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REPORT PREPARED WITH SUPPORT FROM

US EPA and ADEME

covering the

**DETERMINATION OF COMPARATIVE HCFC
AND HFC EMISSION PROFILES FOR THE
FOAM AND REFRIGERATION SECTORS
UNTIL 2015**

(Foam Projections)

Part 2

submitted by

CALEB MANAGEMENT SERVICES LTD

Enquiries to:

Paul Ashford
Caleb Management Services
Grovelands House
Woodlands Green
Woodlands Lane
Almondsbury
Bristol, BS32 4JT

Tel. 44-(0)1454-610220
Fax. 44-(0)1454-610240



Commercial in Confidence
E-mail CalebGroup@compuserve.com





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1. EXECUTIVE SUMMARY

This report covers the foam element of a project supported by ADEME (France) and US Environmental Protection Agency to establish the likely emissions of HFCs and alternative blowing agents (including HCFCs and hydrocarbons) between 1990 and 2015. It responds to a requirement that emerged during the drafting of the IPCC Special Report on HFCs and their alternatives in 2003. The scope of the IPCC Report has subsequently been extended to cover the influence of existing CFC banks and these aspects have been subsequently incorporated into the scope of work during early 2004.

The modelling work that constitutes the basis of this report, has been a development of previous work for AFEAS¹ and the UNEP Technical and Economic Assessment Panel² and introduces the following new elements:

1. A bottom-up analysis based on the construction of new dwellings and the sale of appliances in each of eleven regions in the world
2. Introduction of foam volume ratios to account for wider use of insulation in general and market shifts in product selection (foam vs. fibre).
3. Introduction of four specific end-of-life scenarios:
 - a. Re-use
 - b. Land-fill
 - c. Shredding without recovery
 - d. Shredding with recovery

The foam volume ratio approach mirrors that previously used by Armines within their FIEP model and allows for the later combination of the models in order to provide a default reporting tool. This work is already supported by the Greenhouse Gas Emission Estimation Consortium (GGECC) and will be completed by June 2004.

Blowing agent demand projections have been anchored on the quantitative assessment for 2001 contained in the 2002 UNEP Foam Technical Options Committee Report³. The subsequent application of the new bottom-up methodology has been found to generate figures that are broadly consistent with sales information available from AFEAS with the exception of the gaseous blowing agents HCFC-142b, HCFC-22 and HFC-134a, where correlation has been less exact. Nonetheless, the assessments have been sufficiently consistent to give confidence as 'drivers' for the emissions scenarios.

The emission functions used for this work have built on those used for the TFCRS Report in 2002 with the obvious exception of the inclusion of additional end-of-life scenarios over and above the

¹ 'Development of a Global Emission Function for Blowing Agents used in Closed Cell Foam', Caleb, 2000

² 'Report of the Task Force on Collection Recovery & Storage', UNEP, 2002

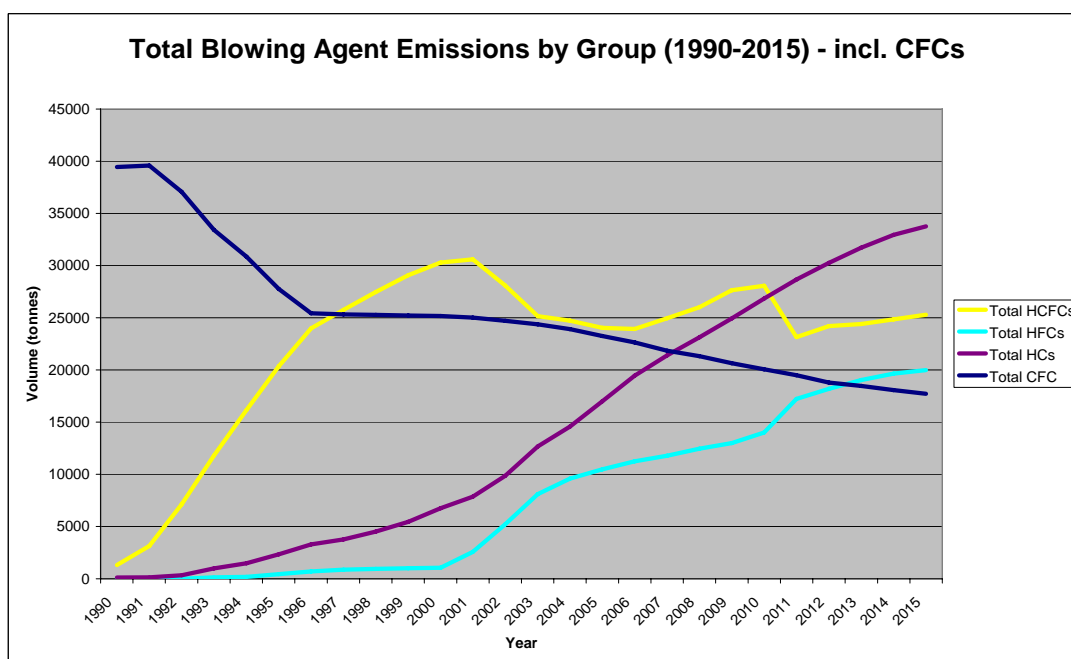
³ '2002 Report of the Rigid and Flexible Foams Technical Options Committee', UNEP, 2003



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“total release” assumption used previously Much work is on-going towards the validation of these emission functions in all three phases of release (manufacturing, in-use and end-of-life). However,

there are few conclusions yet to draw from this work. Most new information⁴ is leading towards the conclusion that emission assumptions should be lower than previously modelled, but this is in contradiction with the atmospheric concentration measurements which, if anything, indicate greater emission rates from foams. This paradox is yet to be resolved satisfactorily in several foam sectors. Nonetheless, the sensitivity of the overall emission forecasts to individual foam sector emission functions is small bearing in mind that 18 sectors are covered in the model. The graph below illustrates the emission projections for the period from 1990-2015.



The importance of emission functions, however, should not be under-estimated when considering the emissions of blowing agents used in only a few sub-sectors. Accordingly, the emission assumptions for XPS have a significant bearing on HFC forecasts. In order to ensure a pessimistic view of HFC emissions, the emission function adopted for XPS have been higher than the industry is currently predicting.

One other aspect which needs to be highlighted is the fact that low emission levels during the in-use phase lead to large potential banks of blowing agent. The estimates in this report show that both CFC and HCFC banks will still be in excess of 1 millions tonnes each at 2015. As HCFC use continues to grow in developing countries during the period to 2015, there will be considerable banks (est. 36% of the global total) in these regions, mostly in domestic and commercial refrigeration units.

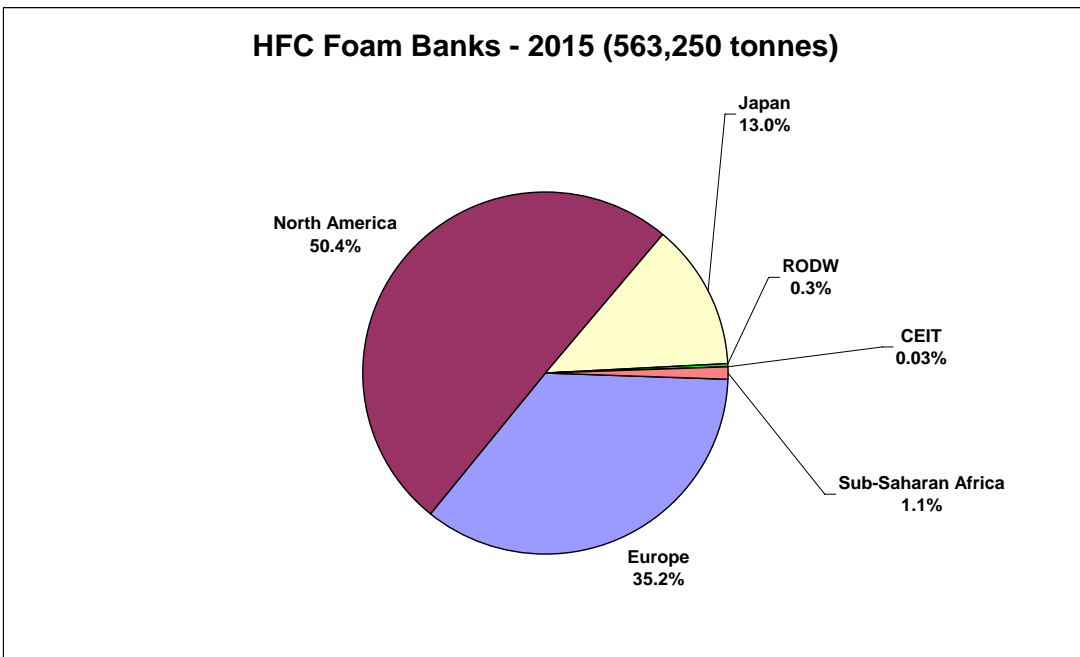
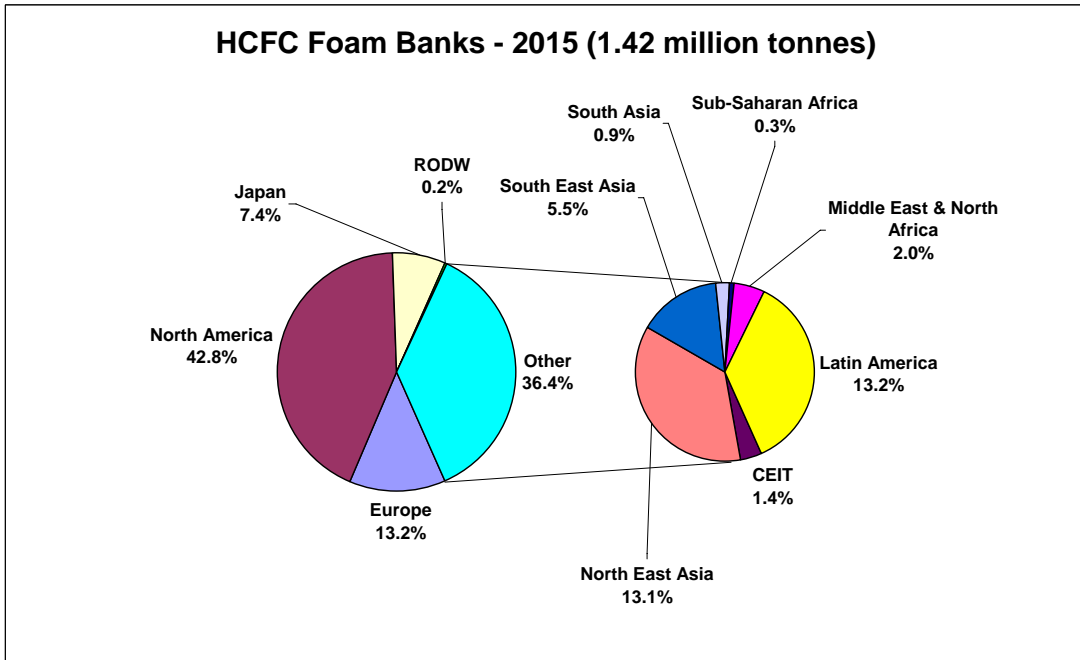
HFC banks will be heavily concentrated in three regions of the world (Europe, North America and Japan) where the greatest potential for recovery at end-of-life exists. However, the ability to

⁴ e.g. Vo and Paquet, ETF, 2004



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 recover will depend on the use of innovative product design, particularly in the construction sector where banks are notoriously difficult to access. The technical feasibility and economic viability of recovery measures is currently being reviewed within a parallel TEAP Task Force on the subject which will report in mid 2005.

The following graphs illustrate the distribution of HCFC and HFC banks in 2015 in order to highlight the points already made.





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The significance of these banks is that many of the anticipated emissions will take place after 2015 as construction applications become due for decommissioning. This, of course, is unless they can be mitigated in some way.



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In summary, the purpose of this project has been to produce a more comprehensive assessment of the patterns of blowing agent consumption, emission and accumulation at global and regional level. This has broadly been achieved as witnessed by the summary table below:

Blowing Agent	CFCs	HCFCs	HFCs	Hydrocarbons
Consumption (mt)	Nil	50,019	72,967	177,249
Emissions (mt)	17,710	25,229	19,974	33,760
GWP-weighted emissions (Mtons CO ₂)	99.94	30.51	20.07	0.51
Average GWP	5,643	1,209	1,005	15
Bank at 2000 (mt)	1,904,552	881,333	3,946	210,337
Remaining Bank at 2015 (mt)	1,228,199	1,416,825	563,232	1,231,703

Projected Global Consumption and Emissions of Blowing Agent by Type as at 2015

Key conclusions from the work include the following:

- Foams are designed to retain their blowing agents as part of the maintenance of important performance criteria. Accordingly losses are low, particularly in the use phase.
- Emission forecasts and their relationship with observed atmospheric concentrations are therefore highly dependent on the accuracy of emission functions used for the use phase since low percentage figures are involved.
- Work continues to quantify these in-use phase losses, particularly in the XPS sector.
- The existing banks of CFCs and HCFCs will both still exceed 1 million tonnes in 2015 leading to a need to evaluate end-of-life options that could be appropriate for insulation materials already installed in buildings.
- HFC emissions are expected to reach 20,000 tonnes per annum by 2015 based on a projected usage of 75,000 tonnes per annum at that date. This figure represents a considerably lower estimate than believed likely in previous analyses (e.g. Petten).
- Developing countries will use very little HFC in the period to 2015 and will remain with HCFCs, as allowed for under the Montreal Protocol
- The increased use of innovative building techniques, including greater pre-fabrication, will assist in the end of life management of HFC-containing foam in Europe, Japan and elsewhere.

P. Ashford - 07/04/04



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2. OBJECTIVES AND SCOPE

Background

In mid-2002, the IPCC, in association with TEAP commissioned the development of a Special Report entitled "Safeguarding the ozone layer and the global climate: issues related to HFCs and PFCs". One of the prime aims of this Report was to evaluate the technical alternatives to HFCs and PFCs and to explore opportunities to minimize emissions. In evaluating these options, it was recognized from the outset that emissions forecasting would be an important element of the work for HFCs.

However, at the first meeting of the Lead Authors of this Special Report held in The Hague 11th-13th August 2003, the need for parallel estimates of HCFC emissions (and emissions of other alternatives such as hydrocarbons) was recognized. This was viewed as particularly relevant in the context of developing countries, where HCFCs will remain a genuine alternative to HFCs and other alternatives through to 2040. Bearing in mind that both refrigeration and foam sectors involve applications where delayed emission is the norm, there was a need not only to look at future emissions from current and future consumption, but also to include future emissions from past consumption (i.e. from the banks of HCFCs accrued in the period from 1990-2003). This is the only way in which it is possible to validate any emission models used with observed atmospheric concentrations.

At the second meeting of the Lead Authors of this Special Report held in Boulder, Colorado 12th-14th January 2004, it was recognized that the banks of CFCs arising in the refrigeration and foams sectors would also be of significance – both in terms of future emission projections and to provide further validation to emission models. The value of CFCs to the latter would be the longer emissions history and atmospheric measurement correlation. Accordingly, it was also decided to include CFCs within the scope of this particular project.

Emissions of HFCs have been reported by Governments at national level since 1997 within the UNFCCC reporting framework. With individual countries often adopting significantly different approaches, reliable comparison has been an on-going challenge. Sectors where delayed emissions occur have been particularly problematic and appropriate Tier 2 reporting guidance has been slow to emerge through the IPCC Greenhouse Gas Inventory Reporting Guidelines (last updated in 1996) and subsequent Good Practice documentation. In lieu of this, efforts have been made to assist emission reporting consistency at the global, regional and national level through various studies sponsored by AFEAS, GGEEC, EPA, ADEME and other organizations [Pal98] [Pal99] [Caleb00] [Pal00] [Pal02]. These studies have formed the basis of current best practice in emissions reporting and projection and will be peer-reviewed in the forthcoming update of the IPCC National Greenhouse Gas Inventory Guidelines which will commence in mid-2004 following a Scoping Meeting back in September 2003. Several authors of these various emissions studies are currently Coordinating Lead Authors or Lead Authors on the IPCC/TEAP Special Report and there is an opportunity to take advantage of this expertise and ensure consistency of approach between various HFC-related IPCC activities.

This report is one of three produced covering the overall project scope. This one deals specifically with emissions from the foam sector under Objective (1) – see overleaf.



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Objectives and Scope

In scoping the overall project, the following two objectives were identified as deliverables:

(1) Emissions Estimates and Projections for CFCs, HCFCs, HFCs and HCs over the period 1990-2015

The project used modifications and extensions of existing models to determine emission projections from existing banks and from future consumption. Substances covered included CFC-11, CFC-12, HCFC-141b, HCFC-142b, HCFC-22, HFC-134a, HFC-152a, HFC-245fa, HFC-365mfc, HFC-227ea, cyclo-pentane, iso-butane, n-pentane and iso-pentane.

In the foams sector, it should be noted that the various forms of CO₂ blowing are also used, but were not included in the quantitative emissions assessment since consumption data was uncertain. Apart from gaseous and liquid injection, several processes generate CO₂ chemically in-situ, thereby making it difficult to track and quantify.

For the foams sector, covered by this report, the following geographic sub-division⁵ was used:

- Europe (including most of Eastern Europe)
- North America
- Japan
- Rest of Developed World
- Countries with Economies in Transition
- North East Asia
- South East Asia
- South Asia
- Sub-Saharan Africa
- Middle East & North Africa
- Latin America

These sub-divisions vary slightly from those used to assess the refrigeration sector. The main reason for this was to keep consistency with the work of the UNEP Foams Technical Options Report produced in 2002.

In assessing consumption and resulting emissions from the various foam sub-sectors, the following analysis was used:

- Domestic Appliances
- Other Appliances
- Reefers and other Refrigerated Transport
- Polyurethane (PU) & polyisocyanurate (PIR) Boardstock
- PU & PIR Continuous Panel
- PU & PIR Discontinuous Panel
- PU Spray Foam
- PU Pipe-injected

⁵ The full country allocation can be found in Appendix 5 of the UNEP Foams Technical Options Report (2002)



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- PU Block - Slabstock
- PU Block – Pipe section
- PU One Component Foam
- Extruded Polystyrene (XPS) Board
- Phenolic (PF) Boardstock
- PF Block – Slabstock
- PF Block – Pipe section
- PF Discontinuous Panel
- Polyethylene (PE) Slabstock
- PE Pipe section

It should be noted that XPS Sheet products and processes were not included in this study because they are primarily open-celled and used in packaging applications rather than those targeted for use of HFCs (primarily thermal insulation applications). For similar reasons, the historic use of CFCs and HCFCs in the flexible PU foam sector has not been included in the baseline for this report, although resulting emissions will have been included within the reverse modeling carried out on atmospheric concentrations (see Objective 2).

It can be seen that the parameters of this study were: **14** blowing agents, **11** geographic regions and **18** foam sub-sectors, making a total of **2,772** permutations. Accordingly, it will be self-evident that this report cannot reasonably include every element of the spreadsheet outputs arising from this work. Nonetheless, the key information is contained in the report and its lengthy Appendices with other information being available from the author directly from the spreadsheets themselves.

The assessment of emissions from the refrigeration and air conditioning sectors has been carried out by Armines of Paris, France and these outputs are available in a complementary report to this one.

(2) Comparisons with atmospheric concentration measurements for HCFCs & HFCs and, where appropriate, CFCs

The validation of the emissions models used in this project was carried out using information about banked substances based on consumption between 1990 and 2001, except in the case of HCFC-22 and CFCs where data as far back as 1960 has been considered. The comparisons are limited to those substances on which good atmospheric concentration data exists and where there are robust models for emissions from aerosol and solvent applications. The other factor governing the scope of this comparative work has been the need to focus on those substances where the sectors examined here constitute a large proportion of total emissions. This is likely to rule out any atmospheric concentration comparison for hydrocarbons, where many other emissions sources exist. Consequently, HCFC-22, HCFC-141b, HCFC-142b and HFC-134a are the most likely candidates for validation with recourse also to CFC-11 and CFC-12 data, as appropriate.

This work was carried out by Marbury Consulting and is again the subject of a separate report. Nonetheless, some references are made to this dimension of the project within this report.



3. BLOWING AGENT CONSUMPTION IN THE FOAMS SECTOR

3.1 AFEAS data

The Alternative Fluorocarbon Environmental Assessment Study (AFEAS) was set up by the producers of fluorocarbons in 1989. Its primary objectives are stated on its website⁶ as two-fold:

- To identify and help resolve uncertainties regarding potential environmental effects of HCFCs and HFCs.
- To stimulate prompt dissemination of accurate scientific information to the research community, government decision makers, affected industries, and the general public.

As part of its programme, AFEAS has collected production and sales data from its members dating right back to the original introduction of the compounds in question. The sales data has inevitably contained some uncertainty because some sales are conducted via distributors, but the major customer base has been well-assessed. For the foams sector, the recording of sales has been split into open and closed cell categories and it is the closed-cell category that has been used as a cross-reference in this study.

It should be noted that the growth of fluorocarbon production in developing countries over recent years has meant that the AFEAS reporting mechanism has become less representative with time. However, AFEAS reporting is still understood to cover over 80% of global production and consumption, particularly in the more recently commercialised materials such as HFCs.

AFEAS has also taken the opportunity to assess the likely emissions associated with sales into various market sectors. However, the algorithms used for these projections are applied at fairly high level (i.e. low levels of market segmentation) and hence are not particularly relevant as a cross-reference for the emission assessments contained in this report.

3.2 UNEP Foams Technical Options Committee assessment for 2001

The UNEP Technical Options Committee on Foams was formed in 1989 to monitor and assess the emerging technical options for foam transitions out of CFC-based technologies. It produces annual updates on progress towards phase-out of CFC and HCFC-based technologies and also reports on barriers to transition.

Every four years, the Technical Options Committee is asked to provide a more thorough assessment of the state of transition. In 1990, this was a quantitative review. However, obtaining such quantitative data proved very challenging and there were considerable inaccuracies, which were subsequently revealed through further research. This led to a decision not to proceed with detailed quantitative assessments in either the 1994 or 1998 Reports, although the 1998 Report did provide a chapter on the current estimates of the time, which were based to a significant

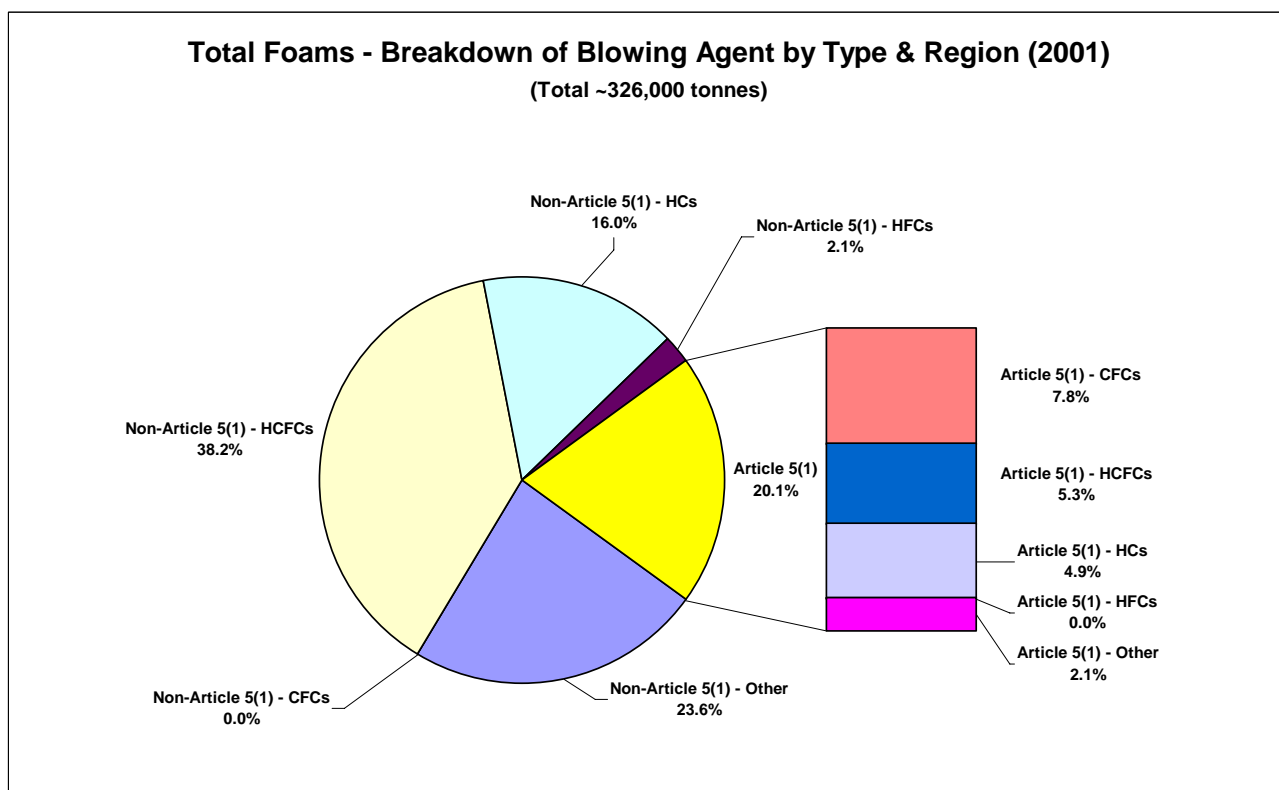
⁶ The AFEAS website is 'www.afeas.org'



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degree on a sub-division of the AFEAS data. UNEP’s own data collection from Parties was of little help in this respect, because this data is only collected on a substance-by-substance basis and does not include any sectoral sub-division.

In preparation for its 2002 Report, the Foams Technical Options Committee (TOC) took the decision to carry out a comprehensive and quantitative review of blowing agent consumption based on 2001 data. This was organised by the distribution of pro-formas among the members of the Committee which were then used to solicit information at country and regional level. Wherever possible, the data was cross-checked from a second source, both a regional level and then finally at global level. Although the response to this approach was not universally consistent, the Technical Options Committee was able to gain sufficient information to have a high level of confidence in the overall consumption parameters. The following graph illustrates the overall status of blowing agent use as at 2001:



This data included transitions in the PU flexible foam sector (unlike this current study) but excluded consideration of XPS Sheet.

One of the aspects of the work carried out by the Foams TOC was that it was conducted during a period of substantial transition, both in terms of the transition from CFCs in developing countries and the transition from HCFCs in developed countries. Accordingly, the Committee will almost certainly repeat the exercise for the 2006 Report based on 2005 consumption data in order to properly characterise the trends in the interim. Nonetheless, the total blowing agent consumption



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figure of 326,000 tonnes was seen as consistent with previous assessments and the knowledge of intervening market growth rates.

In summary, the UNEP Foams TOC assessment represents the most comprehensive global assessment of foam blowing agent consumption undertaken to date including, as it does, a comprehensive analysis of projects funded through the Multilateral Fund set up under the Montreal Protocol.

It was therefore decided to take the regional and sub-sectoral analysis used in that assessment as a basis for this project (see reference in the 'Objectives and Scope' chapter). This explains the selection of parameters outlined there.

However, the blowing agent coverage in this project has been expanded, requiring the breaking down of previous 'liquid HFC' assessments to HFC-245fa and HFC-365mfc components, as well as the inclusion of HFC-227ea. Since most liquid HFC use is still in the future at the time of finalisation of this report, there is inevitably a degree of speculation involved in this approach based on perceived technological trends as at the end of 2003. Similarly, there has been a need to break the 'hydrocarbons' element in the previous Foams TOC assessment into constituent components of cyclo-pentane, iso-pentane, n-pentane and iso-butane. This has been one of the most difficult areas in which to establish quantitative splits and it therefore remains one of the biggest areas of uncertainty in this current study. It should also be noted that the iso-butane statistics are assumed to include all use of Liquid Petroleum Gas (LPG), while the use of 2-chloropropane as a specialist blowing agent in the phenolic boardstock has been treated as n-pentane to save breaking out another very small blowing agent component.

Despite these various expansions and adjustments it has been possible to ensure that the consumption element of the current project is consistent with the 2001 Foams TOC Report throughout, except where new knowledge has come to light (e.g. the consumption of HCFCs in the Japanese polyethylene foam sector). Inspection of the consumption spreadsheets will therefore show that the fixed point on each sheet is the 2001 foam market by weight of foam together with the formulation detail which allows the derivation of blowing agent consumption. The transition status between various blowing agents also reflects the 2001 assessment and these are therefore transposed into the 2001 row of the print-outs attached as Annexes A to K of this report. Growth rates are then used to project consumption forward and re-construct consumption backward in time on the basis outlined in the next sections of this chapter.

3.3 Market growth factors

There are three distinct factors in projecting market changes within the insulating foam sector. These can be listed as follows:

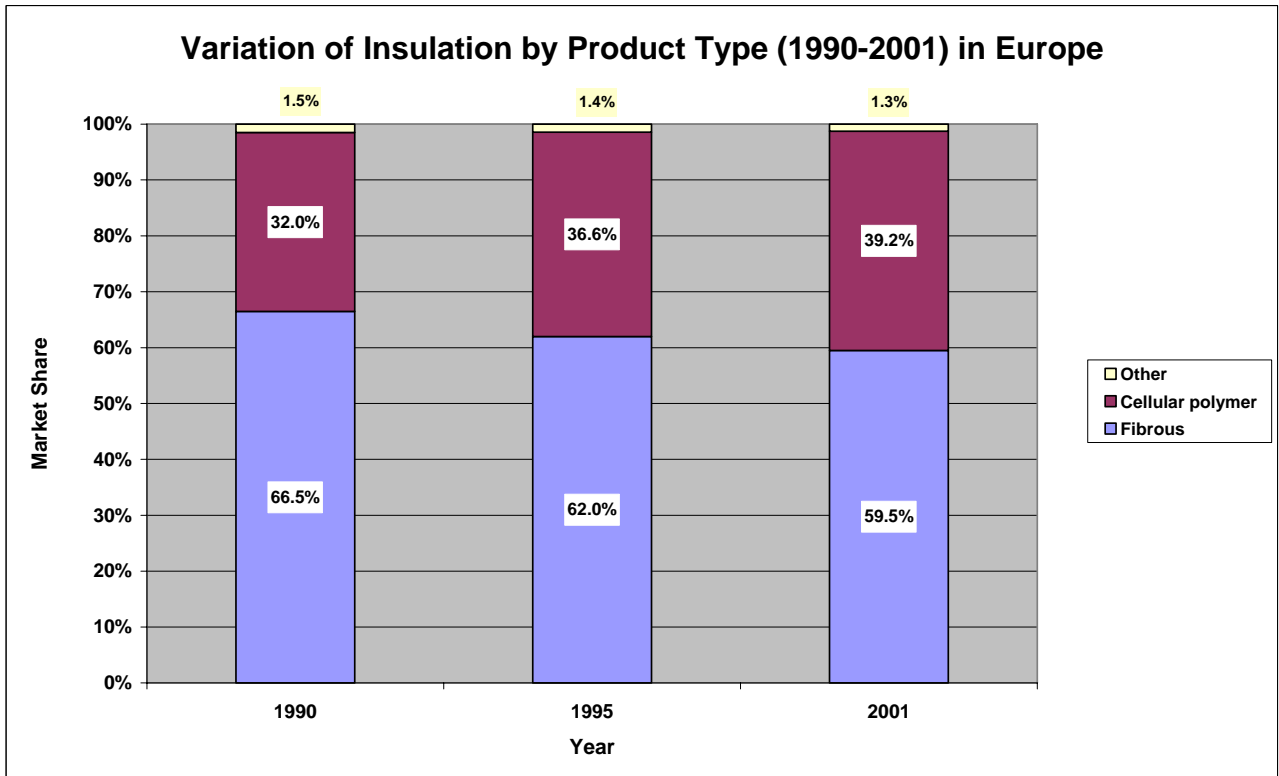
- (1) Overall economic activity based on GDP (as a default) or on the number of units being produced in a given year. Considering the major uses of foams, this would be the number of buildings built/refurbished or the number of appliances (e.g. domestic refrigerators or freezers) being manufactured.
- (2) The amount of insulation used per unit. This has tended to increase as energy standards for appliances have increased or as building regulations have called for more



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insulation in new buildings to meet energy efficiency requirements. The expression used for this measure is the 'foam volume ratio'.

- (3) The third driver for market growth in the foams sector is the relative share of the insulation market related to foams. Although this could trend in either direction depending on product priorities (e.g. fire performance, thermal efficiency, moisture resistance), the general trend in Europe over the last ten years has been gradually towards foams (see graph below). Of course, this is unlikely to be consistent across all foam sub-sectors.



These three factors, in principle, have formed the overall market growth drivers for the assessment of blowing agent consumption from 1960 onwards. However, in practice, it has been more relevant to combine factors (2) and (3) into an overall 'foam volume ratio' growth factor, since it is not normally possible to distinguish at regional level overall insulation market growth "per unit" from market share changes in insulation type used.

3.4 Dwellings as a basis for projecting to 2015

One of the other challenges for the development of consistent market growth assessments has been the need for reference databases at country and regional level. Although the UNECE database in Europe provides some patchy information on the construction of non-domestic buildings (e.g. hospitals, schools, commercial offices, industrial warehousing etc.), it has not been possible to find a global database containing such information. However, the Global Report on

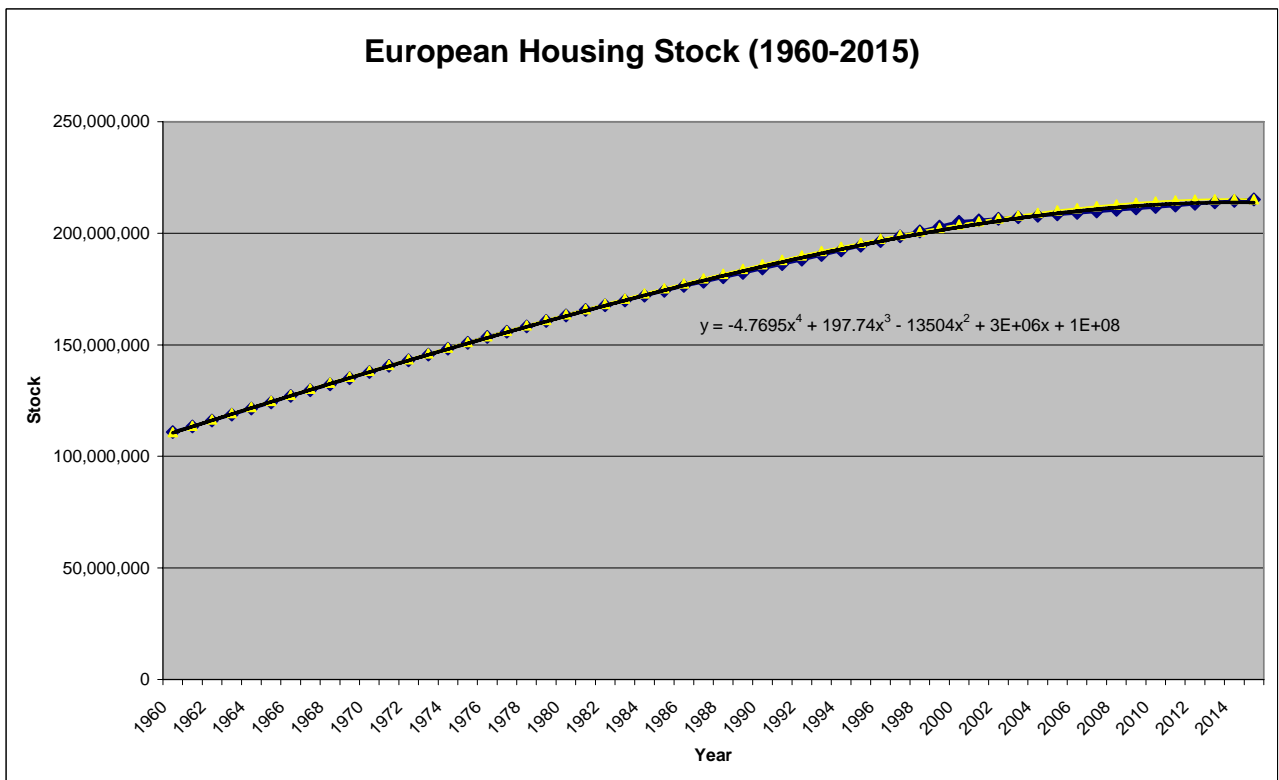


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Human Settlements (2001) published by the Global Urban Observatory has provided a comprehensive review of dwellings by country. This review includes data for 1985 and 2000

together with projections for 2015 and 2030. Caleb has linked this information with population data taken from the 2002 World Bank Atlas⁷ in order to determine current occupancy rates and anticipated trends. For this purposes of this report, the 2030 data has not been incorporated in view of the time-span of emission projections required (to 2015 only). There would also be increased uncertainty about figures relating to 2030.

Bearing in mind that the Global Urban Observatory data only provides four key data-points for each country, it has been necessary to interpolate between the points. However, linear or near-linear trend approaches result in the potential for significant changes in slope between, for example, the 1985-2000 and the 2001-2015 periods. Recognising that the annual change in housing stock (i.e. the slope of the curve) largely defines the market for insulation (c.f. Section 3.1 item (1)), this assessment method can deliver violent and unrepresentative changes in the market. In order to counter this shortcoming, Caleb has used a linear regression approach to obtain a best-fit curve. A fourth order polynomial has been used for this purpose. The example of Europe is shown in the graph below:



⁷ Compiled from the World Development Indicators



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Two other factors need to be considered in determining the trends in the overall market for insulation materials in dwellings. The first is the number of properties demolished in a year. This number should clearly be added to the net change in stock in order to determine the overall new build activity. Although information on the number of demolitions annually is less comprehensive at country level, it is known in Europe that typical demolition rates are below 0.25% per year. In North America, where timber-framed construction is more evident the demolition rates can reach 0.5-1%

per year. Each consumption spreadsheet is designed with the capability of introducing more specific information where known. However, the following default levels have been adopted so far:

Region	Demolition Rate (%)
Europe	0.25
North America	0.5
Japan	0.5
Rest of Developed World	0.5
Countries with Economies in Transition	0.25
North East Asia	0.25
South East Asia	0.25
South Asia	0.25
Sub-Saharan Africa	0.25
Middle East & North Africa	0.5
Latin America	0.5

In reaching these defaults, it has been assumed that, in those developing countries where the number of households outweighs the number of dwellings (i.e. demand outstrips supply), there will be a reluctance to demolish existing properties even if the design-life of the building has been exceeded. As an aside, it is interesting to note that the average occupancy in the developed world is about 2.5 per household and decreasing, while in many parts of the developing world the average occupancy is in excess of 5 per household. Apart from the population growth dynamic, there could also be an impact on the global construction of dwellings over the next 15-30 years if the increase in GDP per capita in developing countries is accompanied by a desire for lower occupancy dwellings. This is one of several parameters which have been included in the Global Urban Observatory projections, but there are inevitably significant uncertainties related to factors of this type. Of course, the impact of such trends on insulation use will depend on climatic conditions and affordability (see Section 3.6).

The second factor influencing the overall insulation market will be the extent to which insulation is used in the refurbishment market. In Europe, with the stock of dwellings moving inexorably towards saturation point and the level of demolition being currently low, the insulation market will only be sustained by significant increases in new-build insulation standards and the greater use of insulation in building renovation activities. At present, this is far from the case and there are examples such as the Netherlands, where the number of houses renovated annually is virtually equivalent to the number of new builds and yet the proportion of the thermal insulation market supplying the renovation sector is 5% or less.



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Bearing this information in mind, Caleb has not sought to introduce a specific parameter into the current spreadsheets for renovation. However, it is recognised that this can (and will be reflected) in the foam volume ratio information emerging with time.

3.5 Limitations of the dwellings approach

Although the approach to market assessment and projection based on dwellings is as close to the reality as can be achieved from the databases available, there are significant short-comings to this approach. These can be summarised as follows:

- (1) The data-set from the Global Urban Observatory does not go back before 1985. Hence there is a need to back-extrapolate to the commencement of CFC use in foams (i.e. around 1960). This delivers a degree of uncertainty.
- (2) In several regions of the world, a significant majority of the insulation foams sold go to non-domestic applications. These are therefore reflected in an artificially boosted foam volume ratio for dwellings. Such a practice would not be an issue for the overall blowing agent consumption and emission projections if the market growth drivers in the non-domestic sector were identical to those in the dwellings sector. However, this is seldom completely the case.

Despite these clear and transparent short-comings, Caleb views that it would be impractical for data availability reasons and difficult for complexity reasons to build a non-domestic growth element into the model. Indeed, most data collection across the insulation industry tends to group domestic and non-domestic sales. As will be seen with the CFC-11 consumption assessment in Section 3.8, the dwellings approach seems to provide an appropriate approximation to reality.

3.6 Foam volume ratios

As noted in previous sections, the foam volume ratio captures a number of growth factors in one place. These include:

- The potential trend to increasing use of insulation in new-build developments
- The demonstrable market shift from traditional fibrous insulation to higher performance foam insulation materials (see section 3.3)
- The predicted increase in the use of insulation in building refurbishment
- The use of insulation foams in the non-domestic sector.

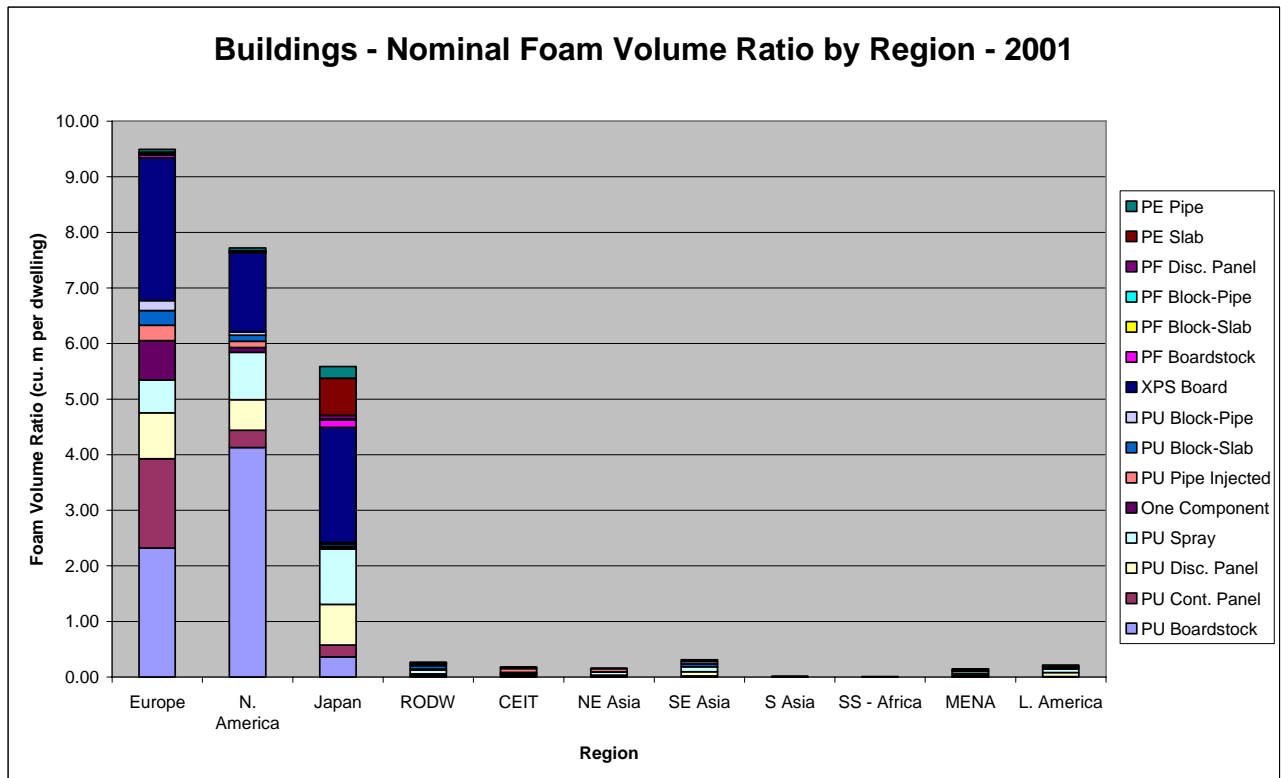


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This cocktail of components will always make it difficult to diagnose precise market dynamics from the spreadsheets developed in this project. Nevertheless, an analysis of foam volume ratio trends identified in the course of this project does reveal clear factors of relevance to the future projection of emissions of all fluorocarbons. The following graph illustrates the regional variation in foam volume ratios by foam sub-sector. The overwhelming dominance of the three major markets is self-evident:



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Projecting the development of these foam volume ratios to 2015 is particularly challenging because of the numerous factors involved. Inevitably the data on the ground is neither sufficiently comprehensive nor timely to be of value to a project such as this. Accordingly, the default position has been to adjust the foam volume ratio development so that, when combined with the overall market growth projections for a region, the total foam growth rate by sub-sector reaches that predicted by the UNEP Foams Technical Options Committee in its 2002 Report development. These predictions were typically in the range of 5-6% per annum depending on foam sub-sector and region. The only exceptions to this approach were in situations where the overall market growth in dwellings was expected to be above the overall rate projected by the Foams TOC (typically in developing countries only). In these cases, the foam volume ratios were assumed to be constant.

In projected the development of foam volume ratios historically, each spreadsheet permitted the inclusion of periodic growth rates which were linearly applied respectively across each of the six periods 1960-65; 1966-70; 1971-75; 1976-80; 1981-85 and 1986-2000.

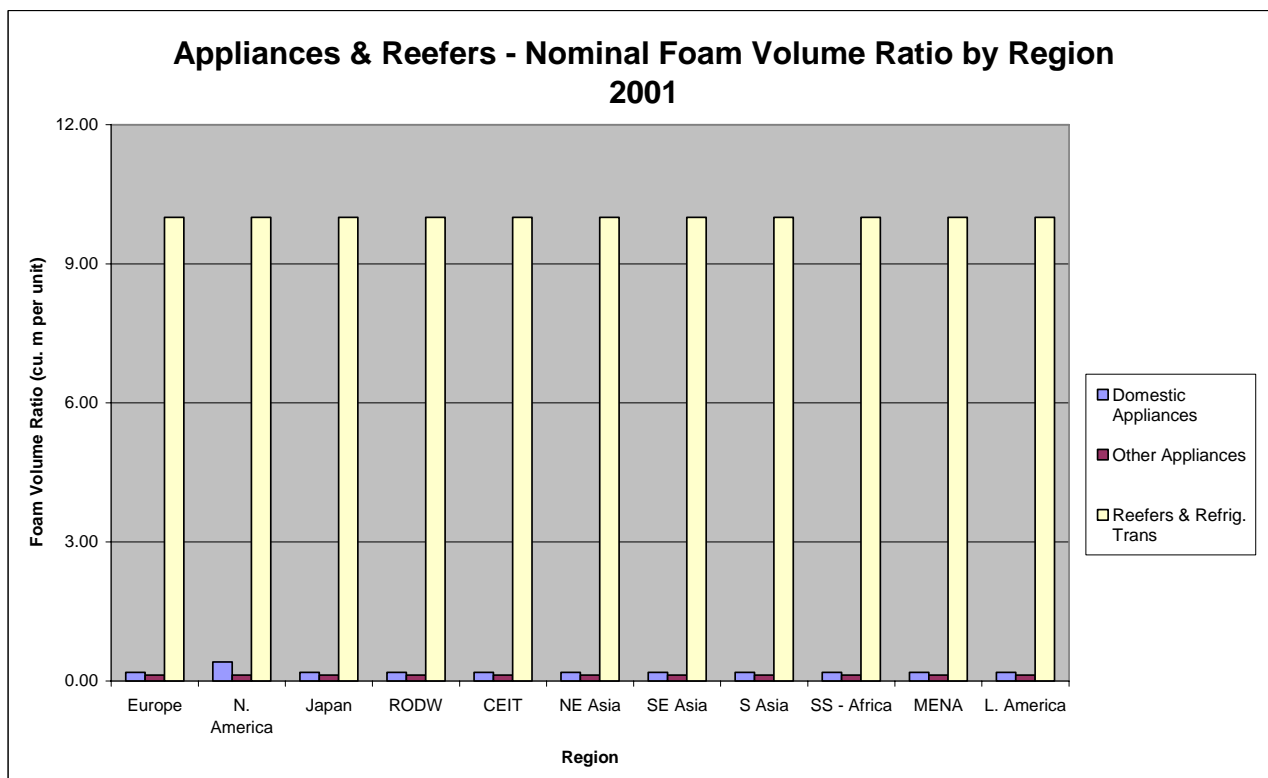
3.7 Appliance assessments

Although data for the appliance sectors was easier to establish than that for buildings, it was not possible for Intellectual Property reasons to make direct cross-reference to the FIEP database developed and utilised by Armines. However, it was possible to have the manufacturing levels projected by Caleb cross-checked by Armines and this provided the necessary quality control.



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As would be expected, there is much less regional variation in foam volume ratio in the refrigeration sector than is evident for buildings. This broadly reflects the stand-alone operation of these items and the globalisation of the industry. For the purposes of this modelling work, the only departure from uniformity relates to the domestic refrigerator foam volume ratio in North America which rests at 0.41 m³ per unit in comparison with the rest of the world at 0.19 m³ per unit. For other appliances the global average has been assumed as 0.125 m³ per unit⁸, while for reefers the global norm has been assumed to be 10 m³ per unit.



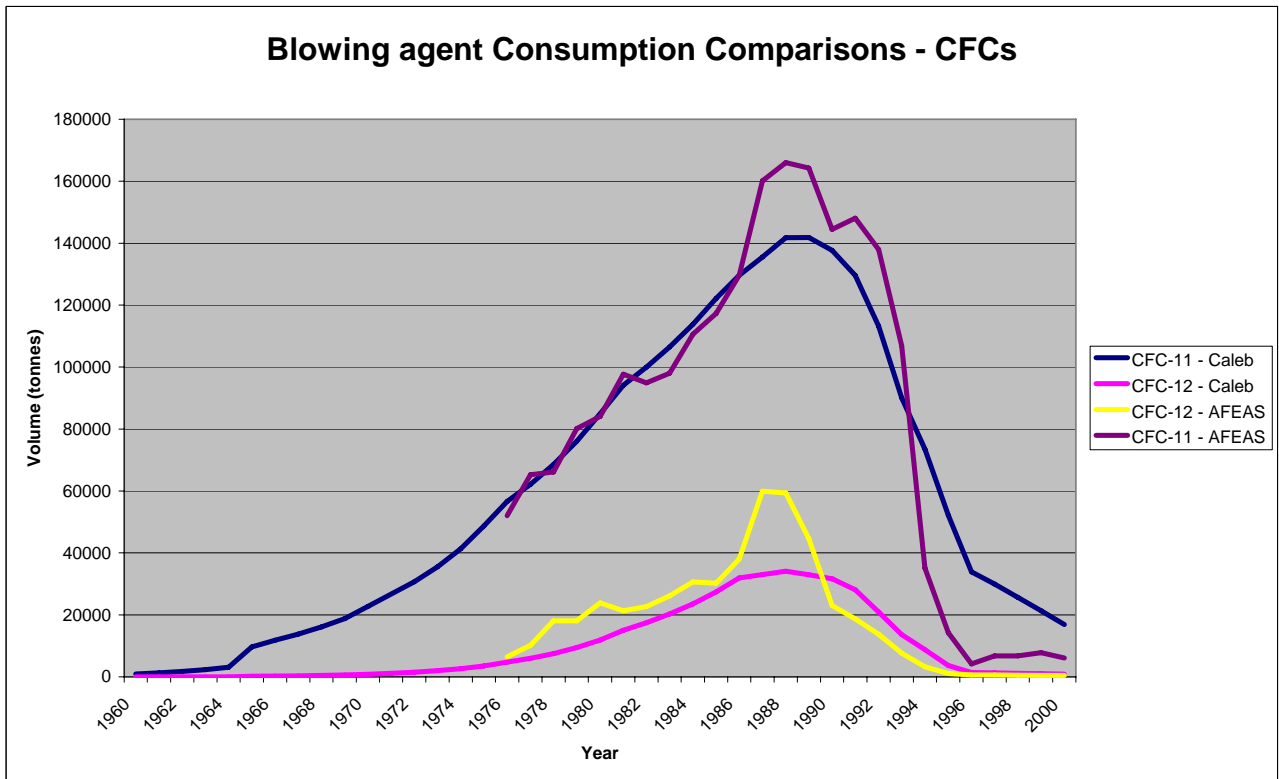
In projecting change in the foam volume ratio over time, each of these sectors has been assumed to change by 0.001 m³ per unit per annum.

3.8 Resulting Consumption Assessments vs. AFEAS

In order to gain a relevant cross-check on the appropriateness of these assumptions and, indeed, of the whole UNEP Foams TOC approach as adopted in its 2002 Report, Caleb has sought to compare the consumption assessments deriving from the approach outlined in this chapter with those recorded by AFEAS in their sales statistics for closed cell foams. The following graphs and commentary provide the outcome of these comparisons.

The first graph, looking at the comparisons for CFC-11 and CFC-12, is shown overleaf:

⁸ This includes water heaters, which bring the average down vis-a-vis commercial refrigeration applications



This graph illustrates strong correlation with the growth phase of CFC-11 demand in the period from 1976 to around 1988. This gives some confidence that the use of dwelling statistics to assess growth is basically sound despite the possible disconnects with non-domestic growth patterns.

The plot then loses connection a little in the period from 1989 to 1994. This could result from an over-emphasis on the effect of the use of reduced CFC-11 formulations in that period. However, it is also clear that the AFEAS sales patterns around that period were somewhat erratic and would have been difficult to model accurately from trend-based algorithms.

The final period from 1994 onwards illustrates the increase in production capacity and developing demand outside of the AFEAS reporting companies. This trend is also evident in the CFC-12 comparison and is consistent with previous assessments.

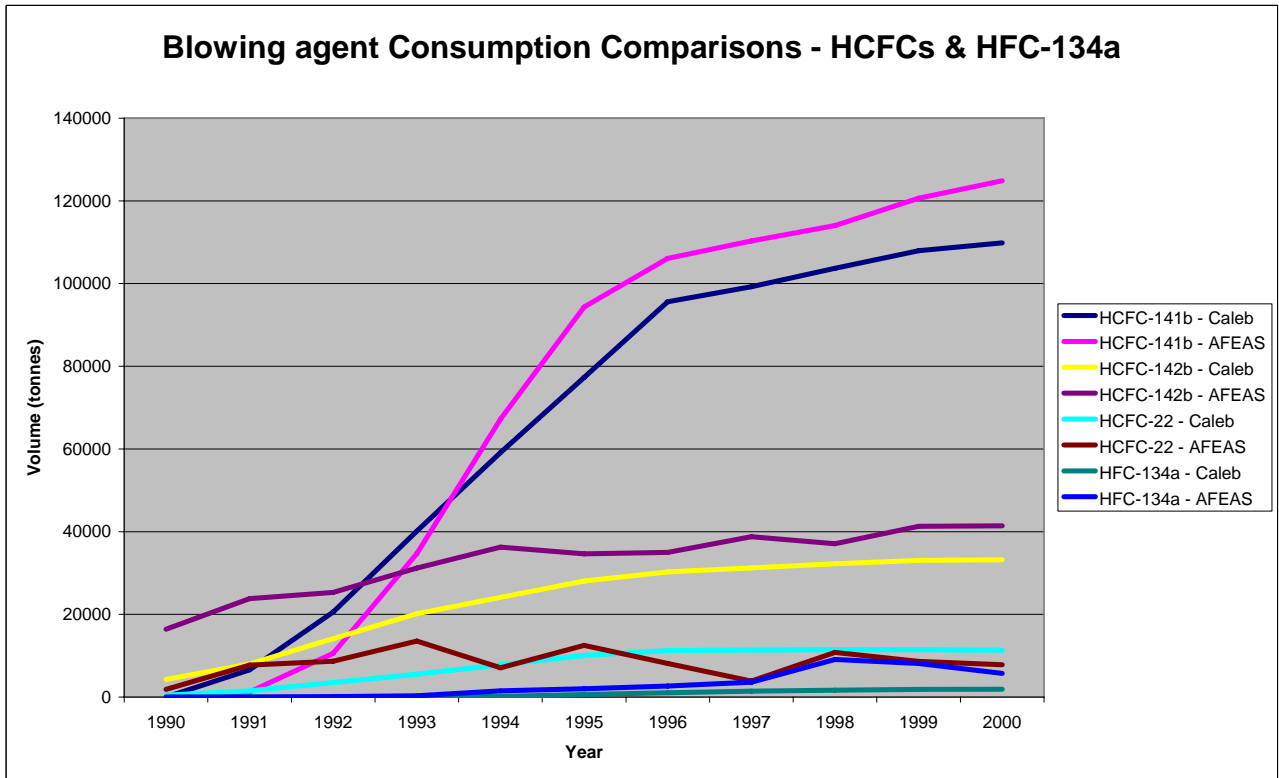
The CFC-12 growth curve is slightly less synchronised than that for CFC-11. Bearing in mind that this is using the same dwelling statistics as used for the CFC-11 assessment, it seems likely that any discrepancy is arising either from a slower market development assumption than was the case in reality (a two year earlier introduction of XPS foams would align the Caleb assessment with the AFEAS sales statistics) or through an under-estimate of the blowing agent content within the formulation. This latter option has been under close consideration during the process because of the nature of the XPS manufacturing process, where material is fully formulated and then often partially recycled in the process. This has been acknowledged in the relevant spreadsheets by introducing a 25% 'incremental consumption' factor. However, it may be that this remains



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insufficient to reflect the reality at that time. It may also be that the formulation distinction between Europe and North America (12% vs. 13.5%) was in fact less of a factor. In any event, the abrupt peak in demand in the 1987-1989 period remains unexplained by normal trend-based algorithms.

For HCFCs and HFCs, the comparison appears slightly more complex because of the number of chemicals involved. In the following graph, HCFC-141b, HCFC-142b, HCFC-22 and HFC-134a are all presented:



For HCFC-141b, the comparison to 1993 shows the conversion from CFC-11 to be slightly more progressed than it actually seems to have been from AFEAS data. However, based on a peak CFC-11 consumption of 140,000 tonnes, errors of less than 10,000 tonnes in periods of high transition activity should be broadly acceptable in a model of this type.

A more concerning trend is the continuing discrepancy between AFEAS and Caleb data as the growth curves flatten in the period after 1994. This discrepancy first came to light during the Foam TOC's 2001 data assessment and has yet to receive a fully satisfactory explanation. The situation will be confounded further by the fact that some production and supply to the foam sector will inevitably take place through non-AFEAS members. Further dialogue with AFEAS may be necessary to fully explain the discrepancy, but there is certainly a strong level of confidence from within the Foam TOC on its analysis. Accordingly, Caleb is reluctant to change the basis of its work at this time, but will progress with discussions at AFEAS to check for items such as misallocation of sales.

The HCFC-142b consumption is below that predicted from AFEAS sales at the same time as the CFC-12 consumption is higher than predicted. This could simply reflect the fact that an earlier



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transition – perhaps by up to two years – took place in key markets. However, the current information used by Caleb is consistent with Vintaging Model assumptions in the United States and it is clear that further evidence would be required from the XPS and PE industries before the two assessments can be fully reconciled.

The HCFC-22 comparison is inevitably difficult with substantial fluctuations present in the AFEAS data. These fluctuations are believed to have emerged from difficulties in separating out sales information in areas of supply often served by distributors and foam systems houses. Apart from the slower introduction predicted by Caleb (which could have the same explanation as HCFC-142b, bearing in mind that both HCFCs are used in blended form in some formulations) the comparison for HCFC-22 looks fairly strong.

The final element for which AFEAS data can be used is the comparison involving HFC-134a. Again, this comparison suffers from the same potential problem that HCFC-22 may well have suffered from - namely that sales as a refrigerant dominate sales for foam applications. This is particularly the case for the phase of HFC-134a consumption tracked in the graph (1990-2000), since this was prior to the mainstream introduction of HFC-134a for foam applications. The main element of consumption in this period was one-component-foam and the volumes for this application were fully researched by the Foams TOC Report based on 2001 data. The only issue might be a difference in formulations at regional level.

It has not been possible for AFEAS to collect sales information on HFC-152a, HFC-245fa, HFC-365mfc and HFC-227ea because of confidentiality concerns. Additionally, most consumption is still in the future. Accordingly, the consumption projections for these materials are the sole output of Caleb, derived from information received in the market and from projections derived thereafter.

In summary, although there may seem a number of discrepancies, these are relatively minor in terms of the overall emissions picture. There are equally some potential errors in the AFEAS data and the levels of discrepancy are not viewed as being sufficiently significant to call into question the approach adopted for this study. Nonetheless, the foam community in general, and Caleb in particular, will continue to resolve the discrepancies.



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4. EMISSION TRENDS IN THE FOAMS SECTOR

4.1 Developments and refinements with respect to emissions functions

The UNEP Foams Technical Options Committee (FTOC, 1998) and, more latterly, the Task Force on Collection, Recovery and Long-term Storage (TFCRS, 2002) have addressed the issue of release profiles from foams and the status, as summarised in the TFCRS Report is as follows:

Foam Type	First year release (%)	Release Rate (%/yr)	Time to Total Release ⁹ (yrs)	Lifetime of Foam (yrs)	Total remaining at decommissioning (%)
PU Integral Skin	95	2.5	2	15	0
PU Cont. Panel	5	0.5	190	50	70
PU Disc. Panel	6	0.5	188	50	69
PU Appliance	4	0.25	384	15	92
PU Com. Refrig.	6	0.25	376	15	90
PU Cont. Block	35	0.75	86	15	54
PU Disc. Block	40	0.75	80	15	49
PU Cont. Lam.	6	1	94	50	44
PU Spray	25	1.5	50	50	0
PU Reefers & Trans	6	0.5	188	15	86.5
PU OCF	100	N/A	0	50	0
PU Pipe in Pipe	6	0.25	376	50	81.5
Phen. Cont. Lam.	6	1	94	50	44
Phen. Disc Block	40	0.75	80	15	49
XPS Board	25	2.5	30	50	0
PE Board	90	5	2	50	0
PE Pipe	100	N/A	0	15	0

The highlighted foam sub-sectors clearly have potential for recovery at end-of-life. However, in the absence of information about end-of-life management of various products at that time, the worst-case scenario was modelled for ODSs – namely instantaneous release of the remaining blowing agent at end of life. This assumption has been a contentious one and has understandably stimulated work to establish further information.

Considerable work has been undertaken on the verification of emissions from foams throughout their lifecycles since the development and publication of the TFCRS Report in 2001/2002. This has included work by the Insulation Technical Advisory Committee of AHAM¹⁰, the Danish Technical University (DTU), the Japan Technical Centre for Construction Materials (JTCCM) [References] and others. The work of JTCCM, in particular, has involved the sampling of foams of varying ages from over 500 buildings and has broadly endorsed the emission functions included in the TFCRS Report. The ITAC work conducted by the DTU has highlighted the potential for varying emission

⁹ Current models assume linear losses in use. Although losses actually follow an exponential decay, the release rates in use tend to be low and a linear approximation is considered adequate.

¹⁰ AHAM – Alliance of Home Appliance Manufacturers – a US-based industry association



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functions for appliances depending on the method used to handle domestic refrigerators at end-of-life.

In developing the initial business-as-usual case, it was decided to maintain the TFCRS emission functions for the most part, since the activities already described on the validation of alternative assumptions is still very much 'work-in-progress'.

4.2 The handling of end-of-life scenarios

In assessing the potential end-of-life scenarios, four possible options have been considered:

1. Re-use
2. Direct Landfill
3. Shredding without blowing agent recovery
4. Shredding with blowing agent recovery

No separate provision has been made for direct incineration of foams, but any identified or predicted activity in this area is considered to have the same loss patterns as shredding with blowing agent recovery, since both are fairly non-emissive in nature. A full assessment of assumptions is contained in Annexes L-V of this Report. These detail end-of-life assumptions by foam sub-sector, date and region in order to capture the effects of changes on end-of-life practices such as those which have recently taken place in the EU. An additional value of this approach is that also allows users to look at the effects of various end-of-life assumptions as well as the potential impact of future measures. This is particularly important when looking at the future end-of-life scenarios for HFC-containing building products. However, it should be noted that even the end-of-life aspects of the earliest CFC-containing building products are not fully reflected in the current scope of work because of the time limit imposed at 2015. The fifty year life-span for foams within buildings means that only pre-1965 constructions would currently be included. There is, therefore, an immediate case for increasing the period of the scope of the study beyond 2015. However, since the model requires parallel new consumption estimates year-by-year, these will become notoriously more inaccurate as the consumption projections extend beyond 15 years.

4.3 Regional Trends

4.3.1 Europe

Europe has been among the most strident of regions in developing policies on the end of life blowing agents in foams. Article 16 of the European Regulation on ozone depleting substances (EC 2037/2000) provided for the recovery of blowing agents from domestic and commercial refrigeration units from 1st January 2002 – a provision which led to the short-term build up of refrigerator mountains in some Member States because of the lack of capacity available for safe dismantling.

Even now, two years on, it is understood that not all Member States have enacted the legislation as intended. A survey has been planned by the European Commission during the first half of 2004 to assess this situation. However, for the sake of this model it has been assumed that the transition is still not fully complete. The following table provides the assessment of the assumptions adopted for the end-of-life transition between 2000 and 2015.



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Year	End-of-life Measure			
	Re-use	Landfill	Shredding w/o Recovery	Shredding with Recovery
2000	10%	70%	10%	10%
2001	10%	65%	10%	15%
2002	10%	45%	10%	35%
2003	10%	40%	10%	45%
2004	10%	25%	5%	60%
2005	10%	10%	5%	75%
2006	10%	5%	5%	80%
2007	10%	0%	5%	85%
2008	10%	0%	5%	85%
2009	10%	0%	5%	85%
2010	10%	0%	5%	85%
2011	5%	0%	5%	90%
2012	5%	0%	5%	90%
2013	5%	0%	5%	90%
2014	5%	0%	5%	90%
2015	5%	0%	5%	90%

For the building and construction sector, European Member States have been much more circumspect about introducing mandatory provisions and Article 16 of EC 2037/2000 requires the recovery of blowing agents at end-of-life only 'if practicable'. This phrase has both technical and economic components and will be the subject of consideration in the forthcoming TEAP Report scheduled for publication in mid-2005. However, it should be noted that there is a much greater use of pre-fabricated elements in European construction than elsewhere (e.g. steel faced panels). This leads to the prospect of greater separation potential at end-of-life.

4.3.2 North America

At the time of the TFCRS Report in 2002, it emerged that little was known about the end-of-life scenarios for foam containing products in the United States. This was a particularly stark observation for the domestic refrigerator sector. Accordingly, the US EPA has worked with AHAM and others to characterise the situation. The most important information has come from the Steel Recycling Institute which has confirmed that upwards of 90% of all refrigerators pass through commercial shredding units. These are primarily used for automobile shredding and hence have no blowing agent capturing facility. This has led to a series of studies to assess the likely release profiles of blowing agent through the shredding process. Since the particle size of the foam outputs remains fairly large (anecdotally, the size of a fist), estimates from the Danish Technical University and others have suggested that losses may be as low as 20%. This has therefore been taken as the baseline emissions scenario for North America. However, there is some concern that the pulverisation of the foam during the process could 'squeeze out' more blowing agent and the sensitivity of emissions to this potential has also been assessed, leading to the conclusion that emissions of HCFC-141b in 2015 could increase by as much as 26% (6,600 tonnes) if the worst case of 100% emission was considered.

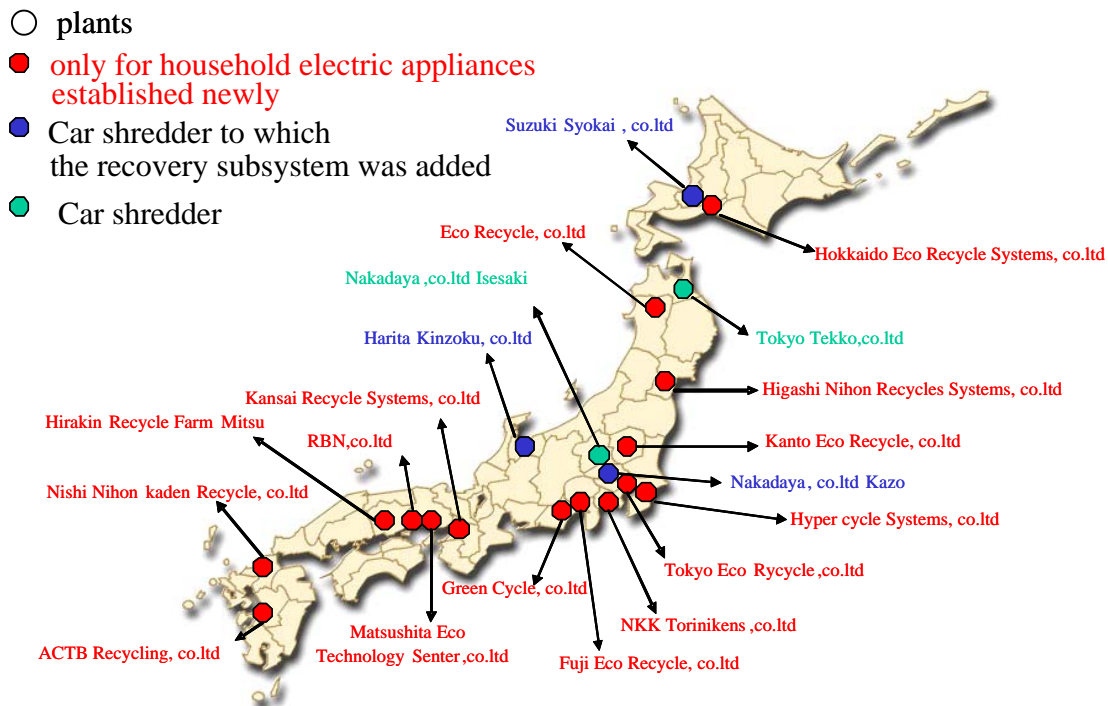


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For the construction sector, much less is known, but with the prevalence of landfill space, it is assumed that the vast majority of construction foams are land-filled without treatment. As with Europe, there is no particular apatite to address this issue further.

4.3.3 Japan

In contrast with North America, Japan has very little space for land-fill and this practice has all but disappeared in recent years. As with Europe, the Japanese have focused primarily on shredding and recovery plants. However, in contrast with Europe, the Government has used wider domestic appliance recycling laws to drive 'producer responsibility' investments in blowing agent recovery. The number of plants in Japan is shown in the map below:



The corresponding assumptions used for end-of-life domestic refrigerators are shown below:

Year	End-of-life Measure			
	Re-use	Landfill	Shredding w/o Recovery	Shredding with Recovery
2000	10%	5%	75%	10%
2001	10%	0%	75%	15%
2002	10%	0%	55%	35%
2003	10%	0%	45%	45%
2004	10%	0%	30%	60%
2005	10%	0%	15%	75%



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2006	10%	0%	10%	80%
2007	10%	0%	5%	85%
2008	10%	0%	5%	85%
2009	10%	0%	5%	85%
2010	10%	0%	5%	85%
2011	5%	0%	5%	90%
2012	5%	0%	5%	90%
2013	5%	0%	5%	90%
2014	5%	0%	5%	90%
2015	5%	0%	5%	90%

For the construction sector, Japan is looking closely at its current building stock recovery options through the four year project being conducted by the Japanese Technical Centre for Construction Materials (JTCCM). This will produce its final report in mid-2005 and will cover both the technical and economic potential for recovery from buildings. In the first two years of work, the project has established that there are between 75,000 and 80,000 tonnes of blowing agents remaining in installed foams in buildings, this number being split approximately 50/50 between CFCs and HCFCs. Ultimate decisions on how to manage these banks will be made once the TEAP has reported and international consensus has been reached

4.3.4 Rest of Developed World

There is little reported activity on blowing agent recovery from foams elsewhere in the developed world. Australia and others have focused under the Montreal Protocol on the importance of controlling use and are planning to extend this to HFCs through the application of 'responsible use' principles via a binding Environment Improvement Plan (EIP).

4.3.5 Developing Countries

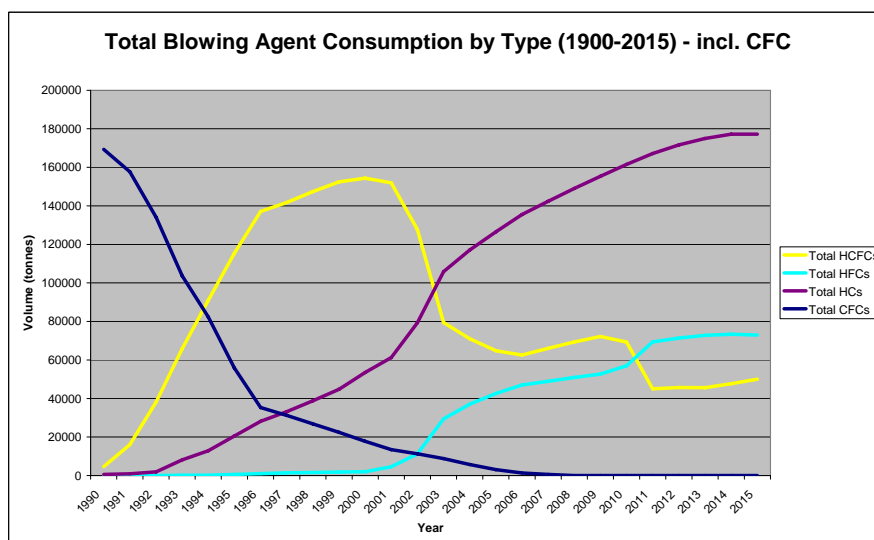
Again, focus has been on the development of use reduction strategies through the implementation of Multilateral Fund projects and, more recently through Country Plans. There is no funding available under the Multilateral Fund for end-of-life projects and, even if there were, the cost effectiveness of projects would be unlikely to fall below the threshold limits of investment. Nonetheless, there are still efforts to work on national end-of-life management plans in the domestic refrigerator sector and Colombia is one country that is actively contemplating this option.



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5. CONSUMPTION, EMISSIONS AND BANKS BY BLOWING AGENT

The overall global pattern for blowing agent consumption in the period from 1990 to 2015 is shown below:

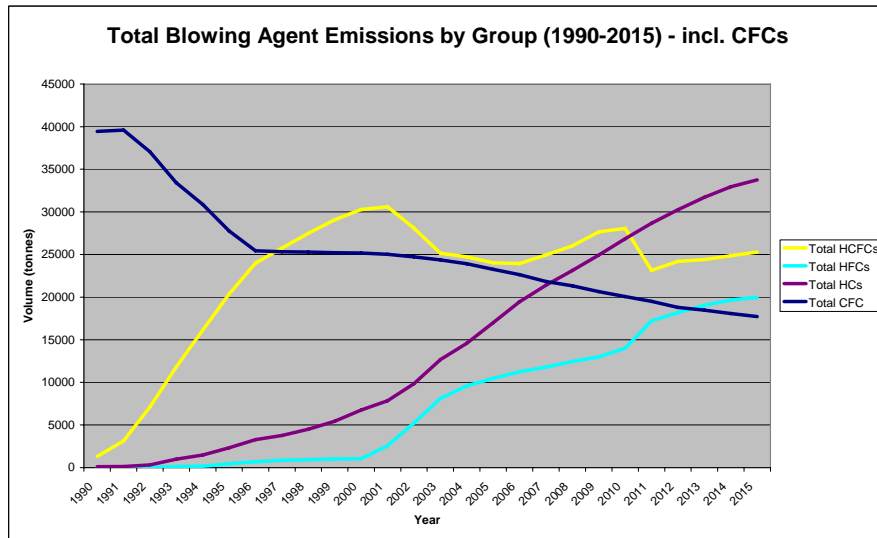


It can be seen that the consumption of CFCs (which peaked in the mid 1980s at around 210,000 tonnes for rigid foams) is higher than the subsequent replacement by HCFCs (155,000 tonnes in 2000) which itself is considerably larger than the projected HFC consumption of 75,000 tonnes in 2015. This trend has occurred in a climate of substantial market growth and illustrates the efforts that have been made by the industry to limit its use of compounds with substantial ozone depleting and/or global warming potentials. As can be seen, much of the balance has been made up through the introduction of hydrocarbons in a number of high volume applications such as domestic appliances, PU boardstock and steel-faced panel products.

The parallel projections of emissions are shown below:



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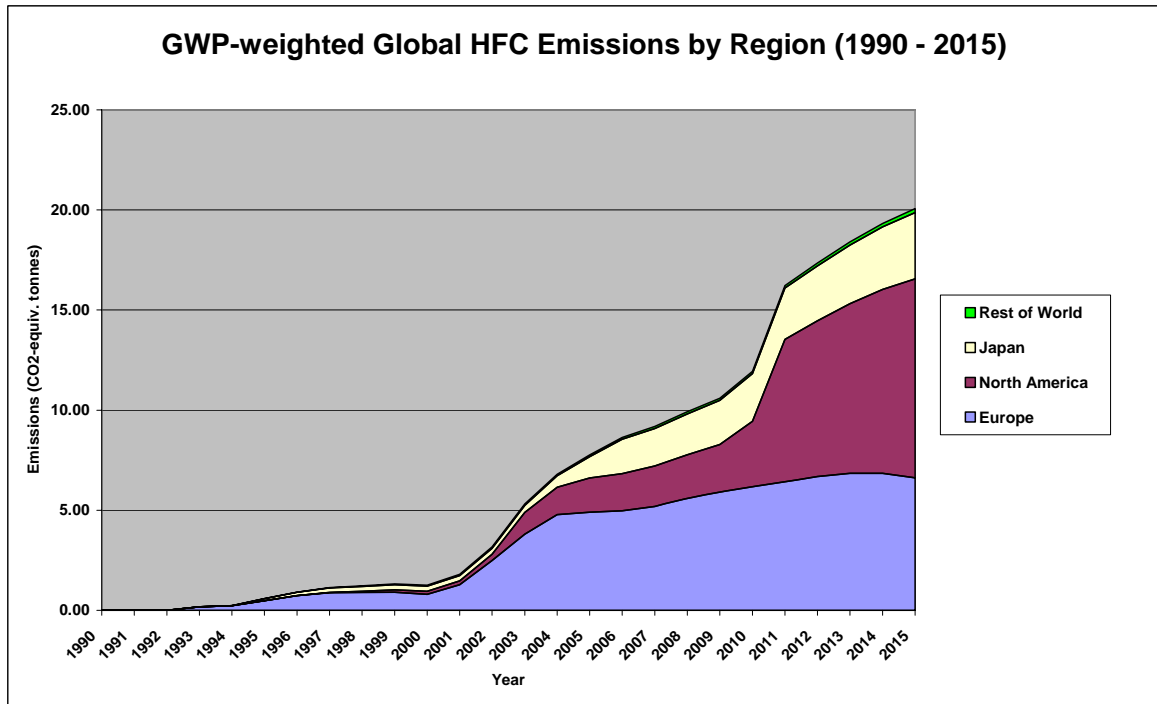


The on-going impact of CFC emissions from banked blowing agent is clearly evident from the graph. Although this falls below the emissions for HCFCs and latterly HFCs, it should be noted that very little end-of-life decommissioning is considered for building applications during the period of this study (1990-2015). Accordingly, there is expected to be a further growth in emissions arising from CFCs after 2015 as products installed from 1965 onwards begin to be decommissioned.

The level of HFC emission is expected to be around 20,000 tonnes at 2015. This will continue to increase gradually as the bank builds. However, all expected transitions to HFCs will have taken place by that date with the exception of any further HCFC to HFC transition that might take place in developing countries in the post 2020 period. As is shown below, the level of HFC uptake (and hence emissions) in developing countries is expected to be very low in the period to 2015. This is partly because of the on-going reliance of HCFCs in the short-term and the lack of building applications for foams in many of the developing country regions.



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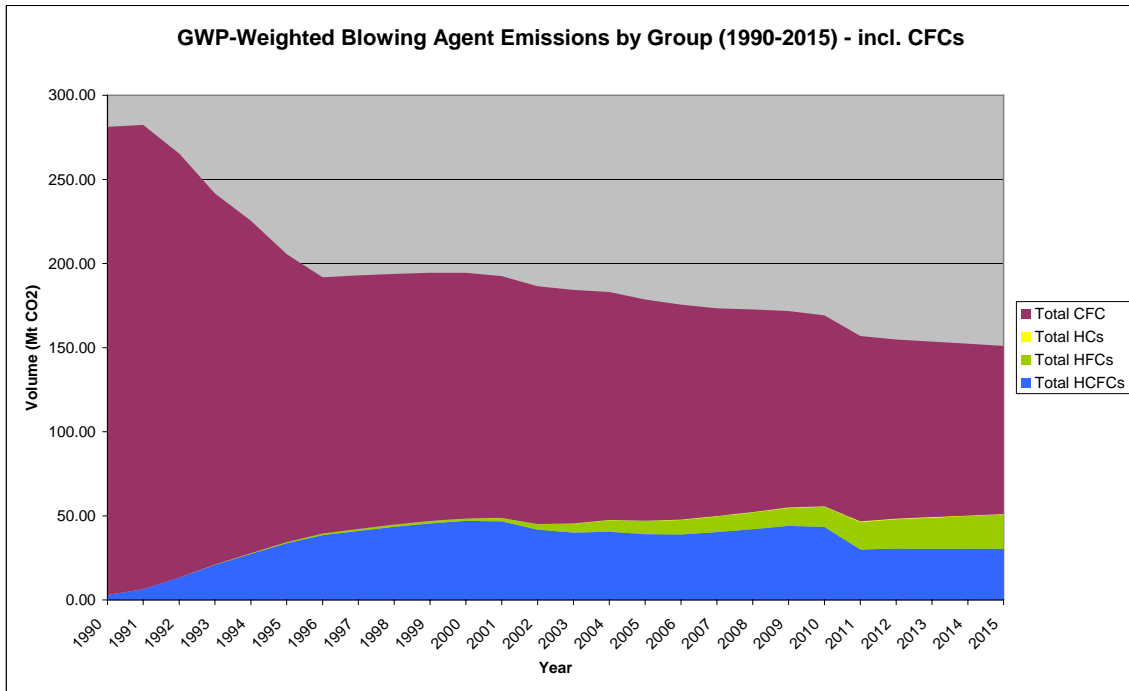


This graph is based in GWP weighted units and illustrates that HFC emissions in 2015 will reach around 20 Mtons CO₂ equivalent. Bearing in mind that the volume of emissions leading to this figure is around 20,000 tonnes, it illustrates that the average GWP for HFCs used in foam blowing is around 1,005. This compares with the parallel figures for CFCs and HCFCs which are 5,643 and 1,209 respectively. The implication of these numbers is that the emissions of CFCs are much more significant in global warming terms than either those of HCFCs or HFCs.

For hydrocarbons, the figure is even lower (around 11) and the consequent graph of comparative emissions in GWP-weighted terms is as follows:

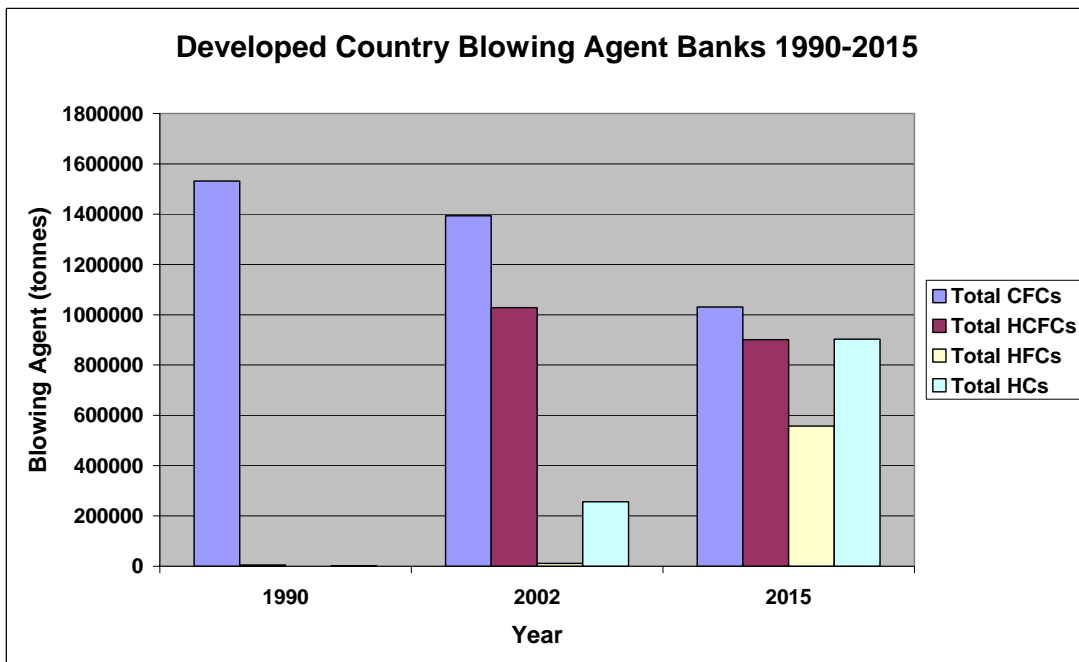


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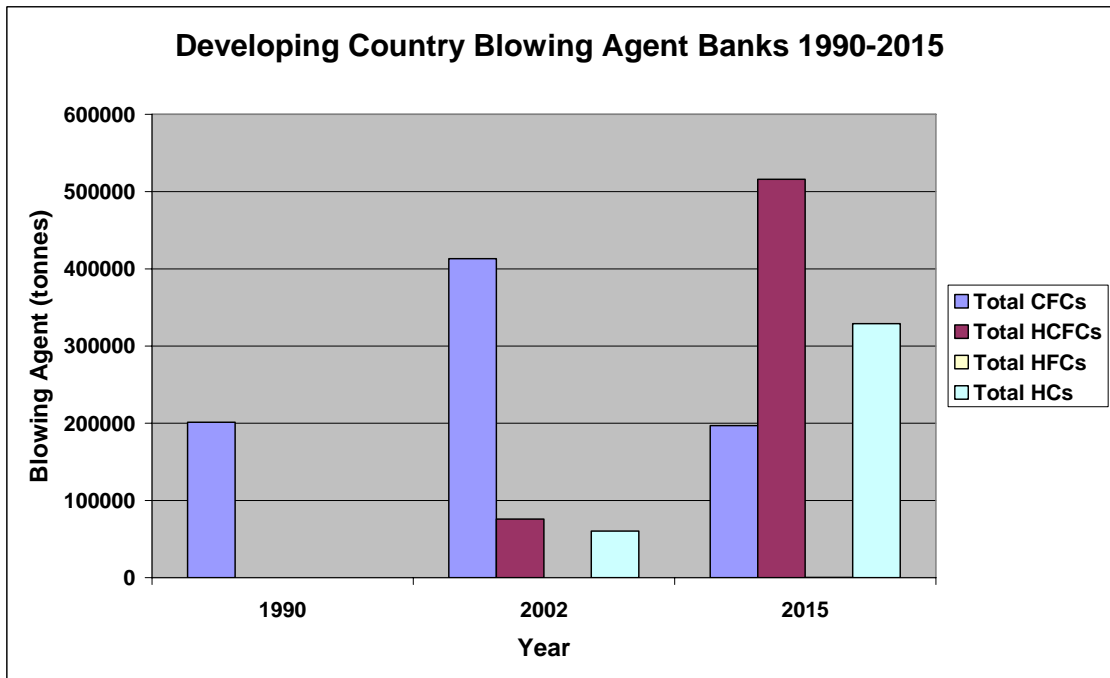
This graph has major implications for the emission reduction strategies both of the foam industry and of policy makers and heavily puts the focus on the need for effective end-of-life measures, particularly if losses from building decommissioning are expected to otherwise grow post-2015.

The development of the banks for the period from 1990 to 2015 is shown for developed and developing countries in the following two graphs:





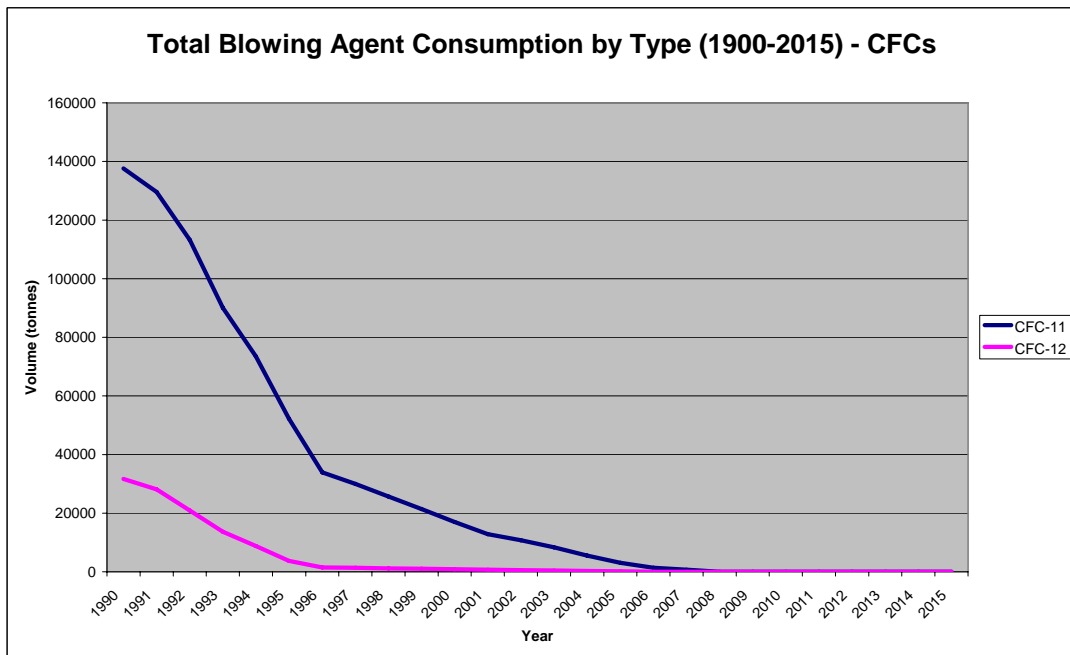
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The lack of any significant HFC bank development in developing countries again reflects the lack of use in these regions over the period. This is illustrated further in Section 5.3.

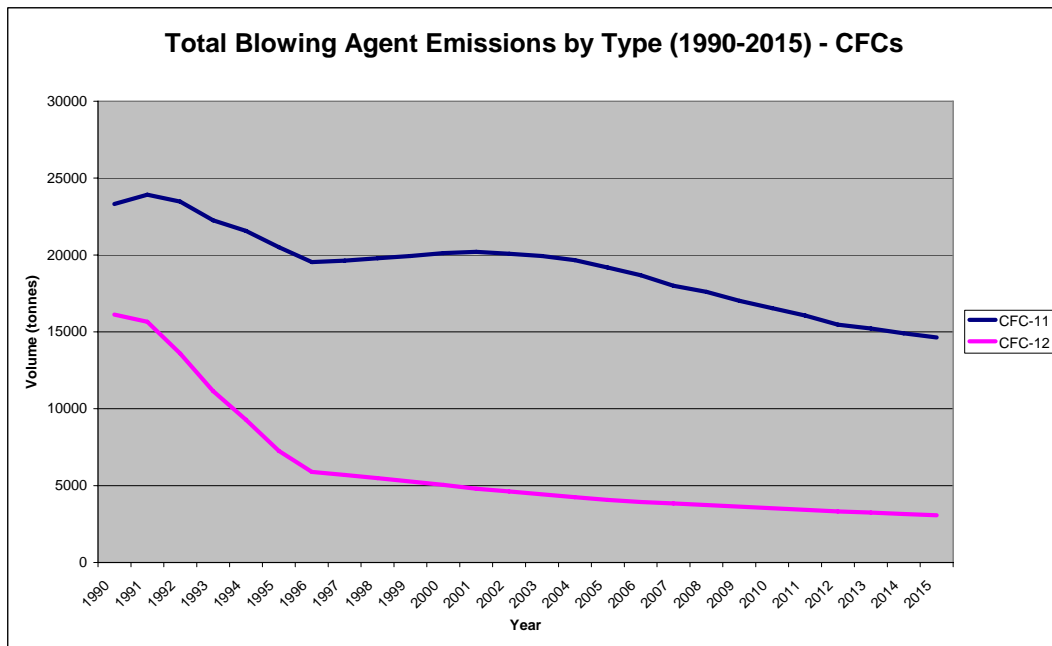
5.1 CFCs

The following four graphs show consumption, emissions and banks for CFCs:

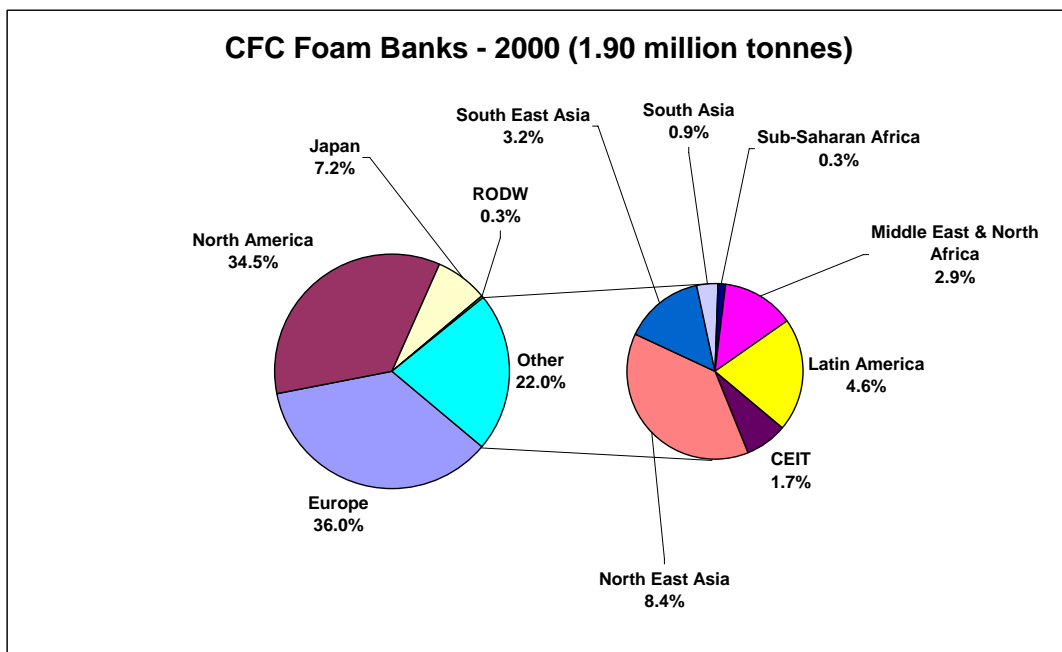


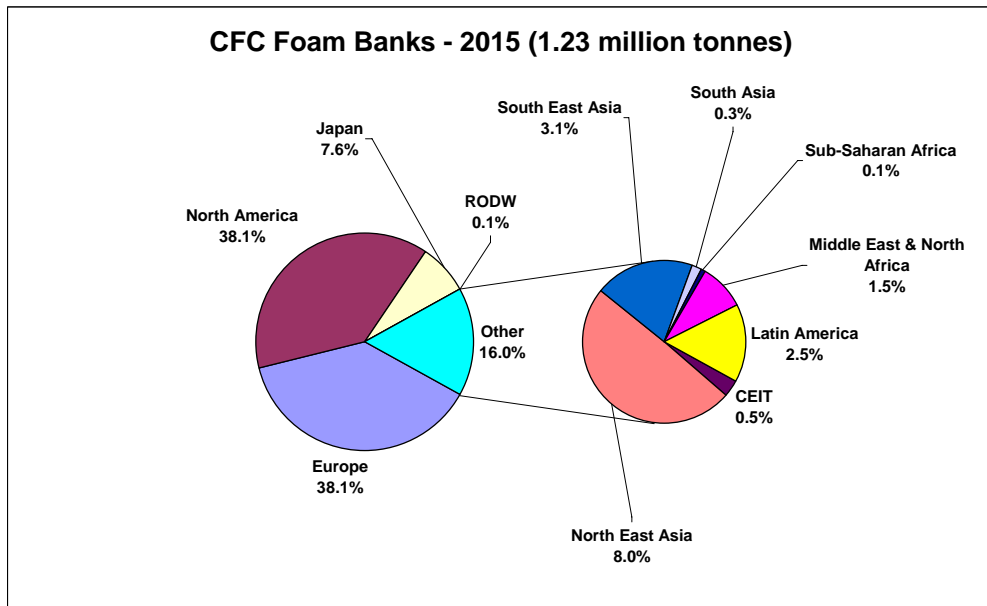


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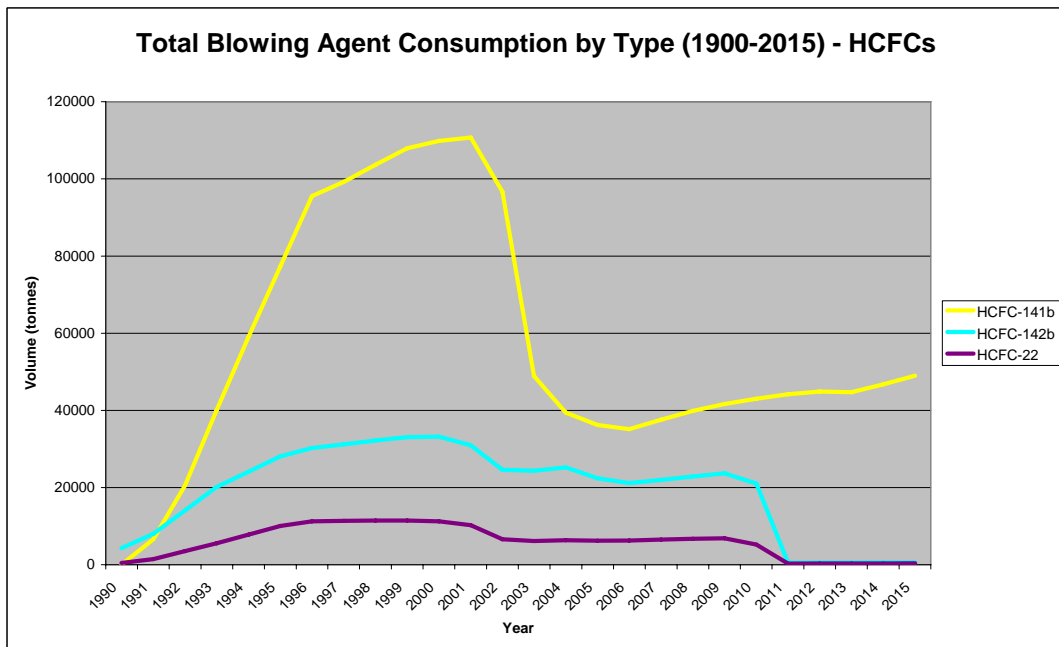
The slow release of blowing agent from the banked blowing agents in construction foams is combined with the peaks of emissions from the tail of CFC consumption in 1990/91 and domestic refrigerators decommissioning (2002/03) in the above graph

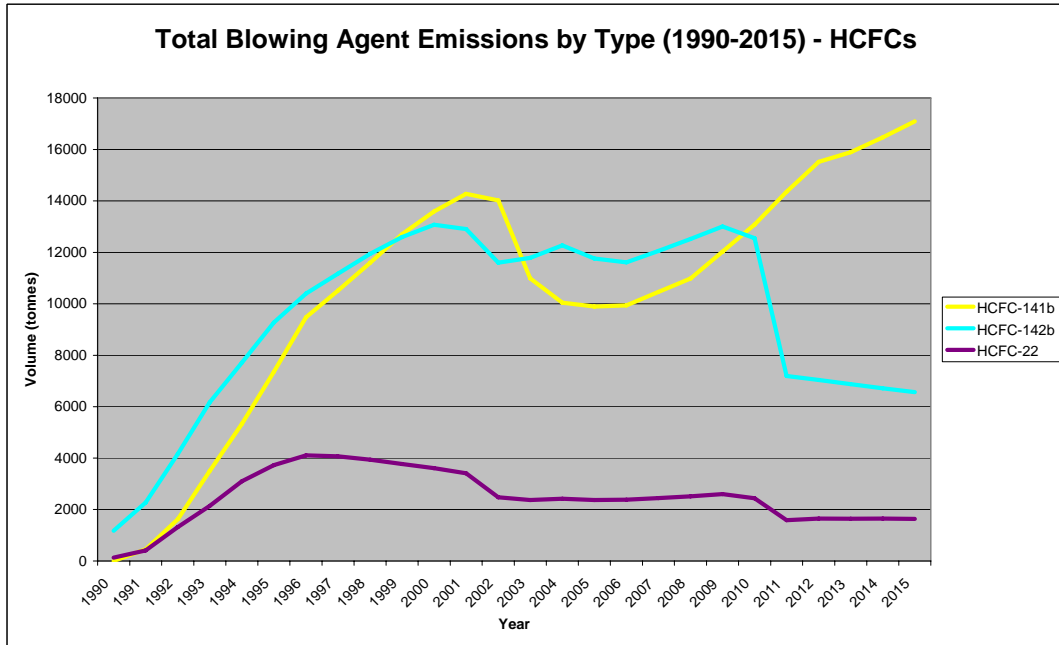




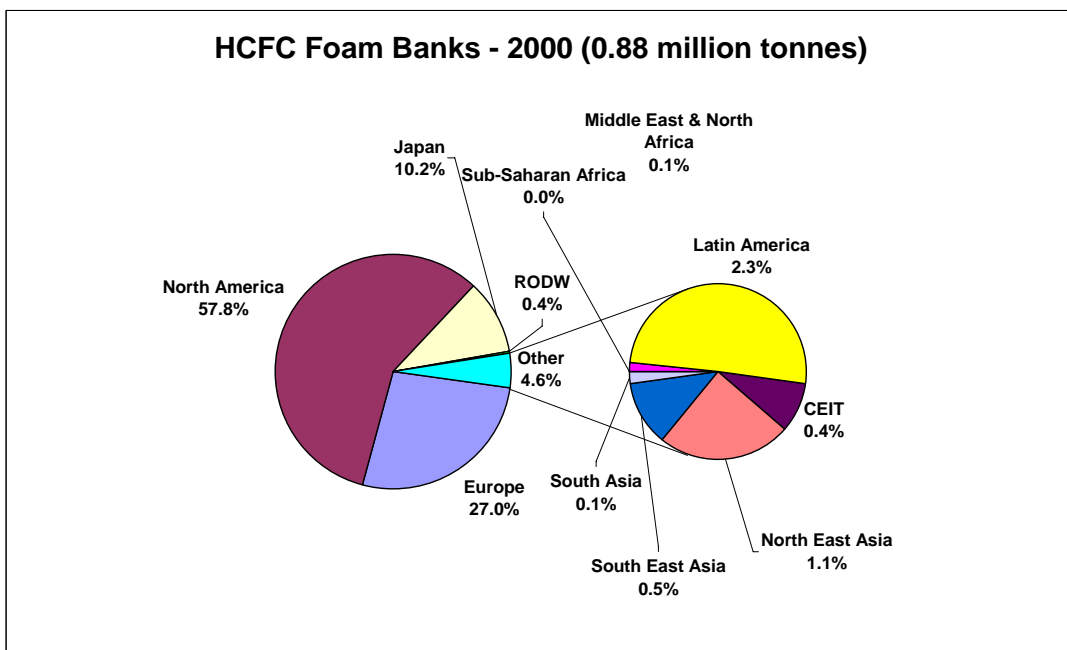
5.2 HCFCs

The following four graphs show consumption, emissions and banks for HCFCs:



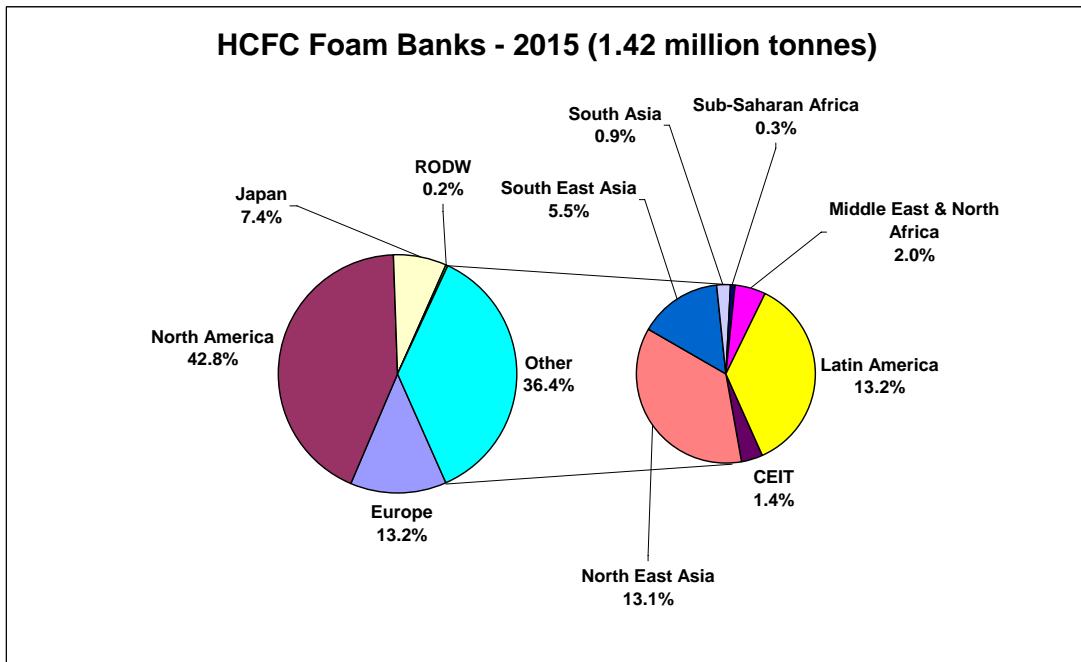


The significant increase in HCFC-141b emissions in the period from 2005 is caused mostly by the decommissioning of North American domestic appliances. The drop in HCFC-142b emissions in 2010 coincides with the phase-out on consumption in the XPS Board sector – a fairly emissive manufacturing process.





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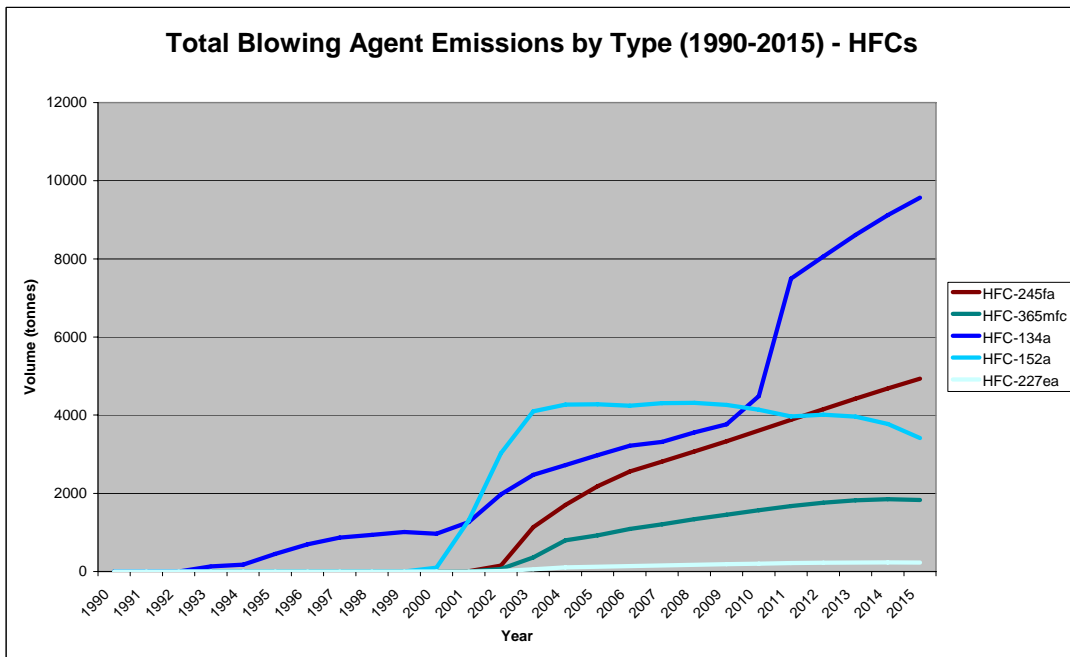
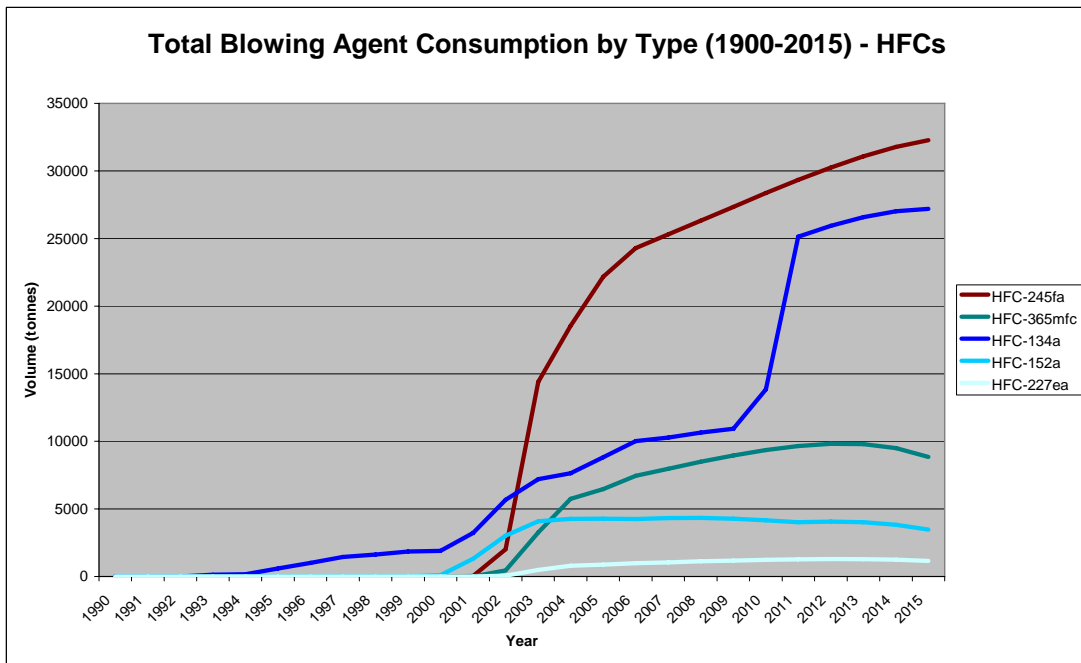
The growth in the developing country share of HCFC banks between 2000 and 2015 reflects the phase-out in consumption in developed countries over this period and also the uptake of HCFCs as replacement for CFCs in developing countries. The banks tend to follow population densities with China and Latin America being the location of significant banks by 2015.

5.3 HFCs

The following three graphs show consumption, emissions and banks for HFCs:



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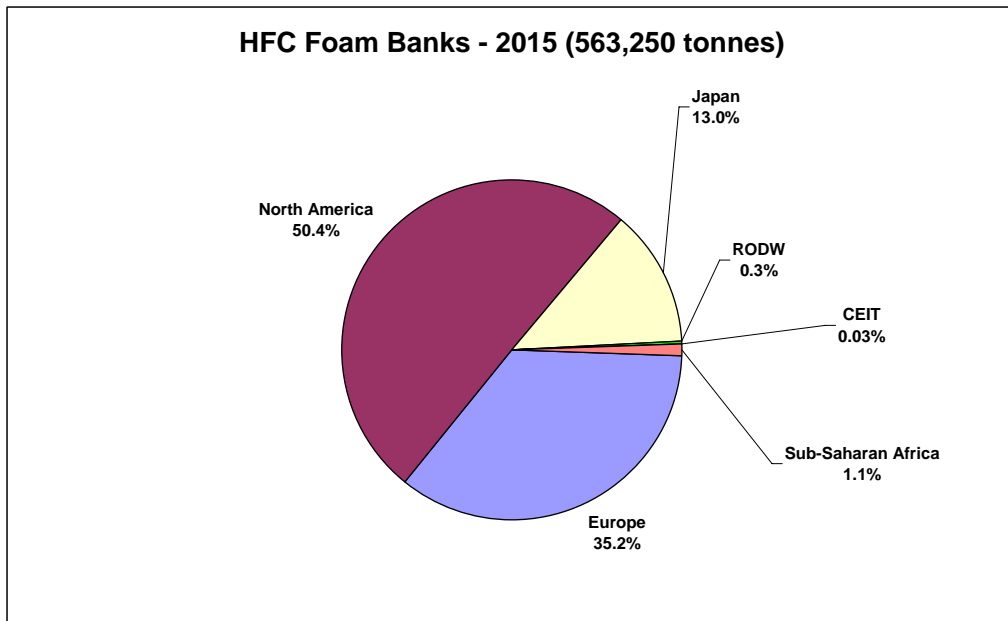


The growth in emissions of HFC-134a in 2010 coincide with the predicted introduction of this as a major blowing agent in the XPS Board sector of the North American market. There is still considerable uncertainty about which technologies will be used and the emission functions that will pertain to HFC use at that stage.

The 2000 bank data is not included in this section, because it is too small for the percentage splits to be meaningful.

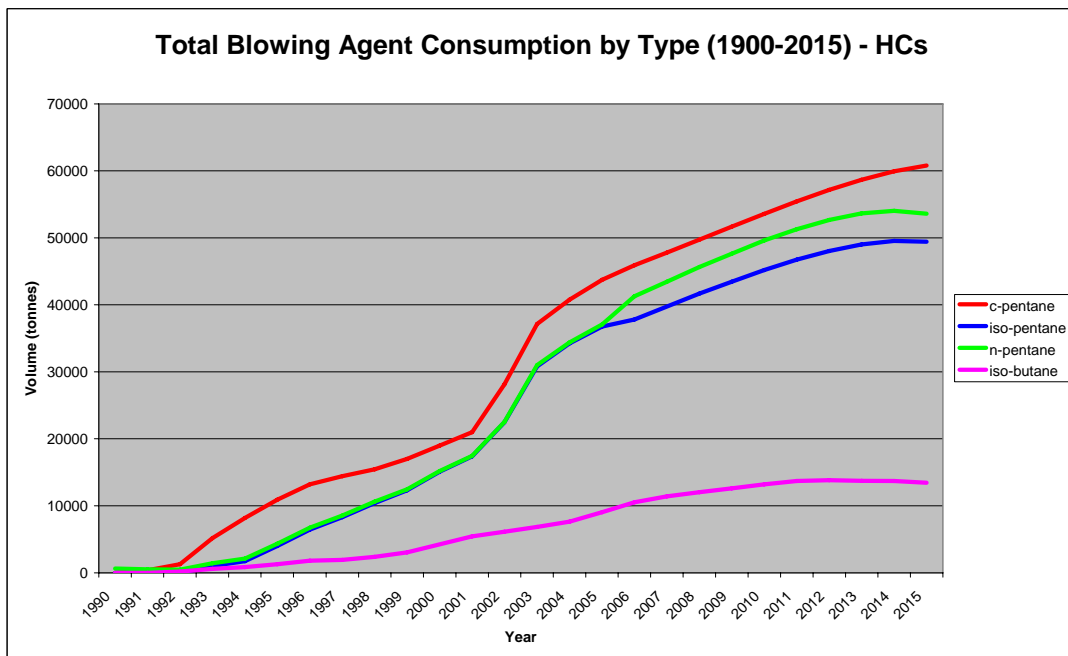


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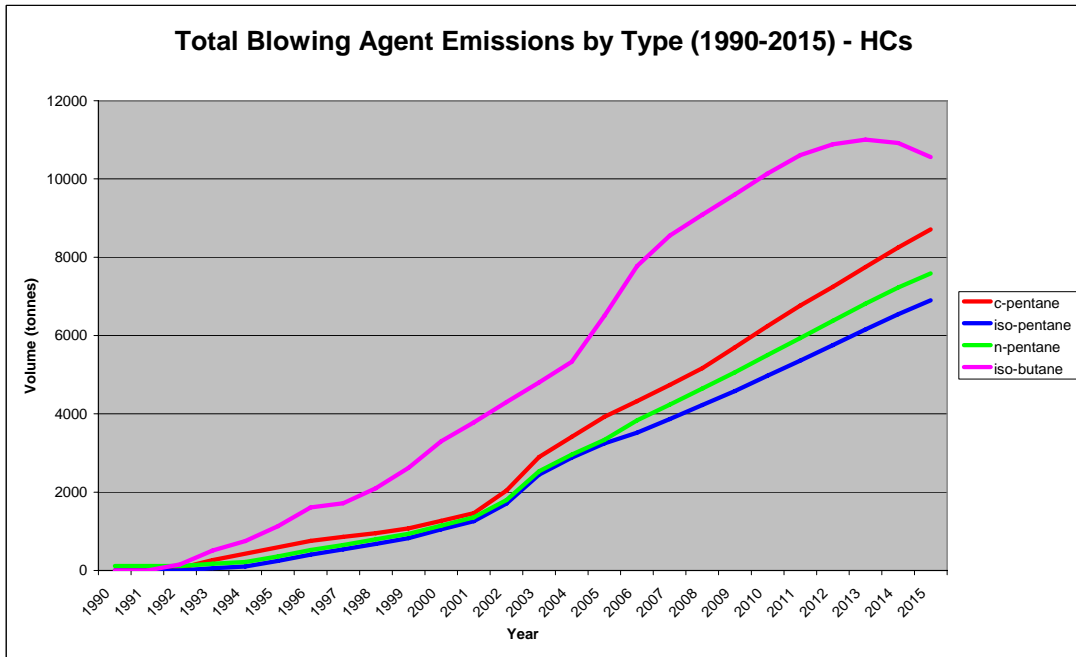
5.4 Hydrocarbons

The following four graphs show consumption, emissions and banks for hydrocarbons:

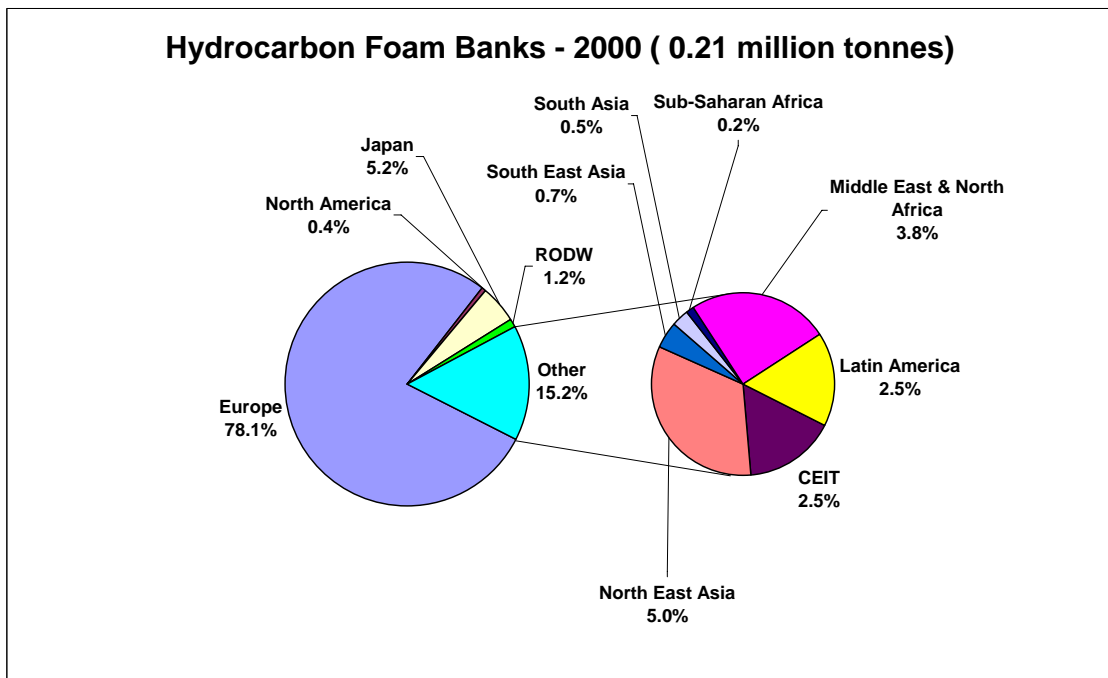




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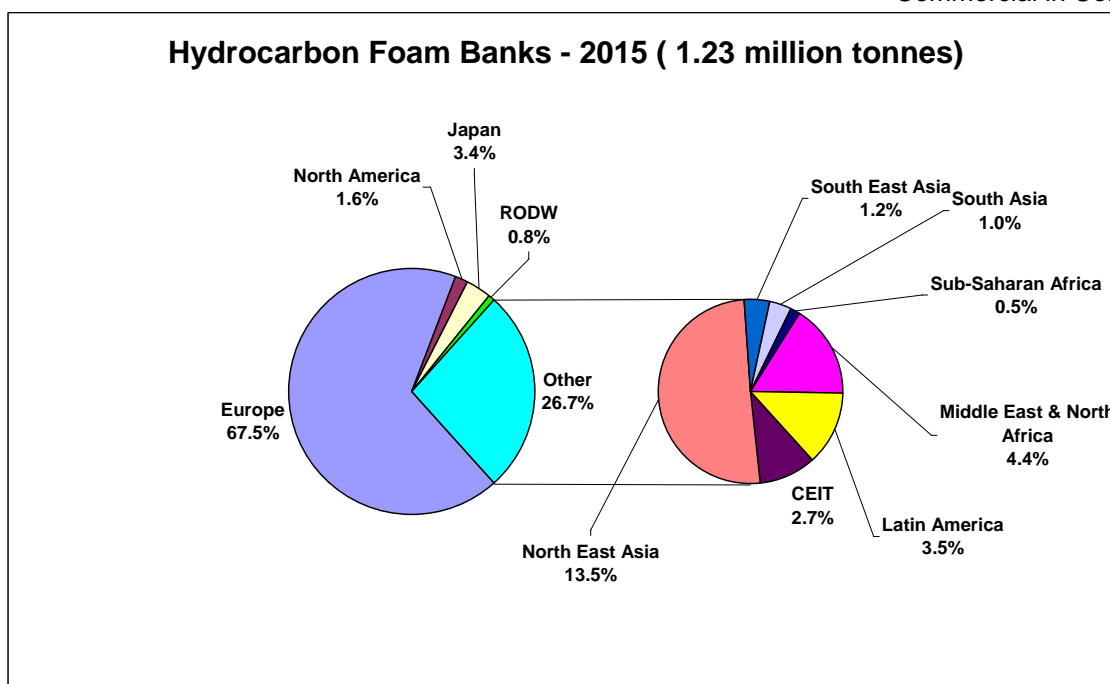


It is interesting to note that iso-butane has greater emissions than the other hydrocarbons even though its usage is less. This reflects its use in emissive applications such as polyethylene slab applications where short-term emission is required for safety reasons.





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Again, the growth of banks in developing countries illustrates the influence of the Multilateral Fund in promoting hydrocarbon technologies in these regions. The size of the bank in North East Asia reflects the predicted growth in domestic refrigerator production in the period to 2015.

6. CONCLUSIONS

The purpose of this project has been to produce a more comprehensive assessment of the patterns of blowing agent consumption, emission and accumulation at global and regional level. This has broadly been achieved as witnessed by the summary table below:

Blowing Agent	CFCs	HCFCs	HFCs	Hydrocarbons
Consumption (mt)	Nil	50,019	72,967	177,249
Emissions (mt)	17,710	25,229	19,974	33,760
GWP-weighted emissions (Mtons CO ₂)	99.94	30.51	20.07	0.51
Average GWP	5,643	1,209	1,005	15
Bank at 2000 (mt)	1,904,552	881,333	3,946	210,337
Remaining Bank at 2015 (mt)	1,228,199	1,416,825	563,232	1,231,703

Projected Global Consumption and Emissions of Blowing Agent by Type as at 2015

Key conclusions from the work include the following:



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- Foams are designed to retain their blowing agents as part of the maintenance of important performance criteria. Accordingly losses are low, particularly in the use phase.
- Emission forecasts and their relationship with observed atmospheric concentrations are therefore highly dependent on the accuracy of emission functions used for the use phase since low percentage figures are involved.
- Work continues to quantify these in-use phase losses, particularly in the XPS sector.
- The existing banks of CFCs and HCFCs will both still exceed 1 million tonnes in 2015 leading to a need to evaluate end-of-life options that could be appropriate for insulation materials already installed in buildings.
- HFC emissions are expected to reach 20,000 tonnes per annum by 2015 based on a projected usage of 75,000 tonnes per annum at that date. This figure represents a considerably lower estimate than believed likely in previous analyses (e.g. Petten).
- Developing countries will use very little HFC in the period to 2015 and will remain with HCFCs, as allowed for under the Montreal Protocol
- The increased use of innovative building techniques, including greater pre-fabrication, will assist in the end of life management of HFC-containing foam in Europe, Japan and elsewhere.

P. Ashford - 07/04/04