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Emissions Scenarios

Table of contents

Other reports in this collection

Table of contents | Previous page | Next page

5.4.3. Halocarbons and Other Halogenated Compounds

Emissions of halocarbons (CFCs, HCFCs, halons, PFCs, and HFCs) and other halogenated compounds (SF_6) on a substance-by-substance basis are described in detail in Fenhann (2000). A list of the substances covered, together with their GWPs and lifetimes (as in IPCC SAR; Houghton, et al. 1996), is given in Table 5-7.

Table 5-7:GWPs and atmospheric lifetimes of halocarbons and other halogenated compounds.

Species	Chemical Formula	100 Years GWP	Atm. Lifetime Years
CFC-11	CCl_3F	4000	50
CFC-12	CCl_2F_2	8500	102
CFC-113	CCl_2FCClF_2	5000	85
CFC-114	$CClF_2CClF_2$	9300	300
CFC-115	CF_3CClF_2	9300	1700
Carbon tetrachloride	CCl_4	1400	42
Methyl chloroform	CH_3CCl_3	110	4.9
Halon-1211	$CBrClF_2$	No data	20
Halon-1301	$CBrF_3$	5600	65
Halon-2402	$CBrF_2CBrF_2$	No data	20
HCFC-22	$CHClF_2$	1700	12.1
HCFC-141b	CH_3CFCl_2	630	9.4
HCFC-142b	CH_3CF_2Cl	2000	18.4
HCFC-123	CF_3CHCl_2	93	1.4
HFC-23	CHF_3	11700	264
HFC-32	CH_2F_2	650	5.6
HFC-43-10	$C_5H_2F_{10}$	1300	17.1
HFC-125	C_2HF_5	2800	32.6
HFC-134a	CH_2FCF_3	1300	14.6
HFC-143a	$C_2H_3F_3$	3800	48.3
HFC-152a	$C_2H_4F_2$	140	1.5
HFC-227ea	C_3HF_7	2900	36.5
HFC-236fa	$C_3H_2F_6$	6300	209
HFC-245ca	$C_3H_3F_5$	560	6.6
Perfluoromethane	CF_4	6500	50000
Perfluoroethane	C_2F_6	9200	10000
Perfluorobutane	C_4F_{10}	7000	2600
Sulfur hexafluoride	SF_6	23900	3200

Importantly, future emissions of halocarbons and other halogenated compounds strongly depend on the technologies involved in their production and use. New uses for these substances may arise or new products or technologies may replace current uses. It is assumed here that the current mix of products continues to exist for the next 100 years to 2100, with some generic technological improvements as described below. This assumption, however, means that emissions projections for industrial gases discussed in this section carry a substantial uncertainty.

Halocarbons are carbon compounds that contain fluorine, chlorine, bromine, and iodine. Halocarbons that contain chlorine (CFCs and HCFCs) and bromine (halons) cause ozone depletion, and their emissions are controlled under the Montreal Protocol and its Adjustment and Amendments. According to the 1987 Montreal Protocol and its subsequent amendments, consumption (the balance of production plus imports minus exports) of CFCs is largely banned in developed countries after January 1996 (and developing countries after 2010), although some countries have failed to meet the deadline. Furthermore, HCFC consumption will be subjected to a gradual phase-out, with cuts from the 1986 base-year values of 35%, 65%, and 90% in 2004, 2010, and 2015, respectively. Final HCFC consumption phase-out will occur in 2020 (2040 for developing countries).

The six modeling teams participating in the SRES process did not develop their own projections for emissions of ODS and their substitutes. Hence, a different approach for the development of long-range estimates for halocarbons and other halogenated compounds was adopted. First, for ODSs the external Montreal Protocol A3 maximum production scenario was used as a direct input to all SRES scenarios (WMO/UNEP, 1998), since most measures in this A3 scenario have been implemented already or are well established and under way (and so no large scenario variation is expected). For other gas species, a simple methodology to develop different emission trajectories consistent with aggregate SRES scenario driving-force assumptions (population, GDP, etc.) was developed. Also, the assumed future control rates have been adopted to conform to the SRES storylines presented in Chapter 4. The underlying literature, scenario methodology, and data are documented in more detail in Fenhann (2000) and are summarized in this section.

The resultant emissions of Montreal gases, HFCs, PFCs, and SF_6 are summarized in Table 5-8. The effect on climate of each of the substances listed in Table 5-9 varies greatly because of differences in both the atmospheric lifetime and the radiative effect per molecule of each gas. A good measure of the net climate effect of halocarbons and other halogenated compounds is provided by their radiative forcing. Radiative forcing will be addressed in IPCC's Third Assessment Report, but is not discussed in this report.

Emissions of individual groups of halocarbons and other halogenated compounds in the four families of SRES scenarios are presented below.

Table 5-8: Global anthropogenic emissions (kt) projections for ODS, HFC, PFC, and SF_6 emissions in the four marker scenarios.

	1990	2020	2050	2100

Marker Scenario		A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2
ODS	1864	253				21				1			
HFC-23	6.4	4.9	4.9	4.9	4.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
HFC-32	0.0	8.3	6.4	6.0	6.2	24.3	14.0	13.9	14.1	30.3	32.8	12.9	25.9
HFC-43-10	0.0	8.8	7.6	6.9	7.2	18.1	10.7	10.7	11.1	30.3	21.8	10.4	17.9
HFC-125	0.0	27.1	20.7	20.6	21.5	80.4	45.6	47.9	48.7	100.8	106.5	44.3	89.1
HFC-134a	0.0	325.5	252.2	248.8	261.9	931.0	506.4	547.4	561.2	980.3	1259.8	486.0	1079.3
HFC-143a	0.0	20.6	16.0	15.0	15.6	60.9	35.1	34.8	35.4	75.7	82.1	32.2	64.7
HFC-227ea	0.0	22.2	16.6	18.5	19.7	62.1	31.5	39.4	40.7	60.6	80.4	34.4	80.0
HFC-245ca	0.0	100.5	78.7	80.3	85.4	292.3	149.2	172.6	178.5	288.5	388.0	150.2	352.7
HFCs-total	6.4	517.9	403.0	401.0	422.4	1470.2	793.5	867.8	890.8	1567.3	1972.4	771.4	1710.5
CF_4	15.8	21.1	25.2	15.7	27.1	43.8	45.6	20.9	52.7	57.0	88.2	22.2	59.9
C_2F_6	1.6	2.1	2.5	1.6	2.7	4.4	4.6	2.1	5.5	5.7	8.8	2.2	6.0
PFCs, total	17.4	23.2	27.7	17.3	29.8	48.2	50.2	23.0	58.2	62.7	97.0	24.4	65.9
SF_6	5.8	7.3	9.7	5.7	8.4	18.3	16.0	10.4	12.1	14.5	25.2	6.5	10.6

Notes: ODS emissions are from scenario A3 in the UNEP/WMO Scientific Assessment of Ozone Depletion (UNEP/WMO, 1998).

5.4.3.1. Hydrofluorocarbons

HFCs are beginning to be produced as replacements for CFCs and HCFCs. Unlike the CFCs and the HCFCs, HFCs do not convey chlorine to the stratosphere and thus do not contribute to ozone depletion.

For the development of future HFC emissions, Fenhann (2000) used a procedure based on the work by Kroeze (1995) that includes two steps:

- "Virtual" future CFC emissions are first calculated assuming a situation without the Montreal Protocol.
- CFCs are substituted with HFCs according to substitution percentages adopted from the literature (Table 5-9) and also the various degrees of emission reduction potentials from better housekeeping measures and technological change.

Concerning the first step of the methodology used in Fenhann (2000), 1990 CFC emissions were taken from the Scientific Assessment of the Ozone Depletion (WMO/UNEP, 1998). Pre-Montreal 1986 emissions were obtained from McCulloch et al. (1994). Future "virtual" (assuming no Montreal protocol) emissions of CFCs were assumed to be proportional to their consumption, for which GDP numbers in the four marker scenarios were used as a driver (see Chapter 4). The saturation level of per capita demands was assumed to be the same in all four SRES scenario families.

The projection of CFC emissions in the absence of the Montreal Protocol shows how emissions would change under conditions of unrestricted production. However, with the Montreal Protocol in place, other chemical compounds will be used to replace the Montreal gases. To compute the amount of CFCs replaced with these other compounds, future CFC emissions with the Montreal Protocol in place (according to the WMO/UNEP A3 ODS scenario) were first subtracted from the "virtual" CFC emissions.

Different assumptions about CFC applications as well as substitute candidates were developed (Fenhann, 2000). These were initially based on Kroeze and Reijnders (1992) and Midgley and McCulloch (1999), and subsequently updated using the latest information from the *Joint IPCC/TEAP Expert Meeting on Options for the Limitation of Emissions of HFCs and PFCs* (WMO/UNEP, 1999).

An important assumption (based on the latest information from the industry) used in the current analysis is that relatively few Montreal gases will be replaced completely by HFCs. Currently, HFC-134a is favored, and it is the only HFC with sufficiently large sales to be included in the current production and sales statistics (AFEAS, 1998). The global emissions of this gas are estimated to be 0.1 kt HFC-134a in 1990 and 42.7 kt HFC-134a in 1997. Current data indicate that substitution rates of CFCs by HFCs will be less than 50%. It was shown recently that in the European Union the substitution rate of CFCs by HCFCs was 26%, and the HFC share was 6% or a total of 32% (McCulloch and Midgley, 1998). Time series data for the global sales from AFEAS (1998) confirm a 763 kt per year reduction in CFC production and use from the peak production year of 1987 through 1996. An increase in the total HFC and HCFC production and use was 340 kt per year, or a 44% substitution up to 1996. In Fenhann (2000) future technological developments are assumed to result in about 25% of the CFCs ultimately being substituted by HFCs (Table 5-9). This low percentage not only reflects the introduction of non-HFC substitutes, but also the notion that smaller amounts of halocarbons are used in many applications when changing to HFCs and that emissions are reduced by increased containment and recycling. A general assumption is that the present trend to not substitute CFCs with high GWP substances, including PFCs and SF6, will continue. The substitution rates shown in Table 5-9 were used in all four scenarios; the technological options adopted are those known at present. Further substitution away from HFCs is assumed to require a climate policy.

Table 5-9: Substitution of CFCs by HFCs and PFCs.

Application	**From**	**HFC-23**	**HFC-32**	**HFC-43-10**	**HFC-125**	**HFC-134a**	**HFC-143a**	**HFC-152a**	**HFC-227ea**	**HFC-236fa**	**HFC-245fa**	**C4F10**	**Total**
Aerosols	CFC					4.0%			4.0%				8.0%
Cleaning/drying	CFC			0.5%									0.5%
Open cell foams	CFC												0.0%
Closed cell foams	CFC					25.0%					25.0%		50.0%
Stationary cooling	CFC		2.0%		5.0%	25.0%	5.0%						37.0%
Stationary cooling	HCFC -22		2.0%		5.0%	25.0%	5.0%						37.0%
Mobile cooling	CFC					25.0%							25.0%
Fire extinguisher (portable)	Halon-1211								1.0%				1.0%
Fire extinguisher (fixed)	Halon-1301								25.0%				25.0%
Other uses	CFC				5.0%	5.0%							10.0%

Hydrocarbons are expected to be the substitutes used in the aerosols/propellant sector, except for situations in which the flammability of hydrocarbons would be a problem and also in metered dose inhalers (to avoid possible adverse clinical effects). HFC-227ea and HFC-134a, and possibly HFC-152a are expected to replace hydrocarbons (Table 5-9; WMO/UNEP, 1999).

CFC-113 was used extensively as a cleaning solvent for metal, electronics, and textiles. The general trend in this area now is toward water-based systems. However, as suggested by Table 5-9 a small fraction (0.5%) of the CFC in this sector is substituted by HFC-43-10 (Kroeze, 1995).

The WMO/UNEP (1998) report states that no fluorocarbons are now used for *open cell foams*, an assumption also adopted in the scenarios.

It is expected that closed *cell foams* and *refrigeration* will be the largest demand sectors for HFCs in the future. For *closed cell* foams, the substitution is expected to be 50%, one-half as HFC-134a and the other half as the liquid HFC-245fa (expected to be commercially available by 2002; Table 5-9) (Ashford, 1999). In some cases, HFC-365mfc will be used instead of HFC-245fa. However, all the calculations in Table 5- 9 were carried out for HFC245fa, since these two substances have almost the same climate effect.

Prior to 1986, the main refrigerants in use were CFCs, HCFCs, and ammonia. In response to the Montreal Protocol, HFC and hydrocarbon refrigerants have been promoted as the primary alternatives (WMO/UNEP, 1999). The main HFC assumed to be used for stationary cooling is HFC-134a, with 5% of the demand substituted by HFC-125 and another 5% by HFC-143a (Kroeze, 1995). This would agree with the reported measurements of these two substances in the atmosphere. According to Kroeze (1995) about 2% might be substituted by HFC-32.

Before 1993, all air-conditioned cars were equipped with systems using CFC-12 as a refrigerant. Over the lifetime of a car, 0.4 kg of this halocarbon was emitted every year. In 1994, two years after the new refrigerant HFC-134a had become available globally in sufficient quantities, almost all major vehicle manufacturers began to use HFC-134a. This conversion was accompanied by a significant reduction in annual losses of refrigerants per car, down to 0.096 kg of halocarbon (Preisegger, 1999). Therefore the substitution rate in Table 5-9 for mobile cooling is assumed to be 25%.

In the fixed fire extinguishers sector, only about 25% of the systems that formerly used halons now use HFCs, mainly HFC-227ea. The rest use CO_2 , inert gas mixtures, water-based systems, foam, dry powder, etc. (WMO/UNEP, 1999). Increased environmental awareness in the industry is assumed to have resulted in the reduction of HFC emissions by a factor of three, compared to former practice.

For portable fire extinguishers the substitution rate is assumed to be only 1%, even less than the 2% assumed by Kroeze (1995).

CFCs have also been used for other purposes, such as sterilants, tobacco expansion, and others. Kroeze (1995) assumes a 30% substitution by HFCs. However, in the SRES scenarios this value is reduced to 10% to remain consistent with the above assumption that HFCs ultimately will substitute for about 25% of the CFCs.

As well as using non-halocarbon substitutes, HFC emissions can be avoided by better housekeeping, for instance by reduced spilling of cooling agents. Leakage control equipment can also serve this purpose. Finally, halocarbons can be recovered for recycling or destruction when equipment is discarded. Some of this emission reduction potential is likely to be implemented as a result of technological changes introduced to control ODSs. In the SRES scenarios, reduction rates were varied over time and between industrialized and developing countries to reflect the definitive features of the underlying storylines (Chapter 4). Generally, the reduction rates are assumed highest in scenarios that emphasize sustainability and environmental policies (B1 family). These reductions, however, were not associated with any explicit GHG reduction policies, as required by the SRES Terms of Reference (see Appendix I). In one scenario family, A2, no reductions were assumed, whereas in the A1 and B2 families reduction rates were set at intermediate levels.

In addition to consumption-related emissions of HFCs, HFC-23 is emitted as an undesired by-product from the HCFC-22 production process. As a result of the Montreal Protocol, the direct use of HCFC-22, and hence the related HFC-23 emissions, will come to a halt in 2050. To calculate the HFC-23 emissions, information from Oram et al. (1998) was used (estimated emissions of HFC-23 at 6.4 kt in 1990). By relating this value to 178.1 kt HCFC-22 emitted in 1990 (WMO/UNEP, 1999), an emissions factor of 0.036 tons of HFC-23 per ton of HCFC-22 was calculated and applied to estimate future emissions. Since this estimation procedure does not take into account any pollution control regulations (that are not driven by climate considerations), it may result in an overestimation of HFC-23 during the early decades of the 21 st century, until HCFC production is phased out under the Montreal Protocol. After the phase-out of HCFC-22 consumption, some HFC-23 emissions will still occur because of the continued HCFC-22 feedstock production allowed under the Montreal Protocol. The resultant projections are shown by individual HFC in Table 5-8.

In general, the SRES scenarios might underestimate HFC emissions if the substitution of CFCs with alternatives that have no radiative forcing effect and with more efficient HFCs-based technologies does not penetrate as quickly as is assumed, especially in developing countries. However, more effective technologies and/or suitable non-HFC alternatives may be developed, which would lead to even lower emissions.

Table of contents | Previous page | Next page
Other reports in this collection

IPCC Homepage