

## IMPACT OF CFCs ON OZONE LAYER AND GLOBAL WARMING

Dr. D.V.Satyanarayana Moorthy<sup>1</sup>, Dr. B. Kotaiah<sup>2</sup>

<sup>1</sup>Associate Professor,SVUCE,Tirupati, <sup>2</sup>Director, SVCET, Chittoor – 517 127 (A.P)

### 1.0 INTRODUCTION:

Over the past few decades, considerable attention has focused on the role of chlorofluorocarbons (CFCs) on causes of stratospheric ozone depletion (Rowland, 1990). These species which contain only carbon, fluorine, and chlorine atoms, were first synthesized in the 1920s. They were widely used as the working fluid in compression refrigeration, as commonly found in air conditioners and food refrigerators. They were also used to manufacture plastic materials such as Styrofoam, incorporated as a propellant in aerosol sprays, and used as industrial solvents.

Molina and Rowland (1974) originally advanced the theory that CFCs could cause stratospheric ozone depletion. Subsequent experimental investigations have substantiated this concern. Above Antarctica, massive springtime ozone destruction has been observed for several successive years. Less dramatic but still detectable ozone depletion has been detected above mid latitudes in the Northern Hemisphere. Estimated contribution of CFCs for global warming is around 17% in 1980s (Toiba et al., 1992).

In the troposphere, CFCs are extremely stable, with estimated atmospheric residence time of about a century. After mixing and transporting through the troposphere slowly, the compounds may reach the lower boundary of the stratosphere. There, intense UV radiation can cause photo-degradation, liberating the chlorine atoms and triggering the ozone-destroying catalytic cycle. Because of the combination of their industrial usefulness, non-toxic properties, and atmospheric stability, the atmospheric concentrations of CFCs grew rapidly.

Through a combination of industry and government efforts that includes substantial cooperation, remarkable progress has been made towards eliminating the production and use of chlorofluorocarbons (Benedick, 1991). However, large scale smuggling activities is the major hurdle in phase out of CFC from the industrial usage. The present paper describes the use of various CFCs, their properties and potential ozone depleting capabilities and ways and means of global reductions in CFC emissions by various methods into the atmosphere.

### 2.0 Ozone in Stratosphere:

Ozone in the stratosphere is maintained in a dynamic balance with a short lifetime changes in the rate of production and destruction of ozone can influence stratospheric concentrations. About 90% of all atmospheric ozone is in the stratosphere with peak mole fractions of about 10ppm occurring at latitude of 15km (over the poles) to 25km (over the equator). (Rowland, 1990).

Stratospheric ozone is produced by photolysis of molecular oxygen, followed by reduction of the oxygen radical with a second oxygen molecule (Abbott and Molina, 1993).



Stratospheric ozone is consumed by photolysis and by reaction with oxygen radicals.

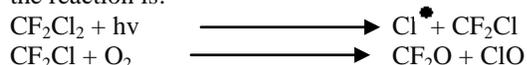


A balance between the rates of production and destruction determines the concentration of stratospheric ozone.

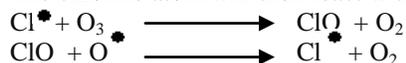
### 3.0 Mechanism of ozone depletion by CFCs:

Scientists believe chlorofluorocarbons diffuse upwards into the earth's stratosphere where the sun's energy is powerful enough to break the tight bonds between the atoms of CFCs to yield atomic chlorine. The chlorine atoms participate in a set of chemical reactions that destroy ozone. These chemical reactions are presented below:

In the stratosphere, the CFC are broken down by UV radiations and release chlorine atom. Using CFC -12, the reaction is:



The chlorine atom will then react with ozone and produce ClO:



The above reaction removes the oxygen radical and prevents it from recombining with an oxygen atom to form an ozone molecule. Thus the chlorine atom acts essentially as a catalyst. It is estimated that chlorine atom can destroy more than 1,00,000 ozone molecules before finally being removed from the stratosphere. List of ozone depleting substances are presented in table -1.

Table - 1 List of Ozone depleting substances

S. No.	Name of Ozone Depleting Substance	Chemical Composition of Ozone Depleting Substance	Chemical formula	Group	Atmospheric lifetime (Y)	Ozone Depleting Potential
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	CFC-11	Trichlorofluoromethane	(CFCl <sub>3</sub> )	I	50-60	1.0
2.	CFC-12	Dichlorodifluoromethane	(CF <sub>2</sub> Cl <sub>2</sub> )	I	150	1.0
3.	CFC-113	Trichlorotrifluoroethane	(C <sub>2</sub> F <sub>3</sub> Cl <sub>3</sub> )	I	85	0.8
4.	CFC-114	Dichlorotetrafluoroethane	(C <sub>2</sub> F <sub>4</sub> Cl <sub>2</sub> )	I	300	1.0
5.	CFC-115	Chloropentafluoroethane	(C <sub>2</sub> F <sub>5</sub> Cl)	I	1700	0.6
6.	Halon-1211	Bromochlorodifluoromethane	(CF <sub>2</sub> BrCl)	II		3.0
7.	Halon-1301	Bromotrifluoromethane	(CF <sub>3</sub> Br)	II		10.0
8.	Halon-2402	Dibromotetrafluoroethane	(C <sub>2</sub> F <sub>4</sub> Br <sub>2</sub> )	II		6.0
9.	CFC-13	Chlorotrifluoromethane	(CF <sub>3</sub> Cl)	III		1.0
10.	CFC-111	Pentachlorofluoroethane	(C <sub>2</sub> FCl <sub>5</sub> )	III		1.0
11.	CFC-112	Tetrachlorodifluoroethane	(C <sub>2</sub> F <sub>2</sub> Cl <sub>4</sub> )	III		1.0
12.	CFC-211	Heptachlorofluoropropane	(C <sub>3</sub> FCl <sub>7</sub> )	III		1.0
13.	CFC-212	Hexachlorodifluoropropane	(C <sub>3</sub> F <sub>2</sub> Cl <sub>6</sub> )	III		11.0
14.	CFC-213	Pentachlorotrifluoropropane	(C <sub>3</sub> F <sub>3</sub> Cl <sub>5</sub> )	III		1.0
15.	CFC-214	Tetrachlorotetrafluoropropane	(C <sub>3</sub> F <sub>4</sub> Cl <sub>4</sub> )	III		1.0
16.	CFC-215	Trichloropentafluoropropane	(C <sub>3</sub> F <sub>5</sub> Cl <sub>3</sub> )	III		1.0
17.	CFC-216	Dichlorohexafluoropropane	(C <sub>3</sub> F <sub>6</sub> Cl <sub>2</sub> )	III		1.0
18.	CFC-217	Chloroheptafluoropropane	(C <sub>3</sub> F <sub>7</sub> Cl)	III		1.0
19.	Carbon tetrachloride	Tetrachloromethane	(CCl <sub>4</sub> )	IV	42	1.1
20.	Methyl chloroform	1, 1, 1-Trichloroethane	(C <sub>2</sub> H <sub>3</sub> Cl <sub>3</sub> )	V	5.8	0.1
21.	HCFC-21	Dichlorofluoromethane	(CHFCl <sub>2</sub> )	VI	2.0	0.04
22.	HCFC-22	Dichlorodifluoromethane	(CHF <sub>2</sub> Cl)	VI	13.3	0.055
23.	HCFC-31	Chlorofluoromethane	(CH <sub>2</sub> FCl)	VI		0.02
24.	HCFC-121	Tetrachlorodifluoroethane	(C <sub>2</sub> HF <sub>2</sub> Cl <sub>4</sub> )	VI		0.04
25.	HCFC-122	Trichlorodifluoroethane	(C <sub>2</sub> HF <sub>2</sub> Cl <sub>3</sub> )	VI		0.08
26.	HCFC-123	2, 2-dichloro-1, 1, 1-trifluoroethane	(C <sub>2</sub> HF <sub>3</sub> Cl <sub>2</sub> )	VI	1.4	0.06
27.	HCFC-123a	1,2-dichloro-1, 1, 2-trifluoroethane	(CHCl <sub>2</sub> CF <sub>3</sub> )	VI		0.02
28.	HCFC-124	2-chloro-1, 1, 1, 2-trifluoroethane	(C <sub>2</sub> HF <sub>4</sub> Cl)	VI	5.9	0.04
29.	HCFC-124a	2-chloro-1, 1, 2, 2-trifluoroethane	(CHFClCF <sub>3</sub> )	VI		0.022

30.	HCFC-131	Trichlorofluoroethane	(C <sub>2</sub> H <sub>2</sub> FCI <sub>3</sub> )	VI		0.05
31.	HCFC-132	Dichlorodifluoroethane	(C <sub>2</sub> H <sub>2</sub> F <sub>2</sub> Cl <sub>2</sub> )	VI		0.05
32.	HCFC-133	Chlorotrifluoroethane	(C <sub>2</sub> H <sub>3</sub> F <sub>3</sub> Cl)	VI		0.06
33.	HCFC-141	Dichlorofluoroethane	(C <sub>2</sub> H <sub>3</sub> FCI <sub>2</sub> )	VI		0.07
34.	HCFC-141b	1, 1-dichloro-1-fluoroethane	(CH <sub>3</sub> CFCl <sub>2</sub> )	VI	9.4	0.11
35.	HCFC-142	Chlorodifluoroethane	(C <sub>2</sub> H <sub>3</sub> F <sub>2</sub> Cl)	VI		0.07
36.	HCFC-142b	1-chloro-1, 1-difluoroethane	(CH <sub>3</sub> CF <sub>2</sub> Cl)	VI	19.5	0.065
37.	HCFC-151	Chlorofluoroethane	(C <sub>2</sub> H <sub>4</sub> FCI)	VI		0.005
38.	HCFC-221	Hexachlorofluoropropane	(C <sub>3</sub> HFCl <sub>6</sub> )	VI		0.07
39.	HCFC-222	Pentachlorodifluoropropane	(C <sub>3</sub> HF <sub>2</sub> Cl <sub>5</sub> )	VI		0.09
40.	HCFC-223	Tetrachlorotrifluoropropane	(C <sub>3</sub> HF <sub>3</sub> Cl <sub>4</sub> )	VI		0.08
41.	HCFC-224	Trichlorotetrafluoropropane	(C <sub>3</sub> HF <sub>4</sub> Cl <sub>3</sub> )	VI		0.09
42.	HCFC-225	Dichloropentafluoropropane	(C <sub>3</sub> HF <sub>5</sub> Cl <sub>2</sub> )	VI		0.07
43.	HCFC-225ca	1, 3-dichloro-1,2, 2,3,3-pentafluoropropane	(CF <sub>3</sub> CF <sub>2</sub> CHCl <sub>2</sub> )	VI	2.5	0.025
44.	HCFC-225cb	1-3-dichloro-1,2,2,3,3-pentafluoropropane	(CF <sub>2</sub> ClCF <sub>2</sub> CHClF)	VI	6.6	0.033
45.	HCFC-226	Chlorohexafluoropropane	(C <sub>3</sub> HF <sub>6</sub> Cl)	VI		0.10
46.	HCFC-231	Pentachlorofluoropropane	(C <sub>3</sub> H <sub>2</sub> FCI <sub>5</sub> )	VI		0.09
47.	HCFC-232	Tetrachlorodifluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>2</sub> Cl <sub>4</sub> )	VI		0.10
48.	HCFC-233	Trichlorotrifluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>3</sub> Cl <sub>3</sub> )	VI		0.23
49.	HCFC-234	Dichlorotetrafluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>4</sub> Cl <sub>2</sub> )	VI		0.28
50.	HCFC-235	Chloropentafluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>5</sub> Cl)	VI		0.52
51.	HCFC-241	Tetrachlorofluoropropane	(C <sub>3</sub> H <sub>3</sub> FCI <sub>4</sub> )	VI		0.09
52.	HCFC-242	Trichlorodifluoropropane	(C <sub>3</sub> H <sub>3</sub> F <sub>2</sub> Cl <sub>3</sub> )	VI		0.13
53.	HCFC-243	Dichlorotrifluoropropane	(C <sub>3</sub> H <sub>3</sub> F <sub>3</sub> Cl <sub>2</sub> )	VI		0.12
54.	HCFC-244	Chlorotetrafluoropropane	(C <sub>3</sub> H <sub>3</sub> F <sub>4</sub> Cl)	VI		0.14
55.	HCFC-251	Trichlorofluoropropane	(C <sub>3</sub> H <sub>4</sub> FCI <sub>3</sub> )	VI		0.01
56.	HCFC-252	Dichlorodifluoropropane	(C <sub>3</sub> H <sub>4</sub> F <sub>2</sub> Cl <sub>2</sub> )	VI		0.04
57.	HCFC-253	Chlorotrifluoropropane	(C <sub>3</sub> H <sub>4</sub> F <sub>3</sub> Cl)	VI		0.03
58.	HCFC-261	Dichlorofluoropropane	(C <sub>3</sub> H <sub>5</sub> FCI <sub>2</sub> )	VI		0.02
59.	HCFC-262	Chlorodifluoropropane	(C <sub>3</sub> H <sub>5</sub> F <sub>2</sub> Cl)	VI		0.02
60.	HCFC-271	Chlorofluoropropane	(C <sub>3</sub> H <sub>6</sub> FCI)	VI		0.03
61.	BFC-21B2	Dibromofluoromethane	(CHFBr <sub>2</sub> )	VII		1.00
62.	HBFC-22B1	Bromodifluoromethane	(CHF <sub>2</sub> Br)	VII	5.8	0.74
63.		Bromofluoromethane	(CH <sub>2</sub> FBr)	VII		0.73
64.		Tetrabromofluoroethane	(C <sub>2</sub> HFBBr <sub>4</sub> )	VII		0.8
65.		Tribromodifluoroethane	(C <sub>2</sub> HF <sub>2</sub> Br <sub>3</sub> )	VII		1.8
66.	HBFC-123B2 HBFC-123aB2	Dibromotrifluoroethane	(C <sub>2</sub> HF <sub>3</sub> Br <sub>2</sub> )	VII		1.6
67.	HBFC-124B1	Bromotetrafluoroethane	(C <sub>2</sub> HF <sub>4</sub> Br)	VII		1.2
68.		Tribromofluoroethane	(C <sub>2</sub> H <sub>2</sub> FBr <sub>3</sub> )	VII		1.1
69.		Dibromodifluoroethane	(C <sub>2</sub> H <sub>2</sub> F <sub>2</sub> Br <sub>2</sub> )	VII		1.5
70.		Bromotrifluoroethane	(C <sub>2</sub> H <sub>2</sub> F <sub>3</sub> Br)	VII		1.6
71.		Dibromofluoroethane	(C <sub>2</sub> H <sub>3</sub> FBr <sub>2</sub> )	VII		1.7
72.	HBFC-124B1	Bromodifluoroethane	(C <sub>2</sub> H <sub>3</sub> F <sub>2</sub> Br)	VII		1.1
73.	HBFC-124B1	Bromofluoroethane	(C <sub>2</sub> H <sub>4</sub> FBr)	VII		0.1
74.		Haxabromofluoropropane	(C <sub>3</sub> HFB <sub>6</sub> )	VII		1.5
75.		Pentabromodifluoropropane	(C <sub>3</sub> HF <sub>2</sub> Br <sub>5</sub> )	VII		1.9
76.		Tetrabromofluoropropane	(C <sub>3</sub> HF <sub>3</sub> Br <sub>4</sub> )	VII		1.8
77.		Tribromotetrafluoropropane	(C <sub>3</sub> HF <sub>4</sub> Br <sub>3</sub> )	VII		2.2
78.		Dibromopentafluoropropane	(C <sub>3</sub> HF <sub>5</sub> Br <sub>2</sub> )	VII		2.0
79.		Bromohaxafluoropropane	(C <sub>3</sub> HF <sub>6</sub> Br)	VII		3.3

80.		Pentabromofluoropropane	(C <sub>3</sub> H <sub>2</sub> FBr <sub>5</sub> )	VII		1.9
81.		Tetrabromodifluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>2</sub> Br <sub>4</sub> )	VII		2.1
82.		Tribromotrifluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>3</sub> Br <sub>3</sub> )	VII		5.6
83.		Dibromotetrafluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>4</sub> Br <sub>2</sub> )	VII		7.5
84.		Bromopentafluoropropane	(C <sub>3</sub> H <sub>2</sub> F <sub>5</sub> Br)	VII		1.4
85.		Tetrabromofluoropropane	(C <sub>3</sub> H <sub>3</sub> FBr <sub>4</sub> )	VII		1.9
86.		Tribromodifluoropropane	(C <sub>3</sub> H <sub>3</sub> F <sub>2</sub> Br <sub>3</sub> )	VII		3.1
87.		Dibromotrifluoropropane	(C <sub>3</sub> H <sub>3</sub> F <sub>3</sub> Br <sub>2</sub> )	VII		2.5
88.		Bromotetrafluoropropane	(C <sub>3</sub> H <sub>3</sub> F <sub>4</sub> Br)	VII		4.4
89.		Tribromofluoropropane	(C <sub>3</sub> H <sub>4</sub> FBr <sub>3</sub> )	VII		0.3
90.		Dibromodifluoropropane	(C <sub>3</sub> H <sub>4</sub> F <sub>2</sub> Br <sub>2</sub> )	VII		1.0
91.		Bromotrifluoropropane	(C <sub>3</sub> H <sub>4</sub> F <sub>3</sub> Br)	VII		0.8
92.		Dibromofluoropropane	(C <sub>3</sub> H <sub>5</sub> FBr <sub>2</sub> )	VII		0.4
93.		Bromodifluoropropane	(C <sub>3</sub> H <sub>5</sub> F <sub>2</sub> Br)	VII		0.8
94.		Bromofluoropropane	(C <sub>3</sub> H <sub>6</sub> FBr)	VII		0.7
95.	Methyl bromide	Bromomethane	(CH <sub>3</sub> Br)	VIII	1.3	0.6

### 3.1 Halocarbon nomenclature:

**Halocarbons without bromine:** CFCs (“Chlorofluorocarbons”) contain only the elements carbon, C, fluorine, F, and chlorine, Cl. HCFCs also contain hydrogen, H. HFCs contain carbon, hydrogen and fluorine, but not chlorine. They therefore do not break down ozone. Examples of non-bromine-containing halocarbons are CFC11 (CFCl<sub>3</sub>), HCFC22 (CHF<sub>2</sub>Cl) and HFC134 (C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>).

The number after the letters is a code for the substance’s molecular formula. The code is interpreted thus:

1. Add 90 to the number. This gives a three-digit number.
2. The first digit gives the number of carbon atoms (C) in the molecule.
  - If the first figure is 1, there is 1 C in the substance (methane derivative)
  - If the first figure is 2, there are 2 Cs in the substance (ethane derivative)
3. The second digit gives the number of hydrogen atoms in the molecule.
4. The third digit gives the number of fluorine atoms in the molecule.
5. The number of chlorine atoms in the molecule is found by subtracting the sum of the digits from 4 for methane derivatives (first digit in numeric code 1) and from 6 for ethane derivatives (first digit 2).

Where there are several possible isomers (substances with the same notional formula but different molecular structures, e.g. CHF<sub>2</sub>CHF<sub>2</sub> and CH<sub>2</sub>FCF<sub>3</sub>, both of which are HFC134), the difference is indicated by adding a letter to the number in the formula (HFC134 and HFC134a respectively) (Pedersen 1992).

#### Examples:

a) **What is the chemical composition of CFC-115?**

**Solution:** CFC-115: Adding 90 to 115 gives 205. Thus, a molecule contains 2 carbons, no hydrogen, and 5 fluorines. Two carbons have 6 bonding sites, 5 of which are taken by fluorine. The remaining site is taken by chlorine. The chemical formula would therefore be: C<sub>2</sub>ClF<sub>5</sub> (or CF<sub>3</sub>CF<sub>2</sub>Cl).

b) **What is the CFC number for CCl<sub>2</sub>FCCLF<sub>2</sub>?**

**Solution:** CCl<sub>2</sub>FCClF<sub>2</sub> has 2 carbons, no hydrogen, and 3 fluorine atoms so its number is 203. Subtracting 90 from 203 gives 113. This is CFC-113, a very commonly used solvent.

**Bromine-containing halocarbons:** The designation “halons” is derived from halocarbons, but the technical designation is used for bromine-and fluorine-containing fully halogenated derivatives of methane or ethane. The partially halogenated bromine –and fluorine-containing (but not chlorine-containing) halocarbons are designated HBFCs.

The halons and the HBFCs numeric designation codes directly for their molecular formula:

1. The first digit is the number of carbon atoms in the molecule.
2. The second digit is the number of fluorine atoms.

3. The third digit is the number of chlorine atoms.
4. The fourth digit is the number of bromine atoms.

**Examples:**

a) **What is the chemical composition of R-1301?**

**Solution:**

1	3	0	1
C	F	Cl	Br

∴ CF<sub>3</sub>Br

b) **What is the HBFCs number for CF<sub>2</sub>CLBr?**

**Solution:**

C	F <sub>2</sub>	Cl	Br
1	2	1	1

∴ R = 1211

Halon 1301 thus has the notional formula CF<sub>3</sub>Br.

The number of hydrogen atoms in the HBFC molecule is found by subtracting the sum of the digits from 4 for methane derivatives (i.e. when the first digit in the numeric code is 1) and from 6 for ethane derivatives (i.e. when the first digit is 2) (Pedersen, 1992).

**3.2 Atmospheric lifetime:**

Atmospheric life depends on the substance's chemical and photochemical stability. These are determined on the basis of atmospheric models (World Meteorological Organization, 1989). There are two important breakdown mechanisms for the halocarbons, reaction with tropospheric hydroxyl radicals (OH) and photolysis especially by UV radiation in the stratosphere.

The fully halogenated CFCs are entirely inert, and they therefore do not react with OH. They are removed exclusively by photolysis in the stratosphere (Fisher et al., 1990).

The partially hydrogen-containing HCFCs are all more or less removed by reaction with OH radicals in the troposphere, and their atmospheric life is therefore an order of magnitude shorter than that of the CFCs. There are some rules of thumb for the dependence of tropospheric lifetime on the HCFC's molecular structure, which

- Decrease with the number of carbon atoms in the molecule,
- Decreases with the presence of chlorine on the same carbon atom that holds hydrogen (in the alpha position),
- Is increased by the presence of fluorine in particular, but also by chlorine on the carbon atom neighbouring that carrying the hydrogen atom (in the beta position) (Nimitz and Skaggs, 1992).

The HCFCs are no more sensitive to stratospheric photolysis than the CFCs, and their stratospheric lifetime is therefore typically of the same order of magnitude as that of the CFCs.

For halons, the molecule is stabilized by the presence of several fluorine atoms (halon 1301, CF<sub>3</sub>Br), while the presence of chlorine and bromine gives the molecules a shorter atmospheric life (CF<sub>2</sub>BrCl) (UKSORG, 1990).

**3.3 Ozone Depletion Potential:** The substance's ODP is calculated as the expected contribution to stratospheric ozone depletion at steady state from a given emission of the substance relative to the contribution to ozone depletion on emission of an equivalent quantity of CFC11. CFC11 was chosen as reference substance because it has been well studied and has been one of the most important ozone depleting substances. Multiplying a known emission of an ozone depleting substance by the substance's ODP gives the size of the CFC11 emission which will result in the same distribution to ozone depletion under the chosen conditions. This is the emission of the ozone depleting substance expressed in CFC equivalents.

ODP values are calculated from atmospheric models which simulate the relevant changes in the atmosphere's chemical composition and other time-dependent conditions of significance for the substances depletion of ozone.

For an ozone depleting substance (i), the effects of emission of a given mass relative to emission of the same mass of the reference substance CFC-11 is considered. The total ODP value is given as:

$$ODP = \frac{\text{Calculated global O}_3 \text{ depletion caused by substance (i)}}{\text{Calculated global O}_3 \text{ depletion caused by CFC11}}$$

Calculation of the ODP value of the ozone depleting substance includes knowledge of its specific ozone depletion capacity (reactivity) and its expected lifetime in the atmosphere (determining its chances of reaching the stratosphere) (Nimitz and Skaggs, 1992).

**Ozone Depletion Capacity:** The specific ozone depletion capacity depends on the possibility of formation of substances from the gas molecule which can increase the breakdown of ozone in the stratosphere. The specific ozone depletion capacity for halocarbons is determined by the substances contents of chlorine and bromine and the speed with which they undergo photo-dissociation in the stratosphere (the stratospheric lifetime).

**Time-Dependent ODP:** To estimate the contribution to ozone depletion from a substance over a period shorter than the substance's total atmospheric life, it is necessary to base the calculation on a knowledge of how rapidly the substances content of chlorine and bromine is released into the stratosphere, including how rapidly upward transport of the substance occurs. Solomon and Albritton (1992) propose the following equation based on actual measurements in the stratosphere.

The expression for time-dependent ODP, ODP<sub>i</sub>(T) for the substance(i), is

$$ODP_i(T) = \frac{F_i}{F_{CFC11}} \cdot \frac{M_{CFC11}}{M_i} \cdot \frac{n_i}{3} \cdot \alpha \cdot \frac{\int_{t_s}^T \exp(-(t-t_s)/\tau_i) dt}{\int_{t_s}^T \exp(-(t-t_s)/\tau_{CFC11}) dt}$$

Where, F<sub>i</sub> and F<sub>CFC11</sub> are the fractions of the added quantity of substance (i) and the fraction of CFC11 which are dissociated and which have thus released their chlorine/bromine content,

M<sub>i</sub> and M<sub>CFC11</sub> are the respective molecular weights of substances (i) and CFC11

n<sub>i</sub> and 3 are the numbers of chlorine atoms per molecule of substance (i) and CFC11

α is a factor which reflects bromine's higher ozone depletion efficiency for the bromine-containing halocarbons.

t<sub>s</sub> is the transport time from the surface of the earth up to the lower part of the stratosphere.

t is the time as integration variable

T is the length of the period of time over which the ozone depletion is quantified,

τ<sub>i</sub> and τ<sub>CFC11</sub> are the respective atmospheric lifetimes of substance (i) and CFC11, defined as the time elapsed before the quantity is reduced to i/e=37% of the quantity emitted (Nimitz and Skaggs, 1992). The lifetime corresponds to 1.41 times the half-life.

#### 4.0 Usage of CFC in Industrial Applications:

CFCs are extremely stable non-flammable, non-toxic and harmless to handle. They are also not water soluble. This makes them ideal for many industrial applications. The applications of CFCs for various industrial uses are presented in table - 2.

**Table 2 The applications of CFCs for various industrial uses:**

Sl. No	Group	Applications
1.	Group- I	Automobile and track air-conditioning units
2.	Group I and Group VI	Domestic and commercial refrigeration and air-conditioning heat pump equipment, e.g. <ul style="list-style-type: none"> <li>❖ Refrigerators</li> <li>❖ Freezers</li> <li>❖ Dehumidifiers</li> <li>❖ Water coolers</li> <li>❖ Ice machines</li> <li>❖ Air conditioning and heat pump units</li> <li>❖ Compressors</li> </ul>
3.	Group I	Aerosol products
4.	Group II	Portable fire extinguishers
5.	Group I	Insulation boards, panels and pipe covers

6.	Group I and Group VI	Pre-polymers or foamed plastics
7.	Group I	Electronic solvent
8.	Group VI	Intermediate (CCl4) in the production of CFC-II, CFC-12 solvents

Table 3 Global CFC use by category

Use	Share of total (%)
Aerosols	25
Rigid foam insulation	19
Solvents	19
Air conditioning	12
Refrigerants	8
Flexible foam	7
Other	10

**5.0 Effects of CFC on Man and Environment:**

Scientists agree that emissions of man-made chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, methyl bromide and other substances are responsible for depletion of the ozone layer. Millions of ozone molecules are being destroyed every minute and this is increasing the amount of harmful ultraviolet radiation that reaches the Earth’s surface. People, animals and plants are being exposed to this radiation, which threatens to cause skin cancer and eye cataracts, and suppression immune response system reduce agricultural productivity and severely damage the marine food chain. CFCs are also potential candidates for global warming.

**6.0 Estimating Future Atmospheric Concentrations of CFCs:**

Because of their importance in the stratospheric ozone problem, CFCs have come under increasing regulatory attention and, hopefully, emissions will be reduced rapidly. The 1987 Montreal Protocol on Substances That Deplete the Ozone Layer, for example, requires a 20-percent reduction in CFC emissions below the 1986 level by 1994, and a total reduction of 50 percent by 1998. The gases specifically listed in the Protocol are CFC-11, CFC-12, CFC-13, CFC-114, and CFC-115.

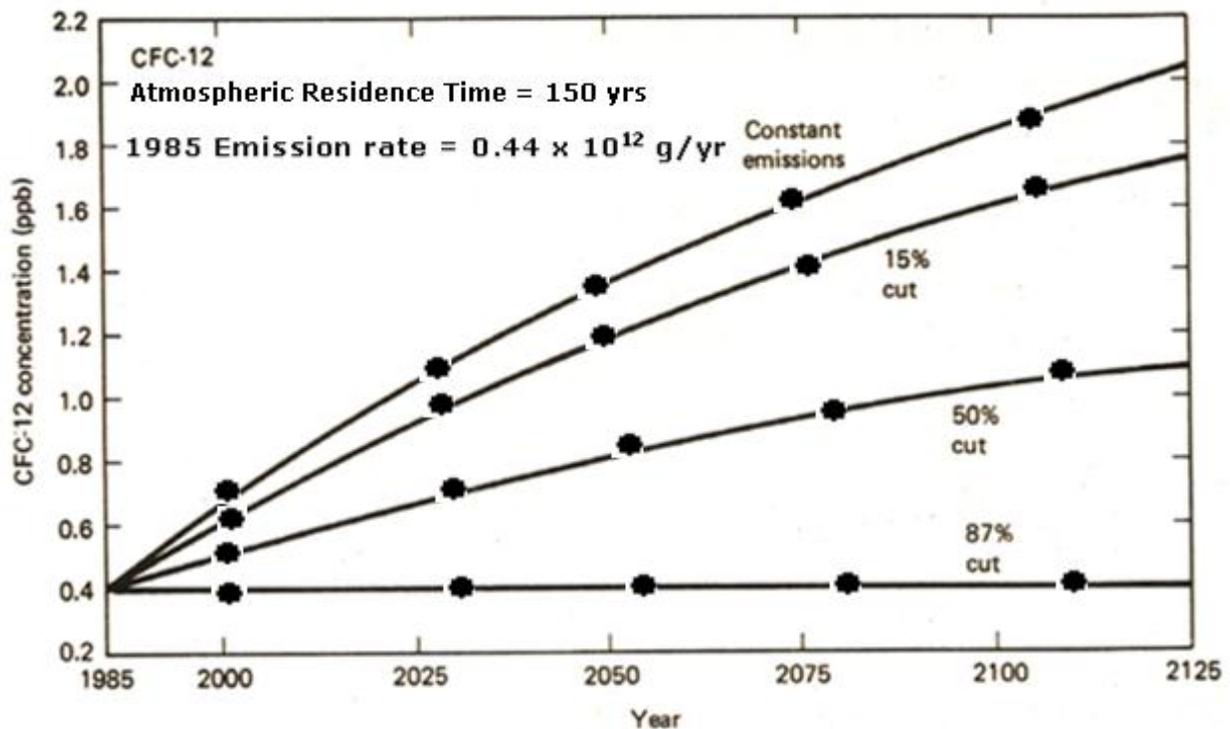
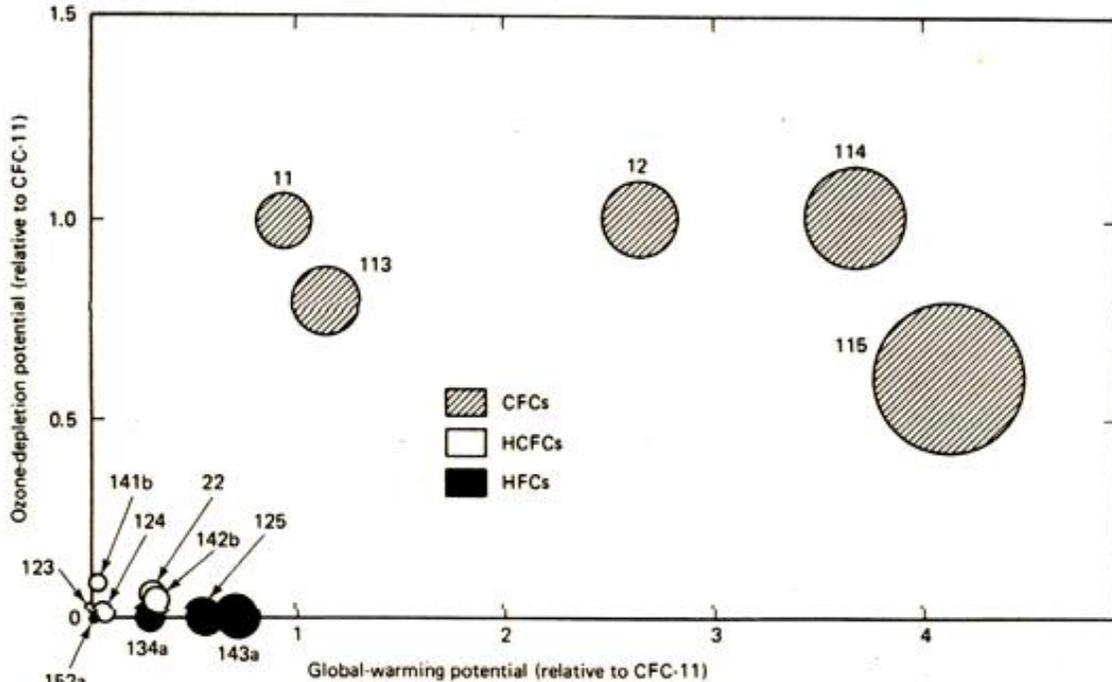


Fig: 1 CFC-12 Emission rates and Atmospheric Concentrations Rise

### 7.0 Global Warming and Ozone-Depletion Impacts of CFCs:

Since CFCs are of concern both for their ozone-depletion potential and for their impact on global temperature, it is important to pay attention to both problems when proposing replacements. Shows the relationship between ozone depletion and global-warming potentials for a number of CFCs, HCFCs, and HFCs. CFC-11 is given an arbitrary value of 1 on each axis, so the impacts of other compounds are measured relative to it. The areas of the circles are proportional to the atmospheric lifetimes of each substance.



**Fig: 2 Global warming potential and Ozone-depletion potential for fully halogenated CFCs, hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) measured relative to CFC-11. The size of the circles is proportional to atmospheric lifetimes**

Fully halogenated CFCs have long atmospheric lifetimes, contain relatively large amounts of chlorine, and absorb strongly within the 7- to 13- $\mu\text{m}$  atmospheric window. As a result, they have considerable potential to affect both global warming and stratospheric ozone depletion. For example, CFC-11 is 77 percent chlorine, has strong absorption bands at 9.22 and 11.82 $\mu\text{m}$ , and its atmospheric residence time is estimated at between 50 and 60 years. CFC-12 is 59 percent chlorine, absorbs at 8.68, 9.13 and 19.93 $\mu\text{m}$ , and its atmospheric residence time is between 55 and 400 years. As can be seen by the smaller size of the circles in fig, the HCFCs have short atmospheric lifetimes. They break down relatively quickly and thus have only modest potential to affect either ozone or global warming. The HFCs contain no chlorine to threaten the ozone layer, but they do have some potential to affect global warming.

### 8.0 The Evolution of Negotiating International Agreements:

Since the Stockholm conference on “Our Common Future” in 1972, the United Nations Environment Programme (UNEP) has been a major player on ozone depletion problem in the stratosphere in the International Environmental arena. The organization was created by the UN general Assembly in response to a UNCHE call for a new UN institution that would inspire and coordinate environmental activities primarily (but not exclusively) through the UN system. UNEP serves the international community as a clearing house for environmental monitoring data and as a facilitator of international agreements.

The process UNEP uses to foster international agreements is well illustrated by events leading up to the Montreal protocol on substances that deplete the ozone layer. UNEP is headquartered in Nairobi, Kenya, and led by an executive director.

**Table 4 The evolution of strategies to curb ozone depletion in stratosphere**

Year	Institutional setting	Trends and innovations (Agend)
1976	UNEPs Governing council	Ozone depletion one of its fire top-priority problem areas
1977	UNEP conference	World plan of action on the ozone layer
1978	Conference of UNEP coordinating committee with NGOs and representatives of Government agencies	Establishing priorities for scientific research to delineate the depletion of ozone problems.
1981	UNEP Ad HOC working group of Legal and Technical expert group	Elaboration of a framework convention for the protection of ozone layer
1982	UNEP Ad HOC working group of Legal and Technical expert group	Formalizing international law making on ozone depletion problems and initiation of convention on legal frame work
1985	Vienna convention for the protection of ozone layer	Convention setout an agenda for research and information exchanges but it did not include any specific obligations
1987	UNEP coordinating committee	Finalization of montreal protocol agenda and initiation of negotiations
1989	Montreal protocol convention	Binding obligations to make CFC reductions in phased manner in regard to 1986 production and consumption rates 50% reduction by 2000.
1990-2011	UNEP sponsored meetings	Strengthening of montreal protocol.

### 9.0 Implementation in phase-out of CFCs:

- Illegal imports of CFCs are a problem in several countries including India, China, Russia and USA.

**Table 5 Illegal trade or Smuggling of CFCs**

Sl. No	Year	Smuggled from	Smuggled into	Quantity (tons)
1.	Sep-2011	Republic of China	Japan	108.5
2.	1995-99	Miami	USA	10,000
3.	1999-2000	Nepal and Bangladesh	India	800
4.	Sep-2000	Nepal and Bangladesh Malasia	Pakistan Vietnam	1426

- In the U.S. for example, over 1 million pounds of illegally imported CFCs were seized by federal authorities in 1995 and second largest illegal import.
- Replacements for CFCs

Applications and replacements for CFCs		
Application	Previously used CFC	Replacement
Refrigeration & air-conditioning	CFC-12 (CCl <sub>2</sub> F <sub>2</sub> ); CFC-11(CCl <sub>3</sub> F); CFC-13(CClF <sub>3</sub> ); HCFC-22 (CHClF <sub>2</sub> ); CFC-113 (Cl <sub>2</sub> FCCClF <sub>2</sub> ); CFC-114 (CClF <sub>2</sub> CClF <sub>2</sub> ); CFC-115 (CF <sub>3</sub> CClF <sub>2</sub> );	HFC-23 (CHF <sub>3</sub> ); HFC-134a (CF <sub>3</sub> CFH <sub>2</sub> ); HFC-507 (a 1:1 azeotropic mixture of HFC 125 (CF <sub>3</sub> CHF <sub>2</sub> ) and HFC-143a (CF <sub>3</sub> CH <sub>3</sub> )); HFC 410 (a 1:1 azeotropic mixture of HFC-32 (CF <sub>2</sub> H <sub>2</sub> ) and HFC-125 (CF <sub>3</sub> CF <sub>2</sub> H))
Propellants in medicinal aerosols	CFC-114 (CClF <sub>2</sub> CClF <sub>2</sub> )	HFC-134a (CF <sub>3</sub> CFH <sub>2</sub> ); HFC-227ea (CF <sub>3</sub> CHF <sub>2</sub> CF <sub>3</sub> )
Blowing agents for foams	CFC-11 (CCl <sub>3</sub> F); CFC 113 (Cl <sub>2</sub> FCCClF <sub>2</sub> ); HCFC-141b (CCl <sub>2</sub> FCH <sub>3</sub> )	HFC-245fa (CF <sub>3</sub> CH <sub>2</sub> CHF <sub>2</sub> ); HFC-365 mfc (CF <sub>3</sub> CH <sub>2</sub> CF <sub>2</sub> CH <sub>3</sub> )
Solvents, degreasing agents, cleaning agents	CFC-11 (CCl <sub>3</sub> F); CFC-113 (CCl <sub>2</sub> FCClF <sub>2</sub> )	None

- Problems exist in enforcing bans on the use of CFCs. In many countries, production of CFCS ended up, but the chemicals could still be used in existing equipment.

- Total ban of CFC use would interfere with life styles in many developed countries. Refrigeration has become almost a necessary, and luxuries such as air conditioning in buildings and cars are considered the norm.
- Environmentally safe alternatives to CFCs for variety of industrial use shall be chiefly available.

#### 10.0 A SUSTAINABLE EMISSION LEVEL:

A sustainable development was defined by the World Commission on Environment and Development (1987) as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

On the basis of observations on developments in the chlorine content of the stratosphere, it is believed that a content of 1.5-2 ppbv of chlorine in the stratosphere will not cause formation of Antarctic ozone holes (UKSORG, 1990); 0.6 ppbv of this chlorine is attributed to a natural marine production of methyl chloride. The stratospheric concentration of chlorine is currently ca. 3.4 ppbv (Nielsen, 1994), but in 1970 the atmospheric chlorine loading from halocarbons was ca. 1.5 ppbv and in 1975 it was a bare 2.0 ppbv (Pratheretal., 1991). With the above operationalization of the concept of sustainability, the emissions in 1970 could thus give an order of magnitude for a sustainable impact from ozone depleting substances, i.e. an emission scenario, which will lead in the long term to an atmospheric concentration (and thus also a stratospheric concentration) of 1.5 ppbv.

If it is assumed for the individual halocarbons that the emissions in 1970 and 1990 have the same mutual ratio as the atmospheric concentrations in these two years, it is possible to calculate an order of magnitude for the emission of halocarbons in 1970. The assumption is not entirely unjustified as gases on average reach the stratosphere 3-5 years after emission (Solomon and Albritton, 1992).

The above emission scenario gives the total emission of halocarbons with an ozone depletion potential of 281kt CFC11-eq/year.

#### Environmental space:

With a global population 2010 of 630 billion, this corresponds to a sustainability-based global reference emission of ozone depleting substances of 45gCFC11-eq/person/ year.

The goal of a sustainable development has not been implemented by any country, but for many countries it is the ideal goal, which their environmental policy must strive to achieve in the longer term.

The politically determined reduction targets for stratospheric ozone depletion today are dictated by the desire for sustainability to a higher degree than for any of the other environmental impact categories. As has been demonstrated, the political reduction targets are even more far-reaching than the sustainability scenario just calculated. On the one hand this reflects the serious political concern for the possible consequences of ozone depletion, and on the other hand it reflects the favourable technical options for substitution of the ozone depleting substances by ozone-neutral alternatives.

#### References:

1. Abbatt, J.P.D, and Molina, M.J. 1993. Status of stratospheric ozone depletion. Annual Review of Energy and the Environment, 18, 1-29.
2. Benedick, R.E 1991. Ozone diplomacy: New directions in safeguarding the planet. Harvard University Press, Cambridge, MA.
3. Center for Investigative Reporting and B. Moyers. 1990. Global Dumping Ground. Washington, D.C. Seven Locks Press.
4. Chin, K. 1996 coustoms, EPA Crack Down on CFC crooks Chemical Engineering 103(4), 43-51.
5. Derwent, R.G. Grennfelt, G., and Hov, Ø. (1991) Photochemical oxidants in the atmosphere. Nordic Council of Ministers, Nord 1991:7, Copenhagen.
6. Elsom, D.M. 1995 Atmospheric pollution: A Global Problem, 2<sup>nd</sup> ed. Oxford: Blackwell.
7. Fisher, D.A., Hales, c.H., Filkin, D.L., Wo, M.K.W., Sze, N.D., Connell. P.S., Wuebbles, D.J., Isaksen, I.S.A., and Stordal, F. (1990) Model calculations of the relative effects of CFCs and their replacements on stratospheric ozone. Nature, 344, 508-512.

8. Karentz, D. (1992) Stratospheric ozone depletion and the Antarctica marine ecosystem. Greenpeace U.K., 1992.
9. Mahlman, J.D. (1992) A looming Arctic ozone hole? *Nature* 360, 209-210, 1992.
10. Molina, M.J. and Rowland, F.S. 1974 Stratospheric sink for chlorofluoromethanes. Chlorine-atom catalyzed destruction of ozone. *Nature*, 249, 810-812.
11. Nimitz, J.S., and Skaggs, S.R.: Estimating tropospheric lifetimes and ozone depletion potentials of one-and two-carbon hydrofluorocarbons and hydrochlorofluorocarbons. *Environ. Sci. Technol.*, 26, 739-744, 1992.
12. Prather, M., Derwent, R., Ephalt, D., Fraser, P., Sanhueza, E., and Zhou, X. (1995) Other trace gases and atmospheric chemistry. In: Houghton, J.T., Meira Filho, L.G., Bruce, J., Lee, H., Callander, B.A., Haites, E., Harris, N., and Maskell, K. (eds.): *Climate change 1994. Radiative forcing of climate change and an evaluation of the IPCC IS92 emission scenarios*. Cambridge University Press.
13. Pedersen, T. (1992) *Atmospheric chemistry: an introduction*. University of Copenhagen, Department of Chemistry.
14. Pyle, J.A., Wuebbles, D., Solomon, S., and Zvenigorodsky, S. (1991) Ozone depletion and chlorine loading potentials. World meteorological organization: Scientific assessment of stratospheric ozone: 1991 Global Ozone Research and Monitoring Project, Report no. 25, Geneva.
15. Robinson, N.A. ed. 1995. *International Environmental Law and Regulation* Charlottesville, VA: Michie.
16. Rowland, F.S. 1990. Stratospheric ozone depletion by chlorofluorocarbons *Ambio*, 19, 281-292.
17. Tolba, M.K., O.A.El-kholy, E.El-Hinnawi, M.W. Holdgate, D.F. McMichael, and R.E. Munn, eds. 1992. *The world Environment 1972-1992*, London: Chapman & Hall.
18. Solomon, S. (1990) Progress towards a quantitative understanding of Antarctica ozone depletion. *Nature*, 347, 347-354.
19. Solomon, S. and Albritton, D.L. (1992) Time-dependent ozone depletion potentials for short-and long-term forecasts. *Nature*, 357, 33-37, 1992.
20. UKSORG (1990) *Stratospheric Ozone 1990*. United Kingdom Stratospheric Ozone Research Group, H.M. Stationery Office, London.
21. United Nations Environment Programme (1993) *Handbook for the Montreal Protocol on substances that deplete the ozone layer*, 3<sup>rd</sup> edn., UNEP Ozone Secretariat, August.
22. Wenzel, H., Hauschild, M. and Alting, L.(1997) *Environmental assessment of products. Volume 1: Methodology, tools and applications in product development*. Chapman and Hall, London.
23. World Commission on Environment and Development (1987) *our common future*. Oxford University Press. U.K.
24. WMO 1990 scientific Assessment of stratospheric ozone: 1989. Vol.1. *Global ozone Research and Monitoring Project, Report No.20*, world meteorological organization, Geneva.