CANSA Thematic Paper

Phasing-out Hydrofluorocarbons in South Asia: Issues and way ahead

October, 2013

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Annexure

1. Introduction

Hydrofluorocarbons (HFCs) is a halogenated gas and a replacement for ozone-depleting substances (ODS) like chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Most ODS' are also potent greenhouse gases (GHGs) and this includes CFCs and HCFCs which are currently being phased out under the Montreal Protocol. HFCs, on the other hand, have zero ozone-depleting potential (ODP) but high global warming potential (GWP). HFCs have much lower GWP than CFCs but comparable GWP to that of HCFCs. For instance, the GWP of most commonly used CFCs -- CFC-12 -- is 10600; most commonly used HCFCs – HCFC-22 -- is 1700 and most commonly used HFCs -- HFC-134a -- is 1300.

HFCs are also regarded by some as short-lived climate forcers (SLCF)[1]. But a substantial fraction of HFCs have a lifetime of 29 years or less and some like HFC-23 has a lifetime of 270 years. In other words, though HFCs have shorter lifetime than CO_2, they have much greater lifetime than SLCF like black carbon (3-8 days), tropospheric ozone (4-18 days) and methane (12 years).

The current contribution to climate forcing of HFCs is about 0.012 W/m^2 (excluding HFC-23 which is a by-product of HCFC-22 production process and has very high GWP). This is less than 1.0% of the total forcing from all other GHGs combine. The total HFCs emissions in 2008 were 0.39 ± 0.03 gigatonnes of CO_2 equivalent (Gt CO_2e). In comparison, the emissions in 2008 of CFCs was 1.1 ± 0.3 Gt CO_2e, HCFCs was 0.74 ± 0.05 Gt CO_2e, N_2O was 3.0 Gt CO_2e and methane was 9.0 Gt CO_2e.[2]

With CFC phase-out completed in 2010 and the scheduled phase-out of most HCFCs by 2030, HFCs are being used more in applications that traditionally used HCFCs -- refrigeration and air-conditioning equipment, blowing agents for foams, aerosol sprays, fire protection systems and solvents. HFCs consumption and emissions are, therefore, rapidly increasing. Between 2004-2008, CO_2 equivalent emissions of HFCs (excluding HFC-23) increased by approximately 8% annually, mostly in the developed countries. As a consequence, the atmospheric abundances of major HFCs have also increased. For example, the atmospheric concentration of HFC-134a, the most abundant HFCs, has increased by 10% per year from 2006 to 2010.[3]

The Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol projects that under a business-as-usual scenario, the emissions of HFCs will increase from 0.21 Gt CO_2e in 2002 to about 0.8 Gt CO_2e by 2020 – a growth rate of about 8% annually. About 80% HFC emissions in 2020 will happen in the developed countries.[4] In long-term, however, it is projected that HFC emissions in the developing countries with outstrip developed countries by a long-margin. But there are huge inconsistencies in the long-term estimates on HFC emissions and the respective

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[1] Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers - A UNEP Synthesis Report

[2] Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project. Report No. 52, World Meteorological Organization, Geneva, Switzerland.

[3] HFCs: A Critical Link in Protecting Climate and the Ozone Layer. United Nations Environment Programme (UNEP), 2011

[4] Task Force Decision XX/8 Report. Assessment of alternatives to HCFCs and HFCs and update of the TEAP 2005 supplement report data. May 2009. UNEP, Nairobi.

contributions of developing (Annex 5 countries under the Montreal Protocol) and developed countries (Non-Annex 5 countries under the Montreal Protocol) to the emissions.

- Velders et al. (2009) projects HFCs emissions in the range of 5.5–8.8 Gt CO_2e per year by 2050.[5] The consumption of HFCs in developing countries becomes larger than that in the developed countries before 2020 and exceeds that in developed countries by up to 800% by 2050.
- Gschrey et al. (2011) estimate much lower HFC emissions of 3.5 Gt CO_2e per year by 2050.[6] In Business-as-usual scenario, developing countries will account for 75% of total fluorinated GHGs in 2050.
- TEAP in its 2009 report states: "With a significant market penetration of low GWP technologies, and good containment practices, it might well be that HFC emissions could stabilise in Article 5 countries in the 2020-2030 decade. This would be contrary to the growth sometimes considered as unavoidable for HFC emissions in Article 5 countries for the decades after 2020 (up to 2030-2040). It may be expected that this could result in a further decrease of total emissions (the sum of CFC, HCFC and HFC emissions) after 2020".

With inconsistencies in estimates withstanding, what is clear is that HFCs emissions is projected to increase under business-as-usual scenario because of the phase-out of HCFCs under the Montreal Protocol. This emissions need to be reduced to keep the world under the $2^{O}C$ target. But a major dispute has emerged between the developed and developing countries on where HFCs reduction should be discussed.

Developing countries want HFCs to be discussed under the United Nations Framework Convention on Climate Change (UNFCCC). As per the Article 4.1 of UNFCCC, all GHGs other than those under the Montreal Protocol should be addressed by UNFCCC. And, HFCs form part of the basket of gases whose emissions are regulated under UNFCCC.

Developed countries, on the other hand, want to address HFCs under the Montreal Protocol. Article 2.1 of the Vienna Convention for the Protection of the Ozone Layer states that countries are obliged to take action to prevent any adverse impact of the activities taken to protect the ozone layer. As HFCs use has increased due to CFCs and HCFCs phase-out pushed by the Montreal Protocol, using Article 2.1 of the Vienna Convention, in 2009, the US and Micronesia submitted proposals to amend the Montreal Protocol to phase down HFCs. Developed countries also argue that the Montreal Protocol has the institutional capacity and the Multilateral Fund to pay for transition in developing countries. They also cite the track record of action under Montreal as evidence of a global agreement that can deliver fast results.

What also goes against UNFCCC is that it is not designed for a phase down or phase out of specific gases. But the counter argument is that HFCs are not the only

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[5] Velders, G.J.M., Fahey, D.W., Daniel, J.S., McFarland, M., Andersen, S.O. (2009) The large contribution of projected HFC emissions to future climate forcing. Proc. Nat. Acad. Sci. 106, 10949-10954.

[6] Gschrey, B., Schwarz, W., Elsner, C., Engelhardt, R., (2011) High increase of global F-gas emissions until 2050. Greenhouse Gas Measurement & Management 1, 85–92.

fluorinated gas in the UNFCCC basket that needs to be phased out. Other F-gases, who are also replacement of ODS', are likely to increase rapidly in the future as well.

Then there are many unanswered questions regarding the HFCs phase-out under the Montreal Protocol. What is the best technology for developing countries to move to? Who will pay for the transition if the costs are high? The Montreal Protocol is low on funds even to phase out HCFCs. And, lately developed countries have started to talk about changing the Annexes of the Montreal Protocol to including emerging economies, especially BASIC countries, in to non-Annex 5 category. There is also demand for voluntary contribution by emerging economies to the Multilateral Fund of the Montreal Protocol.

Then there is the politics of gases and patents. Different developed countries are pushing patented low-GWP products as a substitute for high-GWP HFCs. US companies are pushing for hydrofluoroolefins (HFOs), which are a group of compounds that contain hydrogen, fluorine and carbon similar to HFCs, only they are derivatives of alkenes (olefins) and not alkanes. DuPont is promoting HFOs as the "fourth generation" refrigerant following in the footsteps of CFCs, HCFCs and HFCs. Japanese companies are pushing for HFC-32, a medium-GWP HFC, as most energy efficient drop-in substitute for HCFC-22.

But there are also non-patented gases and substitutes that are fast emerging in most sectors:

- In domestic refrigerators and freezers, use of hydrocarbons (iso-butane or blends of iso-butane and propane) is rapidly increasing. Globally, close to 50% of all new productions use hydrocarbons. In India, close to 10 million HC- 600a refrigerators have been sold in the market so far.
- In domestic air conditioners, propane and CO_2 are slowly catching-up. In both India and China, companies have started commercial production of propane based air conditioners which are much more energy efficient than HCFC or HFC based air conditioners.
- In Polyurethane foams sector, HCFCs is being directly substituted with hydrocarbons in developing countries. China and Brazil, for instance, intend to use methyl formate and other hydrocarbons instead of high-GWP HFCs. India plans to switch to cyclopentane in its first stage of HCFC phase-out management plan for the foam sector.

The assertion that developing countries are going to move to HFCs to phase-out HCFCs is not true. In fact many developing countries do not want to continue with the chemical treadmill – CFCs to HCFCs to HFCs to some other alternative. They want one time transition – HCFCs to a low-GWP alternative.[7]

On a wider canvas, therefore, the issue for the developing countries is not whether HFCs should be phased-out or not. The issue is not whether it should be addressed under Montreal Protocol or the UNFCCC. The issue is what is the best way to phase-out HFCs that does not disrupt the economic development in the sectors that use

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[7] Bangladesh Country Statement at the 24th Meeting of the Parties to the Montreal Protocol –Statement of the Leader of the Delegation http://conf.montreal-protocol.org/meeting/mop/mop-24/presentations/Shared%20Documents/c_Bangladesh-Statement.doc

HFCs and as well as gives the maximum climate and other environmental and health benefits. The issue is if HFC is addressed under the Montreal Protocol, then:

- What relations will it have with UNFCCC?
- How HFCs should be moved to the Montreal Protocol?
- What are all the elements needs to be incorporated from developing countries perspective?

This paper will look at the above issues and discuss the political, economic and technological implications of moving the management of HFCs from the UNFCCC to the Montreal Protocol from the perspective of the developing countries.

2. HFCs: Consumption, Emissions and Radiative Forcing

Hydrofluorocarbons (HFCs), are organic compounds that contain only one or a few fluorine atoms. HFCs have been introduced into commercial use largely because they have proven to be effective substitutes for Ozone Depleting Substances (ODSs) such chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). HFCs do not deplete the ozone layer and but like CFCs and HCFCs they are greenhouse gases. The ability of HFCs to absorb infrared is roughly similar to that of CFCs and HCFCs, on a per-molecule or per mass basis. However, the global warming potential (GWP) of HFCs is much lower than CFCs but comparable to HFCFs. This is mostly due to differences in their atmospheric lifetimes, which determine how much they accumulate in the atmosphere. CFCs have higher atmospheric lifetime than HFCs and HCFCs and hence have very high GWP.

Table 1: CFCs, HCFCs and HFCs and their respective use and GWP

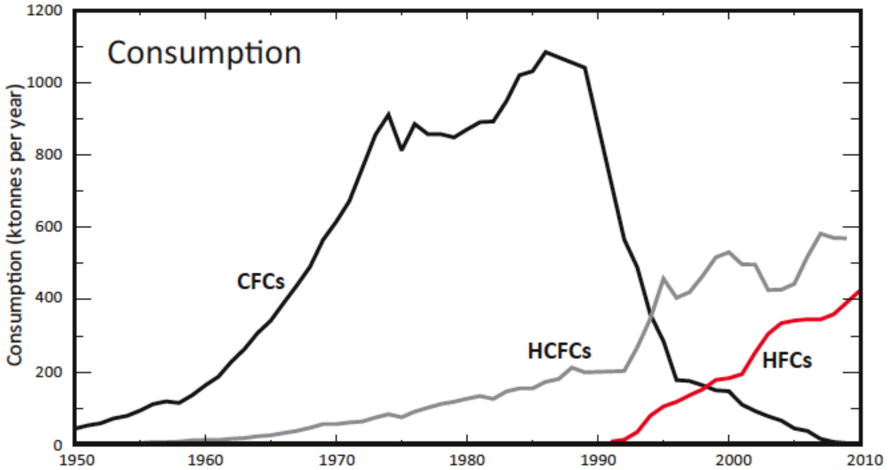
Chemical	Atmospheric Lifetime (years)	GWP	Use
CFC-12 (CCl2F2)	100	10600	Most common chlorofluorocarbon also called as Freon. It was the most widely used refrigerant.
HCFC-22 (CHF2Cl)	12	1700	One of the most widely used refrigerant used in air conditioners, refrigerators, foam blowing etc.
HFC-23 (CHF_3)	260	12,000	Byproduct of HCFC-22 used in very-low temperature refrigeration blend and component in fire suppression. Also used for plasma etching and cleaning in semiconductor production.
HFC-32 (CH_2F_2)	5.0	550	Blend component of numerous refrigerants.
HFC-41 (CH_3F)	2.6	97	Not in use today.
HFC-43-10mee ($C_5H_2F_{10}$)	15	1,500	Cleaning solvent
HFC-125 (C_2HF_5)	29	3,400	Blend component of numerous refrigerants and a fire suppressant.
HFC-134a (CH_2FCF_3)	13.8	1,300	One of the most widely used refrigerant blends, component of other refrigerants, foam blowing agent, fire suppressant and propellant in metered-dose inhalers and aerosols.
HFC-143a ($C_2H_3F_3$)	52	4,300	Blend component of several refrigerant blends.
HFC-152a ($C_2H_4F_2$)	1.4	120	Blend component of several refrigerant blends and foam blowing agent. Also used as an aerosol propellant.
HFC-227ea (C_3HF_7)	33.0	3,500	Fire suppressant and propellant for metered-dose inhalers, and refrigerant.
HFC-236fa ($C_3H_2F_6$)	220	9,400	Refrigerant and fire suppressant.
HFC-236ea ($C_3H_2F_6$)	10.0	1,200	Not in use today.

HFC-245ca ($C_3H_3F_5$)	5.9	640	Not in use today; possible refrigerant in the future.
HFC-245fa ($C_3H_3F_5$)	7.2	950	Foam blowing agent and possible refrigerant in the future.
HFC-365mfc ($C_4H_5F_5$)	9.9	950	Some use as a foam blowing agent; possible refrigerant in the future.

Source: http://www.epa.gov/ozone/geninfo/gwps.html
Note: The GWP and atmospheric lifetime values are from the Intergovernmental Panel on Climate Change Third Assessment Report: Climate Change 2001.

HFCs have found widespread use in various applications – from refrigeration and air conditioning to foam blowing and fire retardants. And there use is increasing as under the Montreal Protocol the phase-out of CFCs have been completed and that of HCFCs is under progress.

Figure 1: Increase in HFCs due to phase-out of CFCs and HCFCs



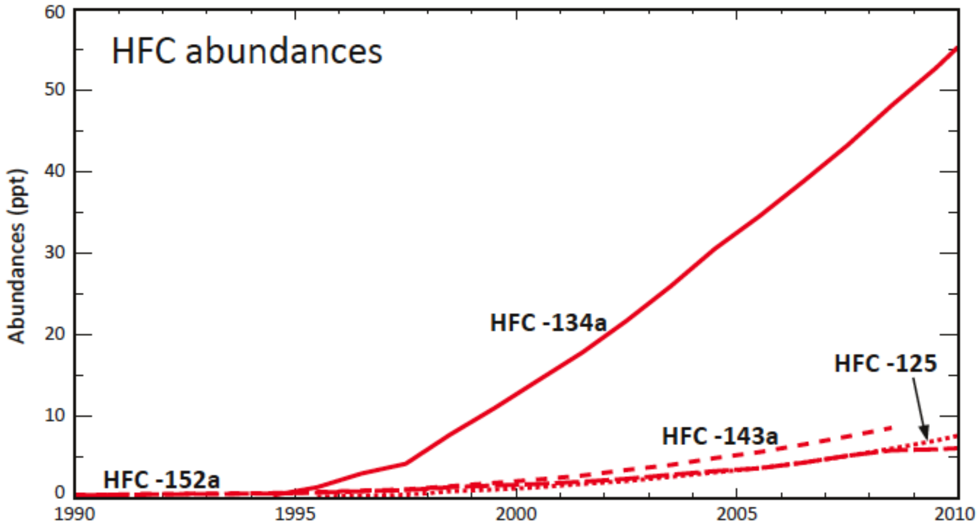
Source: UNEP 2011. HFCs: A Critical Link in Protecting Climate and the Ozone Layer

Atmospheric observations show that the abundance of HFCs in the atmosphere is increasing rapidly[8]:

- HFC-134a increased by about 10% per year from 2006 to 2010, reaching 58 ppt in 2010. HFC-134a, used in mobile air conditioning and many other applications, has become the most abundant HFC in the atmosphere;
- HFC-125, used in refrigeration and air conditioning, increased by more than 15% per year from 2006 to 2010, reaching 8 ppt in 2010;
- HFC-143a, used in refrigeration and air conditioning, increased by about 15% per year from 2004 to 2008, reaching 9 ppt in 2008.

[8] Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project. Report No. 52, World Meteorological Organization, Geneva, Switzerland.

Figure 2: Global average atmospheric abundances of four major HFCs used as ODS replacements since 1990



Source: UNEP 2011. HFCs: A Critical Link in Protecting Climate and the Ozone Layer

The current contribution of HFCs to direct climate forcing is calculated to be approximately 0.012 Wm^{-2}. This is less than 1% of the total climate forcing by other GHGs to date. However, the annual increase in HFC forcing in the past few years is significant. From mid 2003 to mid 2008, total radiative forcing from HFCs increased by about 0.006 Wm^{-2}, which was slightly lower than the increase from HCFCs (0.008 Wm^{-2}), but larger than the increase from methane (0.004 Wm^{-2}). However, they are still relatively small compared to the increase from CO2 (0.14 Wm^{-2}) over this same period.[9]

The major concern with respect to HFCs is not that they are currently large climate forcing agents, but that they might become large contributors to climate forcing in the future if their consumption and emissions is not controlled.

Consumption and emissions

The data on HFCs consumption and emissions are not available for all countries and for all years. [10] However, the available data do show that HFCs consumption and emissions are increasing.

Consumption

Global HFC consumption has more than doubled between 2002 and 2010. The CO_2 equivalent consumption of HFCs increased to more than 1.05 GtCO2e in 2010. Though accurate break-down is not available on the relative contributions of

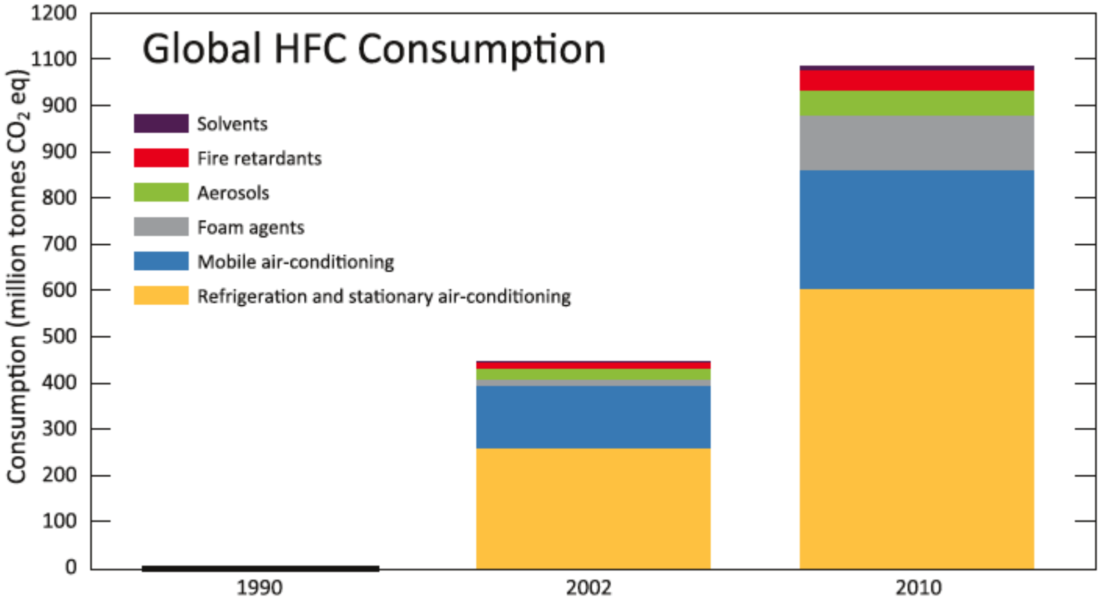
[9] Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project. Report No. 52, World Meteorological Organization, Geneva, Switzerland.

[10] The data on HFCs consumption and emissions are mostly estimates. HFCs consumption and emissions are not reported under the Montreal Protocol. Under UN Framework Convention on Climate Change (UNFCCC) only developed (Annex 1) countries report HFC emissions data and not the production. The only source of data on the global HFCs emissions is the estimates compiled by the U.S. Environmental Protection Agency (USEPA).

developed and developing countries, it is estimated that the majority of the consumption took placed in the developed countries.

HFCs were used in refrigeration and air-conditioning equipment in homes, other buildings and industrial operations (~55% of total HFC use in 2010, expressed in CO_2e) and for air-conditioning in vehicles (~24%). Smaller amounts are used for foam products (~11%), aerosols (~5%), fire protection systems (~4%) and solvents (~1%).[11]

Figure 3: Global HFC consumption.



Source: UNEP 2011. HFCs: A Critical Link in Protecting Climate and the Ozone Layer

Emissions

The total HFCs emissions in 2010 were 0.44 Gt CO_2e. In comparison, the emissions in 2010 of methane was 7.2 Gt CO_2e, of N_2O was 3.5 Gt CO_2e and of CO2 was 33.1 Gt.[12] HFC emissions in 2010 were lower than the 2008 emissions of CFCs (1.1 ± 0.3 Gt CO_2e) and HCFCs (0.74 ± 0.05 Gt CO_2e).[13]

In 2010, HFCs emissions accounted for just 1.0% of the total GHGs emissions. However, the emissions have grown at a rapid pace since 2000. Between 2000 and 2010, HFC emissions increased at 9.3% annually.

Close to 30% of all HFC emissions took place in the US in 2010. In fact, OECD countries accounted for two-thirds of all HFCs emissions in 2010. The contribution of SAARC countries to global HFCs emissions was mere 1.6% in 2010 ***(see Annexure 1: HFCs and Alternatives in SAARC countries)***.

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[11] UNEP 2011. HFCs: A Critical Link in Protecting Climate and the Ozone Layer

[12] Climate Analysis Indicators Tool (CAIT) 2.0. ©2013. Washington, DC

[13] Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project. Report No. 52, World Meteorological Organization, Geneva, Switzerland.

Table 2: HFC emissions (in mtCO2e)

Country	**1995**	**2000**	**2005**	**2010**	**Growth rate: 2000-2010 (%)**
Australia	1.1	3.5	5.8	7.8	8.4
Japan	9.6	24.2	38.2	41.8	5.6
Russia	2.2	6.5	13.5	19.7	11.7
Canada	2.2	6.6	9.6	10.6	4.9
Germany	3.4	7.9	11.8	13.8	5.7
United Kingdom	2.0	4.7	7.1	8.6	6.2
United States	28.5	73.3	103.2	131.1	6.0
China	1.0	7.6	23.5	58.2	22.6
India	0.1	0.6	1.7	5.5	24.8
Brazil	0.3	1.7	3.8	6.5	14.4
South Africa	0.3	1.9	4.7	8.7	16.4
South Korea	0.8	4.7	11.5	17.6	14.1
World Totals	**63.5**	**181.4**	**307.7**	**442.8**	**9.3**
OECD	**57.4**	**151.4**	**231.6**	**291.0**	**6.8**
Contribution of OECD (%)	**90.4**	**83.5**	**75.3**	**65.7**	
SAARC countries	**0.1**	**0.9**	**2.5**	**7.1**	**23**
Contribution of SAARC (%)	**0.16**	**0.50**	**0.82**	**1.61**	

Source: Estimated from Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030, Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, December 2012

The major emitting sector is the refrigerators and air-conditioning (R&AC) sector. In 2010, about 80% of the total HFC emissions happened from the R&AC sector. The emissions from R&AC sector is projected to increase further and account for about 85% of total HFC emissions in 2030.

Table 3: Sector-wise HFCs emissions (in mtCO2e)

	1995	2000	2005	2010	2015	2020	2025	2030
Refrigerator & AC sector	49	157	265	349	508	733	1,200	1,596
Foam Blowing	0.7	1.5	13.7	21.7	29.6	51.8	70.0	91.8
Solvents	1.8	3.9	4.5	5.2	6.0	7.0	8.2	9.7
Aerosols	11.8	14.8	13.2	45.5	84.2	100.4	120.7	145.8
Fire extinguishers	0.2	3.7	11.0	21.2	32.5	43.2	52.2	59.3
Total	63	181	308	443	660	936	1,451	1,903

Source: Estimated from Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030, Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, December 2012

Future emissions and radiative forcing

As stated above, the contribution of HFCs emissions to climate forcing at present is less than 1%. However, there is a fear that this will grow in the coming years on account of increasing HFCs consumption, especially in the developing countries. But there are major inconsistencies between various studies in the projected HFC emissions and the respective contributions of the developing and the developed countries.

a. Technology and Economic Assessment Panel

The Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol projects that under a business-as-usual scenario, the emissions of HFCs will increase from 0.21 Gt CO_2e in 2002 to about 0.8 Gt CO_2e by 2020 – a growth rate of about 8% annually. About 80% HFC emissions in 2020 will happen in the developed countries.[14] TEAP in its 2009 report states "With a significant market penetration of low GWP technologies, and good containment practices, it might well be that HFC emissions could stabilise in Article 5 countries in the 2020-2030 decade. This would be contrary to the growth sometimes considered as unavoidable for HFC emissions in Article 5 countries for the decades after 2020 (up to 2030-2040). It may be expected that this could result in a further decrease of total emissions (the sum of CFC, HCFC and HFC emissions) after 2020".

b. USEPA

USEPA projects that the global HFC emissions will increase by more than four-folds between 2010 and 2030 and reach 1.9 Gt CO_2e in 2030. Between 2010 and 2030, HFC emissions are projected to grow at 5.3% in OECD countries and reach 0.82 Gt CO_2e. In 2030, OECD countries will account for 43% of the global HFC emissions.

In SAARC countries, HFC emissions are projected to grow at 17% annually between 2010 and 2030 (largely because of the smaller base) and reach 0.06 Gt CO_2e. In 2030, SAARC countries will account for about 3.1% of the global HFC emissions.

Table 4: HFCs emissions projections by the USEPA

Country	2010	2015	2020	2025	2030	Growth rate: 2010-2030 (%)
Australia	7.8	10.9	13.6	17.2	19.5	4.7
Japan	41.8	53.9	69.3	89.1	100.4	4.5
Russia	19.7	28.9	40.5	64.6	82.2	7.4
Canada	10.6	14.7	19.2	25.6	28.9	5.1
Germany	13.8	18.2	23.4	29.2	32.2	4.3
United Kingdom	8.6	11.4	14.8	18.6	20.5	4.4
United States	131.1	185.4	246.5	323.3	366.9	5.3
China	58.2	110.0	187.8	377.6	598.9	12.4
India	5.5	11.3	18.0	32.8	50.1	11.7

[14] Task Force Decision XX/8 Report. Assessment of alternatives to HCFCs and HFCs and update of the TEAP 2005 supplement report data. May 2009. UNEP, Nairobi.

Brazil	6.5	9.7	14.1	23.7	31.1	8.1
South Africa	8.7	13.3	18.9	30.6	39.0	7.8
South Korea	17.6	25.5	36.8	62.4	81.3	8.0
World Totals	**442.8**	**660.2**	**935.6**	**1,451.0**	**1,902.7**	**7.6**
OECD	**291.0**	**402.9**	**533.1**	**713.5**	**822.2**	**5.3**
Contribution of OECD (%)	**65.7**	**61.0**	**57.0**	**49.2**	**43.2**	
SAARC	**7.1**	**13.9**	**21.8**	**39.1**	**58.3**	**17.0**
Contribution of SAARC (%)	**1.61**	**2.11**	**2.33**	**2.70**	**3.06**	

Source: Estimated from Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030, Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, December 2012

USEPA projections for HFCs emissions are higher than TEAP. For instance, compared to 8% growth in emissions till 2020 projected by TEAP, USEPA has projected a growth rate of 8.6%.

c. Velders et al. [15]

This 2009 study done by the Netherlands Environmental Assessment Agency, the US National Oceanic and Atmospheric Administration, DuPont Fluoroproducts and the U.S. Environmental Protection Agency is most often quoted by the US to show how HFCs emissions is going to become a big problem in the future.

The study projects HFCs emissions in the range of 5.5–8.8 Gt CO_2e per year by 2050. It also projects that the consumption of HFCs in developing countries will become larger than that in the developed countries before 2020 and exceeds that in developed countries by up to 800% by 2050. Global HFC emissions in 2050 will be equivalent to 9–19% (CO_2e basis) of projected global CO_2 emissions in business-as-usual scenarios and contribute a radiative forcing equivalent to that from 6–13 years of CO_2 emissions near 2050. This percentage increases to 28–45% compared with projected CO_2 emissions in a 450-ppm CO_2 stabilization scenario. Velders et al. estimate an increase of radiative forcing to 0.25–0.40 Wm^{-2} due to HFCs emissions by 2050.

The projection done by Velders et al. is higher than all studies done previously or after. This is largely because of the following:

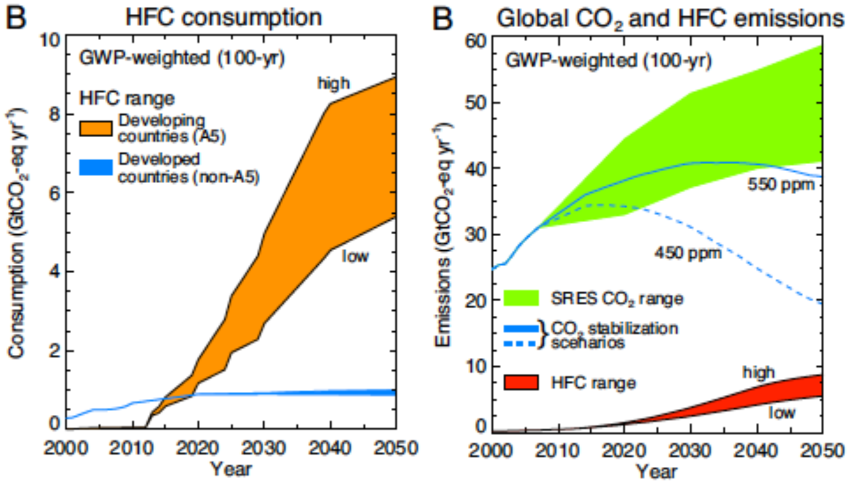
- It has assumed a much higher growth rate in major HFC consuming sectors.
- It has applied trends and growth rates of HCFC consumption to HFC emissions.
- It has also assumed that the shift from HCFCs to HFCs in the developing countries will follow the same pattern as the developed countries.
- It has assumed that no technological changes will happen in the developing countries without regulations.

Most of the above assumptions are not in line with the current trends. Developing countries are actually moving to non-HFCs alternatives at a much faster pace than the developed countries. For instance, where as 75% of all refrigerators sold in China is

[15] Velders, G.J.M., Fahey, D.W., Daniel, J.S., McFarland, M., Andersen, S.O. (2009) The large contribution of projected HFC emissions to future climate forcing. Proc. Nat. Acad. Sci. 106, 10949-10954.

based on hydrocarbons, it only recently that hydrocarbon based refrigerators have been allowed. Similarly, in the first stage of their HCFCs phase-out management plan, almost all developing countries have opted to move to hydrocarbons than HFCs. The projections of Velders et al., therefore, is not likely to reflect the actual scenario.

Figure 4: Projected HFCs consumption and emissions by Velders et al.



d. Gschrey et al. [16]

This 2011 study done by Öko-Recherche GmbH, the German Federal Ministry for the Environment, Nature Conversation and Nuclear Safety and the German Federal Environment Agency estimate much lower HFC emissions of 3.5 Gt CO_2e per year by 2050. HFC emissions (on a CO_2 equivalent basis) calculated from data in Gschrey et al. are about 7% of global CO_2 emissions in 2050. The radiative forcing due to HFCs emissions in 2050 could reach 0.10-0.20 Wm^{-2}. In Business-as-usual scenario, developing countries would account for 75% of total fluorinated GHGs in 2050.

With inconsistencies in estimates withstanding, what is clear is that HFCs emissions are projected to increase under business-as-usual scenario because of the phase-out of HCFCs under the Montreal Protocol. This emissions need to be reduced to keep the world under the 2^{O}C target. But a major dispute has emerged between the developed and developing countries on where HFCs reduction should be discussed.

[16] Gschrey, B., Schwarz, W., Elsner, C., Engelhardt, R., (2011) High increase of global F-gas emissions until 2050. Greenhouse Gas Measurement & Management 1, 85–92.

3. Montreal Protocol vs. UNFCCC

Montreal Protocol (MP) is considered one of the most successful environmental treaties. Global emissions of Ozone Depleting Substances (ODS) have peaked and reduced. In 2010, total ODS emissions, weighted by their Ozone Depleting Potentials (ODPs), were about 25% of the peak in the 1980s. Without the Montreal Protocol, ODS emissions would have continued to increase from their peak in 1988 and could have almost doubled by 2010.[17]

There is emerging evidence that the stratospheric ozone layer is responding to these changes in ODSs and beginning to recover to its 1980 state. Current knowledge suggests that the ozone layer will return to its 1980 levels towards the middle of the 21st century and that the ozone hole will disappear later in the 21st century.[18]

Since most of the ODS are greenhouse gases (GHGs) as well, reductions in ODS emissions have had the added benefit of providing climate protection. The radiative forcing from ODSs reached 0.32 W/m^2 around 2000 (compared with about 1.5 W/m^2 for CO_2 in 2000) and has remained nearly constant since. Without the Montreal Protocol, radiative forcing from ODSs could have reached 0.60 to 0.65 W/m^2, or about 35% of that of CO_2 in 2010.[19] Total avoided net annual ODS emissions are estimated to be equivalent to about 10 Gt CO_2/year in 2010 alone, which is about five times the annual reduction target of the Kyoto Protocol for 2008–201.[20] Furthermore, it is considered cost-effective—Montreal Protocol has not only promoted the recovering of the ozone layer, but has accrued climate benefits of over 100 billion metric tons CO_2e at a cost of just over $0.02 per tonne CO_2e.

Considering the impressive achievements of the Montreal Protocol, many consider Montreal Protocol better suited to address the issue of HFCs. According to Environmental Investigation Agency (EIA), the US based international campaigning organization "The UNFCCC process and the Kyoto Protocol simply will not address HFCs anytime in the near future, and even if they did, they would not be able to phase-out HFCs as quickly, efficiently and cost effectively as the Montreal Protocol."[21]

Following a decision to accelerate the phase-out of HCFCs in 2009, North American states -- US, Canada and Mexico -- and Micronesia have separately filed amendments under the Montreal Protocol to address the issue of HFCs. To start the discussions on the amendment, these countries want to setup a contact group. But developing countries have consistently argued against the setting-up of the contact group and starting the discussions on the amendment. They have opposed the inclusion of HFCs

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[17] HFCs: A Critical Link in Protecting Climate and the Ozone Layer. United Nations Environment Programme (UNEP), 2011

[18] Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project. Report No. 52, World Meteorological Organization, Geneva, Switzerland

[19] Velders, G.J.M., Andersen, S.O., Daniel, J.S., Fahey, D.W., McFarland, M. (2007) The importance of the Montreal Protocol in protecting climate'. Proc. Nat. Acad. Sci. 104, 4814-4819

[20] Synthesis Report: Major findings of the 2010 assessments of the Scientific Assessment Panel (SAP), Environmental Effects Assessment Panel (EEAP), and Technology and Economic Assessment Panel (TEAP). UNEP/OzL.Pro. WG.1/31/3, UNEP, Nairobi

[21] EIA ????

under Montreal Protocol based upon questions regarding the legality of action on HFCs by the Montreal Protocol, lack of information on alternatives, and concerns about costs. At the thirty-third meeting of the open-ended working group (OEWG) of the parties to the Montreal Protocol held in Bangkok in June 2013, the stalemate over amending Montreal Protocol to include HFCs remained. Instead of contact group, developing countries led by India, agreed to a 'discussion group' where disagreements between the developed countries led by the US and developing countries led by the BASIC countries, came out in the open *(see Box: Discussions at Bangkok)*.

Post OEWG in Bangkok, however, the US has stepped-up pressure on BASIC countries, especially India and China, to bring HFCs under the Montreal Protocol *(see Box: Why is the US so interested in HFC?)*.

In June, 2013, the US President Barack Obama and Chinese President Xi Jinping agreed to work together on HFCs under which they agreed to use the Montreal Protocol to phase down HFCs, while the accounting and reporting of HFCs emissions would continue to be under the UNFCCC. Then in September, at the G20 Summit in St Petersburg in Russia, the G20 leaders reiterated the US-China deal.[22] Despite Indian Prime Minister signing on to the G20 communiqué at St Petersburg, the Ministry of Environment and Forests in India, which deals with the Ozone and Climate issues, has steadfastly refused to agree to the US demand. However, India has agreed to setup a joint working group with the US to discuss the issue bilaterally.[23]

What's the debate?

At the twenty-first Meeting of the Parties (MoP) to the Montreal Protocol, held at Port Ghalib in Egypt, Micronesia and Mauritius formally put out a proposal to amend the Montreal Protocol. Another proposal, with a few other additional elements, was presented by Canada, Mexico and the US. Essentially, these Parties proposed a "phase down" or a gradual reduction, of HFC production and consumption in both developed as well as developing countries, but with different schedules.

The rationale for the proposal is that the use of HFCs and their harmful climate effects stemmed from their use as alternatives to ozone-depleting substances; that their use is likely to increase; and that the Montreal Protocol has the expertise needed to deal with the issue with a proven record of success in phasing out ozone depleting substances. Article 2.1 of the Vienna Convention for the Protection of the Ozone Layer, under which the Montreal Protocol is placed, states that countries are obliged to take action to prevent any adverse impact of the activities taken to protect the ozone layer. As HFCs use have increased because of the phase-out of ODS, Montreal Protocol has the moral obligation to address HFCs issue.

Developed countries have supported Montreal over UNFCCC by stating that UNFCCC is not designed to phase-down or phase-out of gases. In the words of a US delegate "UNFCCC neither has the time nor experience to do so".[24] They have also

[22] http://www.whitehouse.gov/the-press-office/2013/09/06/united-states-china-and-leaders-g-20-countries-announce-historic-progres

[23] http://www.thehindu.com/news/resources/joint-statement-on-manmohan-singhs-summit-meeting-with-us-president-obama-in-washington/article5176700.ece

[24] Statement of the U.S. delegate at the OEWG, Bangkok, 2013

quoted the success of the multilateral fund (MLF) to pay for transition in developing countries.

Box: Why is the US so interested in HFC?

HFCs are a part of pollutants called short-lived climate forcers (SLCFs), which warm the climate but have a relatively short lifetime in the atmosphere. Other major SLCFs include methane from oil and gas wells, rice cultivation and enteric fermentation in animals, black carbon (or soot) emitted from diesel vehicles and burning of biomass.

Reducing emissions of SLCFs, which have a shorter lifetime than CO_2 will show rapid results. CO_2 remains in the atmosphere for more than a century. United Nations Environment Programme and World Meteorological Organization have projected that reducing SLCFs, especially methane and black carbon, can slow down warming expected by 2050 by as much as 0.5°C. Regulating HFCs, they estimate, can prevent an additional 0.05°C to 0.1°C by 2050.

The US scientists and the civil society has convinced its government that fast action on SLCFs will give the world time to get an international climate deal. It will also give breathing space to the US, which in any global climate deal will have to take maximum emissions cuts.

But the other reason is that the US multinationals – Honeywell and Dupont – have commercialized the alternatives to high-GWP HFCs -- HFOs. Hydrofluoro-olefins (HFOs), have very low global warming potential. DuPont is promoting HFOs as the “fourth generation” refrigerant following in the footsteps of CFCs, HCFCs and HFCs.

They have introduced HFO-1234yf as a “near drop-in” replacement, requiring minor equipment modifications, to replace HFC-134a in mobile air-conditioning. However, it is the most expensive of all the options and costs more than five times the HFC-134a.

The US is not so vocal about its plans to fast-track reduction of HFCs in its domestic industry as it fears strong opposition from the industry and politicians opposed to climate actions. Instead, it wants to shift the agenda to Montreal Protocol, which it believes will get quick results, both domestically and internationally.

Developed countries have also argued the urgency of addressing the HFC issues by referring to paragraph 222 of the Rio+20 document ‘The future we want’, which recognized that the phase-out of ozone depleting substances had resulted in a rapid increase in the use and release of HFCs into the environment and had therefore supported a gradual phase down in their consumption and production.

To resolve the dispute between the UNFCCC and the Montreal Protocol, the US has suggested that while phase down of production and consumption of HFCs will take place under the Montreal Protocol, the reporting on HFCs emissions would be done under the UNFCCC.[25]

Developing countries opposition

Developing countries, led by India and China, have opposed the amendment because, among other things, Montreal Protocol has the more urgent task to phase out hydrocholorofluorocarbons (HCFCs) and that involves substantial work, which they do not want compromised. They are also unwilling to consider new measures, without understanding the technological and financial risks that would restrict the use of HFCs since they are the main alternative to HCFCs. They fear that such phase down could hamstring economic growth in developing countries.

[25] http://www.whitehouse.gov/the-press-office/2013/09/06/united-states-china-and-leaders-g-20-countries-announce-historic-progres

They are not convinced about the legality of including non-ozone-depleting substances, such as HFCs, within the Montreal Protocol, given that they were already within the purview of the Kyoto Protocol to the UNFCCC, and expressed a preference for avoiding potential political conflicts in international law by maintaining the status quo. Article 4.1 of UNFCCC states that all greenhouse gases other than those under the Montreal Protocol should be addressed by UNFCCC.

Developing countries are not confident about the ability of the MLF to pay for simultaneous phase down and phase out of HCFCs and HFCs as MLF is low on funds even to phase out HCFCs ***(see section 4: MLF)***. They want more clarity on financial and technological issues before they agree to allow HFCs to be discussed under Montreal.

Developing countries are also worried that the amendments to bring in HFCs under the Montreal Protocol might pre-empt the decision to be taken under the UNFCCC in 2015 under the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP). They are also worried that this might be used as a precedence to move climate mitigation under UNFCCC towards sector-wise approach.

To resolve the dispute between the UNFCCC and the Montreal Protocol, developing countries have suggested that a formal decision be taken by the Conference of Parties to the UNFCCC to move HFCs to the Montreal Protocol. After that the discussions regarding the amendment should take place under the Montreal Protocol.

Developing countries have also questioned the focus on only HFCs and not other F-gases that are under the Kyoto Protocol ***(see Annexure 2: F-gases)***.

The fact is under the UNFCCC, countries have targets – mandatory for developed countries under the Kyoto Protocol and voluntary for all major developing countries who have pledged emission reduction. Addressing the reduction of emissions is left to the discretion of the parties who can choose which GHGs they reduce and how. The mechanism available under the UNFCCC is either a market mechanism such as emissions trading (CDM or joint implementation) or a domestic regulatory approach. UNFCCC is therefore not designed for phase-down/ phase-out of any one specific gas *(see Box: Can HFCs be addressed under the UNFCCC?)*. This differs from the strictly regulated phase-down/ phase-out approach used in Montreal Protocol. While this provides certainty, it is claimed that Kyoto's mechanism would factor in cost-effectiveness, as countries would reduce the least cost GHGs first. But as developing countries are paid incremental cost for transition under the Montreal Protocol, the cost-effectiveness is not such an issue for them.

Box: Discussions at Bangkok

The United States submitted its proposal jointly with Canada and Mexico at the thirty-third meeting of the Open-ended Working Group (OEWG 33) of the parties to the Montreal Protocol convened in Bangkok, Thailand from 24-28 June 2013. Yet again, the US explained its intention to phase down HFC production and consumption, giving the justification that it would result in more than 90 gigatonnes of carbon dioxide equivalent benefits; and preserve the legacy and draw on the expertise of the Protocol. Micronesia too introduced its proposal and drew on the Rio+20 document reference and spoke about the benefits of their proposal, describing it as the "logical continuation of the HCFC phase-down".

- US, Canada, Mexico, Micronesia, Morocco, Maldives, Senegal, Nigeria, Dominican Republic, Russian Federation, Australia, EU, Kenya, Japan, New Zealand and Switzerland, called for a contact group to discuss the proposals.
- Morocco stressed that the proposed amendment was equitable and fully in accord with the principle of common but differentiated responsibility in that parties not operating under paragraph 1 of Article 5 would take the first steps, to be followed by parties operating under paragraph 1 of Article 5. The former would provide finance to the Multilateral Fund to allow the latter to meet all their commitments. They added that the proposed amendment rested on a solid legal basis, namely Article 2 of the Vienna Convention for the Protection of the Ozone Layer, under which parties were obliged to take action to prevent any adverse impacts of the activities taken to protect the ozone layer. In accordance with Article 3 of the Convention, the amendment had no impact on the obligations of parties to the Kyoto Protocol to control their emissions of HFCs.
- India asked how the proponents proposed to address the availability of alternative technologies and noted that the Rio+20 outcome document did not specify that HFCs should be addressed under the Montreal Protocol. It cautioned about overstepping the Protocol's mandate by addressing issues that are covered under the UNFCCC.
- South Africa opposed discussion of the proposed amendments in a contact group until the Montreal Protocol is formally invited to do so by the UNFCCC. It also wanted the contact group to consider other HFC-related matters, including availability of alternatives, implications of the new HFC phase-down obligations in the context of existing HCFC obligations in terms of technology pathways, financial needs, additional funding for the MLF to maximize the climate benefit of HCFC phase-out and measures to ensure implementation.
- Uruguay stressed the need for coordination among the Montreal Protocol, the UNFCCC and the Kyoto Protocol.
- Argentina expressed concern about the legal relationship between the Protocol and the UNFCCC, funding to phase down HFCs and the existence of alternatives to HFCs
- Brazil opined that considering the amendments in a contact group would be premature and action should depend on provision of new and additional funding for climate-friendly alternatives
- China observed that action should reflect the principle of common but differentiated responsibilities and queried whether the MLF can provide adequate funding for Article 5 countries. It also said that the feasibility and costs of nascent alternative technologies are uncertain.
- Maldives explained that they had joined in sponsoring the amendment because climate change threatened its very existence. Maldives also underscored that addressing HFCs is not akin to "stepping on someone else's turf."
- EU stressed that the Kyoto Protocol controls emissions from gases while the Montreal Protocol addresses production and consumption, and therefore the processes are complementary. Supported discussing funding and availability of alternatives, emphasizing that the proposals call for a phase-down, not a phase-out, allowed alternatives to emerge
- Senegal described the amendment as a logical follow-up to the Montreal Protocol's phase-down and phase-out of ODS and supported discussions in a contact group
- Mozambique emphasized that actions taken under the Protocol have unintentionally caused adverse effects on the climate system and it is the Protocol's responsibility to address this issue

Procedural issues stopped the discussions from going on further. While the EU, Japan, Norway and the US welcomed further discussion in a contact group, South Africa, India and Argentina, opposed a contact group, stressing that the decision covers items that had not yet been addressed in plenary. Parties could not arrive at a consensus, and discussions went back to the drawing board with respect to whether or not Montreal Protocol should address HFCs. The issue will be taken up again for discussions again in October 2013 in Bangkok where the Meeting of Parties to the Montreal Protocol is scheduled.

Box: Can HFCs be addressed under the UNFCCC?

In the early stages of negotiations under the UNFCCC - just after the Kyoto Protocol, HFCs were almost always considered as a part of the group of F-gases and not separately, although even then its importance as an ODS substitute and high-GWP made it the focus point of several rounds of discussions. The relationship between efforts to protect the ozone layer and to mitigate climate change was placed on the agenda at SBSTA 9 (Buenos Aires, November 1998). COP 4 invited Parties, the bodies of the Montreal Protocol, intergovernmental organizations and NGOs to provide information on "ways and means" of limiting HFC and PFC emissions, including their use as replacements for ozone-depleting substances (Decision 13/CP.4). A joint workshop of the IPCC and TEAP were also convened. While most of the discussions revolved around the technicalities of what substitutes were available and their cost-effectiveness, the chemical industry launched a parallel campaign to advertise the unique characteristics of HFCs and released their own projections to counter the argument that HFCs would contribute significantly to climate change if left unchecked. Options such as hydrocarbons and ammonia were extensively discussed and hydrocarbon technology gained popularity within European countries but was banned from the US.

The issue came back to the negotiating table post-Bali COP in 2007. Between then and COP-15 in 2009, discussions regarding the future treatment of HFC emissions beyond the first commitment period of the Kyoto Protocol were emerging under the AWG-LCA track. One option was to continue to use the CDM or Joint Implementation mechanism to address the phase out of HFCs or under the new market mechanism. It was believed that sectoral trading mechanisms under the new market mechanism could be one vehicle to address HFC emissions arising from the refrigeration and air conditioning sectors. EU had proposed that HFCs be handled in a “separate mechanism” under the UNFCCC. Some believed there could be a separate market mechanism specifically for HFCs, different from all the other GHGs. An alternate proposal was to use a hybrid approach for a regulated phase-down of HFCs wherein UNFCCC would be responsible for controlling emissions of HFCs and the Montreal Protocol would serve as a facilitating body for limiting the consumption and production of HFCs.

Following Copenhagen where nothing materialized, the issue then moved to “various approaches” which discusses both market and non-market mechanisms under the AWG-LCA. The most recent development under the ADP session in Bonn in 2013, EU called for a decision in Warsaw at COP-19 to move HFCs to the Montreal Protocol. This was severely opposed by several developing country parties, particularly by Venezuela speaking for the like-minded group which included India.

The fact is UNFCCC is not designed for regulated phase-down/ phase-out of any one single gas or a group of specific gases say, F-gases. Sectoral market mechanism is the only possible mechanism through which HFCs can be addressed. But unlike HFC-23 where the cost of emission reduction was very low compared to the price of CERs, phasing-out HFCs production and consumption and hence emissions through market mechanism is fraught with uncertainties.

4. The Multilateral Fund

The success of the Montreal Protocol is said to be closely tied to its financial mechanism, the Multilateral Fund (MLF), which was created to provide technical assistance for developing countries to meet their obligations under the Protocol. The financial mechanism, the intent and mandate is discussed under Article 10 of the Protocol where it agreed "Parties shall establish a mechanism for the purposes of providing financial and technical co-operation, including the transfer of technologies, to Parties operating under paragraph 1 of Article 5 of this Protocol." Under this, the creation of the MLF was proposed, whose contributions from developed country parties, would be:

- additional to other financial transfers to Parties
- to meet all agreed incremental costs of such Parties in order to enable their compliance with the control measures
- on a grant or concessional basis

The MLF was established in June 1990 at the Second Meeting of the Parties (MoP) to the Montreal Protocol and began its operation in 1991 as a pilot project. To receive support from the MLF, a developing country's annual per capita consumption and production of ozone depleting substances (ODS) must be less than 0.3 kg.[26] Currently, 147 of the 196 Parties to the Montreal Protocol meet these criteria.

Funds to MLF are not contributed based on the polluter pays principle or the historical responsibility for causing damage to the Ozone layer. Instead, contributions from the industrialized countries, or non-Article 5 countries, are assessed according to the UN scale of assessment which assigns a specific percentage of the budget to each member state, broadly based on its capacity to pay as calculated from its gross national income, modified by various factors. The MLF has been replenished every three years since 1994.

The process usually followed is that, first the Technology and Economic Assessment Panel (TEAP) prepares a study analyzing relevant issues and calculates an appropriate replenishment level to finance the Fund's work over the next three years. After reviewing the TEAP calculated funding needs, the Open Ended Working Group (OEWG) normally asks for additional information and forwards a recommendation on the replenishment to the Parties. A final decision on the replenishment budget is taken at the MOP in the final year of the preceding triennium. Parties can contribute up to 20% of their annual contribution in the form of bilateral assistance. The rest is usually in the form of cash or promissory notes.

The fund separates its management activities from its implementation activities. There is an Executive Committee, with equal membership from developed and developing countries, that administers the replenishment, disbursement and overall accounting of the funds. The work on the ground in developing countries is carried out by four implementing agencies – the United Nations Environment Programme (UNEP),

[26] This provision was considered by many as discriminatory and extremely unfair to the developing countries (**Agarwal et al.**). The developed countries were allowed to increase their annual use of CFCs to 0.3 kg per capita before reducing them to half by 2010. In contrast, the US, with its per capita consumption of 1.7 kg in 1986, was allowed to consume 0.85 kg/capita in the year 2000 when it was to achieve 50 per cent reduction in the CFCs consumption.

United Nations Development Programme (UNDP), United Nations Industrial Development Organization (UNIDO) and the World Bank.

For an Article 5 country to receive assistance from the MLF requires them to submit a government endorsed country programme to the Executive Committee. Approval of the country programme does not mean that all the projects identified in the country programme will be approved or will be funded at a particular funding level. The implementing agencies are required to provide the Fund's Executive Committee with an annual progress report on the implementation of approved work programs and activities related to country programs and projects. Each recipient country is required to report annually to the Executive Committee on the progress of the implementation of its country program.

Initially, funding was provided for single projects, but this has been replaced by funding entire national phase out management plans. This is performance based and funds are accordingly disbursed. Penalties are part of this scheme where countries may get lesser funds on failing to carry out what's on their plans. There, however is flexibility to move funds between different sectors within a country plan.

Funding criteria

The Parties to the Montreal Protocol at their fourth meeting in 1992 agreed an indicative list of costs that the fund will pay for the transition in the developing countries. These include:

- Costs involved in supplying substitutes, including converting existing production facilities and equipment or establishing new facilities, paying for patents, designs and royalties, training personnel, adapting technology to local circumstances, retiring existing capital prematurely and importing substitutes.
- Costs involved where ODS are used in manufacturing, including converting existing equipment and facilities, paying for patents, designs and royalties, training, research and development and paying for raw materials.
- Costs involved in end use, including prematurely modifying or replacing user equipment, recycling and destroying ODS and providing technical assistance to reduce consumption and unintended emissions.

Financial assistance covers only the incremental costs of projects. Incremental cost has generally been agreed to as the difference between status quo and the environmental objective of the global community in the initial text of the Montreal Protocol. Later on, the following guiding principles were added to define the incremental costs[27]:

- Funds should be for the most **cost-effective and efficient** option;
- Project proposals should be carefully scrutinized
- Savings and benefits should be taken into account
- Funds should provide an incentive for **early adoption of technologies**[28]

[27]

[28] During the accelerated phase-down of HCFCs, up to a maximum of 25 per cent above the cost effectiveness threshold is provided for projects that introduce low-GWP alternatives like hydrocarbons.

The result has been that the formula to arrive at the incremental costs has become more and more complicated. For example, the installation of new equipment can produce savings or benefits by itself irrespective of its impact on ozone depletion (say, energy efficiency). Projected savings are deducted from costs to reach the figure for incremental costs, and where this is negative the project is not eligible for Fund assistance. This formula ignores the fact that even in a 'negative cost' projects, there are high upfront capital cost that is not easily available in developing countries.

Also, R&D is not funded under the consumption category since only proven technologies are allowed funding from the MLF. Also, developing countries, can apply for money to buy technology from their northern counterparts but are denied money to develop their own technology. This is unless they sign an agreement that they will never seek money again from the fund if their attempt at developing the technology fails.[29]

Funding and funding issues

The purpose of the MLF is to providing financial and technical assistance to developing countries. The extent to which this purpose is seen as being met depends on how this is read. As far as providing what the MLF itself calls the "base case" or the basic level of funding needed for the activities chosen for a particular financial period, the MLF has not disappointed. The CFC phase-out in developing countries, carried out on time in accordance with the deadlines has been attributed to this.

The Fund has been replenished eight times totaling to just more than $US 3.0 billion. Most of the funding goes towards the consumption sector and technical assistance. In 2011, of the $US 2.6 billion disbursed until then, US$ 2.0 billion was used for the consumption sector, $US 350 million for the production sector and $US 250 million for non-investment purposes such as institutional strengthening, project preparation and training programmes.

However, there has always been a gap between the financial requirements of the developing countries and the amount pledged by the developed countries. However, it is reported that over 97% of pledged amounts have been officially received by the MLF. [30]

Consistently, the amount of money agreed to and pledged by developed countries has been lower than the lower figure of a range or the single estimate (see Table). On average, developed countries have pledged around 70 million US dollars short of the average funding required for a triennium, which is around 15% of the average amount of money promised by developed countries up from 1992 up until 2014. There have also been an issue of delay in the payment of country contributions to the Fund and the sizeable level of outstanding contributions.

What is worrisome for the developing countries is that over years the uncertainty in the financial requirement for the phase-out has increased. In the last two triennium (2009-11, 2012-14), the uncertainty in the funding requirements has been quite considerable. It is projected that the uncertainty would increase as developing countries accelerate their HCFC phase-out activities in the coming years. Also, in the last two triennium the amount pledged by the developed countries has been

[29] Poles Apart, 2001

[30] http://www.multilateralfund.org/MeetingsandDocuments/default.aspx

considerably lower than the funding requirements of the developing countries. Developing countries are not very confident of funds availability for the phase-out of even HCFCs and hence are uncertain of the means of implementation for the proposed HFCs phase-out.[31]

Table 5: Financial requirement and amount pledged under the MLF

	Financial requirement as assessed by TEAP ($million)	Amount pledged by parties ($million)	Difference ($million)
1991 - 93		240	
1994 - 96	510	455	55
1997 - 99	540	466	74
2000 - 02	500	440	60
2003 - 05	530 – 570	474	56-96
2006 - 08	420 - 485*	400.4	19.6-84.6
2009 - 11	340 – 630	400	-60 - 230
2012 - 14	460 – 540	400	60 - 140

Source: http://www.multilateralfund.org/MeetingsandDocuments/default.aspx
* 2005 supplement - China project not accounted for on the basis of complexity of matter

But the real issue is not whether developed countries have stayed true to their promises and commitments. This is just one part of the picture. Presently, a technical assessment is made of the kind of funds required using available data, projections and scenarios to determine a range of the kind of funds required for a future period; this factors in primarily the **cost effectiveness** of moving from one substance to an alternative. It is pretty clear that the MLF takes its **business model** very seriously. Any savings in cost are duly accounted for and is made note of. A brochure put out by the MLF secretariat in 2007 states, "The project review process enables support of all funding requests that meet the Executive Committee's approval criteria but often at a lower level than originally requested, leading to significant savings." So, on the one hand, it provides only the minimum costs to projects based on incremental cost criteria, hence saving the fund dollars and contributing to the efficient use of its funds; on the other hand, there are cases where funds have actually been returned to the MLF by countries which have not been able to apply the funds to particular projects.

Both cases point to the critical application of its incremental cost criteria, which is applied on a case by case basis. The Executive Committee has specific guidelines for how the criteria will be applied depending on the sector and the project under consideration. For example, in the case of Indonesia and a Jordanian plant which was manufacturing heat exchangers for transitioning from HCFC-22 to HFC-410A for unitary air conditioners, there was uncertainty about how the incremental cost would

[31] OEWG, Bangkok, 2013, Minutes of the discussions group

be applied. There was uncertainty (and even distrust) on whether additional funding was actually needed to address a problem that existed as claimed by the parties. The additional funding would differ depending on the size of the sector (small, medium, large) and would at least be to the tune of US$ 50,000. Such cases show the specificity and problem with which the funding is approved for projects.

Issues with MLF

Inadequate financial and technical assistance has been a consistent complaint of the Article 5 countries.[32] There has been criticism against the TEAP for only focusing on technical aspects and for not taking into account a number of important additional components like the socio-economic impacts of the phase-out, while estimating the funding requirements.[33] The unreliability of the cost-effectiveness calculations, not taking account the country-specific circumstances and the particular needs of the small and medium-sized enterprise etc. are other criticisms of the MLF.[34]

One of the main complaints of the developing countries is that their plans are not funded at the level they demand and the amounts are reduced to reflect ‘incremental costs’.[35] However, this aspect is almost treated as a virtue by the MLF Secretariat. According to a brochure put out by the MLF Secretariat: since the inception of the Multilateral Fund, the Executive Committee has allocated a total of **US $2.11 billion** to implement more than **5,500 projects** and activities. Total funding of US $3.72 billion was initially sought for these projects. The savings of US $1.61 billion represents costs that were found to be outside the Executive Committee’s funding guidelines or which did not meet the fundamental Multilateral Fund requirement of being “incremental costs”.[36]

This ‘cost efficiency’ policy of MLF has lead to policies that concern developing countries. For instance, during the HCFC phase out, the Executive Committee pushed the cost further down from the guidelines cost agreed to. Smaller countries were most impacted by this push-down.

The funding under MLF is more of a negotiation than a scientifically-assessed formula. For instance, India had demanded $US 150 million for its phase out of CFCs, but was eventually given only $US 82 million. This explains was the result of a negotiation process. So, although the process to arrive at how much money should be handed out for projects in developing countries involves a lot of technical input, eventually the amount of funding that gets allocated is done politically. So despite there being very precise guidelines on how to decide a project or how much funding it should get, the above statements leads one to infer that this is not always uniformly applied. Another concern is the rather arbitrary application of the guidelines themselves.

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32 MoP 2012

33 MoP 2009

34 MoP 2010

35 MoP 2012

36 MLF Brochure

Another area of concern is if the fund would be effective in a leapfrogging scenario such as the case with the accelerated phase-out of HFCs. This is so since the fund presently does not consider R&D projects and only funds tested technology already in use. This restricts the MLF's ability to actually fund the search for new alternatives, particularly in developing countries. The air conditioning and refrigeration sector provides an example. Refrigerants such as CO2 become less effective when used in higher ambient temperatures. For developing technology suited to the unique conditions of certain developing countries, funds will need to be made available for incentivizing the research for such technology. This is currently nor available under the MLF.

The same is the case for funding the manufacturing plants of consuming sectors. In most sectors, the main substitutes to high-GWP HFCs are hydrocarbons. Hydrocarbons are not patented gases, but the components and equipment's that will use these gases have to be modified. This will require R&D in suitably modifying the equipment's as well as modifying the manufacturing facilities. This cannot be done without investing in R&D as well as paying for the cost of retooling the manufacturing facilities *(see Box: Retooling for hydrocarbons)*.

The issue of retooling costs of manufacturing facilities is already creating differences among the developed and developing countries for the HCFC phase-out. At the MoP 24 in 2012, the Executive Committee concluded that, depending on the alternative technology selected, *some costs* related to retooling for manufacturing heat exchangers in the refrigeration and air conditioning sector *might be* eligible as incremental costs. The extent to which those costs were eligible and incremental, however, was still to be decided. This issue will become big during HFC phase-out as the shift to hydrocarbons in most sectors is about retooling the manufacturing facilities. The incremental cost formula for retooling the manufacturing plants and the formula of not paying for R&D in the consumption sector will have to go to move to alternatives like hydrocarbons.

Lastly, it is not just how the funds are being used and implemented under the MLF, but the source of funds that are increasingly becoming a concern as well. Developed countries have started arguing the case of the financial crisis and other such financial challenges as a reason for voluntary pledges to come forth from developing countries as well. Not just that, as far as the phase-down/out of HFCs go, some developed countries have raised the issue of funding being made available to both developing and developed countries. There is also talk of non-traditional funds and innovative sources of money, very similar to the discussions taking place under climate finance where the private sector has increasingly been afforded a larger role to play. All of this points to questioning the current division of annexes under the Montreal Protocol. Such a take on financing the phase-out of HFCs would serve to only further alienate developing countries from the HFC phase-out, where a key demand of theirs is the reliable and sufficient provision of finance and technology from developed countries.

Box: Retooling for hydrocarbons

In air conditioning sectors, natural refrigerant R290 (propane), is considered as the best alternative to HCFC. It is zero ozone depletion potential, global warming potential approaching zero, safe, energy efficient and cost-effective. However, manufacturers in developing countries are not shifting to R290 because of the high upfront capital cost of modifying the equipment's and retooling the manufacturing plants.

Under the International Climate Initiative of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), GIZ Proklima is partnering with developing country governments and companies to fund shift to R290 in room air-conditioners.

In India, Godrej & Boyce Mfg. Co. Ltd. has installed a production line for room air-conditioners on the basis of R290 to produce approx. 180,000 HCFC/HFC-free, energy-efficient units per year. They received a funding of EUR 2,062,363 from BMU under the GIZ Proklima project.

Similarly, in China Gree Electric Appliances Inc. has received funding from BMU to converted one production line of room air- conditioning systems to use R-290 instead of HCFCs and HFCs, thereby establishing a best-practice model. Gree is the biggest manufacturer of room air-conditioners worldwide with 35 million units manufactured per year. They received a funding of EUR 3,466,456 from BMU under the GIZ Proklima project and are producing 1,80,000 room air-conditioners every year.

For HFCs phase-out, similar funding will have to be made available to the manufacturing plants of the developing countries.

5. Alternatives to HFCs

HFCs find use in several applications across different sectors but more than two-thirds of their consumption is in just three of these sectors—air-conditioning, refrigeration and mobile air-conditioning. This section will take a closer look at what options are technically, economically and politically feasible for HFCs replacement in these three sectors.

Transitioning away from HFCs can take place by utilizing ‘not-in-kind alternatives’ (use of gases like hydrocarbons which will require change in design of the equipment) and ‘drop-in replacements’ (gases that can be used in existing equipment with very little or no modifications to the equipment).

Choosing a replacement refrigerant need to be done by fully assessing the energy efficiency implications of the alternatives.[37] The life cycle climate performance (LCCP) of equipment’s depends on the direct emissions of the refrigerants and the indirect emissions of greenhouse gases due to the energy use during operations. Depending on the application, refrigerant charge, leakage rate and annual energy consumption, the CO_2 emissions associated with the energy consumption of refrigeration or air conditioning systems can contribute significantly more to greenhouse gas emissions than the refrigerant emissions *(see Box: Life cycle climate performance)*. An alternative that compromises on the overall energy efficiency should not be promoted.

Box: Life cycle climate performance

Refrigerators and air-conditioners emit CO_2 indirectly by using electricity largely produced from fossil fuels. In the entire life cycle of these products, one has to look at the contribution of direct emissions of HFCs vis-à-vis indirect emissions due to electricity use. A highly energy-inefficient equipment using a least GWP refrigerant will have more life cycle emissions than a highly energy-efficient equipment using high GWP refrigerant.

It has been found in many LCCP assessments that the refrigerant comprises 5 per cent to 50 per cent in the life cycle greenhouse gas emissions of a product. For instance, in domestic refrigerators, the direct emissions averages only about 1-3 per cent of the total, except where refrigerators suffer large or frequent leakage rates. In commercial refrigerators like the HFC-based supermarket refrigeration, direct emissions could be as high as 20-50 per cent. In domestic air conditioners the refrigerants comprises about 5-10 per cent of life cycle greenhouse gas emissions.

Source: IPCC/TEAP Report, 2005

Alternative gases

The main alternatives to HFCs are hydrocarbons or low-GWP HFCs (also called as HFOs).

1. Hydrocarbons

They have global warming potential of below 20, are not ozone depleting, are non-toxic, less expensive than synthetic refrigerants and accomplish many of the specifications required for refrigerants, foam blowing agents and aerosol propellants.

[37] http://www.unep.ch/ozone/Joint-IPCC-TEAP-HFC-PFC.shtml

However, they are flammable and this has been the most significant barrier against their widespread application. Companies often cite this as a reason for not wanting to move to hydrocarbons. In countries like the US, it is a “psychological” issue. Nevertheless, when used in less quantities they have been found to be safe and are prevalent in several applications including household refrigerators and commercial stand-alone ACs in European and Asian countries. Typically, a refrigeration system designed for HFC uses only about 40-50% of the charge when hydrocarbons are employed. This allows for achieving more refrigeration capacity than the same amount of HFC would have allowed.

There are additional costs for addressing the flammability of hydrocarbons both in production as well as product use phase. At the production level, it includes retrofitting the plants to address leakage issues and adding sensors etc. to raise the alarm on a risk. At the product use level, this includes bringing down the amount of charge, avoiding sparks etc. But most importantly, flammability issue is being addressed most efficiently by training technicians to ensure they follow safety guidelines.

a. Isobutane (HC-600a): It is the standard refrigerant for European and many Asian domestic refrigerators and freezers. Over 40 million appliances are produced annually with isobutane worldwide. Isobutane is also used for smaller commercial plug-in units, e.g. chest freezers for ice cream. They have been found to be more energy efficient than HCFCs or HFCs.

b. Propane (HC-290): It is used by some producers for plug-in bottle coolers, chest freezers and food service cabinets. When used well within statutory requirements for safety (i.e. IEC 60335-2-89), propane is the ideal refrigerant for such units. It can also be used along with mineral oils instead of synthetic oils that need to be used along with HFCs and often has 10% to 15% better energy efficiency than the comparable HFC unit. In last few years, propane based domestic ACs have been introduced in the European and Asian countries, which far more energy efficient than HFC based ACs.

2. Ammonia (R-717)

Ammonia has the lowest GWP (0) of all refrigerants suitable for large refrigeration systems. Ammonia refrigeration systems also usually achieve higher energy efficiency than HFC refrigeration systems. Although ammonia is toxic, it has a pungent odor and thus a high warning effect. Ammonia has been the standard refrigerant for industrial refrigeration systems for more than 125 years. Because of its toxicity, it is only used with indirect systems in public access areas, e.g. systems with liquid and evaporating secondary refrigerant for the medium temperature and/or low temperature range. Recently ammonia has also been used as the higher temperature stage in CO2 cascade refrigeration systems.

3. CO2 (R-744)

In spite of its notoriety as a greenhouse gas, CO2 has very positive characteristics as a refrigerant. It does not deplete the ozone layer and its GWP is 1 (compared to thousands for a typical HFC). It is cheap and has good safety characteristics. Its properties permit the design of smaller components and more compact systems with its main uses being vehicle air-conditioning and supermarket refrigeration.

4. Hydrofluoroolefins (Unsaturated HFCs or HFOs)

They are being promoted as the fourth generation of refrigerants, as replacements to HFCs. HFOs can either be used as single substance, e.g. HFC-1234yf for automotive air conditioning systems, or in mixtures with HFCs, where they reduce the GWP of the blend.

Research is underway with HFO-1234yf in mobile air conditioning, but it may have applications in stationary equipment. Initial analysis states HFO-1234yf has a very low GWP and thermodynamic performance characteristics similar to HFC-134a. There have been strong indications of this replacement being widely used in the mobile air conditioning sector due to the fact that it is a lower pressure refrigerant. However, systems currently running on HFCs will require significant redesigning to use this replacement. Future developments might include higher pressure unsaturated HFCs, for which redesigning will not be required.[38] There are also some concerns regarding the pollution aspects of HFOs *(see Box: HFOs—not exactly environment-friendly)*. HFOs are also the most expensive refrigerants.

Box: HFOs—not exactly environment-friendly

There are concerns about the potential environmental impact of large-scale use of HFOs. Trifluoroacetic acid (TFA), for example, is a common by-product when other HFCs break down, however HFC-1234yf yields more than 90 per cent TFA (4-5 times as much as HFC-134a). Several potential negative impacts that HFO's can have:

- TFA is extremely stable in the environment and therefore accumulates in closed aquatic systems after deposition. The phytotoxic effects of TFA have been demonstrated at rather low concentrations and can act as a co-stress factor on various plants. "TFA may introduce considerable constraints on crops as well as natural vegetation."
- While the production process of HFC-1234yf is not known, the production process of tetrafluoropropene (HFC-1234), an isomer of HFC-1234yf, produces HFC-23 as a by-product during its manufacturing process. There is a possibility that this could apply in the case of HFC1234yf as well.
- The influence of unsaturated HFCs on health is also unclear. Unsaturated HFCs have a low global warming impact because they are rather unstable due to the double carbon binding. This same instability makes them break up into new chemicals inside living organisms.
- Another concern relates to the combustion products of the flammable unsaturated HFC. The decomposition of unsaturated HFC during a fire and subsequent recombination can create decomposition products, e.g. hydrogen fluoride (HF), which are toxic to humans.

Domestic Refrigeration

Approximately 100 million domestic refrigerators and freezers are produced annually, and it is estimated that this quantity is equally divided between developed and developing countries. Typically, a refrigerator contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system containing 50 to 250 grams of refrigerant. Given the average lifespan for a refrigeration unit around 20

[38] Assessment of alternatives to HCFCs and HFCs and update of the TEAP 2005 supplement report data, TEAP, UNEP, 2009

years, the global inventory of installed equipments range from 1500 to 1800 million units.

Presently, the main refrigerants used are HC-600a (isobutane) and HFC-134a. More than 50% of current new production (globally) employs HC-600a, whilst the remainder uses HFC-134a with a miniscule percentage that employs either HFC-152a or HCFC-22 or blends comprising these. HC-600a is widely used in production of refrigerator and freezer units in Europe and some parts of Asia and South America and increasingly in Australasia as well. The exception to this is North America where it is virtually non-existent, largely because of the flammability issues. However, in Europe, its considerable success is reflected in 500 million refrigeration systems that use HC-600a to date and the small proportions in which it is generally used (less than 150 g) have served to eliminate fears regarding its safe use. Similarly, in Japan HC-600a based refrigerators dominated domestic refrigeration market and are continuing to grow in market share.[39]

In developing countries HC-600a based refrigerators are becoming popular. In China alone, 75% of new domestic refrigerators/freezers use isobutane refrigerant. In India, close to 10 million isobutane have been sold in the market without any fire incident. It is predicted that in 10 years, 75% of new units globally will use HC refrigerants.

In North America, public perception regarding this remains unchanged. But even in the US, there are small signs of shift in policy with US EPA approving HC-600a and an HC blend (R-441A) under their Significant New Alternatives Policy Program (SNAP) for household and small commercial refrigerators and freezers.

Some of the other alternatives are HFC-1234yf and R-744. HFC-1234yf is less flammable than HC-600a but more expensive than HFC-134a and yet to reach similar efficiency standards in practice.

Domestic Air conditioners

The world produces over 100 million air-conditioner units annually just for household use. Most unitary AC systems use HCFC-22. Since 2000, developed countries have been transitioning to HFC-410A and, to some extent, HFC-407C. Most developing countries continue to rely on HCFC-22. Currently, HCFC-22 accounts for approximately 60% of all unitary ACs sold, while HFC-410A and HFC-407C account for most of the remainder; propane (R-290) accounts for less than 1%.

HFC-410A is the preferred substitute for new equipment due to a higher refrigeration capacity and consequently a lower cost for compressor plus system. However, it has a high GWP and is not as energy efficient as HCFC-22.

HFC-32 is another alternative that is being marketed aggressively by Japanese companies like Daikin. It is a medium-GWP HFC (GWP of 675). It is also more energy efficient than HFC-410A; a split AC system with HFC-32 achieves higher energy efficiency when compared to HFC-410a and so has better life cycle emissions.

Although HFC-32 is mildly-flammable, the small charge needed reduces the risk of fire. Japanese companies have relaxed patent conditions on HFC 32 and have offered free access to developing countries. HFC-32 has a high potential to penetrate

[39] Transitioning to low-GWP alternatives in domestic refrigeration, U.S. Environment Protection Agency, 2010

domestic AC market due to its balanced property in cost, energy efficiency, and safety.[40]

Another alternative that is gaining acceptance is propane (HC-290). Propane based ACs are 10-15% more energy efficient than HCFC 22 ACs. They also require 40% lower charge. Propane based ACs have been sold for years in Europe and now India and China have started commercial production. For example, China has committed to converting 18 production lines from HCFC-22 to HC-290 by 2015.

HFO-1234yf and HFO-1234ze are also possible alternatives for HFC 410A, but would require system redesign. Then there are low-GWP blends of HFCs and HFOs such as L-41 which are still not commercially available.

Mobile air conditioning

Automobiles across the world moved directly from CFC-12 to HFC-134a, bypassing HCFCs. Presently, 25% of all the HFCs consumed in the world are for mobile air conditioning. Now the world has to switch from HFC-134a to some other low-GWP alternatives. This transition is being hastened the EU's Mobile Air-Conditioning (MAC) directive that required all new cars by 2017 to have refrigerants with a GWP equal to or lower than 150.

There are three key alternatives to HFC-134a in mobile air conditioning:

1. HFO: In 2012, DuPont and Honeywell produced HFO-1234yf, which is being promoted as the preferred choice to replace HFC-134a. HFO-1234yf is a "near drop-in" replacement, requiring minor equipment modifications and is almost as efficient as HFC-134a. This new substance has a GWP of 4, which makes it climate-friendly. But is is also five-times more expensive than the HFC-134a. In the EU, the US and Japan more than 10 car models moved to this product. But it is mildly inflammable.

German manufacturer Daimler did real-life tests and found that when mixed with lubricants it proved inflammable in a hot engine compartment. Based on the new finding, Daimler decided not to use HFC-1234yf in its products. Now, four more German car manufacturers have said they will not use HFC-1234yf but will develop CO2 as an alternative refrigerant.

2. CO2: It is less expensive but requires change in the set of components used in manufacturing of vehicles and can add to the expense. It is yet to become commercially viable and is being developed by German firms. In 2013, several German OEMs announced their intention to develop such systems and preferred to stay with HFC-134a until CO2 is commercialized. [41]

3. Hydrocarbons: Hydrocarbons (mostly propane) are widely used as a refrigerant in mobile air conditioning in the Australian car market due to their low cost and relative performance benefits. A study commissioned by the Australian Government reveals that approximately 8% of passenger and light commercial vehicles in Australia use hydrocarbon refrigerant.[42]

[40] TEAP task force report, 2013

[41] R-744.com

[42] Hydrocarbons 21 News Article - Market analysis: HC share in Australia's MAC service sector exceeds 10% (Available here: http://www.hydrocarbons21.com/news/viewprintable/2739)

The concern with hydrocarbons is their potential flammability. However, the potential flammability can be significantly reduced though the use of a **Secondary Loop System**. This type of system would prevent refrigerant from entering the passenger compartment. The secondary loop system delivers the same performance and comfort as the HFC-134a with a small increase in energy usage.[43]

Conclusion

Low-GWP alternatives to HFCs are available and are being used across the world. They are being more and more used in the developing countries as well. For instance, during the first phase of the HCFC phase-out plan, almost all SAARC countries have decided to move from HCFCs to hydrocarbons ***(see Annexure 1: HFCs and Alternatives in SAARC countries)***. What is most important is that most alternatives (largely hydrocarbons) are also more energy efficient. Shifting away from HFCs therefore as a dual benefit of energy conservation (hence less indirect emissions) as well lower direct emissions of greenhouse gases.

What is also quite clear is that no one gas can meet all requirements. Hence, amongst the alternatives being considered for the transition, the most appropriate one must be selected in accordance with the application and LCCP. So long as an eventual phase-down of HFCs is the issue, natural refrigerants such as ammonia, hydrocarbons and CO2 will have a significant role to play in the long-term.

Developing countries are already moving to hydrocarbons. With little push and incentives, they can leapfrog to low-GWP gases directly from HCFCs. In long-term, it would be economically much more efficient for the developing countries to leap-frog to low-GWP alternatives rather than follow the chemical treadmill.

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[43] SAE Technical Paper, 1999 - An Investigation of R152a and Hydrocarbon Refrigerants in Mobile Air Conditioning

6. HFCs phase-down proposal under the Montreal Protocol

Both the North American and Micronesia proposals to amend the Montreal Protocol to address HFCs were introduced in the year 2009. The US turned in its submission along with Canada and Mexico, ahead of the Copenhagen Conference of Parties to the UNFCCC, saying that this was part of the efforts to address climate change. Micronesia turned in its submission along with Mauritius (which has been subsequently co-sponsored by Maldives and Morocco). Since then, each year, the proposals have been reintroduced at OEWG and MOP meetings of the Montreal Protocol and not much discussion has taken place.

Both the proposals are almost the same, based on the same interpretation of principles within the Montreal Protocol and the UNFCCC; the only exceptions are the difference in schedules suggested for the phase-down of HFCs in both developed and developing countries. Both provide specific legal language needed to bring about the amendment to the text of the Montreal Protocol as it exists now. While the Micronesia proposal gives a justification for moving HFCs from UNFCCC to Montreal Protocol, listing which articles support, such a move, the North American proposal just lays out the elements of the phase-down itself.

Key elements of both proposals

Both proposals recognizes that there may not be alternatives for all HFC applications today and therefore proposes a gradual phase-down with a plateau, as opposed to a phase-out.

Developed country parties would provide, through financial contributions to the Multilateral Fund, the means of implementation for the "agreed full incremental costs" of actions to be undertaken by developing country parties. The Micronesia proposal also provides that any developing country party taking early action to phase down HFCs in advance of its commitments would be entitled to receive support from the Multilateral Fund.

Both proposals address HFC emissions reporting under the Kyoto Protocol, saying this would not be affected and this can continue.

The North American proposal proposes to use weighting by GWP as compared to typical Montreal Protocol weighting by Ozone Depleting Potential

Both submit a list of 19 HFCs under Annex F to be added to the existing substances that are currently controlled by the Montreal Protocol

Both also mention HFC-23 emission reductions projects that can be funded under the Multilateral Fund excepting those that are already covered under the CDM

Both the proposals envisage relationship with the UNFCCC in the following manner:

- Consistent with overall objective of UNFCCC as addressed in Article 2: To achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system is address by the control placed on production and consumption of HFCs.
- Consistent with Article 3.1 of the UNFCCC: Action led by developed country parties and then followed later in time by similar actions taken by developing country parties
- Consistent with Article 4.3 of the UNFCCC: Developed country parties would provide, through financial contributions to the Multilateral Fund, the means of

implementation for the "agreed full incremental costs" of actions to be undertaken by developing country parties

- Amendment, as per its Section III, would have no effect on the status of HFCs under the Kyoto Protocol, nor would it affect the opportunities of Parties to the Kyoto Protocol to meet their commitments under that treaty by reducing HFC emissions

Phase-down schedules

North American Proposal				**Micronesia Proposal ***	
Baseline for developed countries: 85% HCFC + HFC consumption and production (2008 - 10 levels) Baseline for developing countries: 90% of HCFC consumption and production over 2008-10 levels				Baseline: HCFC + HFC consumption and production (2004 - 2006 levels)	
Developed countries		Developing countries		Developed countries	
2016	90%	2018	100%	2016	85%
2022	65%	2025	75%	2019	70%
2029	30%	2030	40%	2022	55%
2033	15%	2043	15%	2025	45%
				2028	30%
				2031	15%
				2034	10%

*In the Micronesia proposal, developing countries are allowed to negotiate their own baseline and phase-out schedule

Problem with the proposal

The phase-down schedule is highly inequitable and discriminates against the developing countries. It is also not designed for one time transition. That is, the proposals want developing countries to first phase-in HFCs and then phase-down to some other alternatives. Developing countries therefore would have to do two times transition to low-GWP alternatives.

The phase-out schedule proposed by the North American countries:

- Allows capping of the emissions for the developed countries at a very high level compared to the developing countries. Assuming that the average GWP of HCFCs and its replacement HFCs as same in the developing countries, the capping of per capita HFCs in developing countries is at least one-tenth of the developed countries.

- Allows developed countries to continue using HFCs at a very high level for the next 20 years. For instance, even in 2033, the US will continue to emit 20 million tonnes CO2e of HFC in 2033 (and per capita of 75 kg CO2e in 2033). In comparison, in 2010, the total HFCs emissions from China and India were 58 million tonnes CO2e (per capita 40 kg CO2e) and 5.5 million tonnes CO2e (per Capita 4.5 kgCO2e), respectively.[44] So, the per capita emissions in the US in 2033

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[44] As HFCs consumption data is not available, HFCs emissions data have been used as a proxy to consumption data.

would be double of China's current per capita emissions and 15 times India's current per capita emissions.

- For the developing countries, the capping of emissions has been fixed at 90% of only HCFC consumption at 2008-10 levels. This doesn't recognizes that in many applications, developing countries are already using HFCs (for instance in mobile air-conditioners).
- The funding mechanism proposed is similar to the existing one with its inherent problem of 'incremental costs' and lack of support to R&D.

The proposals put forth for amending the Montreal Protocol to control HFCs have major limitations and need to be modified to suit the requirements of the developing countries.

7. Discussions

Over the past year, there has been increased political momentum to move the Hydrofluorocarbons (HFC) discussion to the Montreal Protocol. The US has consistently pressured emerging economies to open up discussions on HFCs under the Montreal Protocol, which, at present, is covered under the UN Framework Convention on Climate Change (UNFCCC). However, there are many unanswered questions regarding the HFCs phase-down under the Montreal Protocol. These must be discussed and debated before Montreal Protocol can be amended to control the production and consumption of HFCs.

1. Should HFC be addressed under Montreal Protocol or UNFCCC?

Under the UNFCCC, countries have targets – mandatory for developed countries under the Kyoto Protocol and voluntary for all major developing countries who have pledged emission reduction. Addressing the reduction of emissions is left to the discretion of the parties who can choose which GHGs they reduce and how. The mechanism available under the UNFCCC is either a market mechanism such as emissions trading (CDM or joint implementation) or a domestic regulatory approach. UNFCCC is not designed for phase-down/ phase-out of any one specific gas. Sectoral market mechanism could be another possible mechanism through which HFCs can be addressed. But considering the uncertainty in the carbon market, from a developing country perspective, phasing-out HFCs production and consumption and hence emissions through market mechanism is not the best option. Also, for smaller developing countries, using market mechanism to phase-out small quantities of HFCs would be cumbersome and highly uncertain.

Montreal Protocol uses regulated phase-down/ phase-out approach and developing countries are paid "incremental costs" for phasing-down gases. This provides certainty and assurance. Montreal Protocol also now has an established institutional mechanism to handle technical and financial issues.

Montreal Protocol, therefore, is much more suitable to handle regulated phase-out/phase-own of specific gases than UNFCCC.

2. If HFC is addressed under MP then what relations would it have with UNFCCC? Also, how should HFCs be move it to the Montreal Protocol?

The US wants to start discussions on the amendement to the Montreal Protocol without referring the issue to the UNFCCC. It has publicly stated that discussing HFCs under the Montreal Protocol does not need any endorsements from the UNFCCC. But the fact is HFCs are currently covered under UNFCCC and not Montreal Protocol. While these two conventions have previously discussed the issue of HFCs, there is no formal decision to allow for Montreal Protocol to take over. When aviation and maritime-related emissions were moved to the International Civil Aviation Organisation and International Maritime Organisation all UNFCCC parties had agreed to it. Moving HFCs to the Montreal Protocol should also therefore be agreed by all parties to the UNFCCC. This on one hand give confidence to developing countries that the principles of the UNFCCC are secured and on the other hand it will ensure that 'convention hopping' is done for the benefit of all parties and not for the few.

Once all parties to the UNFCCC have agreed to move HFCs to the Montreal Protocol, they should also agree to the relations between the two conventions. To complement each other, the phase down of production and consumption of HFCs should be addressed under the Montreal Protocol and the reporting on HFCs emissions should be done under the UNFCCC.

3. If HFC is to be addressed in Montreal Protocol then what all elements needs to be incorporated from developing countries perspective?

a. Developed countries should phase-out HFCs very quickly: Developed countries are largest consumers and emitters of HFCs. Under the US and the Micronesian proposals, they would continue using large quantities of HFCs even after 2030. For instance, even in 2033, the US would continue to emit 20 $mtCO_2e$ of HFC in 2033. This is inequitable and unsustainable. Developed countries, therefore, should be asked to phase down HFCs quickly – in next 5-7 years. This will have the additional advantage of opening up the market for alternatives and new environment-friendly technologies for developing countries to leapfrog to.

b. Developing countries should leapfrog to non-HFC alternatives: Developing countries should not follow the chemical treadmill adopted by the developed countries. Instead of moving to HFCs from HCFCs, developing countries should make a one-time transition from HCFCs to non-HFCs alternatives like hydrocarbons. This would be economically efficient apart from the fact that most non-HFC alternatives are energy efficient as well.

c. Reform the Multilateral Fund (MLF): The Multilateral Fund needs reform. While the MLF has been effective in ensuring timely phase-out in the past, its current design does not support a transition that assists in leapfrogging. No research and development (R&D) activities are currently funded under the Montreal Protocol. This severely restricts attempts by developing countries to develop their own alternatives and instead forces them to buy expensive patented technology from their more industrialized counterparts. MLF therefore needs to be reformed to move beyond 'incremental cost' to 'full cost' of transitions to non-HFC alternatives.

d. Discuss all fluorinated gases under the Montreal Protocol, not just HFCs: HFCs are part of the larger family of fluorinated gases that cause global warming. F-gases include HFCs, perfluorocarbons (PFCs), sulfur hexafluoride (SF6) and nitrogen trifluoride (NF3). They all are potent greenhouse gases and some are used as replacements for ozone-depleting substances. NF3, used to make microelectronics, including solar photovoltaic cells, for instance has a global warming potential of 17,200. This means that NF3 is 17,200 times more potent than carbon dioxide. These gases are expected to grow significantly. An approach that addresses only HFCs and overlooks the other super greenhouse gases is a piecemeal solution and, therefore, all the F-gases must be discussed under the Montreal Protocol.

e. Differentiation between developed and developing countries under Montreal Protocol should remain as is: Of late, there has been increasing discussion on blurring the differentiation between developed (non-Article 5) and developing countries (Article 5). Under the Montreal Protocol, developed countries are mandated to support developing countries' transition through financial assistance, but increasingly developing countries have been asked to voluntarily put money into the MLF. This cannot be allowed as this would violate the principle of equity and CBDRRC of the UNFCCC. Such discussions would serve to only further alienate developing countries from the HFC phase-out, where a key demand of theirs is the reliable and sufficient provision of finance and technology from developed countries.

f. Instead of discussing amendments, discuss means of implementation: Developed countries want to setup contact group to discuss amendment to the Montreal Protocol to phase-down HFCs. Emerging economies have resisted this. It would be better to setup a contact group to discuss the management of HFCs including means of implementation. Such a contact group would ensure discussions go beyond just the US's proposed amendments and include the larger issue of management of HFCs, such as the finance and technology aspects of a transition.

Annexure 1: HFCs and Alternatives in SAARC countries

The South Asian Association for Regional Cooperation (SAARC) countries presently uses HCFCs in almost all sectors. The use of HFCs is limited to mobile air-conditioning sector.

The HFC emission in SAARC countries is very small (7.1 million tonnes of CO_2e) and constituted only 1.6% of the global HFCs emissions in 2010. The per capita HFCs emission in 2010 in SAARC region was mere 4.5 $kgCO_2e$ compared to 420 $kgCO_2e$ in the US. In 2010, the contribution of HFCs emissions to all GHGs emissions in SAARC was 1.2%.

Table 1: HFC emissions in SAARC countries (in $mtCO_2e$)

Country	1995	2000	2005	2010	2015	2020	2025	2030	Growth rate: 2010-2030 (%)
Afghanistan	-	-	0.1	0.2	0.3	0.5	0.9	1.1	12.7
Bangladesh	-	-	0.1	0.4	0.8	1.0	1.3	1.7	15.2
Bhutan	-	-	-	-	-	-	-	-	
India	0.1	0.6	1.7	5.5	11.3	18.0	32.8	50.1	18.4
Nepal	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	13.2
Maldives	-	-	-	-	-	-	0.1	0.1	
Pakistan	-	0.2	0.5	0.8	1.1	1.7	3.0	4.0	11.0
Sri Lanka	-	0.1	0.1	0.2	0.4	0.5	0.9	1.1	12.7
South Asia	0.1	0.9	2.5	7.1	13.9	21.8	39.1	58.3	17.0
World Totals	63.5	181.4	307.7	442.8	660.2	935.6	1,451.0	1,902.7	9.5
SAARC as percentage of world total (%)	0.16	0.50	0.82	1.61	2.11	2.33	2.70	3.06	

Source: Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030, Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, December 2012

HFCs emission in the SAARC region is projected to grow at 17% annually from 2010 to 2030. In absolute terms the emissions will grow from 7.1 million tonnes (mt) CO_2e in 2010 to 58.3 $mtCO_2e$ in 2030. But in even 2030, the contribution of SAARC region to the global HFCs emissions will be just 3%.

The projections for 2030 are based on business as usual scenario under which SAARC countries are expected to move from HCFCs to HFCs. But that doesn't seem to be the case. In the first stage of its HCFC phase out management plan, almost all SAARC countries have chosen to move from HCFCs to low-GWP hydrocarbons and have bypassed the HFCs option. Below are the status of HCFCs use in different SAARC countries and the alternatives that these countries are moving towards.

INDIA

On February 20, 2013, India launched the first stage of its HCFC phase out management plan (HPMP). Under Stage I, 10% of HCFCs production and consumption will be reduced and the deadline is January 1, 2015. The first phase of HPMP targets three sub sectors in the Polyurethane (PU) foams sector—domestic refrigeration, continuous sandwich panel and discontinuous sandwich panel. Currently, these sectors use HCFC, and they are expected to move to the hydrocarbon cyclopentane.

HCFCs are used in India in various industry sectors, such as air conditioning (AC), refrigeration, foams, firefighting and solvents. The overall HCFC consumption in India increased from 8,912 MT in 2006 to 21,863 MT in 2010, indicating an average annual growth rate of 19.7%. India currently produces only HCFC-22. The requirement of the other HCFCs—HCFC 141b, HCFC-142b, HCFC-123 and HCFC-124— are met through imports.

- India's refrigeration and AC sector is dominated by HCFCs. Almost all room ACs use HCFC 22. In domestic refrigeration, however, about 15-20% market share is captured by hydrocarbon (HC-600a, or iso-butane). Close to 10 million HC-600a based refrigerators have been sold in India so far.
- In room ACs also, Godrej & Boyce Mfg. Co. Ltd. has installed a production line for room air-conditioners to produce 180,000 propane (R290) based, energy-efficient ACs per year.
- In India, large-sized cold storages and warehouses, large process refrigeration applications mainly use ammonia as a refrigerant; smaller-sized factory-engineered systems use HCFC-22.
- India has started using HFCs in mobile air conditioning sectors and also has a plant to produce HFC 134a.

PAKISTAN

Pakistan's refrigeration & AC sector is dominated by HCFC. Pakistan doesn't produce any HCFCs, and thus, all are imported from different countries. A quota system has been introduced to limit the imports of HCFCs into the country. [45]

Pakistan is promoting the use of hydrocarbons in many applications.

- During the first phase of the HCFC phase-out (2013-2015), Pakistan plans to plans to phase-out HCFC-141b used in the manufacturing of foam sector with cyclopentane.[46]
- Almost all industrial refrigeration, cold storage, cargo ships and food industries use ammonia.
- One new R290 (Propane) line has been added to replace R134a in bottle coolers Pakistan Elektron Limited -- 5,000 units of bottle coolers have been sold.[47]
- One new R600a (Iso-butane) line for domestic refrigerators has been added by Electrolux -- 15,000 units have been sold.
- In the domestic refrigeration sector, hydrocarbons have been adopted in Pakistan.[48]

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[45] http://www.unido.org/fileadmin/user_media/UNIDO_Header_Site/Subsites/Green_Industry_Asia_Conference__Maanila_/Pakistan_MP.pdf

[46] HPMP-Pakistan, http://www.multilateralfund.org/62/English%20Document/1/6244.pdf

[47] http://www.hydrocarbons21.com/news/view/4331

Pakistan has opened a "Natural Fluids refrigeration Center" (NFRC) for natural refrigerants as a Research & Development hub for students and technicians. The NFRC is the result of a partnership between GIK Institute of Engineering Sciences and Technology in collaboration with Isotherm, Inc. USA. It covers all aspects of refrigeration technologies and has been actively conducting research on the thermal-hydraulic characteristics of highly efficient heat exchangers using natural refrigerants.

BANGLADESH

HCFCs are consumed in refrigeration and AC sector in Bangladesh and are primarily imported from China, UAE, India, Singapore and Thailand. [49]

At the 24th meeting of Parties to the Montreal Protocol in 2012, Bangladesh had stated that[50]:

- It is willing to phase out HFCs if financial assistance is provided from Multilateral Fund under the Montreal Protocol.
- Bangladesh, in future, would welcome any alternative to HFC which is ozone friendly, climate friendly, energy efficient as well as cost effective. Bangladesh, has already started using environment friendly Hydrocarbon in the refrigeration sector. In the foam sector, it has chosen zero ODP and low GWP Cyclopentane for conversion of HCFC-141b insulation foam producing process.
- It has prepared its HCFC Phase-out Management Plan in such a manner that the alternatives would not need to be phased-out again and again.

In the first phase of HCFC phase-out, Bangladesh will go for phase-out of HCFC-141b in Walton Industries, which uses HCFC-141b as a foam-blowing agent, with Cyclopentane. Walton is the largest manufacturer of domestic refrigerators with a market share of about 50%.

SRI LANKA

HCFC 141 b is widely used in Refrigeration, AC and foam sector in Sri Lanka. [51] In its HCFC phaseout plan, Sri Lanka is planning to[52]:

1. Restrict import of HCFC based new equipment
    - Central ACs – 01st Jan. 2013
    - Room ACs, industrial refrigeration services – 01st Jan 2015
2. Adopt policy for restricting manufacturing of HCFC equipment - Room ACs, foams using HCFCs
3. Quickly promote adoption of new alternative technologies

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[48] http://www.shecco.com/files/report_UNIDO_Vienna2013.pdf

[49] HPMP – Bangladesh - UNEP/OzL.Pro/ExCom/65/24

[50] *Bangladesh Country Statement at the 24th Meeting of the Parties to the Montreal Protocol* –Statement of the Leader of the Delegation http://conf.montreal-protocol.org/meeting/mop/mop-24/presentations/Shared%20Documents/c_Bangladesh-Statement.doc

[51] Workshop Report on 'Alternatives to HCFCs in refrigeration & AC in Sri Lanka" http://www.noulanka.lk/HCFC%20Report.pdf

[52] Oct. 2013, National Ozone Unit – Sri Lanka - Presentation on – Regulation for facilitating HCFC Phase-Out and their enforcement http://www.docstoc.com/docs/158004419/Regulations-for-facilitatihng-HCFC-Phase-our-in-SL---National-Ozone

Sri Lanka is considering all possible options available in the market including hydrocarbons to phase-out HCFCs. In its Policy enforcement mechanism, the National Ozone Unit prescribes that refrigeration and air conditioning servicing technicians should be equipped with tools and skills for efficient handling of refrigerants, especially hydrocarbons and hydrocarbons based air conditioners.

MALDIVES

Maldives has announced to phase out HCFCs by 2020, ten years ahead of the schedule.[53] However, the main pillars of Maldivian economy are fisheries and tourism, which are highly dependent on air conditioning and refrigeration. Maldives, therefore will face difficulties in phasing-out HCFC’s unless cost-effective and climate friendly alternatives are readily available. Maldives is also not in favour of phasing in HFCs as its HCFC management plan targets the dual goal of climate mitigation and phasing out ODSs.[54]

Maldives has no manufacturing plant for refrigerators or ACs. So all the HCFC consumption comes from the leakage in the servicing sector. In its phaseout, the country is looking forward to training of technicians, ban on import of HCFC-based equipment from mid-2014, etc. For the refrigeration sector, hydrocarbons are being explored and so are some potential non-in-kind (non-gaseous) technologies.[55]

The country is setting up its first carbon-neutral resort in the south of the archipelago, powered by wind and solar and using cold 4 degrees Celsius water from 4 km below the ocean’s surface for cooling equipment to replace air-conditioning. All this will take time, and till then the Maldives is collaborating with the Indian Bureau of Energy Efficiency to label household appliances to cut fuel use.

NEPAL & BHUTAN

Both countries are focusing on reduction of HCFCs in the refrigerators and air conditioners service sector only through training of technicians and enforcement for ban on import of HCFC-based equipment’s.

[53] http://insideclimatenews.org/news/20100614/maldives-phase-out-hcfcs-super-greenhouse-gases-10-years-early
[54] Statement of the Maldivian representative at the 24th MOP, Montreal Protocol, 2012
[55] HPMP - Maldives

Annexure 2: F-gases

Annex A of the Kyoto Protocol lists greenhouse gases that parties to the UNFCCC have to address to mitigate climate change. The gases include:

- Carbon dioxide (CO2)
- Methane (CH4)
- Nitrous oxide (N2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF6)

UNFCCC decided to add another gas -- nitrogen trifluoride (NF3) -- in the second Kyoto compliance period, in its basket of gases. HFCs, PFCs, SF6 and NF3 are collectively called as fluorinated gases or F-gases. F-gases in general are characterized by long life-time and high global warming potential (GWP).

Table 1: PFCs, SF6 and NF3

Chemical	Atmospheric Lifetime (years)	GWP	Use
Perfluoromethane (CF_4)	50,000 50,000 50,000	5,820 6,500 5,700	Plasma etching and cleaning in semiconductor production and low temperature refrigerant.
Perfluoroethane (C_2F_6)	10,000 10,000 10,000	12,010 9,200 11,900	Plasma etching and cleaning in semiconductor production.
Perfluoropropane (C_3F_8)	2,600 2,600 2,600	8,690 7,000 8,600	Plasma etching and cleaning in semiconductor production, low temperature refrigerant and fire suppressant.
Perfluorobutane (C_4F_{10})	2,600 2,600 2,600	8,710 7,000 8,600	Fire suppressant and refrigerant where no other alternatives are technically feasible.
Perfluorocyclobutane (C_4F_8)	3,200 3,200 3,200	10,090 8,700 10,000	Not used much if any. Refrigerant where no other alternatives are technically feasible.
Perfluoropentane (C_5F_{12})	4,100 4,100 4,100	9,010 7,500 8,900	Not used much if any. Precision cleaning solvent-low use refrigerant where no other alternatives are technically feasible.
Perfluorohexane (C_6F_{14})	3,200 3,200 3,200	9,140 7,400 9,000	Precision cleaning solvent-low use, refrigerant and fire suppressant where no other alternatives are technically feasible.
Sulfur hexafluoride (SF_6)	3,200 3,200 3,200	22,450 23,900 22,200	Cover gas in magnesium production, casting dielectric gas and insulator in electric power equipment fire suppression.
NF3	740	10,970	Plasma etching, solar PV, semiconductors etc.

Source: http://www.epa.gov/ozone/geninfo/gwps.html

Note: There are three values given for GWP and atmospheric lifetime. The first value is from the Scientific Assessment of Ozone Depletion, 2002. The second and third values are from the Intergovernmental Panel on Climate Change Second Assessment Report: Climate Change 1995 and the IPCC Third Assessment Report: Climate Change 2001, respectively.

Emissions

The global emissions of F-gases have increased from 262.1 million tonnes (mt) CO_2e in 1990 to 672.1 mtCO_2e in 2010 at an annual growth rate of 4.8%. In 2010, F-gases accounted for 1.4% of total GHGs emissions (excluding LUCF).[56] The per capita emissions of F-gases in 2010 was 0.10 tonnes. In major countries, the per capita emissions ranged from 0.53 tonnes in the US to 0.03 tonnes in India.

Table 1: F-Gas emissions (in million tonnes CO2e)

	US	EU27	Japan	Canada	Australia	China	India	Brazil	South Africa	World
1990	91.8	38.1	31.0	7.8	5.3	5.3	2.6	4.2	1.1	262.1
1995	106.8	48.9	42.3	8.2	3.5	11.9	8.7	4.9	2.4	290.9
2000	136.6	63.0	50.0	11.6	4.8	49.0	19.3	3.4	3.5	428.8
2005	145.8	66.6	48.8	13.3	7.5	137.7	38.6	6.5	6.4	598.2
2010	164.6	72.1	49.2	12.6	8.7	153.4	37.8	8.7	9.9	672.1
Per Capita emissions (tonnes): 2010	0.53	0.14	0.39	0.37	0.40	0.11	0.03	0.04	0.20	0.10
Growth rate: 1990-2010 (%)	3.0	3.2	2.3	2.4	2.5	18.3	14.4	3.7	11.8	4.8
Cumulative emissions (million tonnes): 1990-2010	2715.2	1222.9	946.5	226.5	121.0	1469.4	454.0	112.9	94.6	9392.1
Per Capita cumulative emission (tonnes): 1990-2010	8.8	2.4	7.4	6.6	5.5	1.1	0.4	0.6	1.9	1.4

Source: Climate Analysis Indicators Tool (CAIT) 2.0. ©2013. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org.

Cumulatively the US has emitted the maximum amount of F-gases during 1990-2010 – 2.7 GtCO_2e which is about 29% of the global emissions. China with 1.47 GtCO_2e equivalent F-gases emissions is the distant second. The per capita cumulative emissions of F-gases during 1990-2010 of the US was 8.8 tonnes (calculative on 2010 population) compared to 1.1 tonnes in China and 0.4 tonnes in India.

Of all the F-gases, HFCs are the most abundant. In 2010, HFCs emissions accounted for about 85% of all the F-gases emissions.

Table 2: F-gases vs. HFCs

	US	EU27	Japan	Canada	Australia	China	India	Brazil	South Africa	World
F-Gases	164.6	72.1	49.2	12.6	8.7	153.4	37.8	8.7	9.9	672.1
All HFC (excluding HFC23)	131.1	65.0	41.8	10.6	7.8	58.2	5.5	6.5	8.7	442.8
HFC 23	11.8	1.0	0.2	0.0		62.1	29.1	0.0	0.0	127.9
HFC	142.9	66.0	42.0	10.6	7.8	120.3	34.6	6.5	8.7	570.7

[56] Analysed from Climate Analysis Indicators Tool (CAIT) 2.0. ©2013. Washington, DC: World Resources Institute.

HFCs as per centage of F-gases (%)	86.8	91.5	85.4	84.2	89.1	78.4	91.6	74.9	87.5	84.9

Source: Estimated from Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030, Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, December 2012

Table 4: Emissions of F-gases other than HFCs

	1995	2000	2005	2010
PFCs+SF6+NF3	127.8	115.2	111.5	101.4

Source: Estimated from Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030, Office of Atmospheric Programs, Climate Change Division, U.S. Environmental Protection Agency, December 2012

While the emissions of SF6, PFCs and NF3 don't seem significant presently when compared to HFCs, they do have considerably long lifetimes in the atmosphere (than HFCs) and when combined with their high GWP, it makes them significant in their own right.

PFCs

PFCs are man-made compounds that contain carbon and fluorine. They are relatively stable and owing to their long atmospheric lifetimes, ranging from 800 years up to tens of thousands of years, they have very high GWP placing them in the super greenhouse gas category.

The main use of PFCs is in the electronics sector (manufacture of semi-conductors) and they were used as replacements for CFCs as refrigerants in some operations. At the time of start of the Montreal Protocol, CFCs, PFCs and SF6 were used simultaneously in a few applications, including wind tunnel tests, military dielectric applications, adiabatic applications, leak detection and tracer gases. However, the main releases of PFCs to the environment occur during the manufacture of semi-conductors, refrigeration equipment and the production of aluminum.

UNFCCC reports show a steady decline in PFC emissions in developed countries. In the US, PFC emissions decreased 66% between 1990 and 2011 and in the same period, there was an 88% reduction in the EU. This could be due to some level of regulation placed upon on PFC emissions. The United States EPA listed as unacceptable PFC containing blends in 15 out of 16 refrigeration and air conditioning end-uses and restricted its use in fire suppression and solvents cleaning. Some voluntary measures also exist within the aluminum industry to control PFC emissions. PFCs are also controlled under the EU's F-gas regulations.

PFCs use in the manufacturing of liquid crystal display and photovoltaic cells is increasing and could become significant in the future. Emission levels from semiconductor manufacture were about 30 mtCO_2e in 2000. According to the US EPA, a significant growth in emissions will occur in this sector unless the World Semiconductor Council commitment to reduce PFC emissions by at least 10% by 2010 from 1995 levels is implemented globally and strengthened after 2010.

SF6

SF6 is used in magnesium processing and semiconductor manufacturing, as well as a tracer gas for leak detection. Also used in electrical transmission equipment, including circuit breakers.

Emissions from SF6 also see a declining trend according to GHG reports turned in by parties to the UNFCCC. Between 1990-2011, the emissions SF6, in the EU, US and Japan saw a decrease of 40, 70 and 95%, respectively. All of them, particularly the US and Japan have significant semiconductor production capacity, where SF6 is used.

According to the IPCC AR4 (2007), SF6 emissions in 2000 from the production of medium and high voltage electrical transmission and distribution equipment were estimated at about 10 mtCO_2e. These emissions, mainly located in Europe and Japan, are estimated to have declined, despite a 60% growth in production between 1995 and 2003, mainly due to targeted training of staff and improved gas handling and test procedures at production sites.

Emissions of SF6 at the end-of-life of electrical equipment are growing in relevance, and US EPA estimates total SF6 emissions from production, use and disposal of electrical equipment at 27 mtCO_2e in 2000 growing to 66 mtCO_2e in 2020, if no mitigation actions are taken.

NF3

NF3 is a perfluoro compound. It has a Global Warning Potential of 17200, according to the IPCC report (2007) and a atmospheric lifetime of 740 years. NF3 is a stronger greenhouse gas than the compounds it replaces in many industrial applications.

NF3 is used in the electronics industry (semiconductor and LCD manufacture) for plasma etching and chamber cleaning processes, and is increasingly a replacement for PFCs and SF6. NF3 use is experiencing rapid growth in semiconductor manufacture and this is due both to growth in total semiconductor manufacture (with estimated production increases of 15 – 17% per annum) as well as displacement of older PFC technology for new production lines that use NF3.

Some emission reduction goals have already been established in the semiconductor and LCD industries. Mitigation efforts in the semiconductor industry focus on process improvements/source reduction, alternative chemicals, capture and beneficial reuse, and destruction technologies. While use of NF3 as a replacement for PFCs and SF6 can deliver emission reductions, the relative contribution of NF3 to climate change is likely to increase as the use of NF3 grows, particularly if best practice emissions reduction is not employed.

Until recently, it was considered not possible to directly measure the atmospheric concentration of NF3, and scientists had assumed that only a small percentage of the NF3 used in industry escaped into the atmosphere. New measurement techniques have revealed much higher atmospheric concentrations of NF3 than expected, which has been partially attributed to the fact that industrial losses of the gas had been underestimated. While NF3 emission estimates are not widely reported, NF3 emissions are considered to be increasing rapidly – rates of industrial production increased 40-fold between 1992 and 2007 alone.

In 2011, a group of researchers from University of California, San Diego estimated that the global emissions of NF3 were 1.18 ± 0.21 Gg/year or ~20 Tg CO_2e/year (carbon dioxide equivalent emissions based on a 100-y global warming potential of 16,600 for NF3). The 2011 global mean tropospheric dry air mole fraction was 0.86 ± 0.04 parts per trillion, resulting from an average emissions growth rate of 0.09 Gg/year over the prior decade. In terms of CO_2 equivalents, current NF3 emissions represent between 17% and 36% of the emissions of other long-lived fluorinated compounds from electronics manufacture.

The mean global tropospheric concentration of NF3 has risen quasi-exponentially from about 0.02 ppt (parts-per-trillion, dry air mole fraction) at the beginning of measured record in 1978, to a July 1, 2008 value of 0.454 ppt, with a rate of increase of 0.053 ppt per year, or about 11% per year, and an inter-hemispheric gradient that is consistent with these emissions occurring overwhelmingly in the Northern Hemisphere. This rise rate corresponds to about 620 metric tons of current NF3 emissions globally per year, or about 16% of the poorly constrained global NF3 production estimate of 4,000 metric tons per year. This is a significantly higher percentage than has been estimated by industry, and thus strengthens the case for inventorying NF3 production and for regulating its emissions.

Sources:

- http://www.ec.gc.ca/toxiques-toxics/Default.asp?lang=En&n=98E80CC6-1&xml=AA329670-C3C7-4AD5-A7AB-5FD8A05439F1
- http://www.meti.go.jp/policy/chemical_management/ozone/files/pamplet/panel/08e_basic.pdf
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