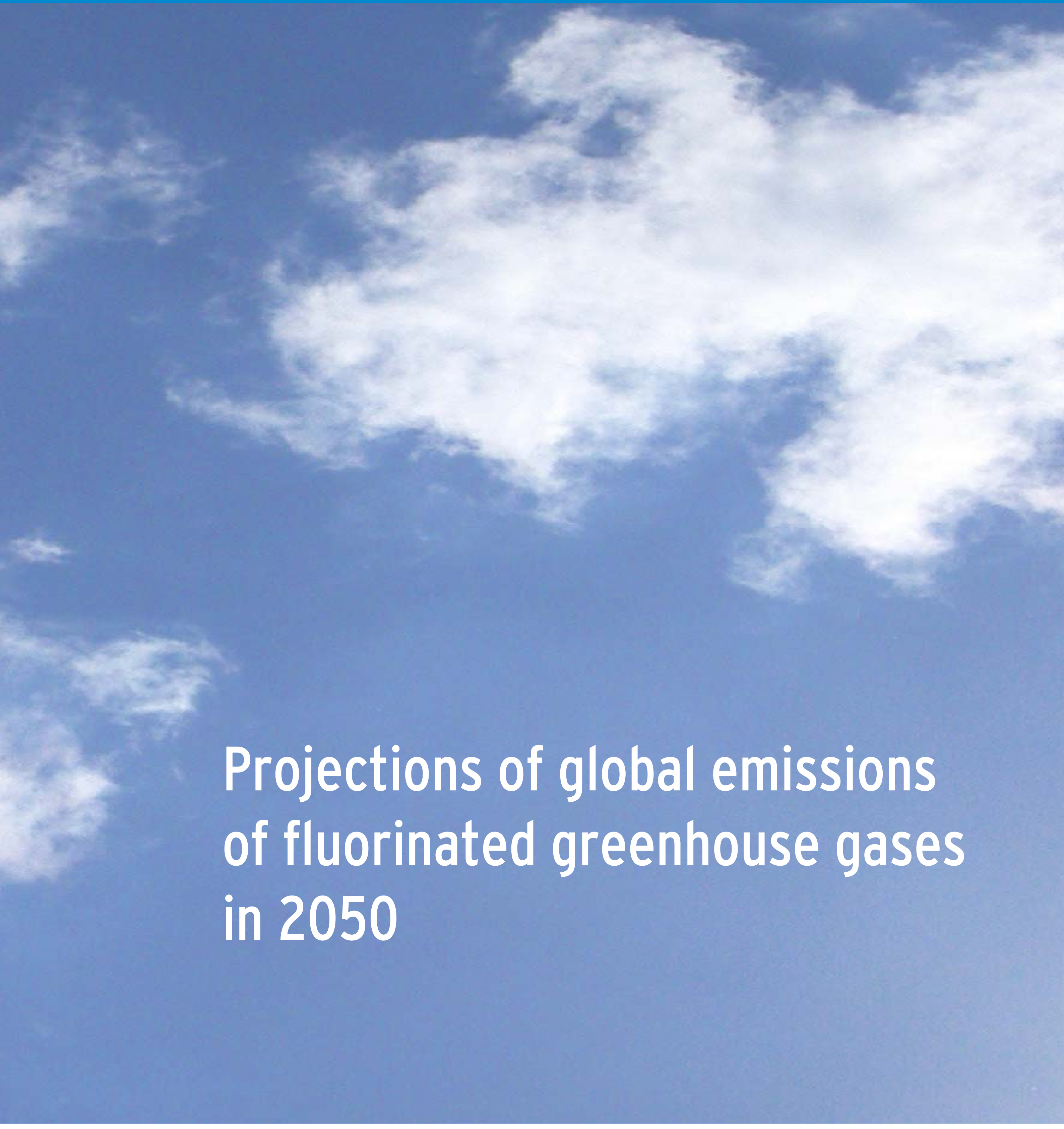

Projections of global emissions of fluorinated greenhouse gases in 2050

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Projections of global emissions of fluorinated greenhouse gases in 2050

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UMWELTBUNDESAMT

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Content

Summary

Emissions of fluorinated greenhouse gases are currently covered under the Montreal Protocol, which focuses on ozone-depleting substances such as CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons), and under the Kyoto Protocol, which controls emissions of HFCs (hydrofluorocarbons), PFCs (perfluorocarbons) and SF_6 (sulfur hexafluoride). This study bridges the gap between political regimes and their reporting systems by giving an overview of banks and emissions of all fluorinated gases in 2005, and projections of banks and emissions of fluorinated gases in 2050.

The Montreal Protocol and its amendments will eventually result in the full phase out of CFCs and HCFCs. Developed countries have already completed the phase out of CFCs and will reach full phase out of HCFCs by 2020. Developing countries, in contrast, will phase out CFCs by 2010 and HCFCs by 2030. Although climate-friendly technology is available for most applications, the risk occurs that substitutes for ozone-depleting substances rely on HFCs, which cause global warming.

This study determines global emissions of HFCs, PFCs and SF_6 (Kyoto F-gases) in 2050 in a "business-as-usual" scenario. The global population is expected to increase to ca. 8.7 billion people, and high economic growth of 3.5% per year is assumed. Emissions in 2050 are quantified for each sector of application as well as for developed and developing countries based on growth rates of each sector.

In 2050, total global emissions of fluorinated greenhouse gases are projected to amount to 4 GT CO_2 eq. which equals ca. 5.9% of the total greenhouse gas emissions at this time. Compared to a relatively small share of F-gas emissions ranging around 1.3% of total greenhouse gas emissions in 2004, this percentage reflects an enormous increase. Relative to projected direct CO_2 emissions alone, the 2050 F-gas emissions will even account for ca. 7.9%. In case of CO_2 mitigation, this share would be significantly higher.

The commercial refrigeration sub sector and the air conditioning (stationary and mobile) sector will account for about 75% of F-gas emissions in 2050. In most sectors, emissions from developing countries will exceed emissions from developed countries. Large banks of HFCs will cause F-gas emissions well beyond 2050.

In order to limit F-gas emissions, it appears crucial to consider measures to reduce emissions from all sectors in both developed and developing countries. The current post-Kyoto negotiation process might provide an opportunity to address these issues within a wider scope. A switch from substances that cause global warming to climate friendly alternatives is considered inevitable to be undertaken in the near future in developed countries. Developing countries, in contrast, are facing the chance to replace ozone-depleting substances directly by climate friendly alternatives, and could hence benefit from technologies developed in the last decades.

The study does not exclude other scenarios on future HFC emissions. Like earlier projections, it underlines the urgent need for mitigation measures of F-gas emissions.

Frankfurt/Main, October 2009

1. Current global emissions of fluorinated greenhouse gases

1.1 Global quantity and share of emissions of fluorinated greenhouse gases

Since 1987, the **Montreal Protocol** and its amendments control production and consumption of ozone depleting substances (ODS). Presently, the regulations apply to 96 chemicals including chlorofluorocarbons (CFCs), halons, hydrobromofluorocarbons (HBFCs), hydrochlorofluorocarbons (HCFCs), and others. Most of the fluorinated ozone-depleting substances (CFCs, HCFCs) are being phased out which has resulted in a significant decrease of ODS production and consumption all over the world since the 1980s.

However, most of the ODS substitutes (HFCs, PFCs) are greenhouse gases which contribute to climate change. Some of the substitutes are hence covered under the **United Nations Framework Convention on Climate Change** (UNFCCC, 1994) and its **Kyoto Protocol** (adopted 2005), which is an agreement on legally binding measures to reduce greenhouse gas emissions.

The UNFCCC stipulates that emissions of greenhouse gases are reported by those countries that have acceded to the Convention (to date 192 countries) in order to tackle the challenge posed by climate change. The UNFCCC requirements do not apply to CFCs and HCFCs already controlled by the Montreal Protocol.

The Kyoto Protocol promotes emission reductions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). HFCs, PFCs and SF_6 are often summed up in the term “fluorinated greenhouse gases” or “**F-gases**”. In this study, they are referred to as “Kyoto F-gases” or “chlorine-free F-gases”. In January 2009, 183 parties had ratified the Kyoto Protocol, out of which 41 developed countries (Annex 1) committed themselves to emission reduction targets. The USA is the only Annex 1 country to the UNFCCC who did not ratify Kyoto Protocol.

In general, fluorinated ozone-depleting substances and Kyoto F-gases are characterized by a long atmospheric lifetime and are therefore estimated to highly contribute to global warming over a long time span. Thus, their **global warming potential (GWP)** is relatively large, and they are sometimes referred to as “high GWP gases”. The IPCC calculates a short term GWP (20 years), a medium term GWP (100 years) and a long term GWP (500 years) for each greenhouse gas. They are referred to as GWP_{20}, GWP_{100} and GWP_{500}.

Under the Kyoto Protocol, the Conference of the Parties decided that the values of GWP_{100} calculated for the IPCC Second Assessment Report (1996) are to be used for converting the various greenhouse gas emissions into comparable CO_2 equivalents when computing and reporting overall sources and sinks. However, the values of GWPs are updated regularly. In this study, GWPs from IPCC 2007 were used (Table 1) unless other GWPs are indicated.

This study focuses on current and future global emissions of fluorinated greenhouse gases. Projections for emissions of fluorinated greenhouse gases in the year 2050 are based on current trends and emissions in developed and developing countries.

Table 1:
Global warming potentials (GWPs) of various fluorinated greenhouse gases

	IPCC 1996	IPCC 2007
Gas	GWP 100	GWP 100
Carbon dioxide (CO_2)	1	1
Methane (CH_4)	21	25
Nitrous oxide (N_2O)	310	298
HFC-23	11,700	14,800
HFC-32	650	675
HFC-125	2,800	3,500
HFC-134a	1,300	1,430
HFC-143a	3,800	4,470
HFC-152a	140	124
HFC-227ea	2,900	3,220
HFC-236fa	6,300	9,810
HFC-245fa	560	1,030
HFC-365mfc	n. e.	794
HFC-43-10mee	1,300	1,640
NF_3	n. e.	17,200
CF_4 (PFC-14)	6,500	7,390
C_2F_6 (PFC-116)	9,200	12,200
C_3F_8 (PFC-218	7,000	8,830
c-C_4F_8 (PFC-318)	8,700	10,300
SF_6	23,900	22,800

n. e. = not estimated

In 2004, global greenhouse gas emissions of ca. 40.5 GT CO_2 eq. were reported (emissions from land use, land use changes and forestry excluded; IPCC, 2007). So far, the share of Kyoto F-gases in global greenhouse gas emissions has been relatively small and ranged around 1.3% of global emissions in 2004 (Diagram 1). However, reported emissions of Kyoto F-gases increased 20% since 1995, which is the base year for these substances in most countries (Netherlands Environmental Assessment Agency, 2006).

Developed countries under the UNFCCC (Annex 1 countries) are obliged to annually report their emissions to the UNFCCC Secretariat. The list of Annex 1 countries comprises 40 parties including most European countries, Turkey, the United Kingdom, the Russian Federation, Japan, Australia, New Zealand, and North America. Under the Kyoto Protocol, emissions of HFCs, PFCs and SF6 caused by developed countries are assessed and monitored. Greenhouse gas emissions from Annex 1 parties currently account for 63.7% of total greenhouse gas emissions (UNFCCC, 2009).

It has to be noted that IPCC estimations of emissions mostly focus on CO_2, N_2O and CH_4, whereas emissions of fluorinated greenhouse gases are neglected due to their small share. The 2004 database of fluorinated greenhouse gas emissions has not been updated since.

Diagram 1:

Global emissions of greenhouse gases (CO_2, CH_4, N_2O, F-gases) in 2004 (IPCC, 2007). Global greenhouse gas emissions amounted to ca. 40.5 GT CO_2 eq. (excluding land use, land use change and forestry). Kyoto-F-gases were estimated to account for 0.54 GT CO_2 eq. (1.3%).

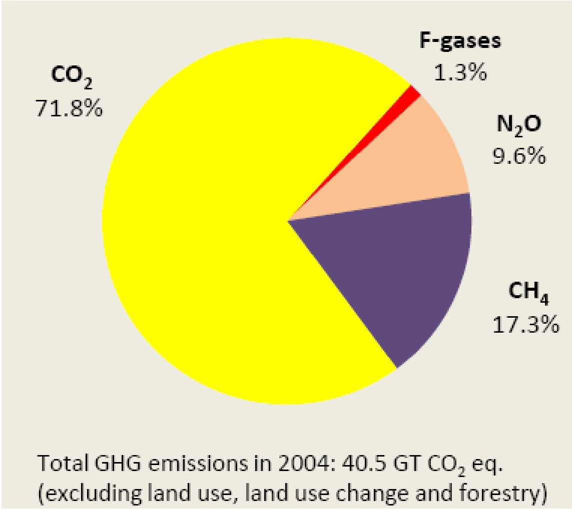


Table 2 shows total greenhouse gas emissions, total emissions of Kyoto F-gases and emissions of HFCs, PFCs and SF_6 in **developed countries** (Annex 1 countries) in 1990, 2000 and 2006 as reported to the UNFCCC.

We estimate, however, that the reported data actually underestimate emissions of Kyoto F-gases. This is due to the facts that, firstly, not all sectors of application are reported by the countries, and secondly, not all Annex 1 countries did report emissions of Kyoto F-gases which, however, do occur undoubtedly.

Table 2: Total greenhouse gas emissions, total emissions of F-gases (MT CO_2 eq.) and share of F-gases (%; HFCs, PFCs, SF_6) in Annex 1 countries in 1990, 2000 and 2006 as reported to the UNFCCC Secretariat. (UNFCCC website)

Annex 1 countries	**1990**		**2000**		**2006**	
	MT CO_2 eq.	%	MT CO_2 eq.	%	MT CO_2 eq.	%
Total GHG emissions	23,157	100	21,734	100	22,171	100
Total F-gases	326	1.4	349	1.6	366	1.6
HFCs	128	39	231	66	278	76
PFCs	97	30	64	18	43	12
SF_6	101	31	54	16	45	12

Although the share of total Kyoto F-gas emissions has not increased from 2000 to 2006 (1.6%), the absolute amount of emissions has increased from 349 MT CO_2 eq. in 2000 to 366 MT CO_2 eq. in 2006. This is mostly due to a rise of emissions of HFCs used as substitutes for ODS which were being phased out in developed countries in the respective time period. The share of HFC emissions in total Kyoto F-gas emissions rose from 39% in 1990, just some years after the adoption of the Montreal Protocol, to 66% in 2000 and 76% in 2006.

A comparison of Kyoto F-gas emissions from Annex 1 countries with total global emissions indicates that developed countries accounted for 65% in 2004.

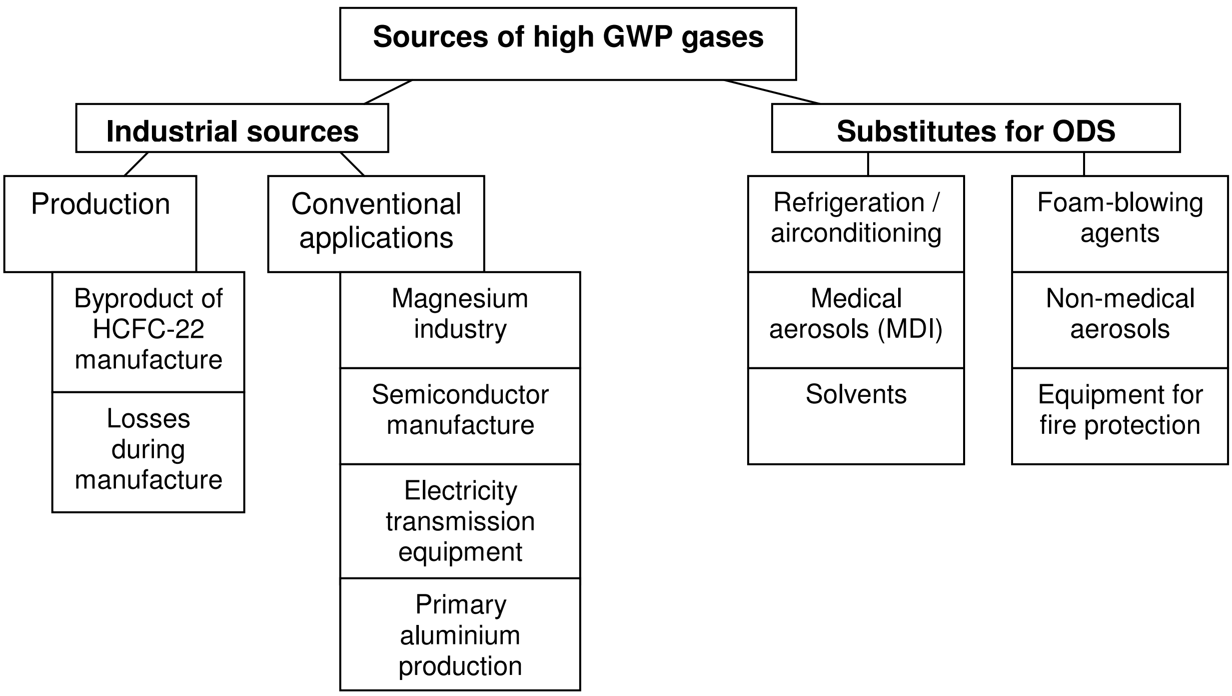
1.2 Emission sources of Kyoto F-gases

Emissions of Kyoto F-gases occur during both their production and their use in industrial applications (Diagram 2). Production emissions are much smaller than emissions arising from use (and decommissioning) of the products.

- **Manufacturing and distribution emissions** result from unintentional losses during manufacture of F-gases in the Chemical industry, from charging of equipment, and from container management. In addition, the undesired by-product HFC-23 arises during the production of HCFC-22.
- **"Conventional applications"** which were introduced in the 1970s such as electric switch gear systems, manufacture of semiconductors, magnesium manufacturing (EPA, S.4-1). (Primary aluminium production is also included in this category.) These sectors of application are usually not included as F-gas emission sectors in the IPCC reports.

Diagram 2:

Emission sources of high GWP gases.



- Kyoto F-gases are used widely as **substitutes for ODS** in a variety of applications, such as refrigeration, stationary and mobile air conditioning, foams, metered dose inhalers (MDI), non-medical aerosols, solvents, and equipment for fire protection, which used to contain ODS. In the early stages of the Montreal Protocol, HCFCs were introduced as interim replacements for CFCs (and halons) in some parts of the world, where they now get substituted by HFCs or low GWP alternatives. In developing countries, however, conversion from CFCs and halons to ODS-substitutes continues.

Despite a significant decrease in production and use of ODS, the quantity of material contained in existing equipment remains considerably large (IPCC SROC, 2005).

1.3 Growing banks of fluorinated greenhouse gases

Banks are the total amount of substances contained in existing equipment, chemical stockpiles, foams and other products which are not yet released to the atmosphere. Although the magnitude of banks remains uncertain, their contribution to global warming is expected to be comparable with that of HFC emissions to the atmosphere in the next few decades.

The UNFCCC addresses anthropogenic emissions by sources of all greenhouse gases not included in the Montreal Protocol. Its Kyoto Protocol regulates emissions of CO_2, N_2O, CH_4, HFCs, PFCs and SF_6. In contrast, the Montreal Protocol, (which deals with ODS only), does not take emissions into account, but rather production and consumption. Therefore, emissions due to releases of CFCs and HCFCs from banks are covered neither by the Montreal Protocol nor the UNFCCC/ Kyoto Protocol. (IPCC SROC, 2005)

Current emissions profiles of ODS and their substitutes are largely determined by historical use patterns. The **bank-turnover** varies for different applications from months (e.g. solvents) to several years (refrigeration) to several decades (foam insulation). The banks stored in equipment and foams leak during use of the products and at the end of the product life-cycle if not recovered or destructed.

Since banks of CFCs and HCFCs are estimated and monitored under the Montreal Protocol, data on quantity and emissions are updated quite regularly. Banks of HFCs, however, are not covered by any global regime, and, thus, are not observed globally.

Global CFC banks currently amount to 450,000 t mostly installed in developing countries (70%). **HCFCs** (mainly HCFC-22) form the dominant **refrigerant banks** of ca. 1,500,000 t which equals about 60% of the global total amount of refrigerants in use. Two thirds of the HCFC banks are installed in developing countries. (RTOC Assessment Report 2006)

Without any bank management, future emissions will be determined significantly by the **build-up of HFC banks** from HFCs substituting ODS in both developed and developing countries. **HCFC banks** will continue growing in developing countries only because production and consumption of HCFCs can continue in these countries until 2030.

In this study, the growing Kyoto F-gas banks in both developed and developing countries play a key role for the emission projections.

1.4 Emissions of chlorine-containing and chlorine-free F-gases

The Kyoto Protocol refers to just a small share of global emissions of fluorinated greenhouse gases as chlorine and bromine containing F-gases are excluded by definition. Since the Montreal Protocol includes chlorine and bromine containing F-gases such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and halons, it was decided not to treat them any further in the Kyoto Protocol which, consequently, applies to chlorine-free and bromine-free F-gases only. Emissions of chlorine and bromine containing F-gases (Montreal Protocol) accounted for 15% of the global direct GHG emissions in 1990.

Before 1990, emissions of chlorine-free F-gases were not caused by ODS substitutes yet but were released from industrial applications only, which were mostly introduced in the 1970s (**"conventional applications"**). Emissions from conventional applications include

- HFC-23 from the production of HCFC-22;
- SF_6 from electrical equipment, magnesium manufacturing, sound-proof glassing, soles of sports shoes, car tyres, military aircraft radars, nuclear industry (uranium hexafluoride production) etc.;
- PFCs from primary aluminium production and manufacturing of semiconductors.

In total, the emissions of HFC-23, SF_6 and PFCs from conventional applications amounted to about 30,000 metric tons in 1990, which accounted for approximately 0.34 GT CO_2 eq. These emissions remained at the same level through 2000. An increase of fluorinated greenhouse gas emissions throughout the last years has been caused completely by ODS-substitutes. During the 1990s, substitutes for chlorine containing F-gases (ODS) were developed and introduced in most sectors such as refrigeration, air conditioning, aerosols, solvents, fire protection and foams.

Since 1991, the **emissions of chlorine-free F-gases** have been driven significantly by production and consumption of **ODS substitutes**. Yet, not all of the applications of HCFCs and CFCs in 1990 were replaced by HFCs as the ban of ODS has also resulted in a series of innovative methods and substances which do affect neither the ozone layer nor the climate. CFCs and HCFCs have hardly been substituted in aerosols, solvents, and fire extinguishing equipment. Concerning emissions of ODS-substitutes, it should be emphasized that the GWP of HFCs is considerably lower than the GWP of most CFCs.

In the "business as usual" scenario of this study, we assume that CFCs and HCFCs (chlorine-containing gases) currently used in various applications will become substituted to some extent by HFCs, which then will contribute to HFC emissions, but also by other alternatives such as natural refrigerants and blowing agents. The **share of non-HFC substitutes** for ODS varies between applications and regions.

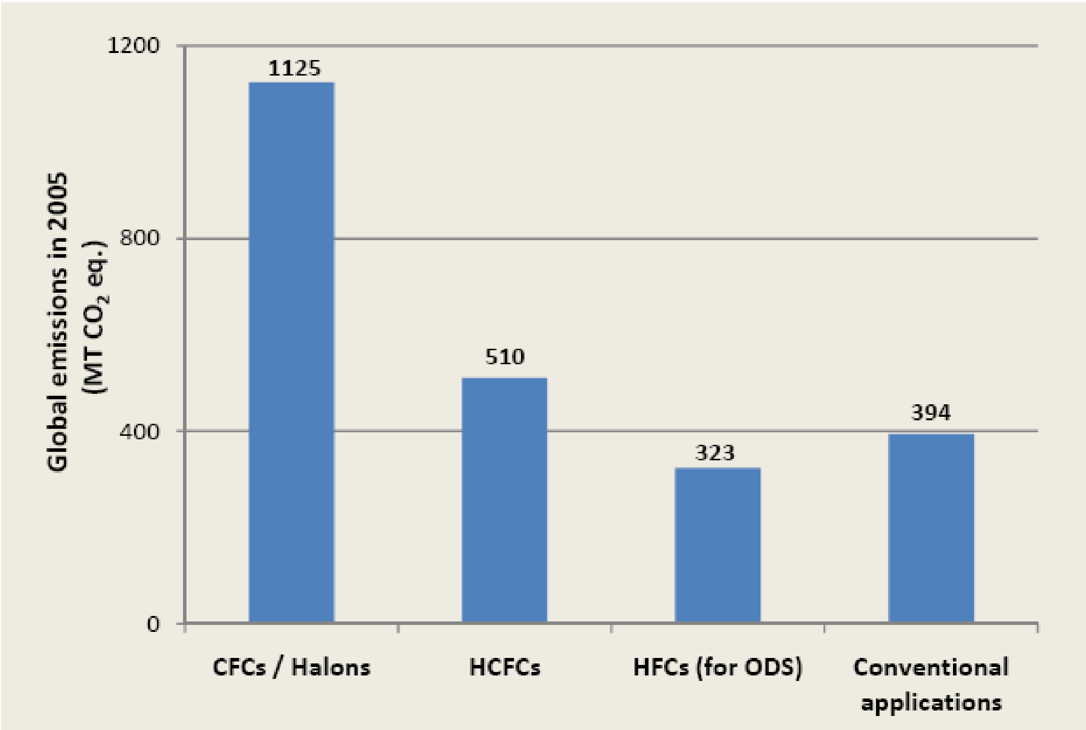
Today, emissions of fluorinated greenhouse gases comprise three categories:

- HFC-23, SF_6, PFCs from conventional applications;
- HFCs which have already substituted ODS;
- CFCs and HCFCs which have not been substituted yet but will be replaced by HFCs and non-HFC alternatives within the next decades.

Diagram 3, which is based on Table 3, illustrates global emissions of CFCs, HCFCs, and Kyoto F-gases, including HFCs used as ODS-substitutes and emissions from conventional applications such as HFC-23, SF_6 and PFCs, in 2005. Total emissions of fluorinated greenhouse gases in 2005 are estimated at 2,352 MT CO_2 eq. (including halons). Emissions from Kyoto F-gases (HFCs for ODS; conventional applications) accounted for 717 MT CO_2 eq. (30%), while the major share was contributed by CFC and HCFC emissions (ODS).

Diagram 3:

Global emissions of CFCs/Halons, HCFCs, and Kyoto F-gases including applications using HFCs as ODS substitutes and conventional applications (i.e. HFC-23 by product emissions, PFCs, SF_6) in 2005 (GWP_{100}; MT CO_2 eq.).



It is striking that the column for CFCs is much higher than the others although major reductions of emitted quantities have been reached as a result of the Montreal Protocol. This is due the high GWP of CFCs. Therefore, emissions are high as well.

Kyoto F-gas emissions (HFCs for ODS; conventional applications) indicated in Diagram 3 are high compared to the data shown in Diagram 1. This can be explained partly by referring to the years the datasets are based on (Diagram 1: 2004/ Diagram 3: 2005). Moreover, the 2005 data (Diagram 3; Table 3) include several emission sources which were not comprised in previous datasets but got compiled from various scientific publications (Annex 1).

Table 3: Global emissions of ODS (CFCs, HCFCs) and Kyoto F-gases (HFCs as ODS substitutes; HFC-23, SF_6 and PFCs from conventional applications) in 2005 (MT CO_2 eq.).

2005	**Refrigeration & Air Conditioning**	**Foams**	**MDI**	**Aerosols & Solvents**	**Fire fighting**	**Total**
ODS						
CFCs	932	109	50	-	-	1,091
Halons	-	-	-	-	34	34
HCFCs	475	29	-	7	1	512
ODS substitutes						
HFCs	284	5	8	25	1	323
Subtotal sectors	*1,679*	*143*	*58*	*32*	*36*	1,960
Conventional applications						
HFC-23 by product						182
SF_6						142
PFCs						68
TOTAL global (MT CO_2 eq.)						**2,352**

Note: This dataset is based on several sources and can be found in Annex 1. The emissions in Table 3 are mostly based on SROC data which used GWP values from IPCC 2001 and WMO 2003. The data in Annex 1 are hence higher than the data in Table 3 as we used GWPs from IPCC 2007 as listed in Table 1.

In 2005, the refrigeration and air conditioning sector accounted for ca. 70% of global ODS and Kyoto F-gas emissions. The largest share of emissions from this subsector was contributed by CFCs and HCFCs which are mostly contained in old equipment.

Emissions from foam blowing agents accounted for ca. 6% of global emissions, which were composed of CFCs and HCFCs mostly, too.

The share of emissions from conventional applications was about 18%.

2. Emissions of fluorinated greenhouse gases and political framework in developing and developed countries

Both, the Montreal Protocol and UNFCCC/ Kyoto Protocol distinguish between **developed countries** (Non-Article 5/ Annex-1 countries) and **developing countries** (Article 5 countries/ Non-Annex-1) according to the agreed timeframe for phase out/ the members' commitments to reduce emissions.

In 2008, 146 countries were listed as operating under Article 5 of the Montreal Protocol (A5 countries) including most of Africa, Latin America and Asia. Eastern European transformation countries and the Russian Federation are no longer A5 countries as their per capita consumption of ODS has increased over the threshold of 0.3 kg per year.

Table 4 shows that the consumption of both CFCs and HCFCs varies significantly between developing and developed countries. Most CFCs are currently consumed in A5 countries, whereas they are almost phased out in developed countries.

Table 4: ODS consumption by CFCs and HCFCs (ODP tons) in developing countries (A5) and developed countries (non-A5) in 2005

	CFCs (ODP tons)	HCFCs (ODP tons)	total
Developing countries (A5)	43,328	21,620	64,948
Developed countries (non A5)	846	10,278	11,124
TOTAL	44,174	31,898	76,072

Source: UNEP Ozone Secretariat website. Recalculation into GWP values is not possible.

The large difference in ODS consumption between developing and developed countries has been caused mostly by the Montreal Protocol. While ODS were phased out within a few years in industrialized countries, developing countries are allowed to organize their phase out over a longer time period. Thus, the potential for emissions of chlorine-free F-gases (HFCs) in developing countries remains high as long as the ODS phase out is not completed. Current **phase out schedules** for HCFCs are shown in Table 5.

Table 5: Accelerated phase out schedule for HCFCs in non- A5 (developed) countries and A5 (developing) countries

Year	Non A5 countries	A5 countries
Baseline	1989	Average of 2009 and 2010 levels
1996	Freeze	
2004	35%	
2010	75%	
2013		Freeze
2015	95%	10%
2020	Full phase out (a reserve of 0.5% of the baseline is allowed for servicing within the decade)	35%
2025		67.5%
2030	100%	Full phase out (97.5% reduction for 10 years; a reserve is allowed for servicing needs)
2040		100%

In absence of the Montreal Protocol, the use of CFCs would have increased significantly all over the world (IPCC SROC, 2005). The adoption of the Protocol, however, caused the almost complete phase-out of use and production of CFCs in developed countries, and a rapid fall in developing countries. CFC production in developed countries was banned in 1996, while in some developing countries production continues until 2010.

The phase out of HCFC production and consumption has also been scheduled under the Montreal Protocol. In September 2007, the Parties to Protocol even agreed to **accelerate the phase-out of HCFCs** (Table 6).

- Developed countries, having already frozen production, are required to fully phase out production and consumption of HCFCs by 2020.
- Developing countries (Article 5 countries whose annual calculated level of consumption of the controlled substances is less than 0.3 kilograms per capita) are required to freeze production in 2013, at average the level of 2009 – 2010, and undertake a graduated step-down in consumption and production to a full phase-out in 2030.

In 2040 at the latest, ODS will be neither produced nor consumed any more in developing countries. However, the risk occurs that today's applications of ODS will turn into future applications of HFCs, which highly contribute to global warming.

The risk that **substitute technologies** will focus on HFCs is quite high as large HFC production capacities are already installed in major developing countries. Financial mechanisms enabling the compliance of developing countries and countries with economies in transition under the Multilateral Fund of the Montreal Protocol and the Global Environmental Facility have fostered the use of HFCs in recent years. After the phase out of CFCs in developed countries, existing markets have now absorbed the production of HFCs and PFCs. Rapidly expanding markets and the phase out of CFCs in developing countries in 2010 have also resulted in an expansion of the HCFC-22 and HCFC-141b production capacity.

It is thus important that additional measures are taken to replace HCFCs with substitutes that have zero or low GWPs, as well as to improve leakage and recycling rates of existing equipment. Some regions that have been supported under the Multilateral Fund for the implementation of the Montreal Protocol have benefited from access to hydrocarbon technologies. Under certain political pressure, it has been possible to convert some production plants in India and China to the use of hydrocarbons (HCs) instead of HFCs.

In contrast, conversion happens slowly and usually towards HFCs in regions such as South Asia and Sub-Saharan Africa, indicating small scale production of many manufacturing plants of appliances.

A number of national initiatives and international cooperation projects have recently focussed on the promotion of zero or low GWP substances in order to take a step forward towards global **HFC phase out**. These initiatives comprise for example legal measures, such as the EU F-Gas Regulation (2006) and an EU-Directive preventing the use of HFC-134a in mobile AC equipment, as well as voluntary commitments by certain sectors (e.g. the initiative

Refrigerants, Naturally! in supermarkets and vending machines) or certain regions (e.g. California).

Technology transfer to developing countries is also supported by the Clean Development Mechanism (CDM), which is an instrument under the Kyoto Protocol fostering investment in environmentally friendly infrastructure in developing countries in order to reduce emissions.

However, a global framework and future emission reduction targets under the UNFCCC post-Kyoto-regime are currently unclear as negotiations for the commitment period from 2012 to 2020 will take place end of the year 2009 in Copenhagen at COP15. Pressure is mounting particularly in large non-Annex 1 countries like Brazil, China, and India to accept binding commitments to reduce their greenhouse gas emissions in the post-2012 period.

As large reductions of total greenhouse gas emissions are relatively cheap and easy to achieve by emission reductions of Kyoto F-gases in comparison with other greenhouse gases (multi-gas abatement strategy), it seems possible that developing countries will approach emission sectors of Kyoto F-gases at an early stage of their potential commitment period. In fact, the abatement option of reducing greenhouse gases other than CO_2 has been acknowledged through the GHG basket approach adopted in the Kyoto Protocol targets and the US administration GHG intensity strategy already, allowing full substitution among CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (Lucas et al. 2007).

3. Main assumptions for the projection of future emissions

The **"business-as-usual" scenario** (BAU) presented in this study is based on some assumptions concerning future trends of emissions. These emissions in developed and developing countries will highly depend on a number of drivers, such as political measures, population growth, the expected worldwide increase in disposable income, etc.

For our projections of the main greenhouse gases (CO_2, N_2O and CH_4) in 2050, we use scenarios from the SRES Report (IPCC SRES, 2000). The report describes four "families" of in total forty scenarios which are explained by one storyline each (A1, A2, B1, B2). Bearing in mind the development of the world since the publication of the SRES report in 2000, the A2 and B2 storylines seem not to take current trends into account, such as globalisation and rapid economic development in certain countries.

Hence we decided to use a scenario that combines the two remaining marker scenarios A1 and B1. They both assume economic growth and rapid introduction of new technologies. The A1 family develops into three groups that describe alternative directions of technological change in the energy system, such as fossil intensive (A1FI), non fossil energy sources (A1T), and balanced across all sources (A1B). As future development will highly depend on political decisions to be made within the next few years, we decided to use the A1B scenario as it seems to be less extreme than A1FI and A1T.

In contrast to A1B, the B1 family describes a convergent world with the same global population as in the A1 storyline but with rapid change in economic structures towards a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental problems.

In order to reflect the range of potential options of the development until 2050 as assumed by SRES, we took the average of the quantitative projections of the two scenarios A1B and B1 for the projections of greenhouse gas emissions in 2050 (Chapter 5), economic growth and population growth.

The population growth assumed by the two SRES scenarios (and their combination) has been well in line with real statistical data of the world population, and the population in developed and developing countries (World Bank statistics 2007). According to the SRES projections, the world population will increase to 8.7 billion people until 2050, which reflects an annual growth rate of ca. 0.6% (2010 – 2050). 17% of the 2050 population will live in developed countries, and 83% in developing countries. The annual growth rate of the population in developed countries amounts to 0.24% until 2050, and to 0.83% in developing countries.

We applied the two categories "developed countries" and "developing countries" in this study in order to illustrate different political, social and economic conditions in different countries. Although the economic and social situation of a specific country might change throughout the next decades, we assume these categories to remain unchanged.

The term “developed countries” refers to non-Article 5 countries under the Montreal Protocol such as North America, Japan, Australia, New Zealand, Europe, Eastern European transforming countries and the Russian Federation. In large parts, this category is also consistent with the list of Annex 1 countries under the Kyoto Protocol. The term “developing countries” covers all Article 5 countries.

Concerning the future **economic situation**, our scenario (combined A1B/B1 from SRES) assumes rapid innovation and change towards a service and information economy. Growth rates range at 2% in developed countries and 5.5% in developing countries.

The assumed high economic growth will cause a **rise in disposable income** in developing countries. This is an important driver of the demand for e.g. household appliances and serves as a basis for the projections of future HFC emissions from the domestic refrigeration subsector.

Equally important for future demand for HFCs is the political framework in both developed and developing countries. We consider in particular the Montreal Protocol and its amendments including the accelerated phase out schedule for HCFCs (Chapter 2) to play a fundamental role for emission reductions. Our projections assume that **all existing political measures will remain in place** such as the accelerated HCFC phase out and relevant national regulations. These also comprise commitments under the Kyoto Protocol which caused some countries to adopt legislation restricting the use of fluorinated greenhouse gases in some applications, e.g. the EU F Gas regulation (2006).

The rates for HFC recovery, reuse and destruction at the end of product life are difficult to assess and can be quantified hardly for future decades. For the projection, **recovery rates are thus assumed to be constant** although new technology might increase recovery rates at some point. Furthermore, it is assumed that the use-phase **emission rates of 2005 will remain unchanged**. Emission rates include both use-phase and disposal emissions.

Table 6 gives an overview of the emission rates applied in the projections for each sector. Emission rates differ between developed and developing countries and are mostly based on the latest TEAP report (UNEP TEAP Task Force Decision XX/8 Report, 2009). Disposal emissions from refrigeration, air conditioning and fire extinguishing equipment are included in bank emissions. Disposal of foam products does not occur until 2050, except for appliances.

Table 6: Emission rates for each sector of application in developed and developing countries as assumed in the projections		
	Developed countries	**Developing countries**
Domestic refrigeration	6%	
Commercial refrigeration	18%	22%
Industrial refrigeration	11%	13.7%
Transport refrigeration	25%	30%
Stationary AC		
Unitary AC systems	11%	13%
Chillers	7.7%	8.8%
Mobile AC	18%	24%
Foam blowing		
XPS	30% First Year, 1% Bank	
PU Rigid	10% First Year, 1% Bank	
PU Integral, OCF	100% First Year	
Appliances	5% First Year, 1% Bank	
Aerosols, Solvents, MDI	100%	
Fire extinguishing		
Portable systems	4%	
Fixed systems	2%	
Filling/ distribution losses	2%	

As HCFC phase out will take place within the next decades and HFC emissions are controlled by the Kyoto Protocol, zero or low GWP alternatives for various applications are increasingly being developed and in use all over the world. In this study, which presents a business-as-usual scenario, we assume the share of alternative technologies to remain constant through 2050.

Unlike a recent publication by Velders et al. (2009), the business as usual scenario in this study follows a sectoral approach. While Velders et al. (2009) base their projections on sales data and assume that the consumption of HFCs will grow proportional to the population from 2020 to 2050, we assume sector-specific growth rates for both developed and developing countries.

4. Global emissions of fluorinated greenhouse gases in 2050

4.1 Population, economic situation and status of phase out in 2050

As outlined earlier, the scenario presented in this study is a so-called "business as usual" scenario which assumes that all existing measures continue and emission rates, recovery rates and common practices remain unchanged.

In 2050, the world population will reach **8.7 billion people** based on SRES projections (IPCC SRES, 2000). About 83% will then live in the current "developing countries" (annual growth rate 0.83%) and 17% will live in the current "developed countries" (annual growth rate 0.24%).

Free trade, continued innovation, and a stable political and social climate are assumed to enable developing regions to access knowledge, technology, and capital. Combined with a rapid demographic transition, this is thought to lead to acceleration of **economic growth** in time and space. The global economy is projected to expand at an average annual rate of 3.5% to 2050. Growth rates in developing countries range at 5.5% and in developed countries at 2% respectively.

Assuming that current **phase out** schedules are implemented, emissions in 2050 will be released from different sources than today.

- Direct CFC emissions will not occur any more, and CFC banks practically do no longer exist.
- Some HCFC emissions are released from refrigeration and AC equipment, as well as from foam products manufactured in developing countries until 2030 and still in use.

Please note that emissions of CFCs and HCFCs from remaining banks are neglected in the emission projections for 2050 as their quantity is expected to be very low. The projections will hence focus on emissions of chlorine-free fluorinated greenhouse gases previously referred to as Kyoto F-gases.

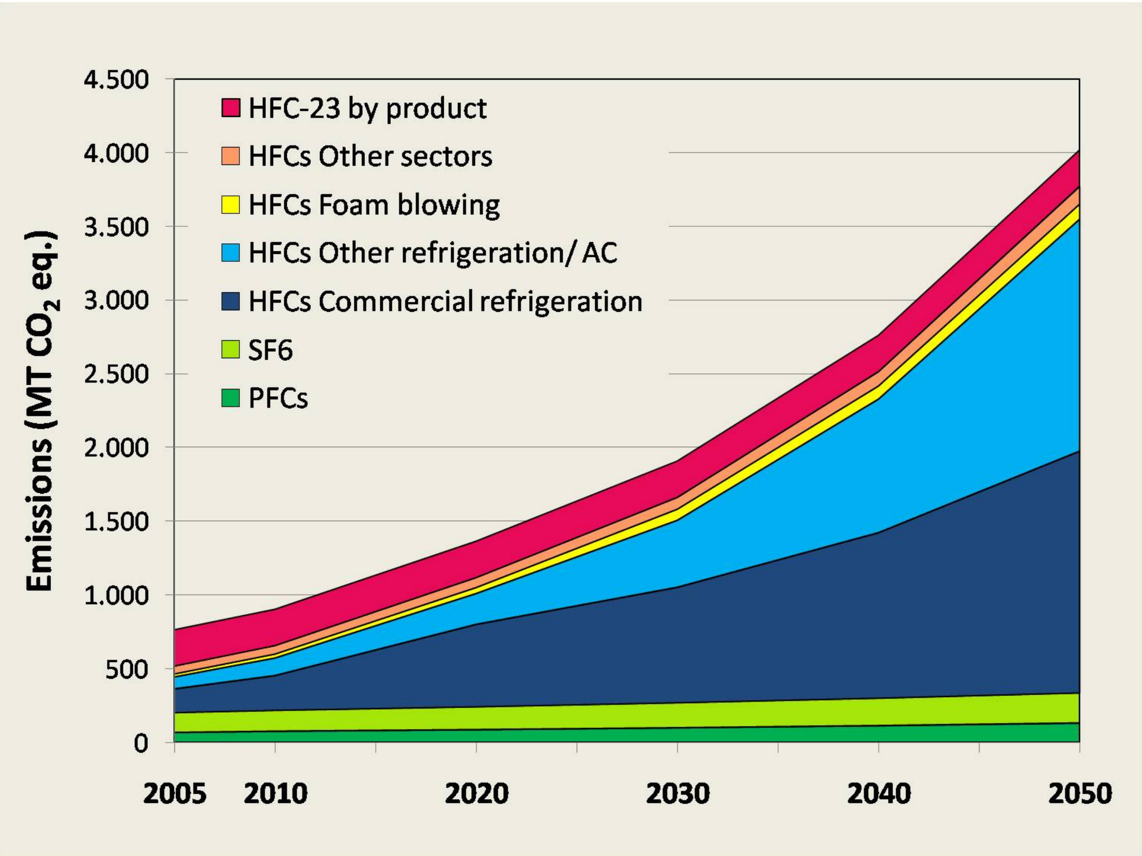
- Considerable emissions of HFCs are expected as they will replace a large share of HCFCs in developed and developing countries until 2030 and beyond. Large HFC banks in equipment will account for future emissions well beyond 2050.
- An increase of emissions from conventional applications is expected to take place mostly in developing countries due to economic growth.

4.2 Quantification of emissions in 2050 per sector

Future growth rates for each sector and resulting emissions in 2050 are identified as follows.

Diagram 4 shows the trend of F-gas emissions through 2050. The diagram does not explicitly reflect certain political milestones, e.g. the global HCFC phase out in 2030, but includes important legal measures, e.g. the EU directive on HFC-134a phase out from passenger cars. This is due to the fact that the year of interest of this study is 2050. Growth rates were hence determined for time periods of several decades. However, the diagram points out that the steep increase of emissions is mostly caused by the refrigeration and air conditioning sector, which will be treated in detail below.

Diagram 4: Trend of global F-gas emissions until 2050 by sectors of application. The steep rise in F-gas emissions until 2050 is primarily caused by the expansion of the refrigeration and air conditioning sector, especially the commercial refrigeration sector



In many cases, this study relies on data for banks and emissions from the IPCC SROC (2005) report and the latest TEAP report (UNEP TEAP Task Force Decision XX/8 Report, 2009) when considering the time period until 2020. The sector-specific market growth in the period 2020 - 2050 is based on own assumptions and projections by market researchers. These long-term growth rates are lower than the data on market growth given by the TEAP report because we assume market saturation. For each sector of application, different growth rates are applied in developed and developing countries until 2050 (Annex 3).

1. Refrigeration and air conditioning

General trends

The refrigeration and AC sector continues to be the main driver of future emissions of fluorinated greenhouse gases. A strong increase of HFC emissions reflects the phase-out of CFCs (completed 2025) and HCFCs (completed 2050) from existing equipment as well as the growing demand for new equipment that operates with HFCs from the beginning.

Current dominant refrigerant options for each sub-sector are listed in Table 7.

Table 7. Dominant refrigerant options by sub sectors in developing and developed countries

	Developing countries	**Developed countries**
Domestic refrigeration	HFC134a, HC-600a	
Commercial refrigeration	HCFC-22	HFC-134a, R-404A
Industrial refrigeration	HCFC-22	HFCs, ammonia
Stationary AC	HFC-134a, HCFC-123	HFC-134a, blends
Mobile AC	HFC-134a	HFC-134a, low-GWP fluids

Source: TEAP 2008.

Future demand for refrigeration and air conditioning equipment will vary between developed and developing countries.

- In **developed countries**, the demand for refrigeration equipment is expected to remain constant as their markets are saturated to a large extent and population growth is expected to be low. The demand for air conditioning, however, is likely to grow in non-saturated markets such as Europe, because average annual temperatures will increase due to climate change.
- **In developing countries**, significant growth of the refrigeration and air conditioning sector is expected as the demand for chilling and cooling rises when population grows, economies develop and urbanisation proceeds.

Domestic refrigeration

An estimated 1,500 to 1,800 million units of domestic refrigerators and freezers are currently installed globally (UNEP TEAP Task Force 2009). Increase in demand for domestic refrigerators is driven by population growth, disposable income, urbanisation, and electrification.

In addition to the projection of a global population of 8.7 billion people in 2050, we assume an ownership rate of 1 unit per household, and average household sizes of 4 in developing countries[1] and of 2 in developed countries[2]. Hence, the total number of domestic refrigerators

[1] The current average household size in China is 3.2 (China Statistical Yearbook 2007), in India 4.8 (International Institute for Population Sciences: National Family Health Survey 2005-2006 National Fact Sheet, 2006. http://www.nfhsindia.org/pdf/IN.pdf).

is estimated to amount to about 2.5 billion units. 70% of the units will be installed in developing countries and 30% in developed countries. The increase in the number of installed domestic refrigerators and freezers reflects an annual growth rate of 1.2%.

At the moment, about 65% of the current new production of domestic refrigerators and freezers employs HFC-134a, and 35% employ hydrocarbon refrigerants (UNEP TEAP Task Force Decision XX/8 Report, 2009). The total number of domestic refrigerators running on HFC-134a in 2050 is hence projected to amount to 1.65 billion units. The vast majority (80%) of the systems running on hydrocarbon refrigerants is installed in developed countries. In the business as usual scenario, we assume these rates to remain constant.

Commercial refrigeration

The sector includes small, medium and large vending and storage equipment in super markets, food trade, etc. The short-term growth rates of the refrigerant banks until 2020 and the banks themselves are from the latest TEAP Report (global: 1,270 kt) (Annex 5, UNEP TEAP Task Force Decision XX/8 Report, 2009).

The commercial refrigeration sector grows faster than the population in both developed and developing countries, as the demand for refrigerated and frozen food increases overproportionally when economies develop and urbanisation proceeds[3]. In developed countries, recent increases in the consumption of chilled and frozen food[4] reflect changes in lifestyle and demography.

Short-term growth rates range from 1.8 - 2.7% in developed countries to 2.6 – 5.2% in developing countries (2002-2015; IPCC SROC 2005; see Annex 3). We assume gradual market saturation during the period 2020-2050 and hence estimate long-term growth rates to be lower than short-term rates. A growth rate of 3.5% per year is assumed for developing countries as population growth and economic development will continue. For developed countries a growth rate of 1% per year is estimated as societies get older and more people are expected to live in urban areas.

Industrial refrigeration

This sector includes food processing, cold storage, and to a smaller part non-food refrigeration and freezing in manufacturing industry, chemical and power-generation plants, etc. In the same way as for the commercial refrigeration sector, we base our projections of the size of refrigerant banks in 2020 on the latest TEAP report (global: 256.8 kt) (Annex 5, UNEP TEAP Task Force Report, 2009).

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[2] The current average household size in Germany amounts to 2.1 and is expected to decrease (Statistisches Bundesamt- Ergebnisse der Haushaltsvorausberechnung 2007). Household size in the USA is 2.61 (2006 American Community Survey, U.S. Census Bureau).

[3] In Brazil, the market for frozen food grew at an annual rate of 7.4% and the market for chilled food at 3.3% (2001–2006). In China, the market for chilled food grew at 13.4% (2001–2006) (Datamonitor 2008: Frozen Food in Brazil to 2011; Chilled Food in Brazil to 2011; Chilled Food in China to 2011).

[4] Sales of chilled convenience food in Germany grew at an annual rate of ca. 7% in the period 2003-2008 (CMA 2008).

Short-term growth rates are estimated at 1% in developed coutries and at 3.6-4% in developing countries (IPCC SROC, 2005). In developed countries, the long-term growth rate (2020-2050) is expected to be lower and to amount to 0.5% per year as market saturation will occur in some countries.

In developing countries, however, the sector is expected to grow at fairly high rates due to a certain backlog in the production of frozen food[5], and because population growth and economic development will continue. For HFC systems only, we assume a growth rate of 3% in developing countries. Systems containing ammonia or other natural fluids are expected to increase at higher rates but will not be considered in the emission projections.

Transport refrigeration

This sector includes refrigerated ship holds, refrigerated road vehicles, and reefer containers. The demand for transport of chilled and frozen food is expected to rise considerably in both developed and developing countries due to changes in lifestyle, urbanization and population growth. The short-term growth rates of the refrigerant banks until 2020 and the banks are from the latest TEAP Report (global: 26.52 kt) (Annex 5, UNEP TEAP Task Force Decision XX/8 Report, 2009).

Short-term growth rates (2002-2015) of the sector were estimated to range from 1-3% in developed countries to 3.3-5.2% in developing countries (IPCC SROC 2005). Since saturation of the global transport refrigeration sector does not seem likely in a globalised world as long as population growth and economic development continue, significant long-term growth is assumed. Projections are based on an annual rate of 1.5% in developed countries and 3.5% in developing countries in the period 2020-2050. As refrigerated transport is strongly linked to consumption of chilled and frozen food, and hence the commercial refrigeration sector, similar growth rates are used for projections of emissions from these sectors.

Stationary Air Conditioning

The sector comprises air conditioning by centralised chillers for large buildings and air conditioning by unitary systems which refer to a variety of decentralised devices for flats or individual rooms in commercial and residential applications: portable, window-mounted, split, multi-split systems, ducted or non-ducted air conditioners and heat pumps, packaged systems etc. Asia-Pacific currently constitutes the largest market for air conditioning equipment in the world (ca. 40% by value), followed by the Americas, while India and the Middle East represent significant potential for future growth[6].

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[5] Example: The Indian market of frozen French fries and potato specialties is only 8,000 t (2009; Quick Frozen Food International, April 2009), which is far below the German market of 420,891 t (2008; Deutsches Tiefkühlinstitut e.V.), although potatoes are known as an everyday meal in both countries.

[6] BSRIA Ltd, 2009: http://www.bsria.co.uk/news/global-air-conditioning-sales-reach-us70-billion-in-2008/

The use of chillers for air conditioning of office space, commercial buildings, hotels etc. has increased at annual rates of over 10% in recent years[7], but experienced a decline of 6% in value in 2008[8] due to the economic crisis. In the last years, a certain portion of sales of commercial air conditioning equipment have shifted from small chillers to unitary systems for lower installation cost and increased flexibility of floor-by-floor large building systems (UNEP RTOC 2006).

As for residential air conditioning, ownership rates vary between developed and developing countries and according to climatic conditions[9]. Recent evolution of the market has shown that air conditioner ownership can increase at higher rates than economic growth in warm climate countries. In 1990, less than 1% of urban Chinese households owned an air conditioning unit; in 2006 the share had increased to 88% (China Statistical Yearbook 2007). Countries in warm climate hence have a higher potential for residential AC ownership than temperate regions, in particular if market saturation is still low.

The projections presented in this study refer to the size of refrigerant banks in 2020 as forecasted by the latest TEAP report (global: 1,758 kt) (Annex 5, UNEP TEAP Task Force Report, 2009). The shares contributed by unitary systems (79%) and by chillers (21%) are adopted from projections by UNEP (UNEP RTOC 2006).

Short-term growth rates (2003 – 2015) of the sector are estimated at 1-3.8% in developed countries and 5.4-6% in developing countries (IPCC SROC, 2005). Long-term growth rates are expected to be lower than short-term rates because of market saturation in some regions[10], but will follow population growth and economic development. Long-term growth rates for unitary systems are assumed to be 1% in developed countries and 4% in developing countries. For chillers we assume long-term growth rates of 1% in developed countries and 3% in developing countries.

Total banks will more than double (from 1,758 kt in 2020 to 3,610 kt in 2050), banks in developing countries will more than triple (from 724 kt in 2020 to 2216 kt in 2050).

Mobile AC

Mobile air conditioning (MAC) refers to air-conditioning systems in motor vehicles (i.e. cars, trucks, and buses), agricultural and construction vehicles and rail vehicles. More than 80% of the refrigerants of this sector are contained in passenger cars. Refrigerant use is already considerably high, especially in cars in USA and Japan. Currently, about 30% of the total

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[7] The total chiller market grew from US$ 5,951 million in 2006 to US$ 6,630 million in 2007 (+11.4%) (JARN- Air conditioning, Heating and Refrigeration News, 2008).

[8] BSRIA Ltd, 2009: http://www.bsria.co.uk/news/global-air-conditioning-sales-reach-us70-billion-in-2008/

[9] Saturation rates for residential air conditioners of several developing countries and their cooling degree days are provided by McNeil & Letschert (2008).

[10] Market saturation for room air conditioners in Europe has been projected to begin around 2025-2030 (Pout & Hitchin 2008). The Japanese market for room air conditioners is mature already (JARN Ltd. 2008: http://www.ejarn.jp/Type_news_inside.asp?id=10307&classid=4). Mexico is projected to reach an ownership of over 80% in 2030 from about 20% in 2005 (McNeil & Letschert, 2008)

global HFC emissions are from MACs including the emissions in production, use, servicing and end-of-life (UNEP TEAP Task Force 2009). In developed countries, the car population is today considerably higher than in developing countries, which indicates an enormous potential for future car ownership.

The global vehicle stock amounted to about 800 million units in 2002 (Dargay et al., 2007), and is expected to increase worldwide within the next decades as economies develop. In 2030, about 2 billion vehicles are projected to be in use (Dargay et al., 2007), which refers to growth rates of 1.4% in developed countries and 6.5% in developing countries (2002–2030). For the period 2030-2050, we assume an annual growth rate of 0.5% in developed countries and 3.5% in developing countries, which will result in a total fleet of 3.3 billion vehicles in 2050. This number includes buses, trucks, heavy duty vehicles, etc. which are assumed to account for ca. 15% of the global fleet.[11]

We assume that just about 85% of the vehicles are equipped with MAC systems that run on HFC-134a. This derives, firstly, from legislation in Europe which prohibits the use of HFC-134a in passenger cars from 2017 onwards. Currently, about 10% of the worldwide car fleet is registered in the EU. Secondly, a certain share of low-cost vehicles in developing countries will not feature a MAC system at all (e.g. Nano by Tata). We estimate this market share to account for about 5% of the global market. In 2050, the number of vehicles with MAC systems will hence amount to 2.8 billion units.

[11] This number is well in line with calculations by Meyer (2005) on the global passenger car fleet, which used the Gompertz model approach and resulted in a global stock of 2.7 billion cars in 2050. Assuming that buses, trucks etc. account about for another 15-20%, the global fleet will amount to 3.3 billion vehicles in total.

2. Foam blowing

The high amounts of CFCs and HCFCs formerly used in this sector will not be replaced by HFCs in the future. Hydrocarbons will be used as blowing agents instead, which are technically equal and much cheaper. HFCs will be limited to applications of particularly high insulation performance or applications that require incombustible blowing agents.

Over the next years, a stable quantity of fluorinated greenhouse gases of ca. 125 kt/ year will be consumed globally for foam products of PU and XPS (UNEP FTOC 2006). Developed countries will use 75 kt/ year of HFCs (HFC-245fa, HFC-134a, HFC-365mfc-227ea, HFC-152a). Developing countries, in contrast, continue using ca 50 kt/ year of HCFCs (HCFC-141b, HCFC-142b, HCFC-22) which will be fully replaced by HFCs by 2030. We assume hydrocarbons to account for the entire future increase in consumption of blowing agents. This implies a long-term rate of HFC consumption we assume to remain constant until 2050 (growth rates are zero in developing and developed countries).

We do not follow the IPCC SROC report (2005) which assumes sharp reduction in HFC consumption from 2015 onwards, but does not give a plausible explanation for this assumption in a no-action scenario. Applications of fluorinated greenhouse gases in the foam sector which will not be replaced by HCs completely include XPS boards, PU spray foam, PU appliances, and PU integral skin. Almost equal shares of emissions arise from three sources: manufacturing, banks, and decommissioning.

3. Metered-Dose Inhalers

Metered-Dose Inhalers (MDI) are used predominantly for the treatment of asthma and COPD (chronic obstructive pulmonary decease). About 300 million people worldwide are known to suffer from asthma (IPCC SROC, 2005), and their number is projected to increase. Assuming that the growth in MDI-treated asthma patients continues to increase significantly faster than the world population, we apply the annual growth rate of 2% for MDIs suggested in the IPCC SROC report (2005) for the entire period 2002-2050.

Developing countries will account for large shares of emissions from MDIs in 2050 as medical care in developing countries will have improved significantly by then, and conventional oral treatment will be replaced by inhaled therapy. Moreover, the number of asthma patients is expected to increase as urbanisation will proceed (smog). Increasing temperature and CO_2 concentrations are also known to have interactive effects on pollen production, eventually resulting in a heightened risk of asthma (Center for Health Study 2005). We thus assume a growth rate of 4.5% in developing countries. In contrast, a growth rate of only 0.8% is assumed in developed countries.

4. Aerosols

Non-medical aerosols using HCFCs and HFCs as propellants are niche products for which often safety or other environmental issues are crucial. Most of them are specific to certain high-technology industries explaining the high share of emissions from developed countries of ca. 80% in 2003 and over 70% in 2010 (IPCC SROC 2005).

For projections of future emissions, we assume emissions from developed countries to be constant at the 2010 level (16.9 MT CO2 eq.; IPCC SROC 2005). Emissions from developing countries are projected to increase at an annual rate of 1%.

5. Solvents

The main field of application of fluorine-containing solvents is precision cleaning. Emissions of HCFCs and HFCs arise mostly from developed countries (> 90%) where high technology industries are primarily located.

In the long term, emissions from developed countries are assumed to remain constant at the 2020 level (ca. 4.2 MT CO_2 eq.; IPCC SROC, 2005) through 2050 as emissions reductions due to HCFC phase out will be balanced by increases in production. Emissions from developing countries will rise at a rate of 2% in the period 2020-2050, because high technology industries will be built up as economies develop.

6. Fire extinguishers

The sector includes fixed and portable fire extinguishing equipment, which were formerly operated with ozone-depleting halons. Fixed systems are used for flooding spaces in electronic, marine, military and aviation applications, etc. Portable systems are applied by hand for selective fire fighting. HFCs such as HFC-227ea and – to a small amount – HFC-23 have been replacing halons in fixed flooding systems[12] since 2000, so that the combined HFC/ halon bank contained already more than one third HFCs in 2005. In portable systems, HFCs (HFC-236fa) play a minor role.

For fixed systems, the use of HFCs increases and over-compensates the replacement of halons by 2 kt per year (3%) resulting in growth of the combined HFC/ halon bank from 65 kt in 2005 to 87 kt in 2015 (IPCC SROC, 2005). If we apply this annual growth of 2 kt to the combined HFC/ halon bank through the subsequent period from 2015 to 2050, we arrive at a bank of 145 kt in 2050 (annual growth rate of 1.5%). From 2035 onwards, fixed systems do no longer contain halons except for small quantities for essential uses (e.g. aircraft). Developing countries held a share bank of 20% of the bank in 2005 (13 kt; UNEP 2006; EPA 2006b, IV-123), but will account for two thirds of the bank in 2050 (ca. 94 kt).

For portable systems, we assume a long-term growth rate for the use of HFCs (HFC-236fa) of 3% per year (IPCC SROC, 2005). We also apply this rate during the period 2015-2050. Developing countries account for ca. 65% of the total bank of the sector in both 2005 and 2050 (9.97 MT CO2 eq.).

7. Conventional applications

<u>SF_6</u>

This gas with highest global warming potential (GWP_{100}: 22,800) is used in electrical equipment (switchgear), in magnesium industry, semiconductor manufacture, and a number of smaller applications like military aircraft radar, particle accelerators, etc. New applications are manufacturing of photovoltaic cells, optical glass fibres, liquid crystal displays.

Emissions in developed countries are expected to remain constant at the 2005 level due to recovery and emission reductions through political measures such as the EU F-Gas Regulation. In contrast, a doubling of bank emissions by 2050 is expected in developing countries as no recovery from electrical equipment takes place, and both switch gear installation and magnesium production will increase as economies develop. This reflects an annual growth rate of 1.5% in developing countries (2005-2050).

China is likely to become the largest SF_6 emitter by 2020 (Oettinger Schaefer et al. 2006) as no legal or voluntary agreement supports SF_6 emissions reductions while the country is likely to remain a large producer of magnesium, semiconductors and equipment for transmission and distribution of electricity.

[12] It should be noted that halons in fixed systems are replaced by HFCs only 20%, while the remaining 80% are being replaced by alternative fluids like e.g. inert gas or not-in-kind technologies.

PFCs

Emissions occur from aluminium production and semiconductor manufacture.

- We assume overall PFC emissions from aluminium industry to increase at an annual rate 1% in developed countries and 2% in developing countries during the period 2005-2050. Emission intensity in developed countries is assumed to decrease due to efforts by the industry. In 2050, about 50% of PFC emissions from aluminium industry will be released in developing countries.

- PFC emissions (including NF_3) from semiconductor industry are estimated to account for 37 MT CO_2 eq. in 2010. Emissions are projected to grow at an annual rate of 0.5% in developed countries and 2% in developing countries during the period 2010-2050 reflecting steady increase in the demand for semiconductors.

In 2050, aluminium industry will account for ca. 53% and semiconductor industry for ca. 47% of global PFC emissions (132 MT CO_2 eq.).

HFC-23

This gas with an extremely high GWP is an unintentional by-product[13] of the manufacture of HCFC-22. The amount formed depends on the conditions used in the production process and lies between 1% and 4% of the production of HCFC-22 (McCulloch & Lindley 2007). Our projections are based on an emission rate of 3% as suggested by the TEAP HCFC Report (UNEP 2007).

Although the production of HCFC-22 as a refrigerant will be banned globally from 2030 onwards, the production of HCFC-22 for feedstock use (PTFE production) is permitted to continue indefinitely. EPA (2006a, b) projects a striking shift of the majority of HFC-23 by product emissions from OECD countries to China and other developing countries; this is in line with the TEAP HCFC Report (UNEP 2007) projecting that 90% of the emissions in 2050 will occur in developing countries.

We do not agree, however, with the high level of HFC-23 by product emissions projected by UNEP TEAP amounting to 450 MT CO_2 eq. in 2050. The related quantity of emissions could be reached by a 4.5% global growth rate for feedstock uses only, which we consider too high. We assume the production of HCFC-22 for feedstock use in 2050 to reach the same level as the 2005 production for all applications (555 kt), and the emission factor to be 3% on average. Based on the TEAP HCFC Report (UNEP 2007), we assume 90% of emissions to occur in developing countries (222 MT CO_2 eq.).

[13] A small part of HFC-23 is captured for the use as low-temperature refrigerant. HFC-23 is also used as a fire extinguishing agent and as an etching gas in semiconductor manufacture.

8. Filling and distribution losses

These emissions mainly refer to refrigerants. Distribution emissions comprise all the emissions related to the refrigerant transfers from bulk containers down to small capacities where the mass varies from 0.5 kg (disposable cans) to 1 tonne (containers). Filling emissions of refrigerants due to the charging process of new equipment are related to the process of connecting and disconnecting the refrigerant container to and from the equipment when it is initially charged.

The 2006 IPCC Guidelines estimate present emissions from refrigerant management of containers and from filling of new equipment between 2 and 13 percent of the market (IPPC 2006, vol. 3, chapter 7.49). As a conservative estimate, we assume the filling emissions to be at 2%, and include also the manufacturing emissions from chemical F-gas production plants into this figure. HFC losses for fire extinguishing equipment are included as well.

Furthermore, emissions from manufacturing and distribution losses of SF_6 used for switch gear were calculated separately. A 2% emission rate was applied as well.

Filling and distribution losses of HFCs and SF_6 were assigned to developed and developing countries according the average shares of HFC and SF_6 emissions from developed and developing countries (HFCs: 25/75; SF_6: 33/67; Table 8).

4.3. Overview of global emissions of fluorinated greenhouse gases in 2050

Based on our "business as usual" scenario, the 2050 global emissions of fluorinated greenhouse gases are projected to amount to about 4 GT CO_2 eq. (GWP_{100}).

Table 8 gives an overview of banks and emissions in 2050 by sector. Based on these data, Diagram 5 shows F-gas emissions in 2050 by sector of application. Diagram 6 illustrates the shares of HFC, PFC and SF_6 emissions contributed by developed countries and developing countries. Detailed information on banks and emissions in developed and developing countries is listed in Annex 4.

Table 8: Banks (kt) and emissions (kt; MT CO_2 eq.) of fluorinated greenhouse gases in 2050 by sector and shares of emissions (% of MT CO_2 eq.) from developed and developing countries

	Banks	Emissions	Emissions GWP_{100}	Developed / developing
	kt	kt	MT CO_2 eq.	%
Sector				
Domestic refrigeration	166	10	14	2 / 98
Commercial refrigeration	2,402	511	1,638	15 / 85
Industrial refrigeration	457	59	145	29 / 71
Transport refrigeration	58	16	31	33 / 67
Stationary AC	3,610	415	854	35 / 65
Mobile AC	1,667	369	528	25 / 75
Foam blowing	3,404	90	103	60 / 40
MDI	-	31	53	44 / 56
Non-medical aerosols	-	20	27	64 / 36
Solvents	-	5	3	85 / 15
Fire extinguishers	156	3	15	35 / 65
HFC filling & distr. losses (2%)	-	20	40	25 / 75
HFC-23 by product emissions	-	17	246	10 / 90
HFCs total	**11,919***	**1,566***	**3,699***	25 / 75
SF_6	120	9	205	33 / 67
SF_6 filling & distr. losses (2%)	-	0.4	1	33 / 67
SF_6 total	**120**	**9**	**206**	33 / 67
PFCs	-	**24**	**132**	45 / 55
TOTAL	**12,039**	**1,599**	**4,037***	25 / 75

* Rounded (+/-1). Shares of developed and developing countries are listed in Annex 4.

Important findings of the emission projections include the following aspects:

- In 2050, HFC emissions (3.7 MT CO_2 eq.) will account for ca. 92% of F-gas emissions. PFCs contribute ca. 3% and SF emissions ca. 5%. Total F gas emissions amount to 4 GT CO_2 eq.

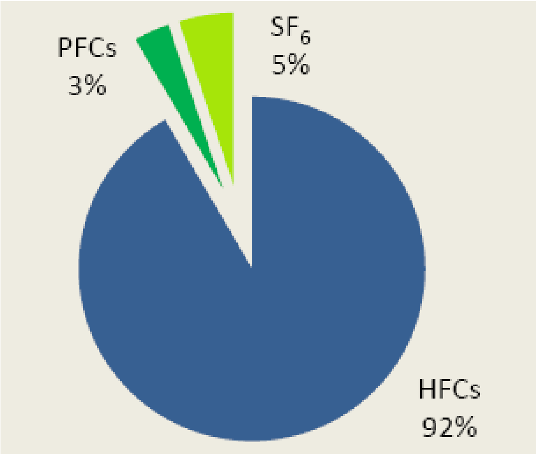

Diagram 5:

Composition of global F-gas emissions in 2050. Total: 4 GT CO_2 eq.

- By far the largest single HFC banks are contained in stationary air conditioning systems (3,610 kt; 30% of total HFC bank), foams (3,404 kt; 29%) and commercial refrigeration equipment (2,402 kt; 20%). HFC banks account for over 99% of the entire F-gas bank in 2050.

- Most global warming emissions in 2050 will arise from commercial refrigeration (1,638 MT CO_2 eq.; 41% of F-gas emissions). The stationary air conditioning sector will account for ca. 21% of F-gas emissions (854 MT CO_2 eq.), and the mobile air conditioning sector for about 13% (528 MT CO_2 eq.). Emissions from foam (ca. 2.6 %) do not play a major role due to relatively low bank leakage rates. Diagram 5 shows projected emissions by sectors. (The category “HFCs other refrigeration” refers to emissions from domestic, industrial and transport refrigeration. “HFCs other sectors” relates to emissions from MDI, aerosols, solvents and fire extinguishers.)

- The share of emissions from commercial refrigeration in total emissions (41% of F-gas emissions; 44% of HFC emissions) is more than twice the sector's percentage in the total bank (ca. 20% of F-gas bank and HFC bank). This is mainly a result of the high emission factor of 18% in developed countries and 22% in developing countries. Emissions from stationary air conditioning, which forms the largest bank (3,610 kt), are the second largest (23% of HFC emissions), because the emission factor is not as high as in commercial refrigeration (11-13% for unitary systems, 7.7 – 8.8% for chillers).

- Emissions from developing countries will exceed emissions from developed countries in most sectors. Developing countries will account for 75% of total global emissions of fluorinated greenhouse gases in 2050. Diagram 6 illustrates the shares contributed to global HFC, PFC and SF_6 emissions by developed and developing countries.

Diagram 6:

Global F-gas emissions (HFCs, PFCs, SF_6) in 2050 by major sectors of application (%). The sectors of commercial refrigeration, stationary air conditioning and mobile air conditioning will contribute 75% of F-gas emissions in 2050.

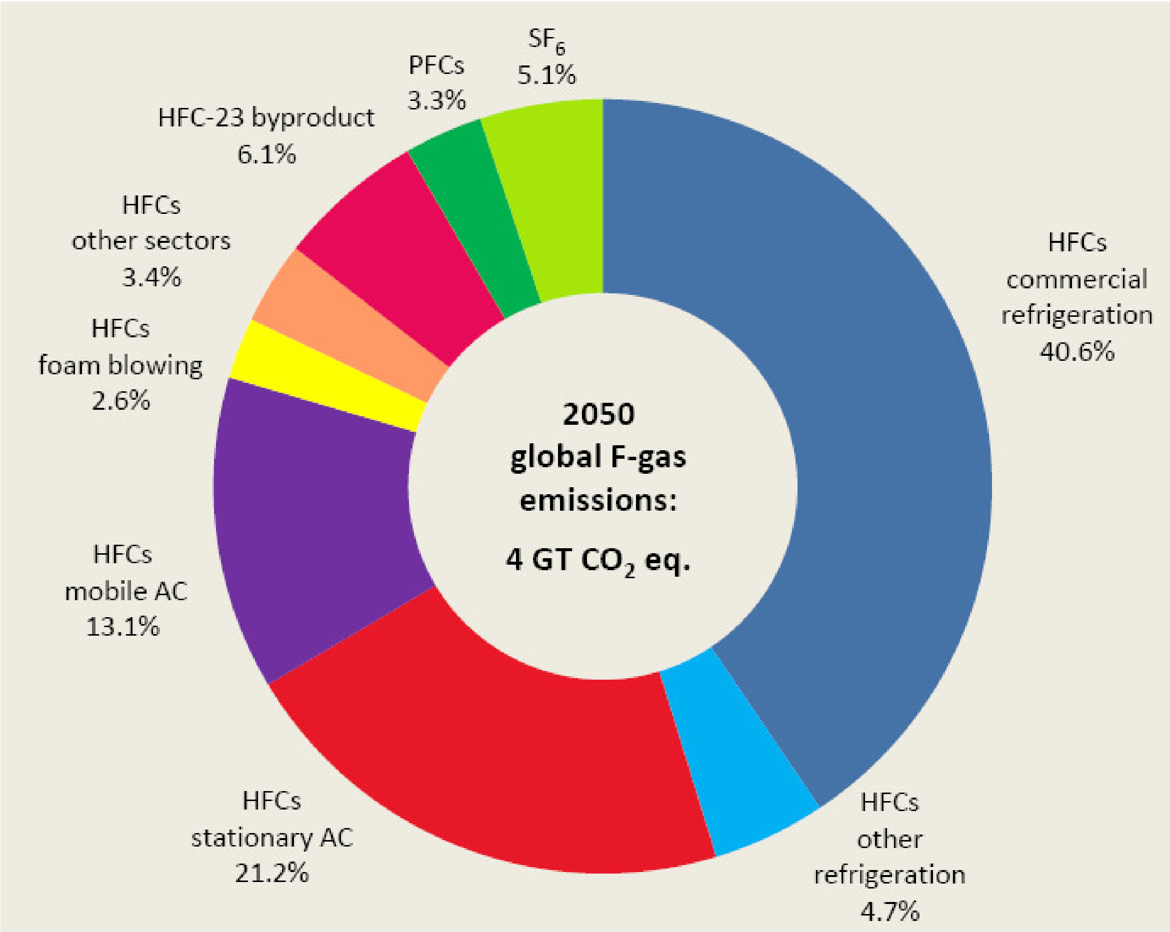

Diagram 7:

Global F-gas emissions (HFCs, PFCs, SF_6) in 2050 in a business-as-usual scenario and shares of emissions (%) contributed by developed and developing countries.

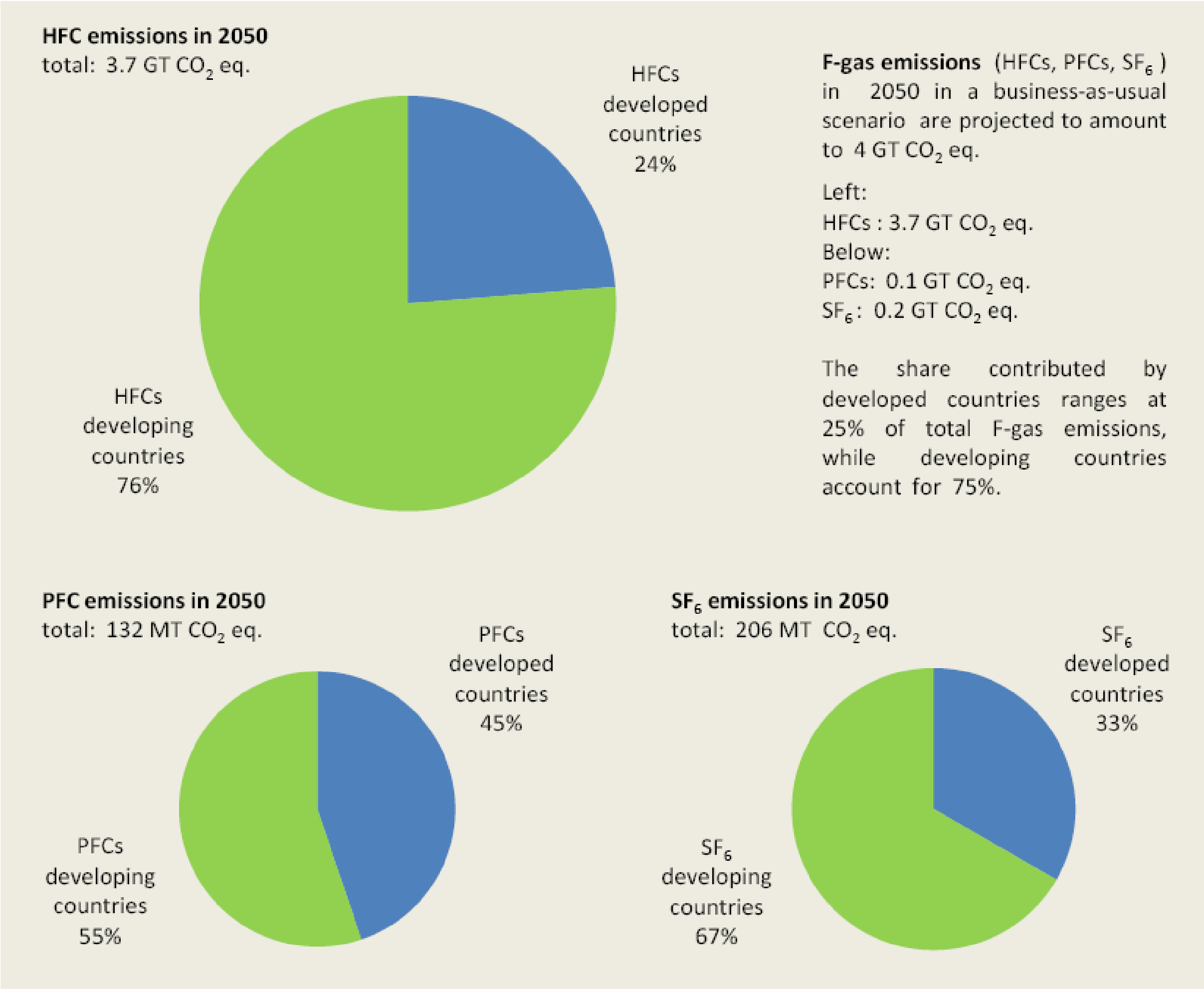

Table 8 and Diagrams 6 and 7 suggest two important aspects which could be taken into account when considering efforts to reduce the projected amounts of fluorinated greenhouse gas emissions.

Firstly, measures to reduce emissions are particularly effective in the commercial refrigeration subsector, the stationary air conditioning sector and the mobile air conditioning sector. In these sectors, large amounts of CFCs, HCFCs and HFCs are used as refrigerants today, while alternative refrigerants play a minor role only. In some developed countries, however, natural refrigerants are already known to have technical and financial advantages.

Secondly, developing countries are playing the key role regarding measures to reduce emissions of fluorinated GHG gases. In the business as usual scenario this study refers to, they would contribute three quarters of the total emissions of fluorinated greenhouse gases in 2050.

5. Contribution of fluorinated GHG gases to global warming in 2050

The projected emissions of fluorinated greenhouse gases shown in the preceding chapter are calculated both in metric quantities and as CO_2 equivalents with respect to the latest GWPs according to IPPC (2007). In 2050, emissions of Kyoto F-gases from all sectors are projected to account for 4 GT CO_2 eq. (GWP_{100}).

In comparison to global emissions of the other greenhouse gases, the important role of fluorinated greenhouse gas emissions becomes evident.
In order to assess the share of projected emissions of Kyoto F-gases in total GHG emissions, an estimation of global direct emissions of the three main greenhouse gases CO_2, N_2O and CH_4 in 2050 is required. We take these data from the IPCC SRES scenarios we referred to before (Chapter 3 on the methodology).

Total direct emissions of the three major greenhouse gases CO_2, N_2O and CH_4 are projected to amount to about 63.7 GT CO_2 eq. in 2050.

- In Annex 1 (developed) countries, emissions will decrease to 16 GT CO_2 eq.
- In non Annex 1 (developing) countries, emissions will jump to 48 GT CO_2 eq.

Table 9 shows projected direct emissions of CO_2, N_2O and CH_4 in the world, in developed and developing countries in 2050 (excluding LULUCF). The table also presents the projected emissions of fluorinated GHG gases (Kyoto F-gases), and their shares in the total GHG emissions. It should be noted that the total GHG values already include F-gases as projected in this study.

Table 9:
2050 emissions of CO_2, N_2O, CH_4, and fluorinated GHG gases, in GT CO_2 eq., in developed and developing countries and worldwide

	Emissions (GWP_{100})
World total	67.7
CO_2, CH_4, N_2O	63.72
Fluorinated GHG gases	4
Share of fluorinated GHG gases	**5.9%**
Developed countries total	17.05
CO_2, CH_4, N_2O	16.06
Fluorinated GHG gases	1.00
Share of fluorinated GHG gases	**5.86%**
Developing countries total	50.45
CO_2, CH_4, N_2O	47.66
Fluorinated GHG gases	3.00
Share of fluorinated GHG gases	**5.92%**

Sources: CO_2, N_2O, CH_4 from IPCC SRES scenarios A1/B1; emissions of F-gases from this study. Emissions from land use, land use change and deforestation (LULUCF) are excluded.

Table 9 shows that the share of emissions of fluorinated GHG gases in the worldwide total GHG emissions will be at 5.9% in 2050. Compared to the relatively small share of Kyoto F-gas emissions of 1.3% in 2004, these percentages reflect an enormous increase. Diagram 8 compares emissions of F-gases to projected CO_2 emissions of 50.37 GT CO_2 eq. in 2050.

Diagram 8:

Global F-gas emissions in 2050 compared to global CO_2 emissions in a business-as-usual scenario.

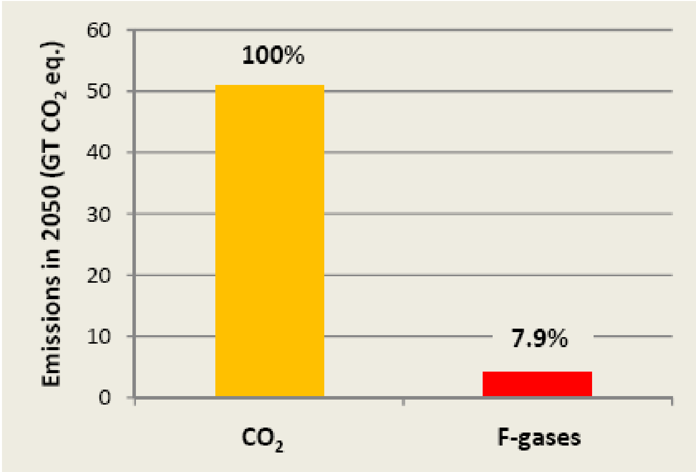

Table 8 underlines the role of developing countries in the emissions of fluorinated GHG gases in 2050. Although the relative shares of emissions of fluorinated GHG gases are at about the same level than in developed countries (5.86% vs. 5.92%), the absolute amounts of global warming emissions of fluorinated GHG gases are three the amounts contributed by the industrialised world (1 GT CO_2 eq. vs. 3 GT CO_2 eq.).

A recent publication by Velders et al. (2009) also projects HFC emissions and their contribution to total global warming emissions. The projections are based on current HCFC and HFC consumption data, but growth rates are not explained further. The demand for HCFCs in developing countries is assumed to grow by 3.8 – 6.3% per year proportional to GDP according to SRES for the period 2013 to 2050. HFC consumption is assumed to grow proportional to the population during the period 2020 to 2050. With emissions closely following consumption, HFC emissions are projected to range between 5.5 – 8.8 GT CO_2 eq. per year by 2050, which is higher than our projections of F-gas emissions (including HFCs, PFCs and SF_6) of 4 GT CO_2 eq. in 2050. In contrast to Velders et al. (2009), these projections do not rely on the general assumptions mentioned, but have been based on sector-specific banks, growth rates, emission rates and global warming potentials. We hence consider our projections described above more detailed and transparent.

In a business as usual scenario without further political measures and compared to projected global CO_2 emissions, the HFC emissions projected by Velders et al. (2009) would account for 9 – 19%. In the projections at hand, emissions of fluorinated gases of 4 GT CO_2 eq. will account for about 5.9% of global total greenhouse gas emissions (including CO_2, CH_4, N_2O, F-gases). Compared to CO_2 emissions only (50.73 GT CO_2 eq.), projected HFC emissions account for ca. 7.9% (Diagram 8).

Velders et al. (2009) put their scenarios into context also by comparing their projections of HFC emissions to projected global CO_2 emissions in a long-term CO_2 stabilization scenario.

Under the condition that atmospheric CO_2 concentrations are stabilized at mixing ratios of 450 and 550 ppm, HFC emissions would account for 28 – 45% and 14 – 23%, respectively, of CO_2 emissions. From a scientific point of view, it is not recommended to compare HFC emissions projected in a business as usual scenario to CO_2 emissions projected in long-term stabilization scenarios in order to explain the future impact of HFC emissions. However, this comparison is useful to illustrate the impact of various political measures addressing greenhouse gas emissions.

6 Conclusions

In contrast to the three main greenhouse gases CO_2, N_2O and CH_4, fluorinated greenhouse gases represent a man-made group of gases and illustrate increasing impact of human industrial activity on the environment. Projections of global emissions of fluorinated gases in 2050 suggest an enormous increase in most sectors of application. In the business-as-usual scenario described, emissions amount to 4 GT CO_2 eq. Kyoto F-gases will account for about 5.9% of total direct greenhouse gas emissions in 2050. Developing countries will cause significantly higher emissions in future decades than today because of population growth and economic development. The share of F-gas emissions from developing countries will grow to ca. 75%.

Political action to reduce emissions of fluorinated gases globally should be undertaken from now onwards. In particular, it seems necessary to limit excessive growth rates of the use of F-gases of 3 or 4% in some sectors in developing countries. Resulting banks and emissions could otherwise easily pervert emission reductions in developed countries.

In 2009, 196 countries have ratified the Montreal Protocol; most of them are listed as Article 5 countries (developing countries). All parties agreed to measures to phase out CFCs and HCFCs within a certain time period. So far, the implementation of the Montreal Protocol is considered very successful. However, emissions of chlorine-free fluorinated gases are covered by the Kyoto Protocol, which has been ratified by 188 countries and the European Economic Community by 2009. In contrast to the Montreal Protocol, only developed countries (Annex 1 Parties to the Convention) are committed to quantified emission reductions within a certain time period. At the moment, 41 developed countries have ratified both the United Nations Framework Convention on Climate Change and the Kyoto Protocol, and thus have agreed to legally binding commitments to reduce their greenhouse gas emissions.

For significant reductions of future emissions of Kyoto F-gases, it hence appears crucial to think about measures to limit emissions from all developed and developing countries. Moreover, the role of equipment containing fluorinated GHG gases and their potential for long term future emissions should be seriously considered. The current post-Kyoto negotiation process might provide an opportunity to address these issues within a wider scope.

In the recent past, developed countries have succeeded in substituting ozone-depleting substances. However, the replacements used in most countries highly contribute to global warming. With regards to climate protection, a second switch to zero or low GWP alternatives is considered inevitable.

Developing countries, in contrast, are now facing the chance to replace ozone-depleting substances directly by zero or low GWP alternatives, and could hence benefit from alternative technologies developed throughout the last decades. Technology transfer to developing countries has been fostered by certain projects under the Multilateral Funds (Montreal Protocol) and the Clean Development Mechanism (Kyoto Protocol). These and further initiatives have already resulted in several applications of zero or low GWP technology in developing countries. For significant emission reductions, further efforts are required.

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Annex 1 Emissions of CFCs, HCFCs and Kyoto F-gases in 2005

2005	Refrigeration and Air con-ditioning	Foams (PU/ XPS)	MDI	Fire extin/ aeros/solv.	**Total**	GWP 100	**Total** (GWP100 weighted)
	t	t	t	t	t		$MTCO_2$ eq.
ODS and ODS substitutes							
CFC-11	5,500	19,000	3,000		27,500	4,750	131
CFC-12	80,000	2,000	4,500		86,500	10,900	943
CFC-114			300		300	10,000	3
CFC-115	9,000				9,000	7,370	66
CFCs	**94,500**	**21,000**	**7,800**		**123,300**		**1,143**
Halons	75% Halon 1211 25% Halon 1301			8,000	**8,000**	Average 3,203	**26**
HCFC-22	270,000	1,000			271,000	1,810	491
HCFC-123	4,500				4,500	77	0.3
HCFC-124	2,000				2,000	609	1.2
HCFC141b		13,000			13,000	725	9
HCFC142b		12,000			12,000	2,310	28
HCFC-225				6,000	6,000	358	2
HCFC	**276,500**	**26,000**		**6,000**	**308,500**		**531**
HFC-23				15,000	15,000	14,800	222
HFC-32	500				500	675	0.3
HFC-125	14,000				14,000	3,500	49
HFC-134a	80,000	2,500	3,000		85,500	1,430	122
HFC-143a	17,000				17,000	4,470	76
HFC-152a	1,000	1,000		1,000	3,000	124	0.4
HFC-227ea		100	1,500		1,600	3,220	5.2
HFC-236fa				20	20	9,810	0.2
HFC-245fa		400			400	1,030	0.4
HFC365mfc		200			200	794	0.2
HFC-43-10				1,000	1,000	1,640	1.6
HFCs	**112,500**	**4,200**	**4,500**	**17,020**	**138,220**		**477**
HFC Filling/ distribution losses					**5,000**	Average 2,119	**11**
HFCs for ODS					**143,220**		**488**
Conventional Applications							
HFC-23 by product					**15,600**	14,800	**231**
SF_6					**6,000**	22,800	**137**
PFCs							**68**
Total emissions from Conventional Applications							**436**
TOTAL emissions							**2,624**

Main data sources of Annex 1:

- Data on CFCs, HCFCs and HFCs were interpolated from SROC data (p.413).

- General cross-checking with data from Schwarz (2004). Data on HCFC-22 were cross-checked with data from McCulloch et al. (2006).
- Filling and distribution losses were calculated based on HFC consumption. An emission rate of 2% was applied.
- HFC-23 byproduct emissions as estimated by McCulloch & Lindley (2007)
- SF_6 emissions as estimated by Oettinger Schaefer et al. (2006) and Cheng (2006).
- PFC emissions from estimates by US-EPA (2006, p. IV 170) and the Report of the International Aluminium Institute (2007).

Annex 2 Calculation of sector-specific GWPs (2050)

The composition of the global HFC banks in 2005 is to be considered the starting point for the calculation of sector-specific GWPs. We assume this composition to remain unchanged until 2050. Based on multiplication of the shares of different types of HFCs and their GWPs (IPCC 4th Assessment Report 2007), a sector-specific GWP is calculated. This sector-specific GWP has been used to calculate sector-specific emissions in 2050.

However, this relatively simple method features high uncertainties as it assumes that HFCs which will replace ODS in the near future will comprise the same shares of types of HFCs as today. Thus, this calculation does not take into account a change of the shares of different types of HFCs or the introduction of new HFC blends.

One might argue that this approach assumes complete substitution of ODS by HFCs until 2050 and ignores the increasing importance of zero or low GWP alternatives. Yet, our business-as-usual projections of the banks in 2050 do include both the role of natural fluids (e.g. hydrocarbons in domestic refrigeration, ammonia in industrial refrigeration etc.) and emission reductions caused by political measures which were implemented already, such as the prohibition of high GWP gases in passenger car air conditioning in the European Union as of 2017. These trends are foreseeable and are therefore included in a business-as-usual scenario, which is supposed to extrapolate current trends. Additional emission reductions are well possible and could be examined in a mitigation scenario.

Emissions of HFCs: applications, shares of different types of HFCs, specific GWPs. Replacement of CFCs and HCFCs by HFCs (types, share)		
applications	**shares of different types of HFC**	**GWP**
Domestic ref	134a (100%)	1,430
Commercial ref	134a (25%)/ 404A (70%)/ 410A (5%)	3,207
Industrial ref	134a (62%)/ 404A (37%)/ 23 (1%)	2,486
Transport ref	134a (80%)/ 404A/507 (18%)/ 410A (2%)	1,892
Stationary AC		
Unitary systems	410A (100%)	2,088
Chillers	134a (35%)/ 410A (65%)	1,858
Mobile AC	134a (100%)	1,430
Foam (PU, XPS)	134a (33%)/ 245fa (61%)/ 365mfc (5%)/ 152a (1%)	1,141
MDI	134a (85%)/ 227ea (15%)	1,699
Non-med. Aerosols	134a (92%)/ 152a (8%)	1,326
Solvents	43-10 (100%)	1,640
Fire extinguishers		
Portable systems	236fa (100%)	9,810
Fixed systems	227ea (95%)/ 23 (5%)	3,799

The absolute contribution of a sector to global warming emissions depends, of course, on the share of zero or low GWP fluids compared to HFCs. The higher the share of low GWP alternatives in the banks, the lower is the GWP of the sector-specific emissions as a whole. It should be pointed out though that the sector-specific GWPs we calculate do not refer to the entire bank or the full amount of emissions of a sector, but to HFCs only.

The table in Annex 2 shows the shares of different types of HFCs (own estimations) used as replacements for CFCs and HCFCs in various sectors of application (Palandre et al., 2004). 100% replacement by HFCs is assumed. Specific GWPs for each sector are listed. GWPs of the different types of HFCs are from IPCC Fourth Assessment Report (2007).

Annex 3 Overview of growth rates

Range of short-term growth rates as estimated by IPCC SROC (2005) and the latest UNEP TEAP report (2009) for the period until 2015/2020. The range of short-term growth rates refers to variations between countries (e.g. EU, USA, Japan). For the mobile air conditioning sector, the growth rates used in projections by Dargay et al. (2007) for the period 2002-2030 are given as well.
Long-term growth rates as applied in the business-as-usual scenario described.

	Short-term growth rates 2002 – 2015/2020		**Long-term growth rates** 2020 - 2050	
	Developed countries	**Developing countries**	**Developed countries**	**Developing countries**
Domestic ref.	1 - 2.2%	2 - 4.8%	1.2%	
Commercial ref.	1.8 - 2.7%	2.6 - 5.2%	1%	3.5%
Industrial ref.	1%	3.6 – 4%	0.5%	3% (HFC systems only)
Transport ref.	1 - 3%	3.3 - 5.2%	1%	3.5%
Stationary AC *Unitary systems*	1 - 3.8%	5.4 - 6%	1%	4%
Stationary AC *Chillers*			1%	3%
Mobile AC	1 - 4% Dargay et al.: 1.4% (2002 – 2030)	6 - 8% Dargay et al.: 6.5% (2002 – 2030)	0.5% (2030 – 2050)	3.5% (2030 – 2050)
Foams	ca. 2%		0	0
MDI	1.5 - 3%		1%	4%
Aerosols	16 % in total		constant at 2010 level	1%
Solvents	0.9% (2005 – 2020)	4.7% (2005 – 2020)	constant at 2020 level	2%
Fire extinguishing *Fixed systems*	0.4% (HCFCs, HFCs, PFCs)		constant at 2005 level	4.5%
Fire extinguishing *Portable systems*			3%	
HFC-23	2.5%		Production for feedstock use at the same level as 2005 production for all applications	
PFCs	n.e.	n.e.	Aluminium: 1% Semicond.: 0.5%	Aluminium: 2% Semicond.: 2%
SF6	n.e.	n.e.	0	1.5% (2005 – 2050)

n.e.: not explicitly estimated.

Annex 4 Projections of F-gas emissions in 2050 by sector

	Use phase and disposal emissions (kt)	Emissions in 2050 ($MT\ CO_2$ eq.)	Shares of emissions %
Domestic refrigeration	**9.93**	**14.2**	100
Developed countries	0.16	0.2	2
Developing countries	9.77	14	98
Commercial refrigeration	**511**	**1,638**	100
Developed countries	79	253	15
Developing countries	432	1,385	85
Industrial refrigeration	**59**	**145***	100
Developed countries	17	42	29
Developing countries	42	104	71
Transport refrigeration	**16**	**31**	**100**
Developed countries	5	10	33
Developing countries	11	21	67
Stationary AC	**415***	**854**	**100**
Developed countries	144	295	35
Developing countries	272	559	65
Mobile AC	**369**	**528**	100
Developed countries	92	132	25
Developing countries	277	396	75
Foam	**90**	**103**	100
Developed countries	54	62	60
Developing countries	36	41	40
MDI	**31**	**53**	100
Developed countries	14	23	44
Developing countries	17	30	56
Aerosols	**20**	**27**	100
Developed countries	13	17	64
Developing countries	7	10	36
Solvents	**3.0**	**4.9**	100
Developed countries	2.6	4.2	85
Developing countries	0.4	0.7	15
Fire extinguishers	**3.3**	**15.3**	100
Developed countries	1.1	5.3	35
Developing countries	2.2	10	65
Filling & distribution losses			
HFCs	**20**	**40**	100
Developed countries	5	10	25
Developing countries	15	30	75

Conventional applications			
SF_6	**9**	**205**	100
Developed countries	3	68	33.33
Developing countries	6	137	66.66
Filling & distribution losses			
SF_6	**0.04**	**0.9**	100
Developed countries	0.01	0.3	33
Developing countries	0.03	0.6	67
PFCs	**24***	**132***	100
Developed countries	11	59	45
Developing countries	12	73	55
HFC-23 by product	**17**	**246**	100
Developed countries	2	25	10
Developing countries	15	222	90
TOTAL	**1,599**	**4,037***	100
Developed countries	445	1,006	25
Developing countries	1,154	3,032	75

* Rounded (+/-1).