Benefits of Addressing HFCs under the Montreal Protocol

June 2013

Stratospheric Protection Division
Office of Atmospheric Programs
Office of Air and Radiation

United States Environmental Protection Agency

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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. Although safe for the ozone layer, the continued emissions of HFCs – primarily as alternatives to ODS and 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. 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) 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.

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

Cumulative HFC Reductions (MMTCO$_2$eq)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
HFC Phasedown – Consumption Reductions				
Non-Article 5 Parties	1,600	9,900	24,100	40,200
Article 5 Parties	-	4,900	19,400	43,200
World	**1,600**	**14,800**	**43,500**	**83,400**
Byproduct Controls – Emissions Reductions				
Non-Article 5 Parties	300	900	2,000	3,800
Article 5 Parties	700	2,100	4,200	7,500
World	**1,000**	**3,000**	**6,200**	**11,300**
World Total	**2,600**	**17,800**	**49,700**	**94,700**

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. HFCs are predominantly 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 2009 paper by Velders et al.,[1] a 2011 paper by Gschrey et al.,[2] and a 2011 report from the United Nations Environment Programme (UNEP),[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 problem today. However, HFC emissions are increasing rapidly. Left unabated, HFC emissions could rise to nearly 20% 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 recent 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 benefit 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] 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

[2] 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.

[3] 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

[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 90% of the average HCFC consumption and production in the years 2008-2010; HCFCs are used in recognition of the HFC data limitations in some countries.
    - For non-Article 5 countries, the baseline is determined from a combination of HFC consumption or production (as relevant) plus 85% of HCFC consumption or production respectively averaged over the years 2008–2010.
    - The amendment uses Global Warming Potential (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 94,700 million metric tonnes of carbon dioxide equivalent ($MMTCO_2eq$) through 2050 – of which 83,400 $MMTCO_2eq$ can be attributed to HFC Phasedown and 11,300 $MMTCO_2eq$ 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 whether their transitions out of HCFC sectors would include an interim step (i.e., HCFC to HFC to low-GWP), occur directly (HCFC to low-GWP), or continue to use fluorocarbons (HCFC to HFC) for the foreseeable future. The estimated cumulative HFC consumption reductions from the phasedown are 1,600 $MMTCO_2eq$ [6] through 2020, and 83,400 $MMTCO_2eq$ 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 1,000 $MMTCO_2eq$ through 2020, and 11,300 $MMTCO_2eq$ 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 all Parties uses data from the years 2008 through 2010. Since HCFC controls for Article 5 countries did not start until 2013, with a freeze in 2013 followed by a 10% reduction step in 2015, only historical HCFC consumption is used to set their baseline. The baseline for Article 5 countries is calculated as 90% of the average 2008–2010 HCFC consumption. The baseline for non-Article 5 countries is calculated as the average, for the years 2008–2010, of HFC consumption plus 85% of HCFC consumption. The formulas to calculate baselines are shown in Table 1.

TABLE 1: BASELINES

Party	**Method** (Average 2008–2010)
Non-Article 5 Parties	100% HFC Consumption + 85% HCFC Consumption
Article 5 Parties	90% HCFC Consumption

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.

[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 purposes 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 regions. 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 1:

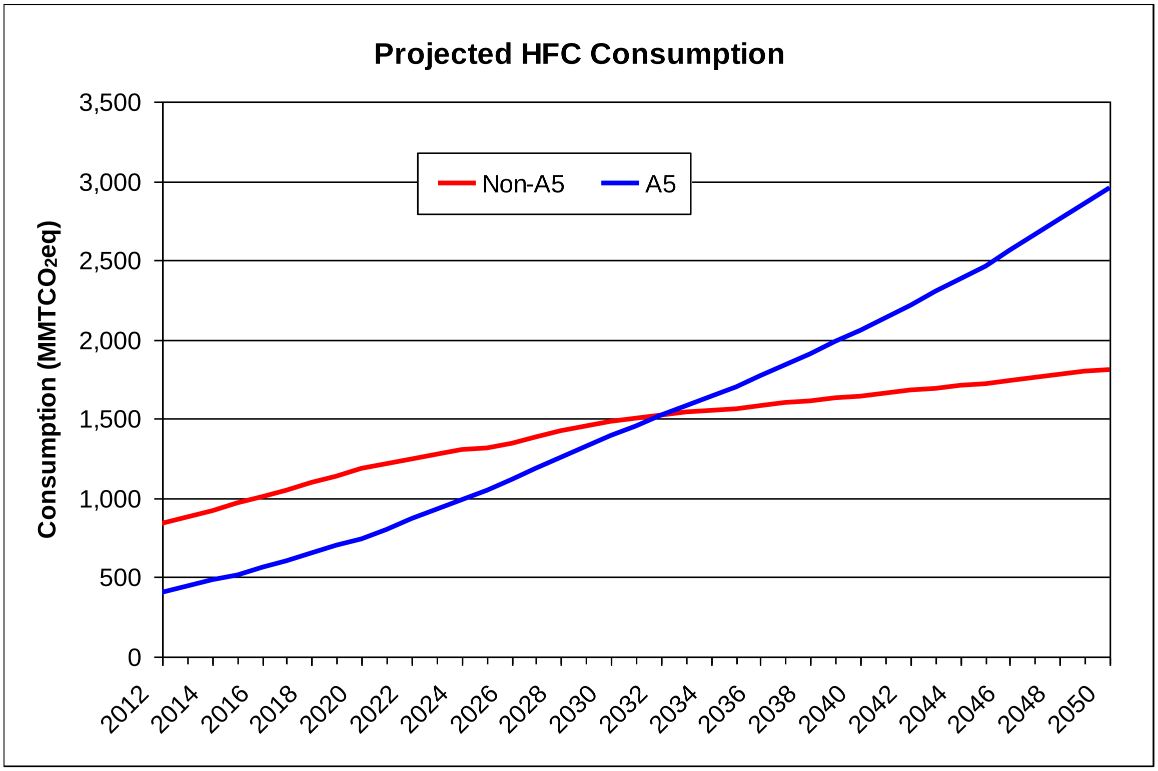
EQUATION 1: ESTIMATING HFC CONSUMPTION FROM ODS CONSUMPTION DATA

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

[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.

Projected consumption estimates for Article 5 and non-Article 5 are shown in Graph 1 below.

GRAPH 1. PROJECTED HFC CONSUMPTION 2012 THROUGH 2050



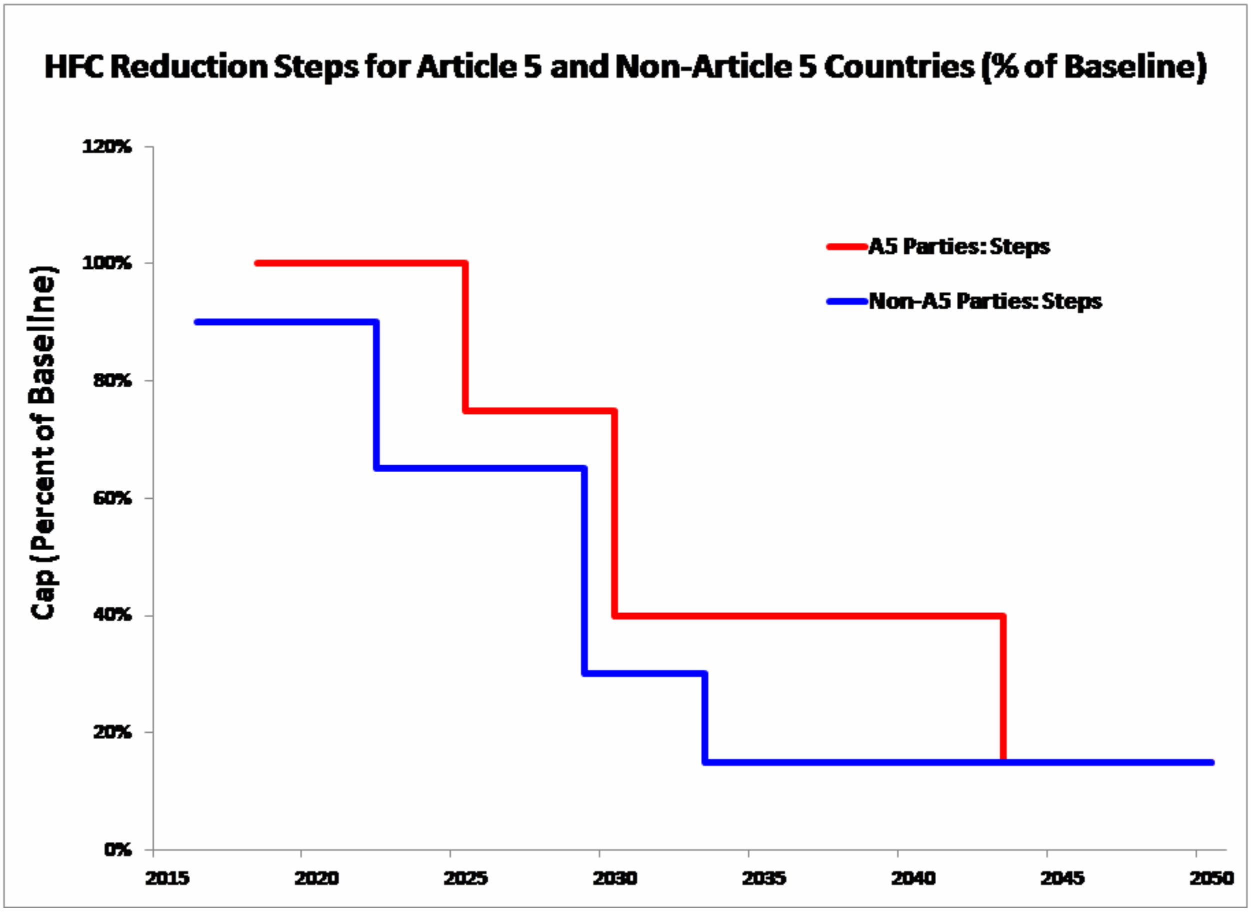
3.3. Reduction Scenario and Results

The reduction schedule used for this analysis appears in Table 2 and Graph 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).

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)
2016	90%	2018	100%
2022	65%	2025	75%
2029	30%	2030	40%
2033	15%	2043	15%

GRAPH 2. PROPOSED HFC REDUCTION SCHEDULES



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 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 ($MMTCO_2eq$)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
Non-Article 5 Parties	1,600	9,900	24,100	40,200
Article 5 Parties	-	4,900	19,400	43,200
World	**1,600**	**14,800**	**43,500**	**83,400**

3.4. New 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.

European Fluorinated Gas Regulation

The European Commission is working to strengthen existing controls on fluorinated gases, with particular focus on HFCs. Proposed requirements would 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 HFC-23 (a production byproduct). Existing regulation on labeling, reporting requirements, and training programs have also been expanded to cover HFCs.

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.

Arctic Council

The May 2013 Kiruna Declaration of the Arctic Council urged the Parties to the Montreal Protocol to "take action as soon as possible to phase-down the consumption and production of hydrofluorocarbons," because HFCs accelerate the melting and thawing of Arctic ice. The Council, a high-level intergovernmental forum, recognized that reducing short-lived climate pollutants such as HFCs can have positive impacts on both climate and human health, and is currently working on a project to responsibly dispose of HFC-containing appliances to reduce the emissions of HFCs in Arctic territories.

Rio +20

At the Rio+20 United Nations Conference on Sustainable Development (June 2012), countries agreed to support a gradual phasedown in the consumption and production of HFCs in the outcome document "The Future We Want." The Montreal Protocol controls consumption and production of intentionally produced substances in the same sectors where HFCs are used, and can effectively mitigate these substances, thus operationalizing paragraph 222 of the Rio+20 outcome document.

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 already 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 is producing case studies to share information about successful transitions to climate-friendly alternatives in areas such as commercial refrigeration. Additional capacity building efforts have been planned.

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. 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.

3.5. Availability of Alternatives for Meeting the Reduction Schedule

When the North American amendment was first proposed in 2010, the availability of alternatives (in this case 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 are known and 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.

As part of the U.S. ozone layer protection program, the U.S. EPA established the regulatory Significant New Alternatives Policy (SNAP) program in 1994. The 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.

SNAP continues to identify substitutes – for ODS as well as HFCs – that offer lower overall risks to human health and the environment. The risk factors considered include:

- 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 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.

Information on existing and potential options to reduce HFCs can be found in Tables 4 through 6. For some subsectors additional information also is available on U.S. EPA's website, as discussed below.

Finally, over the last twelve months, two 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.

TABLE 4. HFC SUBSTITUTES BY SECTOR: AEROSOLS, FOAMS, FIRE SUPPRESSION & SOLVENTS

End-Use		Substitute or Mitigation Strategy	Change in CO_2e Where Adopted*	Years Until Available**
Aerosols	Non-Medical	Replace HFC-134a with HFC-152a	91%	Available Now
		Hydrocarbons	~100%	Available Now
		Not-in-Kind (pumps, roll-ons, etc.)	100%	Available Now
		HFO-1234ze(E)	95.2 to 99.6%	Available Now
	Medical	Dry Powder Inhalers	100%	Available Now
		Injections / Tablets	100%	10+
Fire Suppression	Total Flooding	Inert Gases	100%	Available Now
		Water Mist	100%	Available Now
		Fluorinated Ketone	99.97%	Available Now
	All	Other Low-GWP Substances	~90 to 100%	Available Now to <10
Foam Blowing	Various	Hydrocarbons	~100%	Available Now
	XPS	CO_2, HFO-1234ze(E), HFO-1336mzz(Z), -1233zd(E)	99.3 to 99.9%	<5
	Spray	H_2O, CO_2	99.9 to 100%	<5
	Appliance, Sandwich Panels, Spray	Methyl Formate, HFO-1234ze(E), -1233zd(E)	99.3 to 100%	Available Now
		HFO-1336mzz(Z)	99.0%	<5
	Appliance Foam	Capture / Destruction at End-of-Life (EOL)	~90%	Available Now
	Construction Foam	Capture / Destruction at EOL	~90%	10+
Solvents	Electronics & Precision Cleaning	Aqueous & Semi-Aqueous	100%	Available Now
		Hydrofluoroethers (HFEs)	65 to 96%	Available Now
		-1233zd(E)	99.6%	Available now

* Indicates the reduction achieved where applied. For example, replacing HFC-134a with HFC-152a yields a 91% reduction in consumption (in CO_2-equivalent terms). However, the substitute or mitigation strategy may not be applicable across the entire end-use.

** Key to time-frames

Available Now: option applied in significant amounts; regional and product type variations may exist
<5 Years: option in the early deployment stage and/or SNAP acceptability determination made or proposed
<10 Years: option known to be under development and/or logical extension of other known options
10+ Years: option not known to be under development; more research and testing required

Table 5. HFC Substitutes by Sector: Air Conditioning

End-Use	Substitute or Mitigation Strategy	Change in CO_2e Where Adopted	Years Until Available
All End Uses	Refrigerant Management: Recovery, Reclamation and Destruction	10 to 100%*	Available Now
	Leak Repair	10 to 100%*	Available Now
Auto A/C	Enhanced HFC-134a Systems	50%	Available Now
	HFO-1234yf	99.7%	Available Now
	CO_2, HFC-152a	91.3 to 99.9%	<5
Bus, Train A/C	HFO-1234yf, CO_2	99.7 to 99.9%	<5
Residential & Commercial A/C	Microchannel Heat Exchangers	35 to 50%	Available Now
	HFC-32, Low-GWP Blends	50 to 90%	<5
Room A/C	Hydrocarbons, CO_2, HFO-1234yf	99.8 to ~100%	Available Now to <5
Dehumidifiers	Hydrocarbons, CO_2, HFO-1234yf	99.8 to ~100%	Available Now to <5
Chillers	Ammonia	100%	Available Now
	HFC-32, Low-GWP Blends	~50%	<10
	HFO-1234ze(E), -1233zd(E)	99.5 to 99.6%	<5

* Wide range indicates the wide range of practices across different end-uses and institutional behaviors.

Table 6. HFC Substitutes by Sector: Refrigeration

End-Use	Substitute or Mitigation Strategy	Change in CO_2e Where Adopted	Years Until Available
All End Uses	Refrigerant Management: Recovery, Reclamation and Destruction	10 to 100%*	Available Now
	Leak Repair	10 to 100%*	Available Now
Supermarkets	Low Charge / Low Leak Technologies (e.g., Cascade or Secondary Systems)	90 to 100%	Available Now
	Low-GWP Blends	50 to 90%	Available Now to <10
Chillers	Ammonia	100%	Available Now
	HFC-32, Low-GWP Blends	~50%	<10
	HFO-1234ze(E), -1233zd(E)	99.5 to 99.6%	<5
Home Refrigerators/ Freezers	Hydrocarbons	~100%	Available Now
Stand-Alone Commercial Refrigerators/ Freezers	Hydrocarbons, CO_2	99.9 to ~100%	Available Now
Beverage Coolers	Hydrocarbons, CO_2	99.9 to ~100%	Available Now
Ice Makers	Hydrocarbons, CO_2	99.9 to ~100%	<5
Vending Machines	CO_2, Hydrocarbons	99.9 to ~100%	Available Now to <5
Transport Refrigeration	Hydrocarbons, Ammonia, Low-GWP Blends, CO_2	50 to 100%	<5 to <10
Cold Storage	Ammonia, CO_2	100%	Available Now

* Wide range indicates the wide range of practices across different end-uses and institutional behaviors.

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).

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, some automobile manufacturers, including General Motors, have already begun to introduce HFO-1234yf air conditioning systems in Europe and the United States.

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 are currently available on U.S. EPA's website at: www.epa.gov/ozone/intpol/mpagreement.html:

- Commercial Refrigeration;
- Domestic Refrigeration;
- Motor Vehicle Air Conditioning;
- Unitary Air-Conditioning;
- Transport Refrigeration;
- Construction Foam; and
- Non-Medical Aerosols.

Figures 1 through 5 illustrate some of the transition pathways that have occurred and are emerging as CFCs and HCFCs are being phased out and a combination of HFCs and low-GWP alternatives are being used. In some cases, such as motor vehicle air conditioning (MVAC) (Figure 1), industry moved to one option (HFC-134a), but is now in a position to introduce various low-GWP alternatives, one of which, R-1234yf, is already in use in some models. In other cases, such as domestic refrigeration and unitary air conditioning (Figures 2 through 4), some companies moved directly from ODS to low-GWP options while others first moved to HFCs and are now considering the low-GWP options.

FIGURE 1. REFRIGERANT TRANSITION IN THE MVAC END-USE (PASSENGER VEHICLES AND LIGHT TRUCKS)

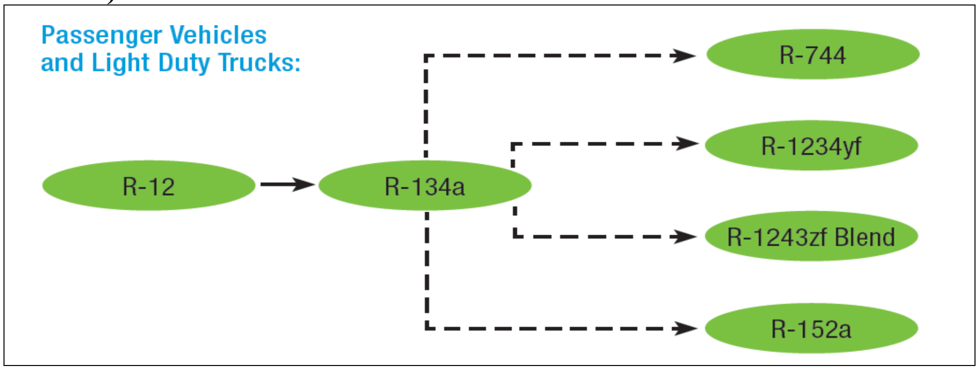


FIGURE 2. REFRIGERANT TRANSITION IN THE DOMESTIC REFRIGERATION END-USE

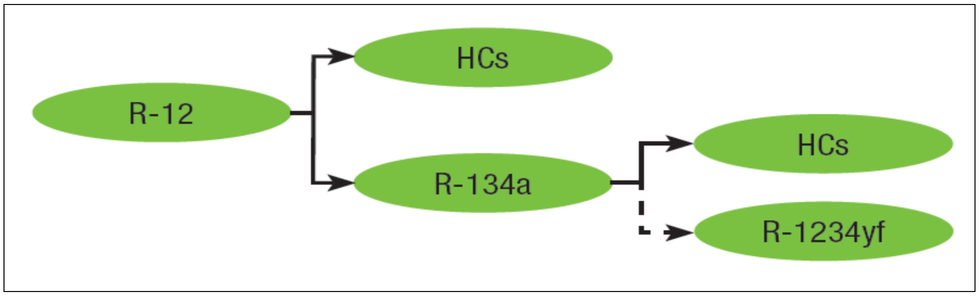


FIGURE 3. BLOWING AGENT TRANSITION IN THE DOMESTIC REFRIGERATION END-USE

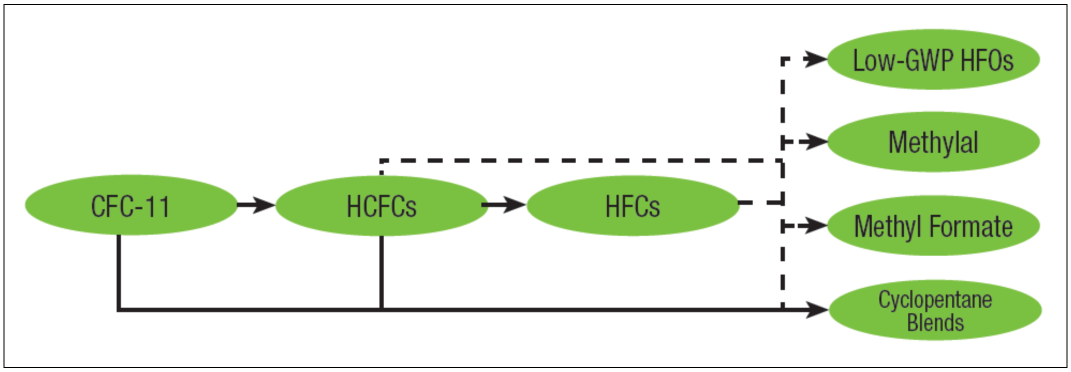


FIGURE 4. REFRIGERANT TRANSITION IN THE UNITARY AIR CONDITIONING END-USE

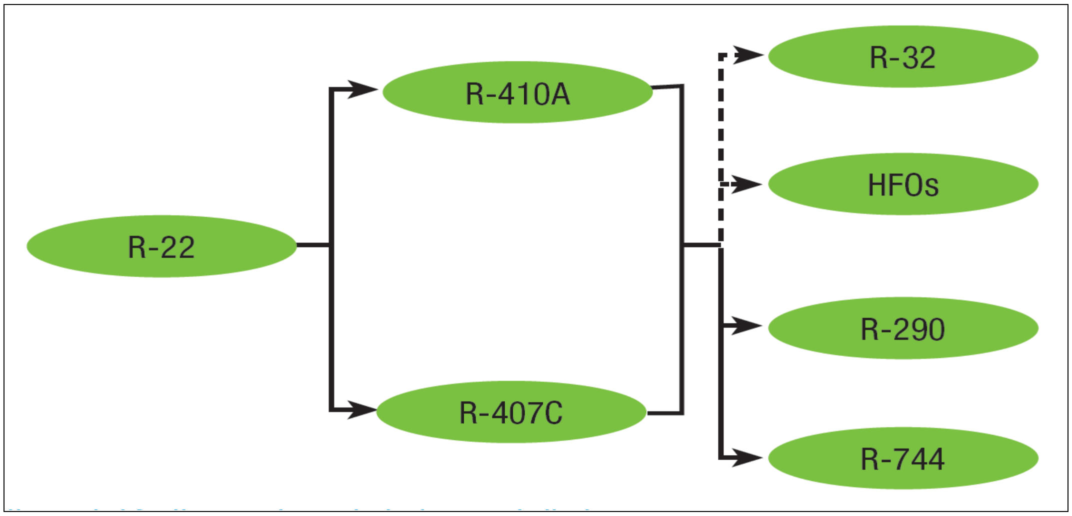
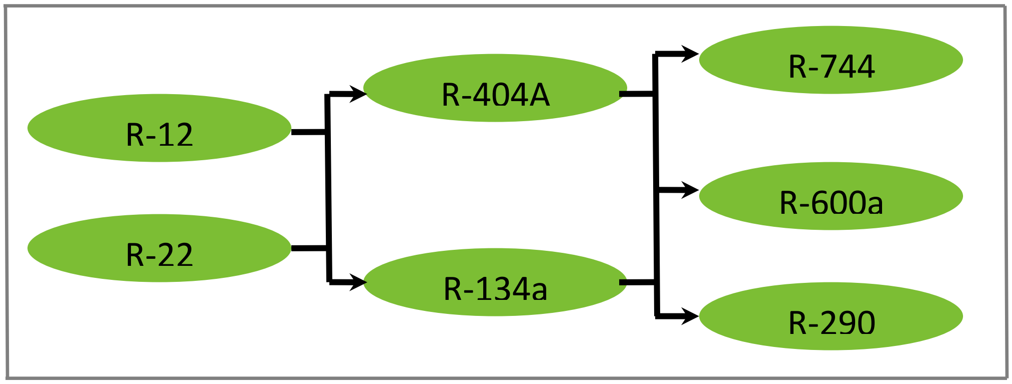


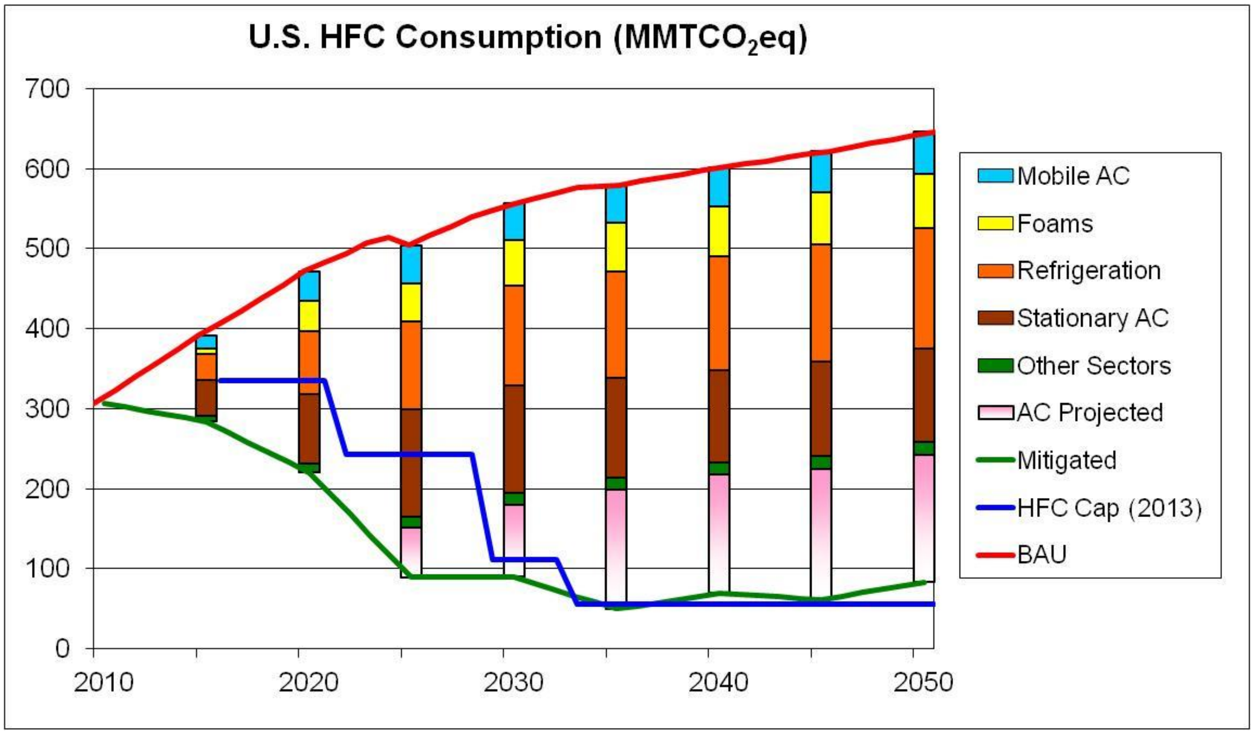
FIGURE 5. REFRIGERANT TRANSITION IN THE COMMERCIAL REFRIGERATION END-USE (STAND-ALONE EQUIPMENT)



These five and 14 other diagrams are available in the seven sector fact sheets listed above.

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 Tables 4 through 6 and in the transition pathways in Figures 1 through 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.[15,16]

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).[17] 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.[18] Australia has

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[15] Honeywell. 2013. Regulations. http://www.honeywell-blowingagents.com/regulation/#european-union
[16] Honeywell. 2011. Honeywell Solstice™ Liquid Blowing Agent. November 2011. http://www.honeywell-blowingagents.com/?document=solstice-liquid-blowing-agent-product-overview-europe&download=1
[17] 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
[18] 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.

evaluated the benefits of new technologies and provided assistance to update supermarket refrigeration equipment.

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.

Hydrocarbon Ice Cream Freezers: Unilever's Experience
In 2000, Unilever, an international food, refreshment, home and personal care products company that owns about 2 million ice cream freezers throughout the world, pledged that it would not buy ice cream freezers that were charged with HFC refrigerants after 2005 in countries where legal and commercially-viable alternatives were available.[19] After deciding that hydrocarbons were the most viable option, the company had 50 R-290 ice cream freezers manufactured for the 2000 Sydney Olympics. Testing of this equipment confirmed that the R-290 cabinets would be able to maintain the correct temperatures even under severe use conditions. It was also found that the cases used considerably less energy than comparable freezers using R-404A (an HFC blend). By mid-2008, there were 270,000 such units in use worldwide;[20] and by 2009, Unilever alone had placed over 400,000 HC ice-cream coolers around the world, including South Africa, China, Europe, Brazil and the United States.[21] Unilever has continued to expand in these markets with more than 900,000 HC freezers in use globally by 2012,[22] and has committed to purchasing a further 850,000 units by 2015.[23]

Carbon Dioxide Vending Machines: Sanyo'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

[19] Australian Institute of Refrigeration, Air Conditioning, and Heating (AIRAH). 2007. "Natural Refrigerant Case Studies." Available online at: http://www.environment.gov.au/atmosphere/ozone/publications/pubs/refrigerants-guide.pdf.
[20] Gerwen, Rene Van, Alan Gerrard, and Fabio Roberti. 2008. "Ice Cream Cabinets Using Hydrocarbon Refrigerant: From Technology Concept to Global Rollout." Prepared for the 8th IIR Gustav Lorentzen Conference on Natural Working Fluids. Available online at: http://www.unilever.com/images/Ice%20Cream%20Cabinets%20Using%20a%20Hydrocarbon%20Refrigerant%20-%20From%20Technology%20Concept%20to%20Global%20Rollout_tcm13-262015.pdf.
[21] 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.
[22] Unilever. 2012. Unilever and Ben & Jerry's Bring Climate-Friendly Freezer Cabinets to U.S. February 14, 2012. http://www.unileverusa.com/media-center/pressreleases/2012/UnileverandBenandJerrysBringClimateFriendlyFreezerCabinets.aspx
[23] Unilever. Undated. Climate-Friendly Refrigeration. http://www.unilever.com/sustainable-living/greenhousegases/climate-friendly-refrigeration/
[24] Sanyo Electric Co. 2008. "CO_2 Vending Machines." Technical Meeting on HCFC Phase-Out.

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] Today, more than 700,000 of Sanyo's CO_2 compressor units are in use globally in vending machines, water fountains, glass door cases, supermarket show cases and heat pumps.[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 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]

Ammonia Supermarket: Supervalu's Experience

Supervalu opened an ammonia-based refrigeration system in their Albertsons store in Carpinteria, California in 2012, the first in the United States. The Carpinteria Albertsons store is a remodeled unit that doubled in size to 40,000 square feet. The store had used HCFC-22 in a conventional direct expansion (DX) refrigeration system, which was

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[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] R744.com. Growing interest in CO2 products - view from 2013 China Refrigeration - Part 2. April 17, 2013. Available online at: http://www.r744.com/news/view/4116

[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.

[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.

replaced with one that uses ammonia as the primary refrigerant with CO_2 for medium-temperature cases, and a combined cascade and DX system for low-temperature cases. A month after operating the new system, Supervalu was impressed with its performance.[34] The new system is expected to result in 30% reduction in annual energy consumption, equating to savings of $100,000 per year.[35]

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 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[36] 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

[34] Supermarket News June 2012 "Supervalu Pleased With Ammonia Refrigerant" Available online at: http://supermarketnews.com/technology/supervalu-pleased-ammonia-refrigerant
[35] U.S. Department of Energy. Undated. Albertsons Carpinteria Remodel & Expansion. http://www4.eere.energy.gov/challenge/showcase/supervalu/albertsons-carpinteria-remodel
[36] Montzka et al.: Recent increases in global HFC-23 emissions, Geophysical Research Letters, 37, L02808, doi:10.1029/2009GL041195, 2010.

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*,[37] 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. 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. Today, the HFC-23 credit market appears to be shrinking, since many countries are no longer willing to purchase these credits. 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 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. It is unclear how offset credits or emissions reduction credits from HFC-23 destruction may be accounted for in the future; therefore, in order to conservatively estimate benefits, this analysis assumes business as usual within CDM.

Approximately 43 HCFC-22 production lines were identified in Article 5 countries.[38] 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. Given that CDM only covers some facilities, 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 do not already have an approved project under the CDM to control emissions of HFC-23.

The timelines for crediting periods vary for each CDM project; they are either granted a one-time 10-year crediting period or a 7-year renewable crediting period for up to 21 total years. Below is a schematic of the time periods. Table 8 illustrates the timeline of the 18 CDM projects[39] and each project's renewal process, if any. The first crediting year of current CDM projects was 2004; the last crediting year will be 2029.

[37] *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

[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 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

[39] Note that two CDM projects in China apply to the same facility. Hence, these 18 projects represent 17 facilities.

TABLE 8: TIMELINE FOR CDM PROJECTS CREDITING PERIODS

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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.[40] 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. As CDM projects go offline, the benefits are included in the cumulative total. Benefits from production lines not covered under CDM, 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[41] 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$_2$eq. Results are shown in Table 9 below.

TABLE 9: ESTIMATED BENEFITS OF HFC-23 BYPRODUCT EMISSION CONTROLS

Cumulative HFC-23 Byproduct Emission Reductions (MMTCO$_2$eq)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
Non-Article 5 Parties	300	900	2,000	3,800
Article 5 Parties	700	2,100	4,200	7,500
World Byproduct Controls	**1,000**	**3,000**	**6,200**	**11,300**

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.

The amendment proposed by Canada, Mexico and the United States includes provisions to reduce emissions of HFC-23 from HCFC-22 production; however, the obligations do not apply to emissions from production lines that have an approved project under CDM to control HFC-23

[40] "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

[41] "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

emissions so long as those emissions are covered by and continue to generate emissions reduction credits under a CDM project. If a facility does not have a CDM project because either it is not eligible or the project has expired, then the obligations would apply and funding from the MLF could be available.

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.[42]

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 10 displays the projected benefits from the Amendment.

[42] 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 10: ESTIMATED BENEFITS OF THE AMENDMENT PROPOSAL, AT VARIOUS INTERVALS

Cumulative HFC Reductions ($MMTCO_2eq$)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
HFC Phasedown – Consumption Reductions				
Non-Article 5 Parties	1,600	9,900	24,100	40,200
Article 5 Parties	0	4,900	19,400	43,200
World	**1,600**	**14,800**	**43,500**	**83,400**
Byproduct Controls – Emissions Reductions				
Non-Article 5 Parties	300	900	2,000	3,800
Article 5 Parties	700	2,100	4,200	7,500
World	**1,000**	**3,000**	**6,200**	**11,300**
World Total	**2,600**	**17,800**	**49,700**	**94,700**

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.