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Item 6 of the agenda for the preparatory segment

High-global-warming-potential alternatives to ozone-depleting substances (decision XX/8)

Analysis of HFC production and consumption controls

Note by the Secretariat

1. The annex to the present note contains an analysis of controls on the production and consumption of hydrochlorofluorocarbons submitted by the United States of America for the information of the Twenty-First Meeting of the Parties.

2. It is presented as submitted and has not been edited by the Secretariat.

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Annex

Analysis of HFC Production and Consumption Controls October 2009

This paper presents a preliminary analysis of potential benefits under a possible scenario for controlling consumption of hydrofluorocarbons (HFCs). HFCs are a subset of the fluorinated greenhouse gases which are intentionally-made compounds used in a number of applications. HFCs predominately are 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 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), and by the fact that these substances were developed and are being widely implemented as alternatives to ODS.

Available information suggests that in 1995, HFC emissions constituted approximately 1% of the existing basket of covered United Nations Framework Convention on Climate Change (UNFCCC) climate gases for the United States (weighted by Global Warming Potential (GWP)).[1] By 2007, HFC emissions had grown significantly to nearly 2% of the basket. If left unaddressed, consumption of HFCs is projected to roughly double by 2020 relative to today, which, assuming relatively constant levels of emissions of other greenhouse gases, could result in HFCs constituting 3-4% of the basket by 2020. Growth of HFCs is anticipated to continue well beyond 2020 if left unconstrained or weakly regulated. A recent study[2] projects that if left unchecked, HFC global emissions (in carbon dioxide (CO_2) equivalent terms) could rise to a significant fraction of CO_2-equivalent emissions by 2050 assuming business as usual for CO_2 emissions. U.S. Environmental Protection Agency's (U.S. EPA) analysis estimates somewhat lower levels of HFC growth as compared to the Velders model but nonetheless indicates substantial increases in HFC use and emissions.

An analysis of a proposed global control on HFCs is presented below. Similar to the Montreal Protocol controls on ODS, the analysis assumes a global phase-down in the consumption of HFCs. The results through 2050 under the two scenarios estimate cumulative HFC reductions of 76,000 to 83,000 million metric tons of CO_2 equivalent ($MMTCO_2eq$) [3] assuming annual global compliance.[4]

[1] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007* (EPA Report #430-R-09-004), April 2009, http://www.epa.gov/climatechange/emissions/usinventoryreport.html

[2] Velders et al., PNAS, 106, June 2009

[3] 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.

[4] The adoption of binding targets for HFCs (separately or in a basket of gases) under the UNFCCC could also accrue significant benefits relative to this baseline. The magnitude of such benefits would depend upon the nature of commitments, how individual countries choose to meet such commitments, and the range of countries (e.g. whether it includes obligations for developing countries) with substantive commitments in an agreement.

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Assumptions for Establishing the Baseline and Projected Consumption

Baseline
U.S. EPA conducted a preliminary analysis of the potential benefits of a global phase-down of HFCs. Because HFCs may replace hydrochlorofluorocarbons (HCFCs) in many applications, the baseline is set using historic information while accounting for this future transition. Therefore, a combination of HCFC plus HFC consumption data for the years 2004 through 2006 was used as the baseline, for all Parties. In addition to estimating 2004-2006 HCFC and HFC consumption, U.S. EPA estimated HFC consumption through 2050 to determine the benefits of the proposed phasedown. Such estimates are prepared regionally and aggregated below to reflect Article 5 (A5), non-A5, and world totals.

Projected Consumption in the United States: HCFCs and HFCs
For estimates of U.S. consumption, U.S. EPA used its bottom-up Vintaging Model,[5] which tracks and projects future use and emissions of chemicals (including HFCs) in products that previously relied on ODS, for the United States. Although each type of product is modeled separately at its respective growth rates as determined through past information, U.S. EPA chose to project 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% (Scenario 1), which equals the approximate population growth rate expected in the United States at that time. To perform a sensitivity analysis, U.S. EPA also used an annual growth rate of 1.8% (Scenario 2), and again applied this growth rate to all product types after 2030.

Projected Consumption in Other Countries: HCFCs
HCFC consumption data as reported under Article 7 of the Montreal Protocol is used to determine total GWP-weighted HCFC consumption. Because reports from United Nations Environment Programme (UNEP) are in Ozone Depletion Potential (ODP)-Tons, assumptions regarding the mix of HCFCs constituting such ODP-Ton consumption are made for Article 5 countries based on UNEP (2007)[6] and for non-A5 countries based on U.S. consumption. Once this breakdown (e.g., HCFC-22, HCFC-141b, HCFC-142b, etc.) is estimated, GWPs from the Intergovernmental Panel on Climate Change's Fourth Assessment Report (IPCC AR4) are used to develop total HCFC consumption in terms of $MMTCO_2eq$.

Projected Consumption in Other Countries: HFCs
HFC consumption was estimated on a country-by-country basis and then aggregated to A5 and non-A5 regions. To develop the global HFC consumption baseline through 2050, the 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)[7] and *Global Mitigation of Non-CO_2 Greenhouse Gases* (U.S. EPA Report #430-R-06-005).[8] This process, as outlined in those reports, generally follows these steps:

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5 Vintaging Model, 10/7/2008.

6 UNEP (2007) "Status/Prospects of Article 5 Countries in Achieving Compliance with the Initial and Intermediate Control Measures of the Montreal Protocol." UNEP/OzL.Pro/ExCom/52/7/Rev.1 9 July 2007.

7 http://www.epa.gov/climatechange/economics/international.html#global_anthropogenic

8 http://www.epa.gov/climatechange/economics/international.html#global_mitigation

1. Gather ozone-depleting substance (i.e., CFC, HCFC, Halon, 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.[9]
2. Split ODS consumption by ODS type into end-use sectors (i.e., refrigeration/air conditioning, aerosols, foams, solvents, and sterilization).
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 EPA's Vintaging Model as described above.
4. Project HFC consumption by the region's Gross Domestic Product (GDP) growth relative to the United States. Historical and projected GDP by region were obtained from EIA (2008).[10]
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 Countries with Economies in Transition (CEITs) and Article 5 countries.
   d. Account for regional transitions in the foams and fire protection sectors by applying data from regional Vintaging Model runs that modeled both the fire protection industry[11] and the foams industry.[12]
6. Multiply the consumption (i.e., metric tons) 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 business-as-usual scenario, the mix of HFCs, and hence the average GWP, is not expected to change significantly thereafter. For instance, it is beyond the upcoming critical U.S. and Montreal Protocol HCFC phaseout step in 2010.

The procedure outlined above is summarized in Equation 1:

Equation 1: Estimating HFC consumption from ODS consumption data

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

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

[10] 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

[11] 2001 Hughes Associates - International Market Share Data

[12] Data provided by Paul Ashford in personal communications with ICF in 2004.

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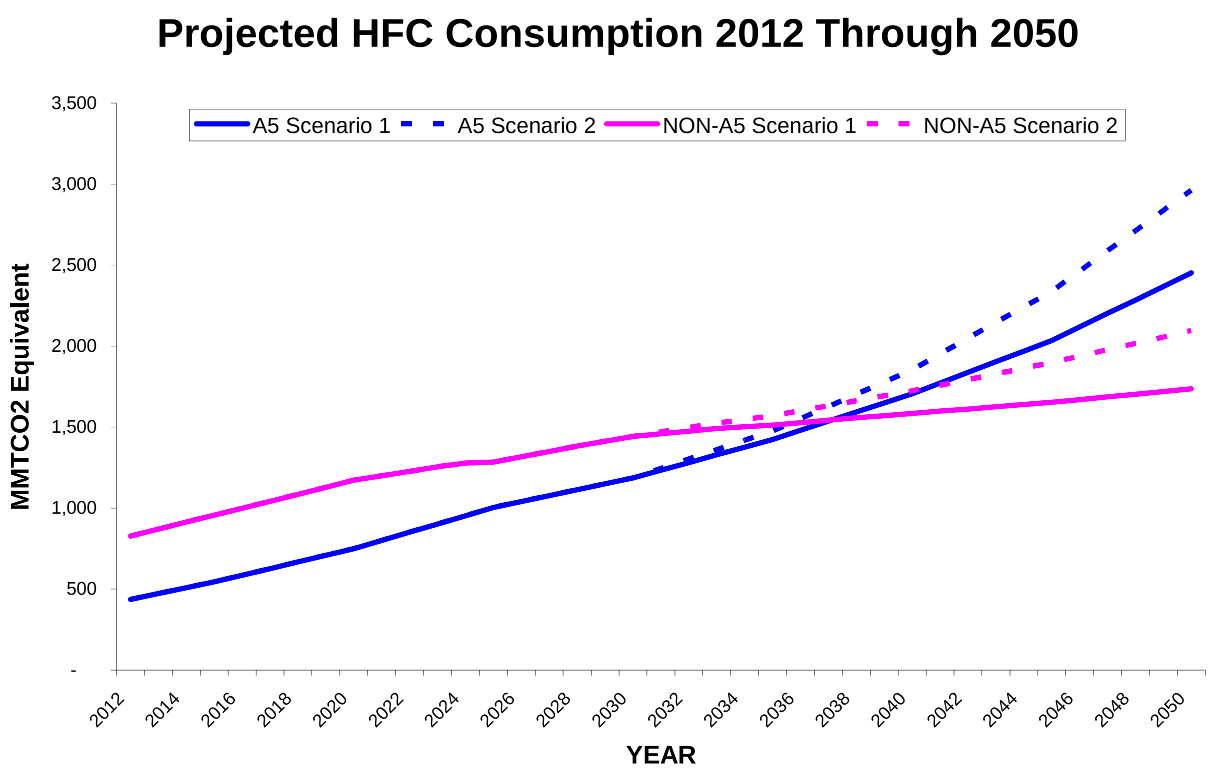
The projected consumption estimates for all regions are shown in Graph 1 below.

Graph 1. Projected HFC Consumption 2012 Through 2050



Reduction Scenario and Results

The reduction schedule used for this analysis appears in Table 1 and Graph 2 below. Targets were set by considering the need to achieve real and significant reductions, the likely availability of alternatives, and other obligations under the Montreal Protocol (e.g., HCFC phaseout). Applying the reduction schedule to the baselines developed as described above and shown in Table 2 yields HFC consumption reductions as shown in Table 3.

Table 1: Proposed HFC Reduction Schedules

HFC Consumption Reduction Schedule			
(Non-Article 5 Parties)		(Article 5 Parties)	
Year	**Cap (% of Baseline)**	**Year**	**Cap (% of Baseline)**
2013	90%	2016	90%
2017	80%	2020	80%
2020	70%	2023	70%
2025	50%	2031	50%
2029	30%	2035	30%
2033	15%	2043	15%

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Graph 2. Proposed HFC Reduction Schedule

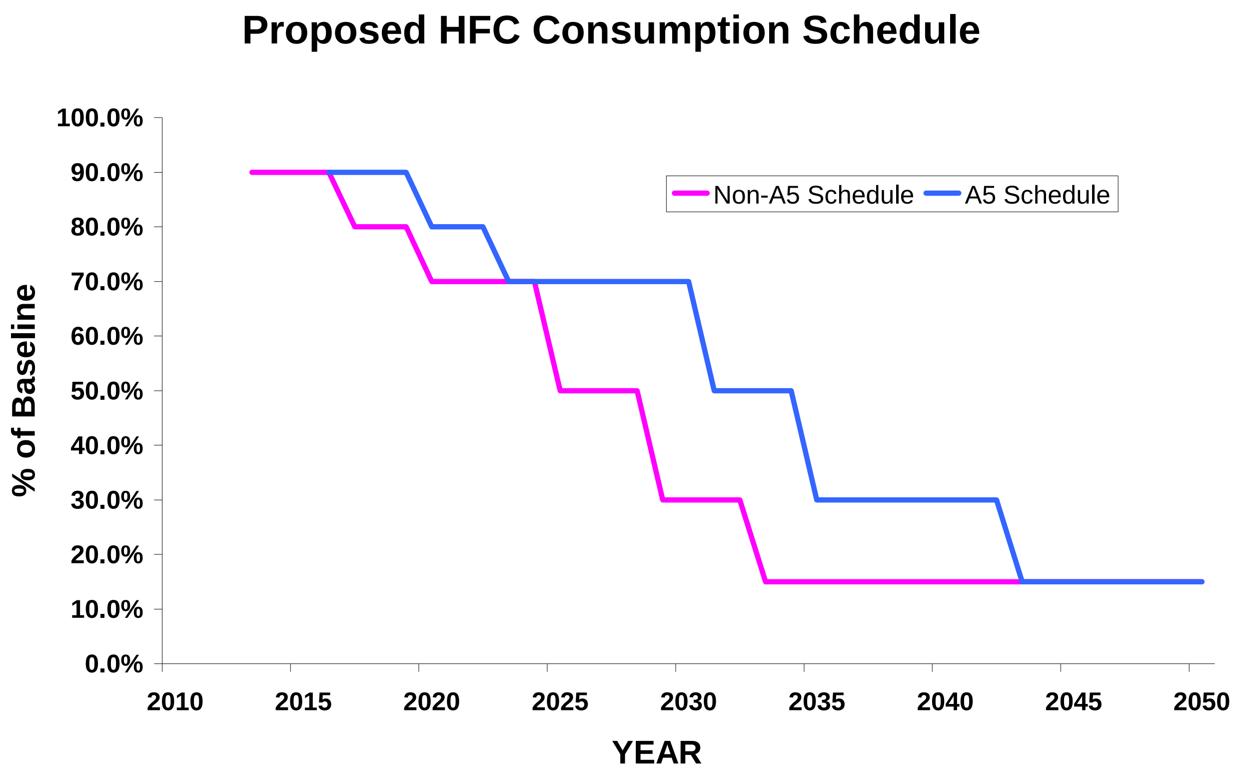

Table 2: Estimated Baselines

Estimated Baselines Average HFC+HCFC Consumption, 2004-2006	
Party	**Baseline (MMTCO$_2$eq)**
Non-Article 5 Parties	883
Article 5 Parties	731
World	**1,614**

Table 3: Estimated Cumulative Reduction of HFC Consumption, 2013-2050

Cumulative HFC Consumption Reductions, 2013-2050 (MMTCO$_2$eq)		
Party	**Scenario 1**	**Scenario 2**
Non-Article 5 Parties	39,600	42,900
Article 5 Parties	36,500	40,500
World	**76,100**	**83,400**

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Availability of Alternatives for Meeting the Reduction Schedule

As part of the United States ozone layer protection programs, the U.S. EPA established the Significant New Alternatives Policy (SNAP) program in 1994. The SNAP program ensures a smooth and timely transition from ODS to a variety of alternatives across major industrial, commercial, and military sectors. Although legally binding only in the United States, the SNAP Program's findings are applicable elsewhere and can be used by other Parties in their own review of alternatives. Through implementation of this program, U.S. EPA has information concerning current and potential substitutes for hydrofluorocarbons (HFCs), as the industry has looked at the SNAP program to provide a review of such substitutes.

U.S. EPA has analyzed certain sector-specific, technically- and economically-viable mitigation options for HFCs. The most promising options to reduce HFC consumption include:

- Substituting HFCs with low- or no-GWP substances in a variety of applications (where safety and performance requirements can be met);
- Implementing new technologies that use significantly lower amounts of HFCs; and,
- Various process and handling options 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. It is clear that many options exist across all major sectors to reduce, or even eliminate, the use of HFCs. While low-GWP alternatives already exist for many end-use applications, additional research may be required to find such alternatives for some important ones, such as residential and light-commercial air conditioning (i.e., unitary air conditioners, mini- and multi-splits). In many ways, the current availability of substitutes (in this case for HFCs) is similar to the availability of CFC substitutes at the 1987 signing of the Montreal Protocol, and similar to when the Parties agreed to phase out HCFCs – in all cases some alternatives were known but not for all applications.

SNAP continues to identify substitutes – for ODS as well as HFCs – that offer lower overall risks to human health and the environment. The environmental 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 approximately 400 substitutes in the refrigeration and air conditioning; fire suppression; foam blowing; solvent cleaning; aerosols; adhesives, coatings, and inks; sterilants; and tobacco expansion sectors. Most substitutes have been found acceptable although in some cases restrictions are applied to protect the environment and human health. Across all sectors, roughly one-third of the substitutes reviewed contain HFCs. For the refrigeration and air conditioning sector, HFCs now dominate. However, the SNAP program is currently considering a number of upcoming rulemakings and projects that should provide additional low- or no-GWP options.

A detailed analysis of *how* the United States or any country might meet the proposed reduction schedule has not been performed. However, taken together, the suite of known alternative chemicals, new technologies, and better process and handling practices can significantly reduce HFC consumption in both the near and long term. Although there is much work to do to fully implement these chemicals, technologies and practices, and some unknowns still remain, the industries currently using HFCs have proven through the ODS phaseout that they can move quickly to protect the environment.

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	95.2 to 99.6%	<5
	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%	10+
Foam Blowing	Various	Hydrocarbons	100%	Available Now
	XPS	CO_2	100%	<5
	Spray	H_2O	100%	<5
	Appliance, XPS, Spray	HFO-1234ze	99.4 to 99.6%	<5
	Appliance Foam	Capture / Destruction at End-of-Life (EOL)	~90%	Available Now
	Various	Capture / Destruction at EOL	~90%	10+
Solvents	Electronics & Precision Cleaning	Aqueous & Semi-Aqueous	100%	Available Now
		HFEs	82 to 96%	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.

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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	Recovery/ Reclamation/ 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, CO_2, HFC-152a	91.3 to 99.9%	<5
Bus, Train A/C	HFO-1234yf, CO_2	99.7 to 99.9%	<10
Residential & Commercial A/C, Chillers	Microchannel Heat Exchangers	35-50%	Available Now
	Low GWP Blends	50-90%	10+
Window A/C units	Hydrocarbons, CO_2, HFO-1234yf	99.7-100%	<10
Dehumidifiers			

* 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	Recovery/ Reclamation/ 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%	10+
Chillers, Cold Storage	Ammonia	100%	Available Now
	Low GWP Blends	50 to 90%	10+
Home Refrigerators/ Freezers	Hydrocarbons, CO_2, HFOs	99.7 to 100%	Available Now
Stand-Alone Commercial Refrigerators/ Freezers			<5
Beverage Coolers			<10
Vending Machines			<5
Ice Makers			<10
Transport Refrigeration	Hydrocarbons, Ammonia, Low GWP Blends	50 to 100%	10+

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