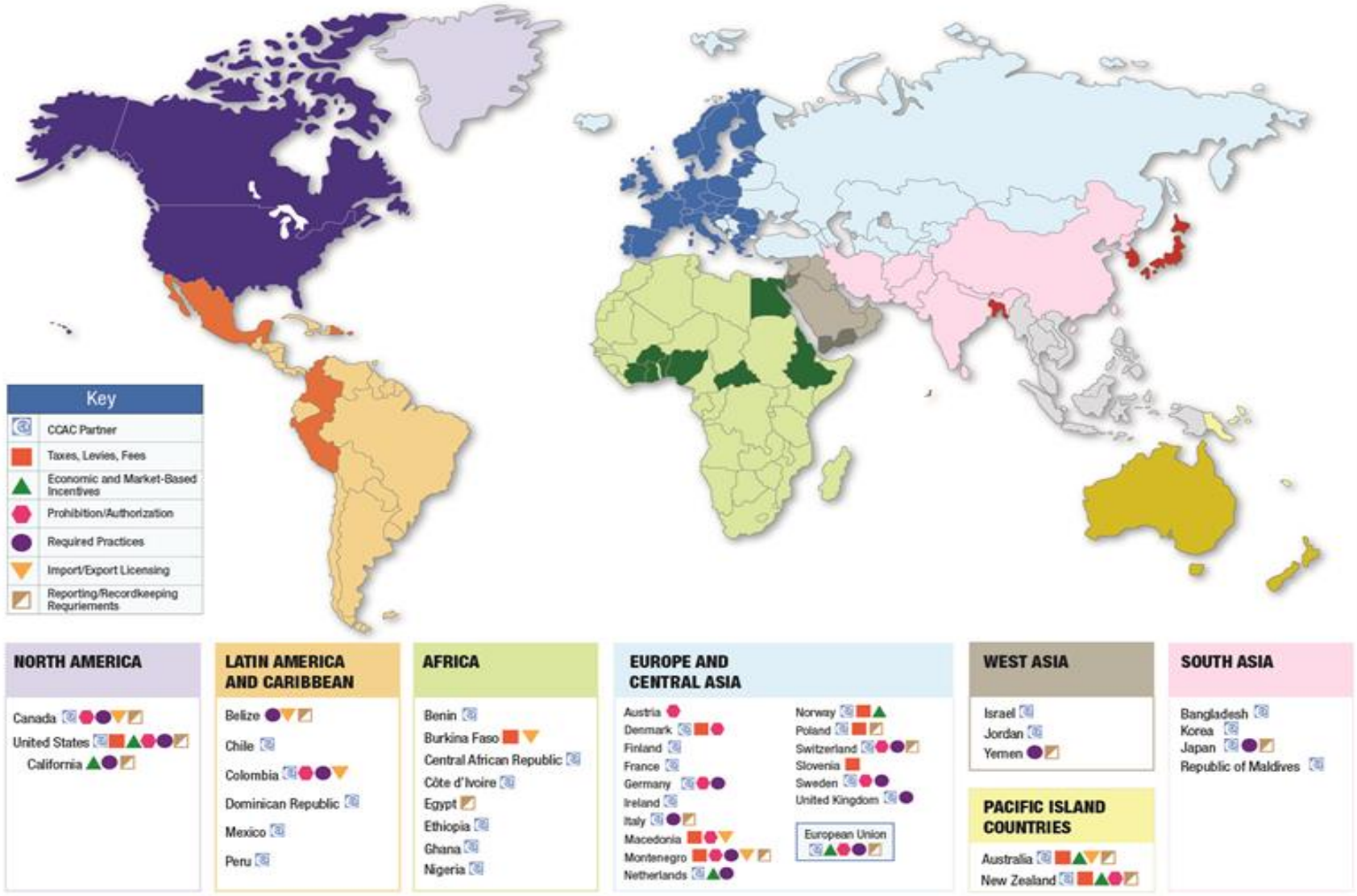
Fulfilling the Vision of Decision XIX/6

In taking the 2007 decision to accelerate the phaseout of HCFCs, the Parties emphasized the need for the Executive Committee to give priority to projects that promote substitutes and alternatives that minimize other impacts on the environment, including on the climate, taking into account global-warming potential, energy use and other relevant factors. While the goal to achieve climate benefits has been considered in many different ways, two significant tools that have been used by the Multilateral Fund are projects designed to demonstrate and optimize alternatives to high-GWP substitutes, and the provision of enhanced funding for those projects that utilize low-GWP technologies. The U.S. EPA's benefits analysis for the accelerated HCFC phaseout produced a range based on the transition to alternatives and improved energy efficiency. If the accelerated HCFC phaseout resulted in transition predominantly to high-GWP HFCs, the benefits through 2040 would be 3 gigatons CO_2eq, while a transition to only low-GWP alternatives would result in 16 gigatons CO_2eq avoided. The assumption was that a mix of low- and high-GWP alternatives would result in 9 gigatons CO_2eq of emissions avoided. Since 2007, a number of additional new climate-friendly alternatives have been developed and deployed.

Global View of HFC Policies

Numerous policies, programs, and other measures have been initiated in all regions of the world to target the consumption and subsequent emissions of HFCs. Countries are engaging industry through various means and, in some cases, have developed policies to address HFCs. Twenty-four countries and the EU have existing or proposed HFC policies. Figure 1 presents a geographic distribution of HFC policies along with countries participating in the Climate and Clean Air Coalition.

FIGURE 1: GLOBAL VIEW OF HFC POLICIES*



[a]CCAC partners and countries with HFC policies are shaded in a darker color. Southeast Asia is noted in grey

3.5. AVAILABILITY OF ALTERNATIVES FOR MEETING THE REDUCTION SCHEDULE

When the North American amendment was first proposed in 2010, the availability of alternatives for HFCs was similar to the availability of CFC alternatives at the 1987 signing of the Montreal Protocol, and similar to when the Parties agreed to phase out HCFCs. Alternatives have been developed and are in use for some end uses, but not in all cases. This is still true today, but over the last several years, a number of new alternatives have been made available and significant experience has been gained in optimizing more mature low-GWP technologies. Accordingly, there are currently fewer end uses for which a menu of proven alternatives is not available.

The U.S. EPA's SNAP program encourages a smooth and timely transition from ODS to a variety of alternatives across major industrial, commercial, and military sectors. The SNAP program's findings are relevant globally and can be used by countries as they consider adopting safer alternatives. The SNAP program currently provides a broad menu of alternatives with a range of GWPs – both HFC and non-HFC options. As the SNAP menu continues to be updated, more low-GWP and no-GWP alternatives are being added. The President's Climate Action Plan directs U.S. EPA to use its authority through the SNAP "to encourage private sector investment in low-emissions technology by identifying and approving climate-friendly chemicals while prohibiting certain uses of the most harmful chemical alternatives."[17]

Therefore, the SNAP program will continue to identify substitutes – for ODS as well as HFCs – that offer lower overall risks to human health and the environment and take action to prohibit the most harmful chemicals. The SNAP program will continue to use the established framework and the same set of risk factors always considered:

- Ozone Depletion Potential (ODP);
- Global Warming Potential (GWP);
- Flammability;
- Toxicity;
- Contributions to smog;
- Aquatic and ecosystem effects; and,
- Occupational health and safety.

To date, U.S. EPA has reviewed over 400 substitutes in the refrigeration and air conditioning; fire suppression; foam blowing; solvent cleaning; aerosols; adhesives, coatings, and inks; sterilants; and tobacco expansion sectors. Across all sectors, since the initiation of the SNAP program in 1994, roughly one-third of the substitutes reviewed contain HFCs. For the refrigeration and air conditioning sector, HFCs have dominated. However, the SNAP program has issued several rulemakings, and is currently considering a number of other such rulemakings and projects, that have and will continue to provide additional low-GWP or no-GWP options including hydrocarbons and low-GWP hydrofluoroolefins (HFOs).

The amendment proposal is GWP-weighted and does not fully phase out HFCs. It is anticipated that countries, including the United States, will use a mixture of fluorinated and non-fluorinated options. U.S. EPA analyzed certain sector-specific, technically- and economically-viable

[17] *The President's Climate Action Plan*, Executive Office of the President, June 2013. Accessible online at: http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf

mitigation options for HFCs. The most promising options to reduce HFC consumption fall into these broad categories:

- Substituting high-GWP HFCs with low-GWP or no-GWP substances in a variety of applications (where safety and performance requirements can be met);
- Implementing new technologies that use, at installation and/or over the lifetime of the equipment, no or significantly lower amounts of HFCs; and,
- Various process and handling options—including the principles of refrigerant recovery and management implemented during the CFC phaseout—that reduce consumption during the manufacture, use, and disposal of products that contain or use HFCs.

In the last two years, three significant international conferences were held in Bangkok, Thailand and Montreal, Canada to review progress on low-GWP alternatives, and the results of those workshops can be found at: http://www.unep.org/ccac/Actions/HFCAlternativeTechnologyandStandards/tabid/104667/Default.aspx.

It is clear that many options exist across all major sectors to reduce—and in some, even eliminate—the use of HFCs. Some of these options are available today, meaning they could be used to meet HCFC phaseout obligations while at the same time contributing to the proposed HFC reductions. Indeed, this was the intent of the Montreal Protocol's decision XIX/6 which called on the Parties to promote the selection of HCFC alternatives that minimize environmental impacts, in particular impacts on climate, as well as meeting other health, safety and economic considerations. While low-GWP alternatives already exist for many end-use applications, additional research is already underway in companies around the world to find alternatives for other important applications, such as large residential and light-commercial air conditioning (i.e., unitary air conditioners and multi-splits).

Information on existing and potential options to reduce HFCs can be found in Table 5, which indicates alternatives that are currently used on a commercial scale; alternatives that have limited use such as for demonstration, trials, niche applications, etc.; and alternatives that are potentially feasible on a commercial scale, based on fluid characteristics[18]. For some subsectors additional information also is available on U.S. EPA's website, as discussed below.

[18] Report of the Technology and Economic Assessment Panel, May 2014, Volume 4, Decision XXV/5 Task Force Report Additional Information to Alternatives on ODS (Draft Report). Accessible online at: http://conf.montreal-protocol.org/meeting/oewg/oewg-34/presession/Background%20Documents%20are%20available%20in%20English%20o1/TEAP_Task%20Force%20XXV5-May2014.pdf

TABLE 5: SUMMARY OF THE APPLICATION OF EACH ALTERNATIVE WITHIN THE RESPECTIVE SUBSECTORS*

GWP	0	1	3 – 5	4	4	6	6	290	330	490	490	600	630	716	1330	1410	1370	1700	1820	2100	2100	3700
	R-717	R-744	HC-290, HC-1270	HC-600a	HFC-1234yf	HFC-1234ze(E)	HCFC-1233zd(E)	"L-40"	R-444B	"L-41"	"DR-5"	R-450A	"XP-10"	HFC-32	R-448A	R-449A	HFC-134a	R-407C	R-407F	R-407A	R-410A	R-404A
Domestic refrigeration				C	F							F	F				C					
Commercial refrigeration																						
— Stand alone equipment		C	C	C	L	F		F	F	F	F	F	F	F	L	F	C	F	F	F	F	C
— Condensing units		L	L	F	F			F	F	F	F	F	F	F	L	F	C	F	F	F	F	C
— Centralised systems	L	C	L		F			F	F	F	F	F	L	F	L	F	C	F	C	C	F	C
Transport refrigeration		C	C		F			F	F	F	F	F	F	F	F	F	C	F	F	F	C	C
Large size refrigeration	C	C	L		F			F	F	F	F	F	F	F	F	F	F	C	C	C	C	C
Air conds and heat pumps																						
— Small self contained		L	C		F				F	F	F	F	F	L	F	F	C	C	F	F	C	F
— Mini-split (non-ducted)		L	C						F	L	F	F	F	C	F	F	F	C	F	F	C	F
— Multi-split		L							F	L	F	F	F	L	F	F	F	C	F	F	C	F
— Split (ducted)		F	F						F	F	F	F	F	L	F	F	F	C	F	F	C	F
— Ducted split comm. & non-split		F	L						F	F	F	F	F	L	F	F	C	C	F	F	C	F
— Hot water heating HPs	C	C	C	C	F	F		F	F	F	F	F	F	L	F	F	C	C	F	F	C	F
— Space heating HPs	C	L	C	L	F	F		F	F	F	F	F	F	L	F	F	C	C	F	F	C	C
Chillers																						
— Positive displacement	C	C	C		L	L		F	F	L	F	L	L	L	F	F	C	C	F	F	C	C
— Centrifugal			L		L	L	L										C					
Mobile air conditioning																						
— Cars		F	F		C							F	F				C					
— Public transport		F			L							F	F				C	C			C	

"C" indicates current use on a commercial-scale

"L" indicates limited use such as for demonstration, trials, niche applications, etc

"F" indicates use is potentially feasible on a commercial scale, based on fluid characteristics

** Source: TEAP, May 2014, Volume 4, Decision XXV/5 Task Force Report Additional Information to Alternatives on ODS (Draft Report).*

3.6. TRANSITIONING TO LOW-GWP ALTERNATIVES

A detailed analysis of how individual Parties might meet the proposed reduction schedule has not been performed, as related choices would depend on national circumstances and preferences. However, many types of transitions can be foreseen and are shown schematically in Figures 1 through 5 below. For example, many automobile manufacturers have already begun to introduce HFO-1234yf air conditioning systems in Europe and the United States and the number of cars using HFO-1234yf globally is expected to exceed 2 million by the end of 2014 (Automotive World 2014).

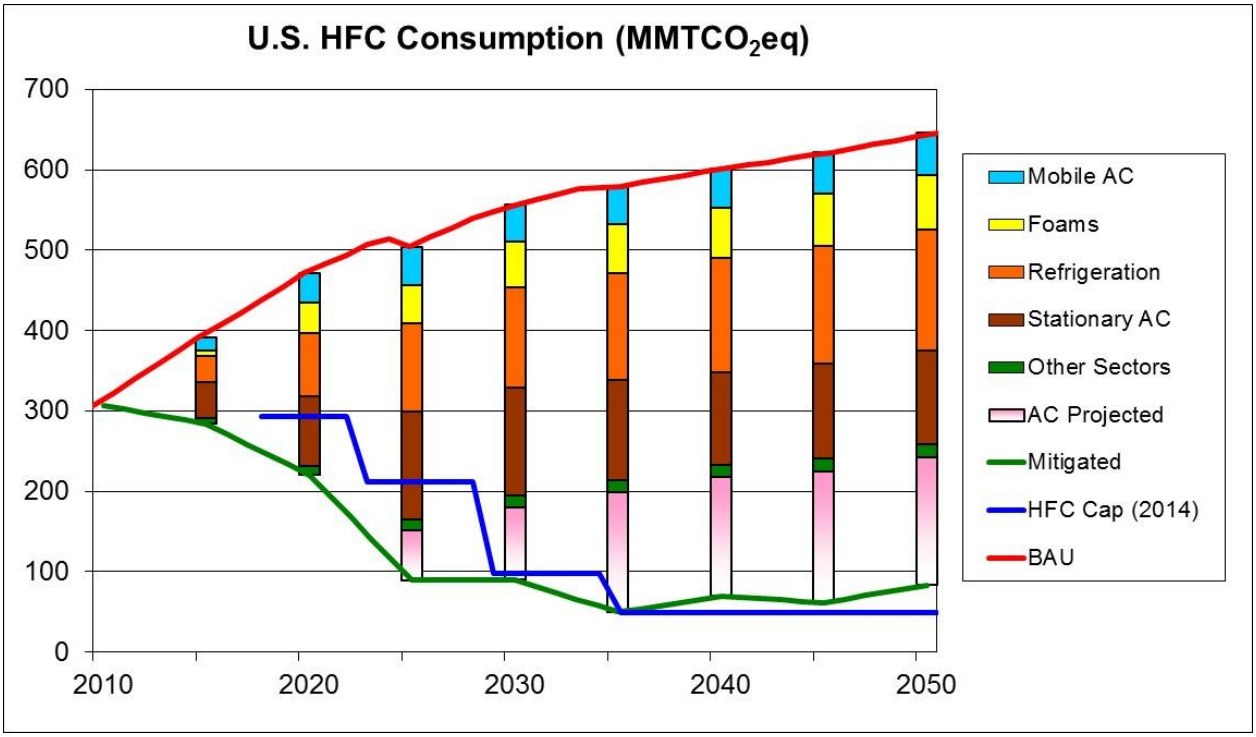
Several options in foam-blowing, including hydrocarbons and HFOs, also offer an opportunity for non-Article 5 countries to reduce HFC consumption, and for Article 5 countries to leap frog HFCs altogether in certain applications. Many types of hermetic air-conditioning and refrigeration equipment—including domestic refrigerators, vending machines, and bottle coolers—are becoming available worldwide with low-GWP alternatives in lieu of HCFC-22, HFC-134a and other high-GWP chemicals. A number of key multinational corporations have also pledged to phase out the use of HFCs as refrigerants in newly manufactured equipment.

Over the past few years, a number of Article 5 countries have included a range of lower-GWP alternatives in their HCFC Phaseout Management Plans (HPMPs). For example, rather than using R-410A (an HFC blend with a GWP of 2,088), Indonesia is using R-32 (an HFC with a GWP of 675) for certain air conditioning applications. China agreed to convert at least 18 manufacturing lines for the production of room air-conditioning equipment, including both window units and mini-splits, to the hydrocarbon R-290. Many countries included hydrocarbons in their foam sector HPMPs when phasing out of HCFC-141b.

U.S. EPA has developed a series of sector-specific fact sheets to provide more current information on low-GWP or no-GWP alternatives. Seven fact sheets on Commercial Refrigeration, Domestic Refrigeration, Motor Vehicle Air Conditioning, Unitary Air-Conditioning, Transport Refrigeration, Construction Foam, and Non-Medical Aerosols are currently available on U.S. EPA's website at: www.epa.gov/ozone/intpol/mpagreement.html.

U.S. EPA performed a preliminary analysis of how HFC consumption could be reduced in the United States. Multiple alternatives were analyzed, including many of those highlighted in Table 5. As shown in Graph 3, a multi-sector approach could be used by the United States to reduce HFC consumption from the increasing business-as-usual projection to levels necessary to meet the proposed amendment. It is assumed here that some HFC use will continue to be used beyond 2033, as anticipated in the reduction to a 15% level called for in the proposed Amendment. In this example, it is clear that the majority of reductions come from the refrigeration and air conditioning sectors, but that reductions from the other sectors also play an important part. Existing options could help the United States meet its obligations in the near term; however, some projected alternatives need to be developed and implemented in the next decade or so, and potentially other or better reduction alternatives need to be found, for compliance in the long term.

GRAPH 3. POTENTIAL HFC CONSUMPTION REDUCTIONS BY SECTOR FOR THE UNITED STATES



3.7. CASE STUDIES IN THE TRANSITION TO LOW-GWP ALTERNATIVES

3.7.1. TRANSITIONS AT THE REGIONAL AND NATIONAL LEVELS

The following are summaries of transitions certain nations or regions have taken to adopt low-GWP alternatives in specific sectors. These four examples show how national circumstances can be taken into account while adopting low-GWP alternatives. Example national and regional level transition summaries are available from the U.S. EPA sector fact sheets.

Unitary Air Conditioning: China's Experience

China manufactures half of the world's 50 million mini-split air conditioner (AC) systems annually. It is the largest manufacturer of AC equipment in the developing world. A significant portion of production is for the export market—China supplies nearly 85% of the window, wall, and mini-split AC imports to the United States, and is also a major supplier to Europe, Asia and elsewhere. While R-22 continues to dominate unitary AC domestically, China manufactures both R-22 and R-410A units. The R-410A units are in high demand as exports to developed countries. China has commercialized room ACs with R-290 and, under their HPMP, agreed to convert a number of their production lines for unitary AC products to R-290 as well as R-32.

Construction Foams: Europe's Experience

The European Union phased out HCFCs in construction foam by the early 2000s and much of the building/construction sector transitioned directly to hydrocarbons (HCs), having used these blowing agents in other products since the early 1990s. Some smaller companies, as well as those making foams with stringent end-use flammability standards, used HFCs. Through product development, most of these standards now can be met with HC-based foams, and HFC use has

diminished. Notably, even in the spray foam application, which has relied primarily on HFCs due to the higher flammability risks (relative to other foam applications), next-generation low-GWP alternatives, such as
-1233zd(E), have recently started to become available.[19,20]

Refrigerated Transport Trucks and Trailers: Norway's Experience
In 2007, liquid CO_2 refrigerant-based cryogenic systems were introduced into Norway's road transport refrigeration market. Cryogenic truck and trailer systems use liquid CO_2 for refrigeration to minimize environmental impact and noise while providing high reliability and lower maintenance.

In 2011, approximately 16% of new refrigerated truck and trailer systems sold in Norway were equipped with cryogenic refrigeration systems. One of Norway's largest food distributors has committed to making cryogenic system-equipped vehicles the standard for all of their future purchases. In addition, a major manufacturer of cryogenic systems has partnered with one of Norway's largest refrigerant suppliers to provide CO_2 filling stations across the country. Cryogenic systems are currently used in other European countries (e.g., Sweden, Denmark, Finland, France, the Netherlands, and Germany), and are being piloted in the United States. Use of liquid CO_2 refrigerant-based cryogenic systems is expected to expand further in the future, particularly in Western Europe.

Commercial Refrigeration Systems: Australia's Experience
Australia's major supermarkets have committed to reducing commercial refrigeration emissions through lower GWP refrigerants, advanced refrigeration technology, and innovative store designs. The supermarket chains determined that half of their emissions (in CO_2eq) are from refrigeration systems. Losses from HFC refrigerants account for a significant portion of these emissions. Supermarkets are incorporating CO_2 cascade and transcritical refrigeration systems to meet their target reductions in CO_2eq emissions. Shifting from HFCs to CO_2 can eliminate direct system emissions while potentially also reducing indirect emissions associated with energy consumption: CO_2 transcritical systems operate most efficiently in cooler climates, where they have been found to perform an estimated 5% to 10% more efficiently than conventional systems using an HFC refrigerant in regions with an average annual temperature below 50°F (10°C).[21] However, due to a possible energy penalty, the use of CO_2 transcritical systems in warmer climates is currently considered less viable. That said, significant work is underway that could result in greater use of transcritical systems in warmer climates. As of 2011, at least 51 stores have implemented this new technology.[22] Australia has evaluated the benefits of new technologies and provided assistance to update supermarket refrigeration equipment.

[19] Honeywell. 2013. Regulations. http://www.honeywell-blowingagents.com/regulation/#european-union
[20] Honeywell. 2011. Honeywell Solstice™ Liquid Blowing Agent. November 2011. http://www.honeywell-blowingagents.com/?document=solstice-liquid-blowing-agent-product-overview-europe&download=1
[21] Supermarket News. 2012. "Refrigeration Systems Chillin' with Carbon Dioxide." Available at: http://supermarketnews.com/technology/refrigeration-systems-chillin-carbon-dioxide?page=1 showtext.cfm?t=ptb0810
[22] Rees, Brian (McAlpine Hussmann Ltd.). 2011. "Supermarket Refrigeration Trends in the Asia Pacific Region." September 2011. Available at: http://www.epa.gov/greenchill/downloads/non_us_refrigeration_trends_asia.pdf.

3.7.2. TRANSITIONS AT THE COMPANY AND PROJECT LEVELS

Some examples of specific company actions to adopt low-GWP alternatives are discussed below. These illustrate how individual companies are already moving towards a low-GWP future, often without any regulatory requirements to do so. In addition, some specific case studies of projects are shown below as examples of actions to adopt environmentally sound alternatives.

New Foam Blowing Agents for Household Refrigerators

Conversions to new foam blowing alternatives is underway. Whirlpool Corporation announced it is implementing Slostice-1233zd(E) to reduce the GWP and improve energy efficiency for all U.S.-made refrigerators and freezers. The GWP is 99.9%i lower than HFC-245fa. Typically, insulation is applied to the interior of the refrigerator door panel and refrigerator cabinet in a liquid form at the plant. The insulation includes foaming agents that trap bubbles of gas inside the insulation as it expands and dries. The two-part mixture was integrated without the need for new machinery or extensive capital investment. By the end of 2014, Whirlpool plans to convert all its U.S. refrigerator and freezer manufacturing to -1233zd(E).[23]

Carbon Dioxide Vending Machines: Sanyo's and Coca-Cola's Experience

Sanyo has produced CO_2 compressors since 2001, originally developed for heat pump water heaters. Using this technology, Sanyo developed the first CO_2 vending machine, which was field tested in February 2004 in Australia. Results from these tests showed that the CO_2 system consumed 17% less energy compared to the comparable HFC-134a system during the summer season. Beginning in 2005, CO_2 vending machines began being sold in Japan and have represented a significant and growing portion of the Japanese market—estimated at 116,000 units in 2010.[24,25] Coca-Cola is using CO_2 as the refrigerant in vending machines (listed as acceptable by the SNAP program in 2012). Several years ago, Coca-Cola installed 35 units under a test market agreement in the U.S. Capitol buildings as part of the House's former "Green the Capitol" program.[26] Coca-Cola Company announced in January 2014 that it installed its 1 millionth HFC-free cooler. This milestone marks significant progress in Coca-Cola's effort to phase out using HFC refrigerants in their dispensers, vending machines and coolers globally.[27]

Transcritical Carbon Dioxide Supermarkets: Sobeys' Experience

Since the first supermarket transcritical CO_2 system installation in 2002—at a Coop store in Lestans, Italy—around 1,200 such systems have been installed across Europe.[28] The technology is now spreading to North America. Sobeys, Canada's second largest food retailer, installed its first transcritical CO_2 system in July 2006 and has plans to implement the technology in all of its

[23] Whirlpool showcases new technology, http://www.corridorbusiness.com/news/whirlpool-showcases-new-technology/

[24] Sanyo Electric Co. 2008. "CO_2 Vending Machines." Technical Meeting on HCFC Phase-Out.

[25] Greenpeace. 2010. "Cool Technologies: Working without HFCs." Available online at: http://www.hysave.com/wp-content/uploads/2010/07/COOLING-WITHOUT-HFCs-June-2010-Edition.pdf.

[26] R744.com. 35 CO_2 vending machines installed at the US Capitol. April 29, 2010. Available online at: http://www.r744.com/articles/2010-04-29-35-co2-vending-machines-installed-at-the-us-capitol.php

[27] Coca-Cola Installs 1 Millionth HFC-Free Cooler Globally, Preventing 5.25MM Metrics Tons of CO2http://www.coca-colacompany.com/press-center/press-releases/coca-cola-installs-1-millionth-hfc-free-cooler-globally-preventing-525mm-metrics-tons-of-co2

[28] ACR News. "UK a leader in transcritical CO2 refrigeration." Available online at: http://www.acr-news.com/news/news.asp?id=2767&title=UK+a+leader+in+transcritical+CO2+refrigeration.

1,300 stores in 15 years. In one study of three transcritical stores compared to 22 conventional stores using R-507 (an HFC blend), Sobeys found the transcritical system required 18% to 21% less energy. Also, Sobeys did not experience significant problems with the systems despite operating during the higher-than-normal temperatures experienced in Quebec in the summers of 2010, 2011, and 2012.[29]

Low-GWP HFC Air Conditioning: Daikin's Experience

In 2011, the Indonesia Ministry of Environment and Ministry of Industry; the Japan Ministry of Economy, Trade and Industry; Daikin and Panasonic, and with support of the United Nations Development Programme (UNDP), reached an agreement to introduce HFC-32 air conditioners in the Indonesian market. Soon after, Fujitsu General, Hitachi, and Toshiba also joined the new partnership.[30] Today, R-32 AC products are available in Japan[31] and India,[32] while manufacturers in other developing countries also plan to transition to R-32 AC systems—including Algeria, China, and Thailand.[33]

Propane Refrigerated Cases: H-E-B's Experience

H-E-B opened a newly constructed supermarket in Austin, Texas in 2013 that is the first in the United States to use propane-based refrigeration to cool the majority of its refrigerated cases, walk-in coolers, and freezers. H-E-B worked with Hussmann to design self-contained propane refrigerated cases, each with a 150 gram charge size to comply with U.S. regulations. The cases are connected to a central water-chilled condenser, which is also used for heating and cooling the store as an additional energy-saving measure. Compared to a baseline store that only uses traditional HFC refrigerants, the propane store is projected to have an 85% reduction in its carbon footprint. While the capital costs to build the store were higher, the plug-in design for the cases significantly lowered installation costs, and maintenance and energy costs are also expected to be reduced. H-E-B has plans to expand the technology to future stores.[34]

Liquid Propane Extruded Polystyrene (XPS) Foam: Egypt's Experience

The United Nations Development Programme (UNDP) implemented a project in Egypt to phase out the use of ODS in XPS foam. Although butane and isobutane were considered for the conversion, ultimately liquid propane gas was used due to its lower cost and because the gas could be obtained easily for this project. Local contractors were hired to complete the conversion. The conversion resulted in improved quality of the foam; the foam had a softer touch (which consumers preferred) and was less brittle. Its density was also reduced, which improved

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[29] Supermarket News, 2012. "Refrigeration Systems Chillin' with Carbon Dioxide." Available online at: http://supermarketnews.com/technology/refrigeration-systems-chillin-carbon-dioxide.

[30] JARN News, August 2011 "Indonesia-Japan HFC-32 Partnership Targets Room Air Conditioner Market" Available online at: http://www.ejarn.com/news.asp?ID=16248

[31] Daikin. September 27, 2012. News Release: World's First Commercialization of Air Conditioning Equipment Using Next-Generation Refrigerant HFC32. Obtained February 14, 2013 at: http://www.daikin.com/press/2012/120927/index.html.

[32] ACR-News. 2013. Daikin launches R32 units in India. February 12, 2013. Available online at: http://www.acr-news.com/news/news.asp?id=3200&title=Daikin+launches+R32+units+in+India.

[33] Stanga, Mark (Daikin Industries, Ltd). 2012. "Alternative Refrigerant R-32 in Air Conditioning." Presented at *Advancing Ozone and Climate Protection Technologies: Next Steps*, Bangkok, Thailand, July 22, 2012. Available online at: http://www.unep.org/ccac/Portals/24183/docs/Bangkok%20Technology%20Conference%20-%20Report%20and%20Cover%20-%20FINAL.pdf.

[34] CCAC, 2014. "Low-GWP Alternatives in Commercial Refrigeration: Propane, CO_2 and HFO Case Studies." Available online at: http://www.unep.org/ccac/portals/50162/docs/Low-GWP_Alternatives_in_Commercial_Refrigeration-Case_Studies-Final.pdf

the market position of the company. The project performed a safety audit that concluded that the plant was operated safely with use of liquid propane gas as the blowing agent.

4. BYPRODUCT EMISSIONS OF HFC-23

4.1. PROPOSED AMENDMENT AND CURRENT MITIGATION ACTIVITIES

The Mexico, Canada, and U.S. Amendment proposal includes provisions that limit HFC-23 byproduct emissions resulting from the production of HCFCs and HFCs beginning in 2016. HFC-23 is a potent greenhouse gas that is 14,800 times more damaging to the Earth's climate system than carbon dioxide. HFC-23 is a known byproduct from the production of HCFC-22. HCFC-22 is used primarily as a refrigerant and as a feedstock for manufacturing synthetic polymers. HCFC-22 is an ODS; non-feedstock production of it is scheduled for phaseout by 2040 under the Montreal Protocol. However, given the extensive use of HCFC-22 as a feedstock, its production is projected to continue indefinitely. While a small amount of HFC-23 is used predominantly in plasma-etching processes in semiconductor manufacturing, as a fire suppressant, and either neat or as a blend component in cryogenic refrigeration, the vast majority of HFC-23 produced is not used and is either emitted, captured or destroyed. Recent studies[35] indicate that HFC-23 emissions continue to increase in developing countries, despite global efforts to curb emissions.

Nearly all producers in non-Article 5 countries have implemented process optimization and/or thermal destruction to reduce HFC-23 emissions. For example, U.S. EPA worked in partnership with production facilities located in the United States to develop and implement technically feasible, cost-effective processing practices or technologies to reduce HFC-23 emissions from the manufacture of HCFC-22. Since 2010, U.S. emissions of HFC-23 from the production of HCFC-22 must be reported to U.S. EPA as part of the Greenhouse Gas Mandatory Reporting Rule (40 CFR Part 98). U.S. EPA's report, *Global Mitigation of Non-CO_2 Greenhouse Gases,*[36] analyzes technology options that can be deployed in both Article 5 and non-Article 5 countries to minimize such emissions.

Some developing country HFC-23 emissions have been mitigated through Clean Development Mechanism (CDM) projects using destruction technologies, namely thermal oxidation or plasma arc. The CDM allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one ton of CO_2. The HFCF-22 facilities with CDM projects have destruction technologies installed, however, not all HCFC-22 facilities have been eligible to earn credits under CDM; therefore, a number of facilities may not have emission reduction technology installed. In 2011, the European Commission formally adopted a ban on HFC-23 credits in the European Union's Emissions Trading System. The ban recently went into effect as of May 2013. Many questions concerning the state of the HFC-23 market remain, including whether there are longer term contracts (at fixed prices in some cases) that

[35] Montzka et al.: Recent increases in global HFC-23 emissions, Geophysical Research Letters, 37, L02808, doi:10.1029/2009GL041195, 2010.

[36] *Global Mitigation of Non-CO_2 Greenhouse Gases (USEPA 430-R-06-005, June 2006)*. Available at: http://www.epa.gov/climatechange/Downloads/EPAactivities/GlobalMitigationFullReport.pdf

may keep this market alive into the future to some extent. Also, individual countries may have national regimes that include HFC-23 offsets. However, many countries in the European Union as well as Australia and New Zealand have announced that they too will not accept credits generated from HFC-23 destruction. Today, the HFC-23 credit market appears to be defunct, since many countries are no longer willing to purchase these credits. Therefore, in order to estimate benefits, this analysis assumes production lines that previously generated credits from CDM would leave HFC-23 emissions unabated.

Approximately 43 HCFC-22 production lines were identified in Article 5 countries.[37] There are about 23 production lines in Article 5 countries with CDM Projects approved. An estimated 20 production lines are assumed to not currently have emission control technologies installed. This benefits analysis assumes that the provisions in the Amendment proposal apply to all countries and that controls to mitigate (i.e., destroy) HFC-23 emissions are installed in all production lines that did not already have an approved project under the CDM to control emissions of HFC-23.

4.2. BENEFITS FROM BYPRODUCT CONTROLS

Benefits were calculated with UNEP reported and projected data for HCFC consumption, feedstock production estimates (Montzka, 2009), publicly available data on individual CDM Projects (accessible at: http://cdm.unfccc.int/), and data from the MLF Secretariat.[38] Using the data from the CDM, the annual amount of CERs for each project, which is based on IPCC Second Assessment Report (SAR) GWP values, is transformed to reflect the updated GWPs in AR4 and the Amendment proposal. Benefits from all production lines, from both Article 5 and non-Article 5 countries, are assumed to accrue beginning in 2016.

A number of assumptions were made to estimate the benefits: HCFC-22 production for feedstock is projected to increase at a rate of 5% per year through 2050 (based on Montzka, 2009); HCFC-22 production for consumption (i.e., non-feedstock uses) is derived from HCFC consumption data for 2009 through 2012[39] and adjusted to reflect the HCFC phasedown; and, the baseline (i.e., without the amendment proposal) fraction of HFC-23 produced per tonne of HCFC-22 is estimated to be 3% in Article 5 countries based on CDM methodologies and 1% in non-A5 countries. Once the total HCFC-22 production is estimated from adding together the adjusted consumption plus projected feedstock, the total is multiplied by the estimated fraction of HFC-23 produced per tonne of HCFC-22. That result is then multiplied by the GWP of HFC-23 and finally divided by 1,000,000 to yield the benefits for that year in $MMTCO_2eq$. Results are shown in Table 6 below.

[37] "Summary of Information Publicly Available on Relative Elements of the Operation of Clean Development Mechanisms and the Amounts of HCFC-22 Production Available for Credits" by Executive Committee of the Multilateral Fund for the Implementation of the Montréal Protocol, Fifty-seventh Meeting, Montreal, 30 March – 3 April 2009. Available at: http://www.multilateralfund.org/sites/57th/Document%20Library2/1/5762.pdf and "Preliminary Data on the HCFC Production Sector in China" Excel worksheet (HCFC PRODUCTION SECTOR PLANT.xls) accessible online at: https://www.ungm.org/Notices/Item.aspx?Id=14001

[38] "Summary of Information Publicly Available on Relative Elements of the Operation of Clean Development Mechanisms and the Amounts of HCFC-22 Production Available for Credits" by Executive Committee of the Multilateral Fund for the Implementation of the Montréal Protocol, Fifty-seventh Meeting, Montreal, 30 March – 3 April 2009. Available at: http://www.multilateralfund.org/sites/57th/Document%20Library2/1/5762.pdf

[39] "Updated Model Rolling Three-Year Phase-Out Plan: 2011-2013 (Decision 59/5), Table 7." Document 62/7 by Executive Committee of the Multilateral Fund for the Implementation of the Montréal Protocol, Sixty-second Meeting, Montreal, 29 November – 3 December 2010. Available at: http://www.multilateralfund.org/62/English%20Document/1/6207.pdf

TABLE 6: ESTIMATED BENEFITS OF HFC-23 BYPRODUCT EMISSION CONTROLS

Cumulative HFC-23 Byproduct Emission Reductions ($MMTCO_2eq$)				
	2016 to 2020	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
World Byproduct Controls	**1,800**	**4,600**	**7,700**	**12,900**

In April 2013, the Executive Committee of the MLF reached an agreement with China to phase out all HCFC production for consumption by 2030. China is by far the largest Article 5 producer of HCFC-22 and has 34 out of the 43 identified production lines. While the agreement will phase out the HCFC-22 production for consumption, this analysis already accounted for the HCFC-22 phaseout as well as the growth in HCFC-22 for feedstock use; thus, no adjustment is necessary.

5. SUMMARY

The Montreal Protocol has been an unparalleled environmental success story. It is the only international agreement to achieve universal ratification. It has completed an enormous task in the phaseout of CFCs and halons—chemicals that were pervasive in multiple industries. It established a schedule to phase out the remaining important ODS (namely, HCFCs) by 2040. Under the Montreal Protocol, Article 5 and non-Article 5 countries together have not only set the ozone layer on a path to recovery by mid-century but have reduced greenhouse gases by over 11 gigatons CO_2eq per year, providing an approximate 10-year delay in the onset of the effects of climate change.[40]

This legacy is now at risk. Although safe for the ozone layer, the continued emissions of HFCs—primarily as alternatives to ODS but also from the continued production of HCFC-22—will have an immediate and significant effect on the Earth's climate system. Without further controls, it is predicted that HFC emissions could negate the entire climate benefits achieved under the Montreal Protocol. HFCs are rapidly increasing in the atmosphere. HFC use is forecast to grow, mostly due to increased demand for refrigeration and air conditioning, particularly in Article 5 countries. There is a clear connection between the Montreal Protocol's CFC and HCFC phaseout and the increased use of HFCs. However, it is possible to maintain the climate benefits achieved by the Montreal Protocol by using climate-friendly alternatives and addressing HFC consumption.

Recognizing the concerns with continued HFC consumption and emissions, the actions taken to date to address them, the need for continued HFC use in the near future for certain applications, and the need for better alternatives, Canada, Mexico and the United States have proposed an amendment to phase down HFC consumption and to reduce byproduct emissions of HFC-23, the HFC with the highest GWP. The proposed Amendment would build on the success of the Montreal Protocol, rely on the strength of its institutions, and realize climate benefits in both the near and long-term. Table 7 displays the projected benefits from the Amendment.

[40] Velders, G. J. M., Andersen, S. O., Daniel, J. S., Fahey, D. W., and McFarland, M.: The importance of the Montreal Protocol in protecting climate, P. Natl. Acad. Sci. USA, 104, 4815-4819, 2007. Accessible at: http://www.pnas.org/content/104/12/4814.full.pdf+html

TABLE 7: ESTIMATED BENEFITS OF THE AMENDMENT PROPOSAL, AT VARIOUS INTERVALS

Cumulative HFC Reductions ($MMTCO_2eq$)				
	2016 to 2020	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
HFC Phasedown – Consumption Reductions				
World	**800 – 1,300**	**13,500 –17,700**	**41,600 – 53,600**	**80,900 -- 102,100**
Byproduct Controls – Emissions Reductions				
World	**1,800**	**4,600**	**7,700**	**12,900**
World Total	**2,600 – 3,100**	**18,100 – 22,300**	**49,300 – 61,300**	**93,800 – 115,000**

U.S. EPA also estimated the range of cumulative benefits over a 40-year time horizon to be consistent with the original time horizon of the 2010 amendment proposal. The results of the 40-year benefits horizon including benefits from byproduct controls are shown in Table 8.

TABLE 8: ESTIMATED BENEFITS OF THE HFC PHASEDOWN, 40- YEAR TIME HORIZON

Cumulative HFC Phasedown Consumption Reductions ($MMTCO_2eq$) – 40-Year Time Horizon	
Phasedown World Total	100,100 – 125,400
Byproduct Emissions Benefits	15,700
2014 HFC Amendment Proposal	**115,800 – 141,100**

Taken together, the suite of known alternative chemicals, new technologies, and better process and handling practices can significantly reduce HFC consumption and emissions in both the near and long term, while simultaneously completing the HCFC phaseout. Since the Amendment was first introduced, a number of actions by countries and multinational corporations have built momentum to address HFC use and emissions. Although there is much work to do to fully implement these alternatives, technologies and practices, the industries currently using HCFCs and HFCs have proven through the ODS phaseout that they can move quickly to protect the environment.