



IPCC/TEAP SPECIAL REPORT:
SAFEGUARDING THE OZONE LAYER AND THE GLOBAL CLIMATE SYSTEM:
ISSUES RELATED TO HYDROFLUOROCARBONS AND PERFLUOROCARBONS

SUMMARY FOR POLICYMAKERS

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1. Introduction

This IPCC Special Report was developed in response to invitations by the *United Nations Framework Convention on Climate Change* (UNFCCC)¹ and the *Montreal Protocol on Substances that Deplete the Ozone Layer*² to prepare a balanced scientific, technical and policy relevant report regarding alternatives to ozone-depleting substances (ODSs) that affect the global climate system. It has been prepared by the IPCC and the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol.

Because ODSs cause depletion of the stratospheric ozone layer³, their production and consumption are controlled under the Montreal Protocol and consequently are being phased out, with efforts made by both developed and developing country parties to the Montreal Protocol. Both the ODSs and a number of their substitutes are greenhouse gases (GHGs) which contribute to climate change (see Figure SPM-1). Some ODS substitutes, in particular hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), are covered under the UNFCCC and its Kyoto Protocol. Options chosen to protect the ozone layer could influence climate change. Climate change may also indirectly influence the ozone layer.

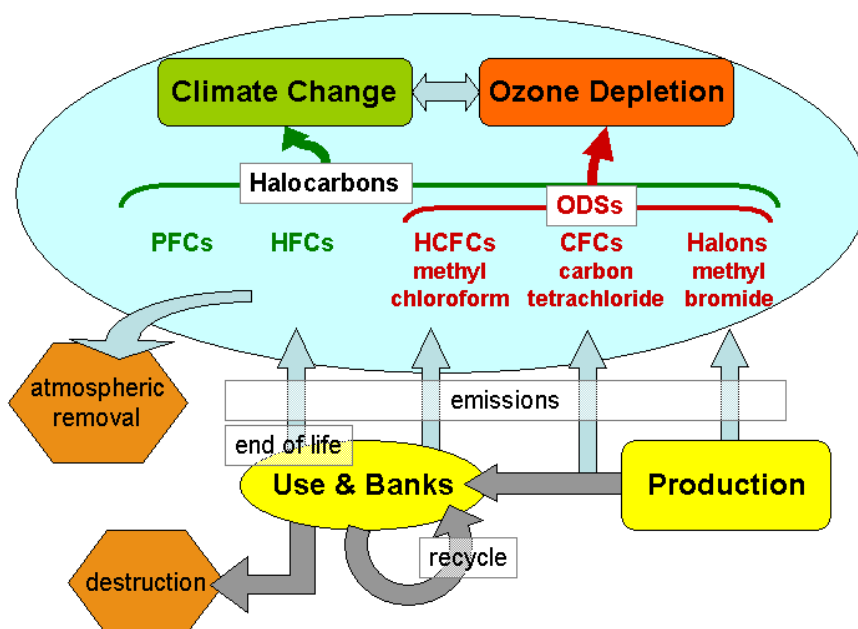


Figure SPM-1. Schematic diagram of major issues addressed by this report. Chlorofluorocarbons (CFCs), halons and hydrochlorofluorocarbons (HCFCs) contribute to ozone depletion and climate change, while hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) contribute only to climate change and are among possible non-ozone depleting alternatives for ODSs. Red denotes gases included under the Montreal Protocol and its amendments and adjustments⁴ while green denotes those included under the UNFCCC and its Kyoto Protocol. Options considered in this report for reducing halocarbon emissions include: improved containment, recovery, recycling, destruction of byproducts and existing banks⁵, and use of alternative processes, or substances with reduced or negligible global warming potentials.

¹ Decision 12/CP.8, FCCC/CP/2002/7/Add.1, page 30.

² Decision XIV/10 UNEP/OzL.Pro.14/9, page 42.

³ Ozone within this report refers to stratospheric ozone unless otherwise noted.

⁴ Hereafter referred to as the Montreal Protocol.

⁵ Banks are the total amount of substances contained in existing equipment, chemical stockpiles, foams and other products not yet released to the atmosphere.

This report considers the effects of total emissions of ODSs and their substitutes on the climate system and the ozone layer. In particular, this provides a context for understanding how replacement options could affect global warming. The report does not attempt to cover comprehensively the effect of replacement options on the ozone layer.

The report considers, by sector, options for reducing halocarbon emissions, options involving alternative substances, and technologies, to address greenhouse gas emissions reduction. It considers HFC and PFC emissions insofar as these relate to replacement of ODSs. HFC and PFC emissions from aluminum or semiconductor production or other sectors are not covered.

The major application sectors using ODSs and their HFC/PFC substitutes include refrigeration, air conditioning, foams, aerosols, fire protection and solvents. Emissions of these substances originate from manufacture and any unintended byproduct releases, intentionally emissive applications, evaporation and leakage from banks contained in equipment and products during use, testing and maintenance, and end-of-life practices.

With regard to specific emission reduction options, the report generally limits its coverage to the period up to 2015, for which reliable literature is available on replacement options with significant market potential for these rapidly evolving sectors. Technical performance, potential assessment methodologies and indirect emissions⁶ related to energy use are considered, as well as costs, human health and safety, implications for air quality, and future availability issues.

⁶ It should be noted that the National Inventory Reporting community uses the term ‘indirect emissions’ to refer specifically to those greenhouse gas emissions which arise from the breakdown of another substance in the environment. This is in contrast to the use of the term in this report, which specifically refers to energy-related CO₂ emissions associated with Life Cycle Assessment (LCA) approaches such as Total Equivalent Warming Impact (TEWI) or Life Cycle Climate Performance (LCCP).

2. Halocarbons, ozone depletion and climate change

2.1 What are the past and present effects of ODSs and their substitutes on the Earth's climate and the ozone layer?

Halocarbons, and in particular ODSs, have contributed to positive direct radiative forcing⁷ and associated increases in global average surface temperature (see Figure SPM-2). The total positive direct radiative forcing due to increases in industrially produced ODS and non-ODS halocarbons from 1750 to 2000 is estimated to be $0.34 \pm 0.03 \text{ W m}^{-2}$, representing about 14% of the total due to increases in all well-mixed greenhouse gases over that period. Most halocarbon increases have occurred in recent decades. Atmospheric concentrations of CFCs were stable or decreasing in the period 2001–2003 (0 to –3% per year, depending on the specific gas) while the halons and the substitute hydrochlorofluorocarbons (HCFCs) and HFCs increased (+1 to +3% per year, +3 to +7% per year, and +13 to +17% per year, respectively). [1.1, 1.2, 1.5 and 2.3]⁸

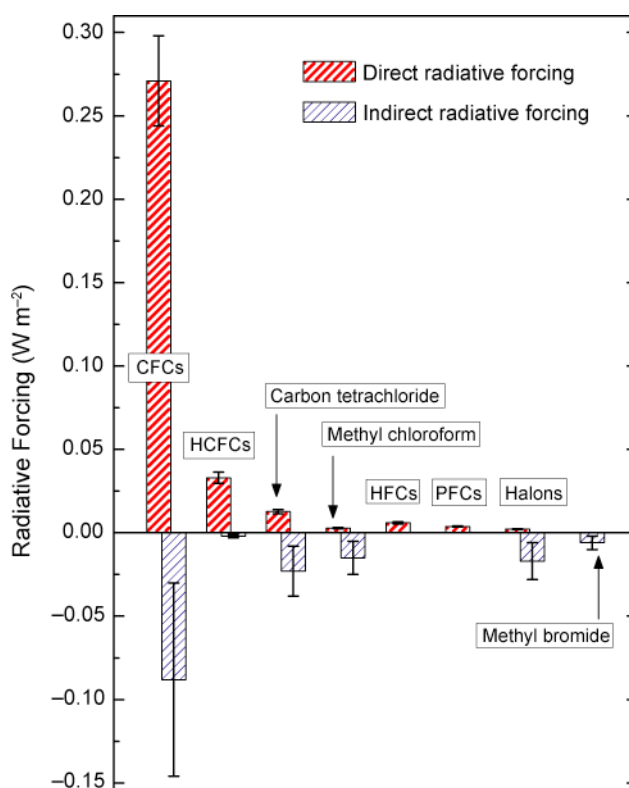


Figure SPM-2. Direct and indirect radiative forcing (RF) due to changes in halocarbons from 1750 to 2000.⁹ Error bars denote ± 2 standard-deviation uncertainties. [Based on Table 1.1]

⁷ Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in watts per square meter (W m^{-2}). A greenhouse gas causes direct radiative forcing through absorption and emission of radiation and may cause indirect radiative forcing through chemical interactions that influence other greenhouse gases or particles.

⁸ Numbers in square brackets indicate the sections in the main report where the underlying material and references for the paragraph can be found.

⁹ PFCs used as substitutes for ODSs make only a small contribution to the total PFC radiative forcing.

Stratospheric ozone depletion observed since 1970 is caused primarily by increases in concentrations of reactive chlorine and bromine compounds that are produced by degradation of anthropogenic ODSs, including halons, CFCs, HCFCs, methyl chloroform (CH₃CCl₃), carbon tetrachloride (CCl₄) and methyl bromide (CH₃Br). [1.3 and 1.4]

Ozone depletion produces a negative radiative forcing of climate, which is an indirect cooling effect of the ODSs (see Figure SPM-2). Changes in ozone are believed to currently contribute a globally averaged radiative forcing of about $-0.15 \pm 0.10 \text{ W m}^{-2}$. The large uncertainty in the indirect radiative forcing of ODSs arises mainly because of uncertainties in the detailed vertical distribution of ozone depletion. This negative radiative forcing is *very likely*¹⁰ to be smaller than the positive direct radiative forcing due to ODSs alone ($0.33 \pm 0.03 \text{ W m}^{-2}$). [1.1, 1.2 and 1.5]

Warming due to ODSs and cooling associated with ozone depletion are two distinct climate forcing mechanisms that do not simply offset one another. The spatial and seasonal distributions of the cooling effect of ozone depletion differ from those of the warming effect. A limited number of global climate modelling and statistical studies suggest that ozone depletion is one mechanism that may affect patterns of climate variability which are important for tropospheric circulation and temperatures in both hemispheres. However, observed changes in these patterns of variability cannot be unambiguously attributed to ozone depletion. [1.3 and 1.5]

Each type of gas has had different greenhouse warming and ozone depletion effects (see Figure SPM-2) depending mainly on its historic emissions, effectiveness as a greenhouse gas, lifetime and the amount of chlorine and/or bromine in each molecule. Bromine-containing gases currently contribute much more to cooling than to warming, whereas CFCs and HCFCs contribute more to warming than to cooling. HFCs and PFCs contribute only to warming. [1.5 and 2.5]

2.2 How does the phase-out of ODSs affect efforts to address climate change and ozone depletion?

Actions taken under the Montreal Protocol have led to the replacement of CFCs with HCFCs, HFCs, and other substances and processes. Because replacement species generally have lower global warming potentials¹¹ (GWPs), and because total halocarbon emissions have decreased, their combined CO₂-equivalent (direct GWP-weighted) emission has been reduced. The combined CO₂-equivalent emissions of CFCs, HCFCs and HFCs derived from atmospheric observations decreased from about $7.5 \pm 0.4 \text{ GtCO}_2\text{-eq}$ per year around 1990 to $2.5 \pm 0.2 \text{ GtCO}_2\text{-eq}$ per year around 2000, equivalent to about 33% and 10%, respectively, of the annual CO₂ emissions due to global fossil fuel burning. Stratospheric chlorine levels have approximately stabilized and may have already started to decline. [1.2, 2.3 and 2.5]

Ammonia and those hydrocarbons (HCs) used as halocarbon substitutes have atmospheric lifetimes ranging from days to months, and the direct and indirect radiative forcings associated with their use as substitutes are *very likely* to have a negligible effect on global climate. Changes in energy-related emissions associated with their use may also need to be considered. (See Section 4 for treatment of comprehensive assessment of ODS replacement options.) [2.5]

¹⁰ In this Summary for Policymakers, the following words have been used where appropriate to indicate judgmental estimates of confidence: *very likely* (90–99% chance); *likely* (66–90% chance); *unlikely* (10–33% chance); and *very unlikely* (1–10% chance).

¹¹ GWPs are indices comparing the climate impact of a pulse emission of a greenhouse gas relative to that of emitting the same amount of CO₂, integrated over a fixed time horizon.

Based on the Business-As-Usual scenario developed in this report, the estimated direct radiative forcing of HFCs in 2015 is about 0.030 W m^{-2} ; based on scenarios from the IPCC Special Report on Emission Scenarios (SRES), the radiative forcing of PFCs⁹ in 2015 is about 0.006 W m^{-2} . Those HFC and PFC radiative forcings correspond to about 1.0% and 0.2%, respectively, of the estimated radiative forcing of all well-mixed greenhouse gases in 2015, with the contribution of ODSs being about 10%. While this report particularly focused on scenarios for the period up to 2015, for the period beyond 2015 the IPCC SRES scenarios were considered but were not re-assessed. These SRES scenarios project significant growth in radiative forcing from HFCs over the following decades, but the estimates are likely to be very uncertain due to growing uncertainties in technological practices and policies. [1.5, 2.5 and 11.5]

Observations and model calculations suggest that the global average amount of ozone depletion has now approximately stabilized (for example, see Figure SPM-3). Although considerable variability in ozone is expected from year to year, including in polar regions where depletion is largest, the ozone layer is expected to begin to recover in coming decades due to declining ODS concentrations, assuming full compliance with the Montreal Protocol. [1.2 and 1.4]

Over the long term, projected increases in other greenhouse gases could increasingly influence the ozone layer by cooling the stratosphere and changing stratospheric circulation. As a result of the cooling effect and of reducing ODS concentrations, ozone is *likely* to increase over much of the stratosphere, but could decrease in some regions, including the Arctic. However, the effects of changes in atmospheric circulation associated with climate change could be larger than these factors, and the net impact on total ozone due to increases in atmospheric concentrations of greenhouse gases is currently uncertain in both magnitude and sign. Based on current models an Arctic ‘ozone hole’ similar to that presently observed over the Antarctic is *very unlikely* to occur. [1.4]

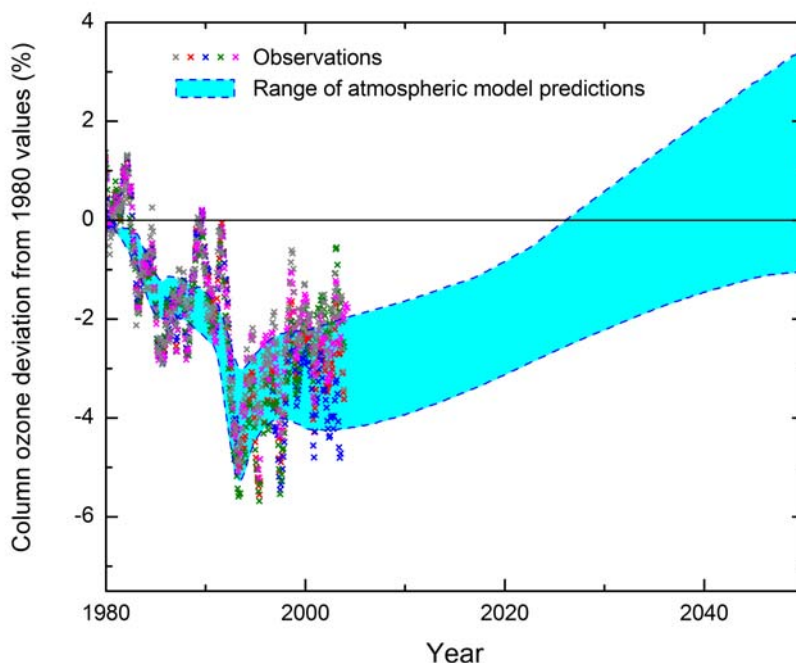


Figure SPM-3. Observed and modelled low- and mid-latitude (60°S–60°N) column ozone amounts as percent deviations from the 1980 values. [Box 1.7]

Table SPM-1. GWPs of halocarbons commonly reported under the Montreal Protocol and the UNFCCC and its Kyoto Protocol and assessed in this report relative to CO₂, for a 100-year time horizon, together with their lifetimes and GWPs used for reporting under the UNFCCC. Gases shown in blue (darker shading) are covered under the Montreal Protocol and gases shown in yellow (lighter shading) are covered under the UNFCCC. [Tables 2.6 and 2.7]

| Gas | GWP for direct radiative forcing ^a | GWP for indirect radiative forcing (Emission in 2005 ^b) | Lifetime (years) | UNFCCC Reporting GWP ^c |
|---|---|---|------------------|-----------------------------------|
| <i>CFCs</i> | | | | |
| CFC-12 | 10,720 ± 3750 | -1920 ± 1630 | 100 | n.a. ^d |
| CFC-114 | 9880 ± 3460 | Not available | 300 | n.a. ^d |
| CFC-115 | 7250 ± 2540 | Not available | 1700 | n.a. ^d |
| CFC-113 | 6030 ± 2110 | -2250 ± 1890 | 85 | n.a. ^d |
| CFC-11 | 4680 ± 1640 | -3420 ± 2710 | 45 | n.a. ^d |
| <i>HCFCs</i> | | | | |
| HCFC-142b | 2270 ± 800 | -337 ± 237 | 17.9 | n.a. ^d |
| HCFC-22 | 1780 ± 620 | -269 ± 183 | 12 | n.a. ^d |
| HCFC-141b | 713 ± 250 | -631 ± 424 | 9.3 | n.a. ^d |
| HCFC-124 | 599 ± 210 | -114 ± 76 | 5.8 | n.a. ^d |
| HCFC-225cb | 586 ± 205 | -148 ± 98 | 5.8 | n.a. ^d |
| HCFC-225ca | 120 ± 42 | -91 ± 60 | 1.9 | n.a. ^d |
| HCFC-123 | 76 ± 27 | -82 ± 55 | 1.3 | n.a. ^d |
| <i>HFCs</i> | | | | |
| HFC-23 | 14,310 ± 5000 | ~0 | 270 | 11,700 |
| HFC-143a | 4400 ± 1540 | ~0 | 52 | 3800 |
| HFC-125 | 3450 ± 1210 | ~0 | 29 | 2800 |
| HFC-227ea | 3140 ± 1100 | ~0 | 34.2 | 2900 |
| HFC-43-10mee | 1610 ± 560 | ~0 | 15.9 | 1300 |
| HFC-134a | 1410 ± 490 | ~0 | 14 | 1300 |
| HFC-245fa | 1020 ± 360 | ~0 | 7.6 | - ^e |
| HFC-365mfc | 782 ± 270 | ~0 | 8.6 | - ^e |
| HFC-32 | 670 ± 240 | ~0 | 4.9 | 650 |
| HFC-152a | 122 ± 43 | ~0 | 1.4 | 140 |
| <i>PFCs</i> | | | | |
| C ₂ F ₆ | 12,010 ± 4200 | ~0 | 10,000 | 9200 |
| C ₆ F ₁₄ | 9140 ± 3200 | ~0 | 3200 | 7400 |
| CF ₄ | 5820 ± 2040 | ~0 | 50,000 | 6500 |
| <i>Halons</i> | | | | |
| Halon-1301 | 7030 ± 2460 | -32,900 ± 27,100 | 65 | n.a. ^d |
| Halon-1211 | 1860 ± 650 | -28,200 ± 19,600 | 16 | n.a. ^d |
| Halon-2402 | 1620 ± 570 | -43,100 ± 30,800 | 20 | n.a. ^d |
| <i>Other Halocarbons</i> | | | | |
| Carbon tetrachloride (CCl ₄) | 1380 ± 480 | -3330 ± 2460 | 26 | n.a. ^d |
| Methyl chloroform (CH ₃ CCl ₃) | 144 ± 50 | -610 ± 407 | 5.0 | n.a. ^d |
| Methyl bromide (CH ₃ Br) | 5 ± 2 | -1610 ± 1070 | 0.7 | n.a. ^d |

^a Uncertainties in GWPs for direct positive radiative forcing are taken to be ±35% (2 standard deviations) (IPCC, 2001).

^b Uncertainties in GWPs for indirect negative radiative forcing consider estimated uncertainty in the time of recovery of the ozone layer as well as uncertainty in the negative radiative forcing due to ozone depletion.

^c The UNFCCC reporting guidelines use GWP values from the IPCC Second Assessment Report (see FCCC/SBSTA/2004/8, <http://unfccc.int/resource/docs/2004/sbsta/08.pdf>).

^d ODSs are not covered under the UNFCCC.

^e The IPCC Second Assessment Report does not contain GWP values for HFC-245fa and HFC-365mfc. However, the UNFCCC reporting guidelines contain provisions relating to the reporting of emissions from all greenhouse gases for which IPCC-assessed GWP values exist.

The relative future warming and cooling effects of emissions of CFCs, HCFCs, HFCs, PFCs and halons vary with gas lifetimes, chemical properties and time of emission (see Table SPM-1). The atmospheric lifetimes range from about a year to two decades for most HFCs and HCFCs, decades to centuries for some HFCs and most halons and CFCs, and 1000 to 50,000 years for PFCs. Direct GWPs for halocarbons range from 5 to over 10,000. ODS indirect cooling is projected to cease upon ozone layer recovery, so that GWPs associated with the indirect cooling effect depend on the year of emission, compliance with the Montreal Protocol and gas lifetimes. These indirect GWPs are subject to much greater uncertainties than direct GWPs. [1.5, 2.2 and 2.5]

2.3 *What are the implications of substitution of ODSs for air quality and other environmental issues relating to atmospheric chemistry?*

Substitution for ODSs in air conditioning, refrigeration, and foam blowing by HFCs, PFCs, and other gases such as hydrocarbons are not expected to have a significant effect on global tropospheric chemistry. Small but not negligible impacts on air quality could occur near localized emission sources and such impacts may be of some concern, for instance in areas that currently fail to meet local standards. [2.4 and 2.6]

Persistent degradation products (such as trifluoroacetic acid, TFA) of HFCs and HCFCs are removed from the atmosphere via deposition and washout processes. However, existing environmental risk assessment and monitoring studies indicate that these are not expected to result in environmental concentrations capable of causing significant ecosystem damage. Measurements of TFA in sea water indicate that the anthropogenic sources of TFA are smaller than natural sources, but the natural sources are not fully identified. [2.4]

3. Production, banks and emissions

3.1 How are production, banks and emissions related in any particular year?

Current emissions of ODSs and their substitutes are largely determined by historic use patterns. For CFCs and HCFCs, a significant contribution (now and in coming decades) comes from their respective banks. There are no regulatory obligations to restrict these CFC and HCFC emissions either under the Montreal Protocol or the UNFCCC and its Kyoto Protocol, although some countries have effective national policies for this purpose.

Banks are the total amount of substances contained in existing equipment, chemical stockpiles, foams and other products not yet released to the atmosphere (see Figure SPM-1). The build-up of banks of (relatively) new applications of HFCs will – in the absence of additional bank management measures – also significantly determine post 2015 emissions.

3.2 What can observations of atmospheric concentrations tell us about banks and emissions?

Observations of atmospheric concentrations, combined with production and use pattern data, can indicate the significance of banks, but not their exact sizes.

The most accurate estimates of emissions of CFC-11 and CFC-12 are derived from observations of atmospheric concentrations. Those emissions are now larger than estimated releases related to current production, indicating that a substantial fraction of these emissions come from banks built up through past production. Observations of atmospheric concentrations show that global emissions of HFC-134a are presently smaller than reported production, implying that this bank is growing. The total global amount of HFC-134a currently in the atmosphere is believed to be about equal to the amount in banks. [2.5 and 11.3.4]

In the case of CFC-11 and some other gases, the lack of information on use patterns makes it difficult to assess the contribution to observed emissions from current production and use. Further work in this area is required to clarify the sources.

3.3 How are estimated banks and emissions projected to develop in the period 2002 to 2015?

Banks of CFCs, HCFCs, HFCs and PFCs were estimated at about 21 GtCO₂-eq in 2002^{12,13}. In a Business-As-Usual (BAU) scenario, banks are projected to decline to about 18 GtCO₂-eq in 2015¹⁴. [7, 11.3 and 11.5]

In 2002, CFC, HCFC and HFC banks were about 16, 4 and 1 GtCO₂-eq (direct GWP weighted), respectively (see Figure SPM-4). In 2015, the banks are about 8, 5 and 5 GtCO₂-eq, respectively, in the BAU scenario. Banks of PFCs used as ODS replacements were about 0.005 GtCO₂-eq in 2002.

¹² Greenhouse gas (GHG) emissions and banks expressed in terms of CO₂-equivalents use GWPs for direct radiative forcing for a 100-year time horizon. Unless stated otherwise, the most recent scientific values for the GWPs are used, as assessed in this report and as presented in Table SPM-1 (Column for 'GWP for direct radiative forcing').

¹³ Halons cause much larger negative indirect than positive direct radiative forcing and, in the interest of clarity, their effects are not given here.

¹⁴ In the BAU projections, it is assumed that all existing measures continue, including Montreal Protocol (phase-out) and relevant national policies. The current trends in practices, penetration of alternatives, and emission factors are maintained up to 2015. End-of-life recovery efficiency is assumed not to increase.

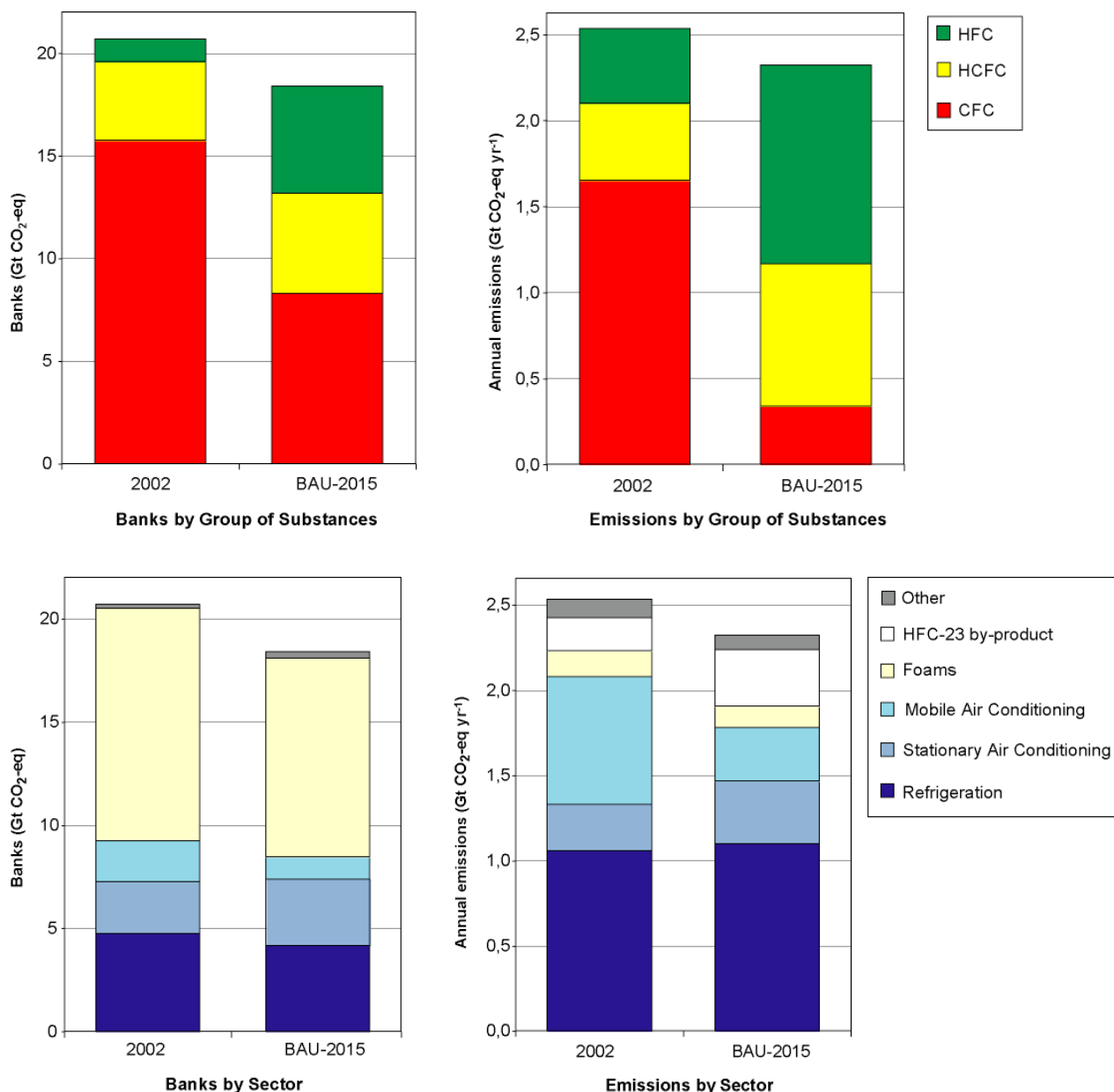


Figure SPM-4. Historic data for 2002 and Business-As-Usual (BAU) projections for 2015 of greenhouse gas CO₂-equivalent banks (left) and direct annual emissions (right), related to the use of CFCs, HCFCs and HFCs. Breakdown per group of greenhouse gases (top) and per emission sector (bottom). ‘Other’ includes Medical Aerosols, Fire Protection, Non-Medical Aerosols and Solvents. [11.3 and 11.5]

CFC banks associated with refrigeration, stationary air-conditioning (SAC)¹⁵ and mobile air-conditioning (MAC) equipment are projected to decrease from about 6 to 1 GtCO₂-eq over the period 2002 to 2015, mainly due to release to the atmosphere and partly due to end-of-life recovery and destruction. CFC banks in foams are projected to decrease much more slowly over the same period (from 10 to 7 GtCO₂-eq), reflecting the much slower release of banked blowing agents from foams when compared with similarly sized banks of refrigerant in the refrigeration and air-conditioning sector.

¹⁵ In this Summary for Policymakers the ‘refrigeration’ sector comprises domestic, commercial, industrial (including food processing and cold storage) and transportation refrigeration. [4] ‘Stationary air conditioning (SAC)’ comprises residential and commercial air conditioning and heating. [5] ‘Mobile air conditioning (MAC)’ applies to cars, buses and passenger compartments of trucks.

HFC banks have started to build up and are projected to reach about 5 GtCO₂-eq in 2015. Of these, HFCs banked in foams represent only 0.6 GtCO₂-eq, but are projected to increase further after 2015.

In the BAU scenario, total direct emissions of CFCs, HCFCs, HFCs and PFCs are projected to represent about 2.3 GtCO₂-eq per year by 2015 (as compared to about 2.5 GtCO₂-eq per year in 2002). CFC and HCFC emissions are together decreasing from 2.1 (2002) to 1.2 GtCO₂-eq per year (2015), and emissions of HFCs are increasing from 0.4 (2002) to 1.2 GtCO₂-eq per year (2015)¹⁶. PFC emissions from ODS substitute use are about 0.001 GtCO₂-eq per year (2002) and projected to decrease. [11.3 and 11.5]

Figure SPM-4 shows the relative contribution of sectors to global direct greenhouse gas (GHG) emissions that are related to the use of ODSs and their substitutes. Refrigeration applications together with SAC and MAC contribute the bulk of global direct GHG emissions in line with the higher emission rates associated with refrigerant banks. The largest part of GHG emissions from foams is expected to occur after 2015 because most releases occur at end-of-life.

With little new production, total CFC banks will decrease due to release to the atmosphere during operation and disposal. In the absence of additional measures a significant part of the CFC banks will have been emitted by 2015. Consequently, annual CFC emissions are projected to decrease from 1.7 (2002) to 0.3 GtCO₂-eq per year (2015).

HCFC emissions are projected to increase from 0.4 (2002) to 0.8 GtCO₂-eq per year (2015), owing to a steep increase expected for their use in (commercial) refrigeration and SAC applications.

The projected threefold increase in HFC emissions is the result of increased application of HFCs in the refrigeration, SAC and MAC sectors, and due to byproduct emissions of HFC-23 from increased HCFC-22 production (from 195 MtCO₂-eq per year in 2002 to 330 MtCO₂-eq per year in 2015 BAU).

Uncertainties in emission estimates are significant. Comparison of results of atmospheric measurements with inventory calculations shows differences per group of substances in the order of 10 to 25%. For individual gases the differences can be much bigger. This is caused by unidentified emissive applications of some substances, not accounted for in inventory calculations, and uncertainties in the geographically distributed datasets of equipment in use. [11.3.4]

The literature does not allow for an estimate of overall indirect⁶ GHG emissions related to energy consumption. For individual applications, the relevance of indirect GHG emissions over a life cycle can range from low to high, and for certain applications may be up to an order of magnitude larger than direct GHG emissions. This is highly dependent on the specific sector and product/application characteristics, the carbon-intensity of the consumed electricity and fuels during the complete life cycle of the application, containment during the use-phase, and the end-of-life treatment of the banked substances. [3.2, 4 and 5]

¹⁶ For these emission values the most recent scientific values for GWPs are used (see Table SPM-1, second column, 'GWP for direct radiative forcing'). If the UNFCCC GWPs would be used (Table SPM-1, last column, 'UNFCCC Reporting GWP'), reported HFC emissions (expressed in tonnes of CO₂-eq) would be about 15% lower.

4. Options for ODS phase-out and reducing greenhouse gas emissions

4.1 *What major opportunities have been identified for reductions of greenhouse gas emissions and how can they be assessed?*

Reductions in direct GHG emissions are available for all sectors discussed in this report and can be achieved through:

- **improved containment of substances;**
- **reduced charge of substances in equipment;**
- **end-of-life recovery and recycling or destruction of substances;**
- **increased use of alternative substances with a reduced or negligible global warming potential; and**
- **not-in-kind technologies¹⁷.**

A comprehensive assessment would cover both direct emissions and indirect energy-related emissions, full life-cycle aspects, as well as health, safety and environmental considerations. However, due to limited availability of published data and comparative analyses, such comprehensive assessments are currently almost absent.

Methods for determining which technology option has the highest GHG emission reduction potential address both direct emissions of halocarbons or substitutes and indirect energy-related emissions over the full life cycle. In addition, comprehensive methods¹⁸ assess a wide range of environmental impacts. Other, simplified methods¹⁹ exist to assess life-cycle impacts and commonly provide useful indicators for life-cycle greenhouse gas emissions of an application. Relatively few transparent comparisons applying these methods have been published. The conclusions from these comparisons are sensitive to assumptions about application-specific, and often region- and time-specific parameters (e.g. site-specific situation, prevailing climate, energy system characteristics). [3.5]

Comparative economic analyses are important to identify cost-effective reduction options. However, they require a common set of methods and assumptions (e.g. costing methodology, time-frame, discount rate, future economic conditions, system boundaries). The development of simplified standardized methodologies would enable better comparisons in the future. [3.3]

The risks of health and safety impacts can be assessed in most cases using standardized methods. [3.4 and 3.5]

GHG emissions related to energy consumption can be significant over the lifetime of appliances considered in this report. Energy efficiency improvements can thus lead to reductions in indirect emissions from these appliances, depending on the particular energy source used and other circumstances, and produce net cost reductions, particularly where the use-phase of the application is long (e.g. in refrigeration and SAC).

¹⁷ Not-in-kind technologies achieve the same product objective without the use of halocarbons, typically with an alternative approach or unconventional technique. Examples include the use of stick or spray pump deodorants to replace CFC-12 aerosol deodorants; the use of mineral wool to replace CFC, HFC or HCFC insulating foam; and the use of dry powder inhalers (DPIs) to replace CFC or HFC metered dose inhalers (MDIs).

¹⁸ Comprehensive methods, e.g. Life Cycle Assessment (LCA), cover all phases of the life cycle for a number of environmental impact categories. The respective methodologies are detailed in international ISO standards ISO 14040:1997, ISO 14041:1998, ISO 14042:2000, and ISO 14043:2000.

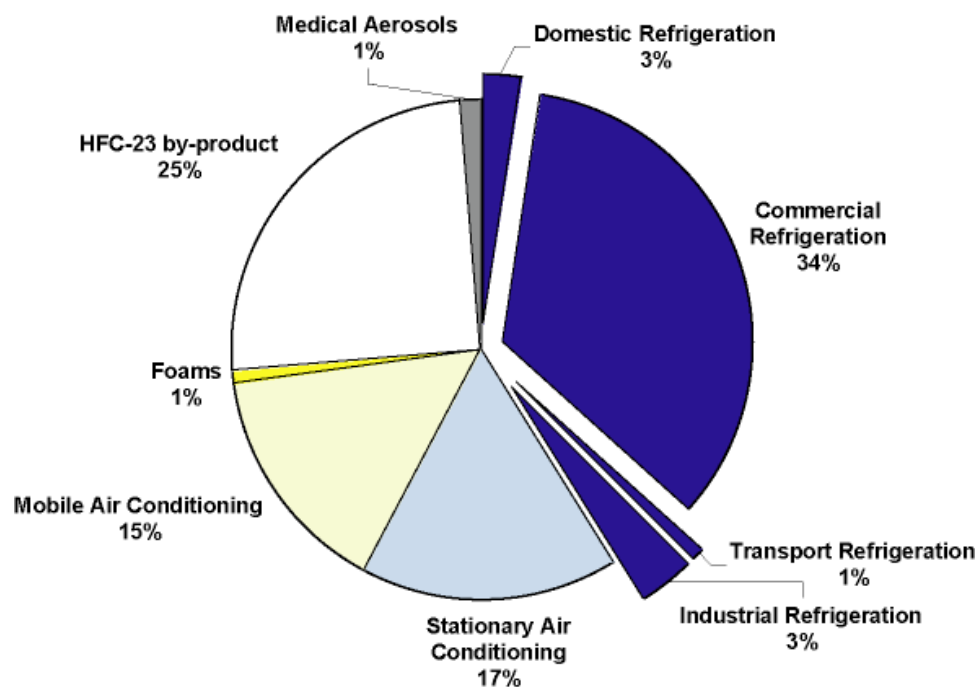
¹⁹ Typical simplified methods include Total Equivalent Warming Impact (TEWI), which assesses direct and indirect greenhouse emissions connected only with the use-phase and disposal; and Life Cycle Climate Performance (LCCP), which also includes direct and indirect greenhouse emissions from the manufacture of the active substances.

The assessed literature did not allow for a global estimate of this reduction potential, although several case studies at technology and country level illustrate this point.

Through application of current best practices²⁰ and recovery methods, there is potential to halve (1.2 GtCO₂-eq per year reduction) the BAU direct emissions from ODSs and their GHG substitutes by 2015²¹. About 60% of this potential concerns HFC emissions, 30% HCFCs and 10% CFCs.

The estimates are based on a Mitigation Scenario²² which makes regionally differentiated assumptions on best practices in production, use, substitution, recovery and destruction of these substances. Sectoral contributions are shown in Figure SPM-5. [11.5]

Of the bank-related emissions that can be prevented in the period until 2015, the bulk is in refrigerant-based applications where business-as-usual emission rates are considerably more significant than they are for foams during the period in question. With earlier action, such as recovery/destruction and improved containment, more of the emissions from CFC banks can be captured.



Sectoral Emission Reduction Potentials 2015

Figure SPM-5. Sectoral reduction potentials for direct emissions of CFCs, HCFCs and HFCs in 2015 as compared to the BAU projections. The overall reduction potential is about half (1.2 GtCO₂-eq per year) of the BAU direct GHG emissions.

²⁰ For this Report, best practice is considered the lowest achievable value of halocarbon emission at a given date, using commercially proven technologies in the production, use, substitution, recovery and destruction of halocarbon or halocarbon-based products (for specific numbers, see Table TS-6).

²¹ For comparison, CO₂ emissions related to fossil fuel combustion and cement production were about 24 GtCO₂ per year in 2000.

²² The Mitigation Scenario used in this Report, projects the future up to 2015 for the reduction of halocarbon emissions, based on regionally differentiated assumptions of best practices.

4.2 What are the sectoral emission reduction potentials in 2015 and what are associated costs?

In refrigeration applications direct GHG emissions can be reduced by 10% to 30%. For the refrigeration sector as a whole, the Mitigation Scenario shows an overall direct emission reduction of about 490 MtCO₂-eq per year by 2015, with about 400 MtCO₂-eq per year predicted for commercial refrigeration. Specific costs are in the range of 10 to 300 US\$/tCO₂-eq^{23,24}. Improved system energy efficiencies can also significantly reduce indirect GHG emissions.

In full supermarket systems, up to 60% lower LCCP¹⁹ values can be obtained by using alternative refrigerants, improved containment, distributed systems, indirect systems or cascade systems. Refrigerant specific emission abatement costs range for the commercial refrigeration sector from 20 to 280 US\$/tCO₂-eq.

In food processing, cold storage and industrial refrigeration, ammonia is forecast for increased use in the future, with HFCs replacing HCFC-22 and CFCs. Industrial refrigeration refrigerant specific emissions abatement costs were determined to be in the range from 27 to 37 US/tCO₂-eq. In transport refrigeration, lower GWP alternatives, such as ammonia, hydrocarbons and ammonia/carbon dioxide have been commercialized.

The emission reduction potential in domestic refrigeration is relatively small, with specific costs in the range of 0 to 130 US\$/tCO₂-eq. Indirect emissions of systems using either HFC-134a or HC-600a (isobutane) dominate total emissions, for different carbon intensities of electric power generation. The difference between the LCCP¹⁹ of HFC-134a and isobutane systems is small and end-of-life recovery, at a certain cost increase, can further reduce the magnitude of the difference. [4]

Direct GHG emissions of residential and commercial air-conditioning and heating equipment (SAC) can be reduced by about 200 MtCO₂-eq per year by 2015 relative to the BAU scenario. Specific costs range from -3 to 170 US\$/tCO₂-eq²³. When combined with improvements in system energy efficiencies, which reduce indirect GHG emissions, in many cases net financial benefits accrue. Opportunities to reduce direct GHG (i.e. refrigerant) emissions can be found in (i) more efficient recovery of refrigerant at end-of-life (in the Mitigation Scenario assumed to be 50% and 80% for developing and developed countries, respectively); (ii) refrigerant charge reduction (up to 20%); (iii) better containment and (iv) the use of refrigerants with reduced or negligible GWPs in suitable applications.

Improving the integrity of the building envelope (reduced heat gain or loss) can have a significant impact on indirect emissions.

HFC mixtures and hydrocarbons (HCs) (for small systems) are used as alternatives for HCFC-22 in developed countries. For those applications where HCs can be safely applied, the energy efficiency is comparable to fluorocarbon refrigerants. Future technical developments could reduce refrigerant charge, expanding the applicability of HCs. [5]

²³ The presented cost data concern direct emission reductions only. Taking into account energy efficiency improvements may result in even net negative specific costs (savings).

²⁴ Costs in this report are given in 2002 US dollars unless otherwise stated.

In mobile air conditioning, a reduction potential of 180 MtCO₂-eq per year by 2015 could be achieved at a cost of 20 to 250 US\$/tCO₂-eq²³. Specific costs differ per region and per solution. Improved containment, and end-of-life recovery (both of CFC-12 and HFC-134a) and recycling (of HFC-134a) could reduce direct GHG emissions by up to 50%, and total (direct and indirect) GHG emissions of the MAC unit by 30 to 40% at a financial benefit to vehicle owners. New systems with either CO₂ or HFC-152a, with equivalent LCCP, are likely to enter the market, leading to total GHG system emission reductions estimated at 50 to 70% in 2015 at an estimated added specific cost of 50 to 180 US\$ per vehicle.

Hydrocarbons and hydrocarbon blends, which have been used to a limited extent, present suitable thermodynamic properties and permit high energy efficiency. However, the safety and liability concerns identified by vehicle manufacturers and suppliers limit the possible use of hydrocarbons in new vehicles. [6.4.4]

Due to the long life-span of most foam applications, by 2015 a limited emission reduction of 15 to 20 MtCO₂-eq per year is projected at specific costs ranging from 10 to 100 US\$/tCO₂-eq²³. The potential for emission reduction increases in following decades.

Several short-term emission reduction steps, such as the planned elimination of HFC use in emissive one-component foams in Europe, are already in progress and are considered as part of the BAU. Two further key areas of potential emission reduction exist in the foams sector. The first is a potential reduction in halocarbon use in newly manufactured foams. However, the enhanced use of blends and the further phase-out of fluorocarbon use both depend on further technology development and market acceptance. Actions to reduce HFC use by 50% between 2010 and 2015, would result in emission reduction of about 10 MtCO₂-eq per year, at a specific cost of 15 to 100 US\$/tCO₂-eq, with further reductions thereafter²³.

The second opportunity for emission reduction can be found in the worldwide banks of halocarbons contained in insulating foams in existing buildings and appliances (about 9 and 1 GtCO₂-eq for CFC and HCFC, respectively in 2002). Although recovery effectiveness is yet to be proven, and there is little experience to date, particularly in the buildings sector, commercial operations are already recovering halocarbons from appliances at 10 to 50 US\$/tCO₂-eq²³. Emission reductions may be about 7 MtCO₂-eq per year in 2015. However, this potential could increase significantly in the period between 2030 and 2050, when large quantities of building insulation foams will be decommissioned. [7]

The reduction potential for medical aerosols is limited due to medical constraints, the relatively low emission level and the higher costs of alternatives. The major contribution (14 MtCO₂-eq per year by 2015 compared to a BAU emission of 40 MtCO₂-eq per year) to a reduction of GHG emissions for metered dose inhalers (MDIs) would be the completion of the transition from CFC to HFC MDIs beyond what was already assumed as BAU. The health and safety of the patient is considered to be of paramount importance in treatment decisions, and there are significant medical constraints to limit the use of HFC MDIs. If salbutamol MDIs (approximately 50% of total MDIs) would be replaced by dry powder inhalers (which is not assumed in the Mitigation Scenario) this would result in an annual emission reduction of about 10 MtCO₂-eq per year by 2015 at projected costs in the range of 150 to 300 US\$/tCO₂-eq. [8]

In fire protection, the reduction potential by 2015 is small due to the relatively low emission level, the significant shifts to not-in-kind alternatives in the past and the lengthy procedures for introducing new equipment. Direct GHG emissions for the sector are estimated at about 5 MtCO₂-eq per year in 2015 (BAU). Seventy five percent of original halon use has been shifted to agents with no climate impact. Four percent of the original halon applications continue to employ halons. The remaining 21% has been shifted to HFCs with a small number of applications shifted to HCFCs and to PFCs. PFCs are no longer needed for new fixed systems and are limited to use as a propellant in one manufacturer's portable extinguisher agent blend. Due to the lengthy process of testing, approval and market acceptance of new fire protection equipment types and agents, no additional options will likely have appreciable impact by 2015. With the introduction of a fluoroketone (FK) in 2002, additional reductions at an increased cost are possible in this sector through 2015. Currently those reductions are estimated to be small compared to other sectors. [9]

For non-medical aerosols and solvents there are several reduction opportunities, but the reduction potentials are likely to be rather small because most remaining uses are critical to performance or safety. The projected BAU emissions by 2015 for solvents and aerosols are about 14 and 23 MtCO₂-eq per year, respectively. Substitution of HFC-134a by HFC-152a in technical aerosol dusters is a leading option for reducing GHG emissions. For contact cleaners and plastic casting mould release agents, the substitution of HCFCs by hydrofluoroethers (HFEs) and HFCs with lower GWPs offers an opportunity. Some countries have banned HFC use in cosmetic, convenience and novelty aerosol products, although HFC-134a continues to be used in many countries for safety reasons.

A variety of organic solvents can replace HFCs, PFCs and ODSs in many applications. These alternative fluids include lower GWP compounds such as traditional chlorinated solvents, HFEs, HCs and oxygenated solvents. Many not-in-kind technologies, including no-clean and aqueous cleaning processes, are also viable alternatives. [10]

Destruction of byproduct emissions of HFC-23 from HCFC-22 production has a reduction potential of up to 300 MtCO₂-eq per year by 2015 and specific costs below 0.2 US\$/tCO₂-eq according to two European studies in 2000.

Reduction of HCFC-22 production due to market forces or national policies, or improvements in facility design and construction also could reduce HFC-23 emissions. [10.4]

4.3 What are the current policies, measures and instruments?

A variety of policies, measures and instruments have been implemented in reducing the use or emissions of ODSs and their substitutes, such as HFCs and PFCs. These include regulations, economic instruments, voluntary agreements and international co-operation. Furthermore, general energy or climate policies affect the indirect GHG emissions of applications with ODSs, their substitutes, or not-in-kind alternatives.

This report contains information on policies and approaches in place in some countries (mainly developed) for reducing the use or emissions of ODSs and their substitutes. Those relevant policies and approaches include:

- Regulations (e.g., performance standards, certification, restrictions, end-of-life management)
- Economic instruments (e.g., taxation, emissions trading, financial incentives and deposit refunds)
- Voluntary agreements (e.g., voluntary reductions in use and emissions, industry partnerships and implementation of good practice guidelines)
- International co-operation (e.g., Clean Development Mechanism)

It should be noted that policy considerations are dependent on specific applications, national circumstances and other factors.

4.4 What can be said about availability of HFCs/PFCs in the future for use in developing countries?

No published data are available to project future production capacity. However, as there are no technical or legal limits to HFC and PFC production, it can be assumed that the global production capacity will generally continue to satisfy or exceed demand. Future production is therefore estimated in this report by aggregating sectoral demand.

In the BAU scenario, global production capacity is expected to expand with additions taking place mainly in developing countries and through joint ventures. Global production capacity of HFCs and PFCs most often exceeds current demand. There are a number of HFC-134a plants in developed countries and one plant in a developing country with others planned; the few plants for other HFCs are almost exclusively in developed countries. The proposed European Community phase-out of HFC-134a in mobile air conditioners in new cars and the industry voluntary programme to reduce their HFC-134a emissions by 50% will affect demand and production capacity and output. Rapidly expanding markets in developing countries, in particular for replacements for CFCs, is resulting in new capacity for fluorinated gases which is at present being satisfied through the expansion of HCFC-22 and 141b capacity. [11]

Annex I: Glossary of Terms

The definitions in this glossary refer to the use of the terms in the context of the Summary for Policymakers of the Special Report on Ozone and Climate.

Aerosol

A suspension of very fine solid or liquid particles in a gas. Aerosol is also used as a common name for a spray (or “aerosol”) can, in which a container is filled with a product and a propellant and is pressurized so as to release the product in a fine spray.

Banks

Banks are the total amount of substances contained in existing equipment, chemical stockpiles, foams and other products not yet released to the atmosphere.

Best practice

For this Report, best practice is considered the lowest achievable value of halocarbon emission at a given date, using commercially proven technologies in the production, use, substitution, recovery and destruction of halocarbon or halocarbon-based products.

Blends/Mixtures (Refrigeration)

A mixture of two or more pure fluids. Blends are used to achieve properties that fit many refrigeration purposes. For example, a mixture of flammable and nonflammable components can result in a nonflammable blend. Blends can be divided into three categories: azeotropic, non-azeotropic and near-azeotropic blends.

Blowing Agent (Foams)

A gas, volatile liquid, or chemical that generates gas during the foaming process. The gas creates bubbles or cells in the plastic structure of a foam.

Business as Usual (BAU) Scenario (2015, this report)

A baseline scenario for the use of halocarbons and their alternatives, which assumes that all existing regulation and phase-out measures, including the Montreal Protocol and relevant national regulations, continue to 2015. The usual practices (including end-of-life recovery) and emission rates are kept unchanged up to 2015.

Carbon Dioxide (CO₂)

A naturally occurring gas which occurs as a by-product of burning fossil fuels and biomass, as well as other industrial processes and land-use changes. It is the principal anthropogenic greenhouse gas that affects the Earth’s radiative balance and is the reference gas against which other greenhouse gases are generally measured.

Chlorofluorocarbons (CFCs)

Halocarbons containing only chlorine, fluorine, and carbon atoms. CFCs are both ozone-depleting substances (ODSs) and greenhouse gases.

Climate Change

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Note that Article 1 of the Framework Convention on Climate Change (UNFCCC) defines “climate change” as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability, observed over comparable time periods”. The UNFCCC thus makes a distinction between “climate change” attributable to human activities altering the atmospheric composition, and “climate variability” attributable to natural causes.

Climate Variability

Variations in the mean state and other statistics (such as the standard deviation and the occurrence of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events. Climate variability may be caused by natural internal processes within the climate system (internal variability), or by variations in natural or anthropogenic external forcings (external variability). See also: Climate change.

CO₂-Equivalent

The amount of carbon dioxide (CO₂) that would cause the same amount of radiative forcing as a given amount of another greenhouse gas. When used with concentrations this refers to the instantaneous radiative forcing caused by the greenhouse gas or the equivalent amount of CO₂. When used with emissions this refers to the time integrated radiative forcing over a specified time horizon caused by the change in concentration produced by the emissions. See Global Warming Potential.

Column Ozone

The total amount of ozone in a vertical column above the Earth’s surface. Column ozone is measured in Dobson Units (DU).

Containment (Refrigeration)

The application of service techniques or special equipment designed to preclude or reduce loss of refrigerant from equipment during installation, operation, service, or disposal of refrigeration and air-conditioning equipment.

Destruction

Destruction of ozone-depleting substances (ODSs) by approved destruction plants, in order to avoid their emissions.

Dry Powder Inhaler (DPI) (Medical Aerosols)

An alternate technology to metered dose inhalers (MDIs) that can be used if the medication being dispensed can be satisfactorily formulated as microfine powder, thus eliminating the use of a chemical propellant.

Fluorocarbons

Halocarbons containing fluorine atoms, including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Fluoroketones (FKs)

Organic compounds in which two fully fluorinated alkyl groups are attached to a carbonyl group (C=O).

Global Warming Potential (GWP)

An index, comparing the climate impact of an emission of a greenhouse gas relative to that of emitting the same amount of carbon dioxide. GWPs are determined as the ratio of the time-integrated radiative forcing arising from a pulse emission of 1 kg of a substance relative to that of 1 kg of carbon dioxide, over a fixed time horizon. See also: Radiative forcing.

Greenhouse Gases (GHGs)

The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation within the spectrum of the thermal infrared radiation that is emitted by the Earth's surface, by the atmosphere, and by clouds. This property causes the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapour (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and ozone (O₃). Moreover, there are a number of entirely anthropogenic greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances that are covered by the Montreal Protocol. Some other trace gases such as sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) are also greenhouse gases.

Halocarbons

Chemical compounds containing carbon atoms, and one or more atoms of the halogens chlorine (Cl), fluorine (F), bromine (Br), or iodine (I). *Fully halogenated halocarbons* contain only carbon and halogen atoms, whereas *partially halogenated halocarbons* also contain hydrogen (H) atoms. Halocarbons that release chlorine, bromine, or iodine into the stratosphere cause ozone depletion. Halocarbons are also greenhouse gases. Halocarbons include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and halons.

Halons

Fully halogenated halocarbons that contain, bromine, and fluorine atoms.

Hydrocarbons (HCs)

Chemical compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms.

Hydrochlorofluorocarbons (HCFCs)

Halocarbons containing only hydrogen, chlorine, fluorine and carbon atoms. Because HCFCs contain chlorine, they contribute to ozone depletion. They are also greenhouse gases.

Hydrofluorocarbons (HFCs)

Halocarbons containing only carbon, hydrogen and fluorine atoms. Because HFCs contain no chlorine, bromine, or iodine, they do not deplete the ozone layer. Like other halocarbons, they are potent greenhouse gases.

Hydrofluoroethers (HFEs)

Chemicals composed of hydrogen, fluorine and ether, which has similar performance characteristics to certain ozone-depleting substances (ODSs) that are used as solvents.

Life Cycle Assessment (LCA)

An assessment of the overall environmental impact of a product over its entire life cycle (manufacture, use, and recycling or disposal).

Life Cycle Climate Performance (LCCP)

A measure of the overall global-warming impact of equipment based on the total related emissions of greenhouse gases over its entire life cycle. LCCP is an extension of the total equivalent warming impact (TEWI). LCCP also takes into account the direct fugitive emissions arising during manufacture, and the greenhouse gas emissions associated with their embodied energy.

Metered Dose Inhalers (MDIs) (Medical Aerosols)

A method of dispensing inhaled pulmonary drugs.

Miscible

The ability of two liquids or gases to uniformly dissolve into each other. Immiscible liquids will separate into two distinguishable layers.

Not-in-kind technologies (NIK)

Not-in-kind technologies achieve the same product objective without the use of halocarbons, typically with an alternative approach or unconventional technique. Examples include the use of stick or spray pump deodorants to replace CFC-12 aerosol deodorants; the use of mineral wool to replace CFC, HFC or HCFC insulating foam; and the use of dry powder inhalers (DPIs) to replace CFC or HFC metered dose inhalers (MDIs).

One-component foam (OCF)

A foam in which the blowing agent acts both as a frothing agent and as a propellant. These foams are primarily used for gap filling (to prevent air infiltration) rather than for thermal insulation per se. As such the use of blowing agent is fully emissive.

Ozone

The triatomic form of oxygen (O₃), which is a gaseous atmospheric constituent. In the troposphere it is created by photochemical reactions involving gases occurring naturally and resulting from anthropogenic activities (“smog”). Tropospheric ozone acts as a greenhouse gas. In the stratosphere ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O₂). Stratospheric ozone plays a major role in the stratospheric radiative balance. Its concentration is highest in the ozone layer.

Ozone-Depleting Substances (ODSs)

Substances known to deplete the stratospheric ozone layer. The ODSs controlled under the Montreal Protocol and its amendments are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, methyl bromide (CH₃Br), carbon tetrachloride (CCl₄), methyl chloroform (CH₃CCl₃), hydrobromofluorocarbons (HBFCs), and bromochloromethane.

Ozone Depletion

Accelerated chemical destruction of the stratospheric ozone layer by the presence of substances produced by human activities.

Perfluorocarbons (PFCs)

Synthetically produced halocarbons containing only carbon and fluorine atoms. They are characterized by extreme stability, non-flammability, low toxicity, zero ozone depleting potential, and high global warming potential.

Radiative Forcing

Radiative forcing is the change in the net irradiance (expressed in Watts per square meter: W m⁻²) at the tropopause due to an internal change or a change in the external forcing of the climate system, such as a change in the concentration of carbon dioxide (CO₂) in the atmosphere or in the output of the Sun. Usually radiative forcing is computed after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with all tropospheric properties held fixed at their unperturbed values. Radiative forcing is called *instantaneous* if no change in stratospheric temperature is accounted for. See also: Global warming potential.

Recovery

The collection and storage of controlled substances from machinery, equipment, containment vessels, etc., during servicing or prior to disposal without necessarily testing or processing it in any way.

Recycling

Reuse of a recovered controlled substance following a basic cleaning process such as filtering and drying. For refrigerants, recycling normally involves recharge back into equipment and it often occurs “on-site”.

Refrigerant (Refrigeration)

A heat transfer agent, usually a liquid, used in equipment such as refrigerators, freezers and air conditioners.

Solvent

Any product (aqueous or organic) designed to clean a component or assembly by dissolving the contaminants present on its surface.

Specific costs (of abatement options)

The difference in costs of an abatement option as compared to a reference case, expressed in relevant specific units. In this Report the specific costs of greenhouse gas emission reduction options are generally expressed in US\$ per tonne of avoided CO₂-equivalents (US\$/tCO₂-eq).

SRES Scenarios

Emission scenarios developed by the IPCC Special Report on Emission Scenarios (2000).

Stratosphere

The highly stratified region of the atmosphere above the troposphere. It extends from an altitude of about 8 km in high latitudes and 16 km in the tropics to an altitude of about 50 km. This region is characterised by increasing temperature with altitude.

Total Equivalent Warming Impact (TEWI)

A measure of the overall global-warming impact of equipment based on the total related emissions of greenhouse gases during the operation of the equipment and the disposal of the operating fluids at the end of life. TEWI takes into account both direct fugitive emissions, and indirect emissions produced through the energy consumed in operating the equipment. TEWI is measured in units of mass of CO₂ equivalent. See also: Life cycle climate performance (LCCP).

Troposphere

The lowest part of the atmosphere above the Earth's surface, where clouds and “weather” phenomena occur. The thickness of the troposphere is on average 9 km in high latitudes, 10 km in mid-latitudes, and 16 km in the tropics. Temperatures in the troposphere generally decrease with height.

Annex II: Major Chemical Formulae and Nomenclature

This annex presents the formulae and nomenclature for several halogen-containing and other species that are referred to in the Summary for Policymakers.

The *Montreal Protocol on Substances that Deplete the Ozone Layer* controls the production and consumption of the following halocarbons: chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, hydrobromofluorocarbons (HBFCs), carbon tetrachloride (CCl₄), methyl chloroform (CH₃CCl₃), methyl bromide (CH₃Br) and bromochloromethane (CH₂BrCl).

The *United Nations Framework Convention on Climate Change (UNFCCC)* covers anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol. The *Kyoto Protocol* of the UNFCCC covers the basket of greenhouse gases carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆).

Halocarbons

For each halocarbon the following information is given in columns:

- Chemical compound [Number of isomers if more than one] (or common name)
- Chemical formula
- Chemical name (or alternative name)

| <i>Chlorofluorocarbons (CFCs)</i> | | [Production and consumption are controlled by the Montreal Protocol] ¹ |
|-----------------------------------|---|---|
| CFC-11 | CCl ₃ F | Trichlorofluoromethane |
| CFC-12 | CCl ₂ F ₂ | Dichlorodifluoromethane |
| CFC-13 | CCIF ₃ | Chlorotrifluoromethane |
| CFC-113 [2] | C ₂ Cl ₃ F ₃ | Trichlorotrifluoroethane |
| CFC-113 | CCl ₂ FCCIF ₂ | 1,1,2-Trichloro-1,2,2-trifluoroethane |
| CFC-113a | CCl ₃ CF ₃ | 1,1,1-Trichloro-2,2,2-trifluoroethane |
| CFC-114 [2] | C ₂ Cl ₂ F ₄ | Dichlorotetrafluoroethane |
| CFC-114 | CCIF ₂ CCIF ₂ | 1,2-Dichloro-1,1,2,2-tetrafluoroethane |
| CFC-114a | CCl ₂ FCF ₃ | 1,1-Dichloro-1,2,2,2-tetrafluoroethane |
| CFC-115 | CCIF ₂ CF ₃ | Chloropentafluoroethane |

| <i>Hydrochlorofluorocarbons (HCFCs)</i> | | [Production and consumption are controlled by the Montreal Protocol] ¹ |
|---|---|---|
| HCFC-21 | CHCl ₂ F | Dichlorofluoromethane |
| HCFC-22 | CHClF ₂ | Chlorodifluoromethane |
| HCFC-123 [3] | C ₂ HCl ₂ F ₃ | Dichlorotrifluoroethane |
| HCFC-123 | CHCl ₂ CF ₃ | 2,2-Dichloro-1,1,1-trifluoroethane |
| HCFC-123a | C ₂ HCl ₂ F ₃ | 1,2-Dichloro-1,1,2-trifluoroethane |
| HCFC-123b | C ₂ HCl ₂ F ₃ | 1,1-Dichloro-1,2,2-trifluoroethane |
| HCFC-124 [2] | | Chlorotetrafluoroethane |
| HCFC-124 | CHClFCF ₃ | 2-Chloro-1,1,1,2-tetrafluoroethane |
| HCFC-124a | C ₂ HClF ₄ | 1-Chloro-1,1,2,2-tetrafluoroethane |
| HCFC-141b | CH ₃ CCl ₂ F | 1,1-Dichloro-1-fluoroethane |
| HCFC-142b | CH ₃ CCIF ₂ | 1-Chloro-1,1-difluoroethane |
| HCFC-225ca | CHCl ₂ CF ₂ CF ₃ | 3,3-Dichloro-1,1,1,2,2-pentafluoropropane |
| HCFC-225cb | CHClFCF ₂ CCIF ₂ | 1,3-Dichloro-1,1,2,2,3-pentafluoropropane |

¹ Note that the substances presented here are a selection of the substances that are controlled by the Montreal Protocol.

| <i>Halons</i> | | [Production and consumption are controlled by the Montreal Protocol] |
|---------------|------------------------------|---|
| Halon-1202 | CBr_2F_2 | Dibromodifluoromethane |
| Halon-1211 | CBrClF_2 | Bromochlorodifluoromethane (Chlorodifluorobromomethane), R-12B1 |
| Halon-1301 | CBrF_3 | Bromotrifluoromethane, R-13B1 |
| Halon-2402 | $\text{CBrF}_2\text{CBrF}_2$ | 1,2-Dibromotetrafluoroethane (1,1,2,2-Tetrafluoro-1,2-dibromoethane, 1,2-Dibromo-1,1,2,2-tetrafluoroethane) |

| <i>Other Halocarbons</i> | | [Production and consumption are controlled by the Montreal Protocol] |
|--------------------------|---------------------------|--|
| Carbon tetrachloride | CCl_4 | Halon 104, R-10 |
| Methyl chloroform | CH_3CCl_3 | 1,1,1-Trichloroethane |
| Methyl bromide | CH_3Br | Halon-1001, Bromomethane |
| Bromochloromethane | CH_2BrCl | Halon-1011 |

| <i>Hydrofluorocarbons (HFCs)</i> | | |
|----------------------------------|---|--|
| HFC-23 | CHF_3 | Trifluoromethane |
| HFC-32 | CH_2F_2 | Difluoromethane (Methylene fluoride) |
| HFC-41 | CH_3F | Fluoromethane (Methyl fluoride) |
| HFC-125 | CHF_2CF_3 | Pentafluoroethane |
| HFC-134 [2] | $\text{C}_2\text{H}_2\text{F}_4$ | Tetrafluoroethane |
| HFC-134 | CHF_2CHF_2 | 1,1,2,2-Tetrafluoroethane |
| HFC-134a | CH_2FCF_3 | 1,1,1,2-Tetrafluoroethane |
| HFC-143 [2] | $\text{C}_2\text{H}_3\text{F}_3$ | Trifluoroethane |
| HFC-143 | CH_2FCHF_2 | 1,1,2-Trifluoroethane |
| HFC-143a | CH_3CF_3 | 1,1,1-Trifluoroethane |
| HFC-152 [2] | $\text{C}_2\text{H}_4\text{F}_2$ | Difluoroethane |
| HFC-152 | $\text{CH}_2\text{FCH}_2\text{F}$ | 1,2-Difluoroethane |
| HFC-152a | CHF_2CH_3 | 1,1-Difluoroethane |
| HFC-161 | $\text{CH}_3\text{CH}_2\text{F}$ | Monofluoroethane (Ethyl fluoride) |
| HFC-227 [2] | C_3HF_7 | Heptafluoropropane |
| HFC-227ca | $\text{CF}_3\text{CF}_2\text{CHF}_2$ | 1,1,1,2,2,3,3-Heptafluoropropane |
| HFC-227ea | $\text{CF}_3\text{CHF}_2\text{CF}_3$ | 1,1,1,2,3,3,3-Heptafluoropropane |
| HFC-236 [4] | $\text{C}_3\text{H}_2\text{F}_6$ | Hexafluoropropane |
| HFC-236ca | $\text{CHF}_2\text{CF}_2\text{CHF}_2$ | 1,1,2,2,3,3-Hexafluoropropane |
| HFC-236cb | $\text{CH}_2\text{FCF}_2\text{CF}_3$ | 1,1,1,2,2,3-Hexafluoropropane |
| HFC-236ea | $\text{CHF}_2\text{CHF}_2\text{CF}_3$ | 1,1,1,2,3,3-Hexafluoropropane |
| HFC-236fa | $\text{CF}_3\text{CH}_2\text{CF}_3$ | 1,1,1,3,3,3-Hexafluoropropane |
| HFC-245 [5] | $\text{C}_3\text{H}_3\text{F}_5$ | Pentafluoropropane |
| e.g. HFC-245ca | $\text{CH}_2\text{FCF}_2\text{CHF}_2$ | 1,1,2,2,3-Pentafluoropropane |
| HFC-245fa | $\text{CHF}_2\text{CH}_2\text{CF}_3$ | 1,1,1,3,3-Pentafluoropropane |
| HFC-365mfc | $\text{CH}_3\text{CF}_2\text{CH}_2\text{CF}_3$ | 1,1,1,3,3-Pentafluorobutane |
| HFC-43-10mee | $\text{CF}_3\text{CHFCH}_2\text{CF}_2\text{CF}_3$ | 1,1,1,2,2,3,4,5,5,5-Decafluoropentane (2H,3H-Perfluoropentane) |
| HFC-c-447ef | $\text{c-C}_5\text{H}_3\text{F}_7$ | Heptafluorocyclopentane |

| <i>Perfluorocarbons (PFCs)</i> | | |
|--------------------------------|--|--|
| PFC-14 | CF ₄ | Tetrafluoromethane (Carbon tetrafluoride) |
| PFC-116 | C ₂ F ₆ (CF ₃ CF ₃) | Perfluoroethane (Hexafluoroethane) |
| PFC-218 | C ₃ F ₈ (CF ₃ CF ₂ CF ₃) | Perfluoropropane (Octafluoropropane) |
| PFC-318 or PFC-c318 | c-C ₄ F ₈ (-(CF ₂) ₄ -) | Perfluorocyclobutane (Octafluorocyclobutane) |
| PFC-3-1-10 | C ₄ F ₁₀ | Perfluorobutane |
| PFC-5-1-14 | C ₆ F ₁₄ | Perfluorohexane |
| PFC-6-1-16 | C ₇ F ₁₆ | Perfluoroheptane |
| PFC-7-1-18 | C ₈ F ₁₈ | Perfluorooctane |

| <i>Fluorinated Ethers</i> | | |
|---------------------------|--|---|
| HFE-449s1 | C ₅ H ₃ F ₉ O | Methyl nonafluorobutyl ether |
| | CF ₃ (CF ₂) ₃ OCH ₃ (CF ₃) ₂ CFCF ₂ OCH ₃ | Perfluoroisobutyl methyl ether |
| HFE-569sf2 | C ₆ H ₅ F ₉ O | Ethyl perfluorobutyl ether |
| | CF ₃ (CF ₂) ₃ OCF ₂ CF ₃ (CF ₃) ₂ CFCF ₂ OCF ₂ CF ₃ | Ethyl perfluoroisobutyl ether |
| HFE-347pcf2 | C ₄ H ₃ F ₇ O (CF ₃ CH ₂ OCF ₂ CHF ₂) | 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl ether |

| <i>Other Halocarbons</i> | | |
|----------------------------|--|-----------------|
| Trifluoroacetic acid (TFA) | C ₂ HF ₃ O ₂ (CF ₃ COOH) | Perfluoric acid |

Non-Halogenated Hydrocarbons

| | | |
|------------|---|-----------------------------------|
| Methane | CH ₄ | R-50 |
| Ethane | C ₂ H ₆ (CH ₃ CH ₃) | R-170 |
| Propane | C ₃ H ₈ (CH ₃ CH ₂ CH ₃) | R-290 |
| Butane | C ₄ H ₁₀ (CH ₃ CH ₂ CH ₂ CH ₃) | R-600, n-Butane |
| Isobutane | C ₄ H ₁₀ ((CH ₃) ₂ CHCH ₃) | R-600a, i-Butane, 2-Methylpropane |
| Pentane | C ₅ H ₁₂ (CH ₃ (CH ₂) ₃ CH ₃) | R-601, n-Pentane |
| Isopentane | C ₅ H ₁₂ ((CH ₃) ₂ CHCH ₂ CH ₃) | R-601a, i-Pentane, 2-Methylbutane |