MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

2002 REPORT OF THE
RIGID AND FLEXIBLE FOAMS
TECHNICAL OPTIONS COMMITTEE

2002 ASSESSMENT

Montreal Protocol on Substances that Deplete the Ozone Layer

United Nations Environment Programme (UNEP)
2002 Report of the Rigid and Flexible Foams
Technical Options Committee

2002 Assessment

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2002 RIGID AND FLEXIBLE FOAMS REPORT

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2002 RIGID AND FLEXIBLE FOAMS REPORT

EXECUTIVE SUMMARY

INTRODUCTION

Historically, the blowing agent selection made by the foam plastics manufacturing industry was based heavily on CFCs. This was particularly the case in closed cell insulating foams. An assortment of CFCs and other ozone depleting substances (ODSs), including CFC-11, CFC-12, CFC-113, CFC-114 and methyl chloroform were used in numerous foam plastic product applications. However, the effect of the phase-out process has been to create further diversification.

The first technology transition in the early 1990s led to the introduction of transitional substances such as HCFCs as well as the increasing use of hydrocarbons and other non-ODSs. This transition is still taking place in Article 5(1) countries. In non-Article 5(1) countries, particularly in Europe and North America, attention is now firmly focused on the second phase of technology transition out of the transitional substances. This transition is concentrating attention on the emerging HFC-based technologies, although it should be stressed that much consideration is still being given to the optimisation of hydrocarbon and CO_2 technologies[1] and these technologies are gaining market share in several sectors.

As before, this report details, for each foam type, the technically viable options available to eliminate CFC and other ODS use as of 2002. However, by way of departure from previous reports, this review concentrates primarily on the transition status by product group and region and on issues affecting transition. Coverage of technical options per se is now located for information purposes within the appendices only.

TRANSITION STATUS

- Several developing countries are approaching final phase-out of CFC use in the foam sector. However, delays in other developing countries have limited progress and are threatening compliance.

- Several developed countries are currently occupied with the management of HCFC phase-out strategies. Approaches vary by region and a variety of challenges are being faced, both in terms of the readiness of replacement technologies and the uncertainty surrounding future product requirements and standards.
- The technical acceptability of hydrocarbons, particularly in polyurethane formulations, has expanded as several previous shortcomings have been overcome. In several key sectors market penetration now exceeds 50%.

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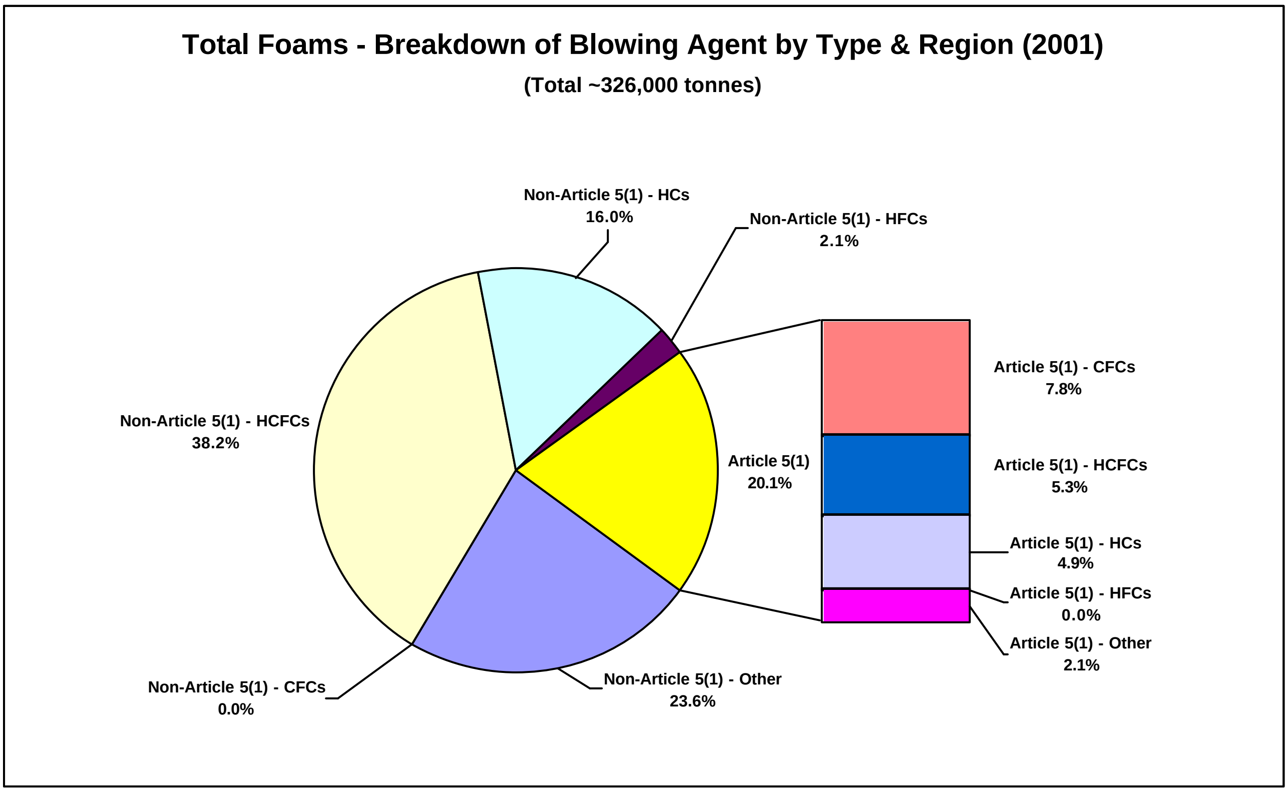
[1] Carbon dioxide or CO_2 as a blowing agent in polyurethane foam can be chemically generated from the reaction between water and isocyanate but also added in both polyurethane and other foams as an auxiliary blowing agent in liquid or gas form. The different options are hereafter referred to as CO_2 (water), CO_2 (LCD) or CO_2 (GCD).

- The commercial introduction of new HFC blowing agents has taken place and HFC-245fa and HFC-365mfc are now readily available in key transitional markets. There is now also a better view of how HFCs will ultimately be used in practice. However, issues remain concerning non-flammable blends and these are receiving attention. Issues of responsible use are continually being reinforced to ensure that emissions of HFCs are minimised.

- In this respect, focus has also increased on end-of-life management of foamed products. Because of their long application lifetimes (up to 50 years), it has been recognised that significant ‘banks’ of ODSs still exist and, in many cases, can be managed. Actions are already underway in Europe, Japan and elsewhere in this regard.

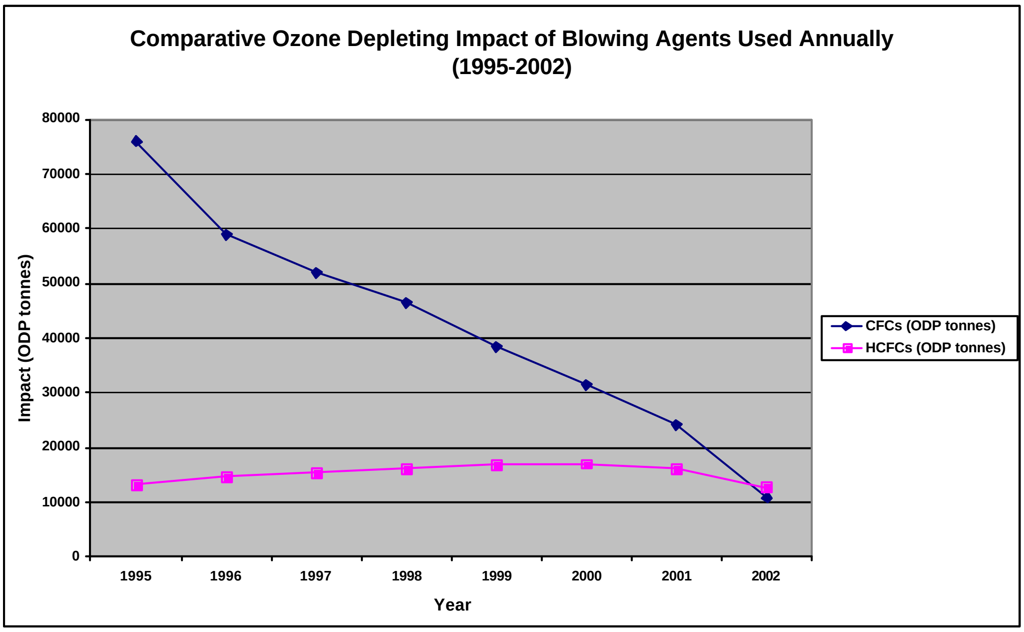
- The market share of insulation foams continues to grow against alternative insulation materials because of their excellent insulation efficiency and structural integrity. Increased concerns over climate change will continue to drive this growth further.

The chart below illustrates the overall status of transition for Article 5(1) and non-Article 5(1) countries in the combined rigid & flexible foam sectors as at 2001.



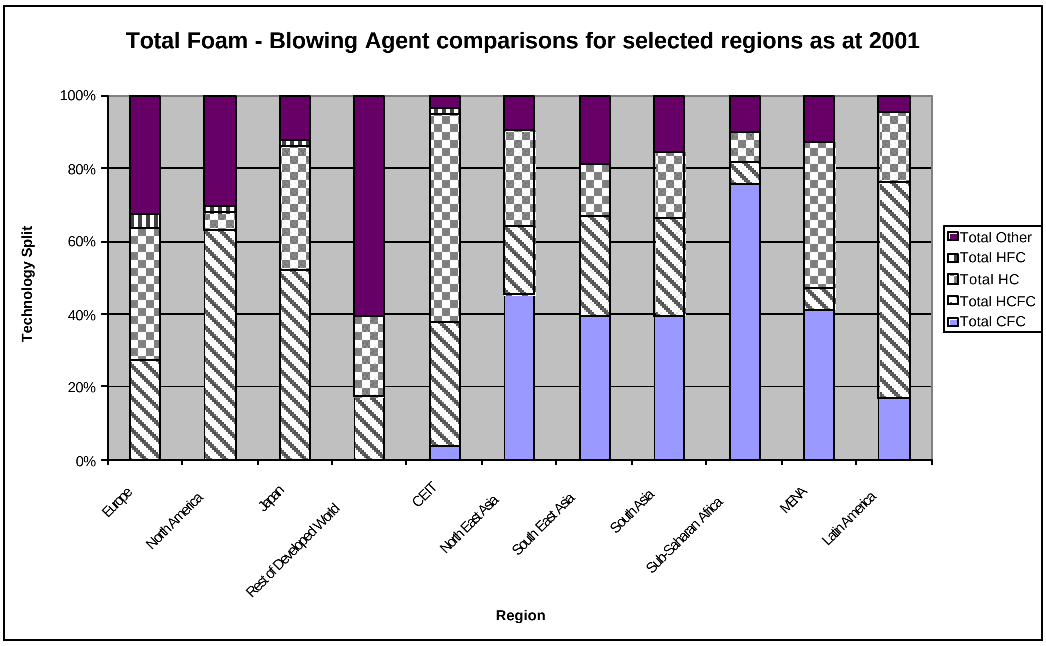
This chart suggests that, for the first time, the ozone depleting impact of HCFC-based blowing agents is approaching that of on-going CFC use.

The following graph illustrates the trend further.



However, the convergence is caused primarily by the on-going phase-out of CFCs rather than any further growth in HCFC use. As can be seen, this peaked in 2000.

The following graph provides further analysis of some of the regional variations in phase-out progress and in preferred technology options:



Zero ODP alternatives are currently the substitutes of choice in many foam types and applications. The major zero ODP applications are:

- extruded polystyrene sheet with CO_2 (LCD), hydrocarbons and, under certain circumstances, HFC-134a and/or HFC-152a;
- polyolefin with hydrocarbons;
- polyurethane packaging with CO_2 (water or LCD);
- flexible polyurethane slabstock for cushioning with methylene chloride or CO_2 (water or LCD) and flexible moulded polyurethane with CO_2 (water, LCD or GCD), and methylene chloride (hot cure only);
- extruded polystyrene rigid insulation foams with CO_2 (LCD), alone or with organic secondary blowing agents, HFC-134a /152a blends, HFC-134a and even HCs in specific Japanese markets;
- polyurethane rigid insulation foams where energy efficiency and fire safety requirements can be met with hydrocarbons, HFC-134a, or CO_2 (water);
- polyurethane rigid insulating foams, especially in SMEs where insulating value, end product fire performance or processing safety considerations are important, and can be met with HFCs 245fa or 365mfc (and blends);
- phenolics foams with HFC 245fa or HFC 365mfc (and blends) and, in some cases, hydrocarbons
- polyurethane integral skin where skin quality requirements can be met with CO_2 (water), HFC-134a, or hydrocarbons.

However, during this transitional period, the choices are expected to vary with time and country status as shown in the following tables:

Foam Type	**CFC Alternatives**		
	Currently in Use (2000/2001)	**Anticipated in 2005-2010 period**	
		Developed Countries	**Developing Countries**
Polyurethane: Rigid			
Domestic Refrigerators and Freezers	HCFC-141b, HCFC 141b/22, HCFC-142b/22 blends, hydrocarbons, HFC-134a	HFC-245fa, HFC-134a, hydrocarbons	HCFC-141b, hydrocarbons
Other Appliances	HCFC-141b, HCFC-22, HCFC-22/HCFC-142b	CO_2 (water), HFC-134a, hydrocarbons, HFC 245fa, HFC 365mfc/HFC 227ea	HCFC-141b, CO_2 (water), hydrocarbons
Reefers & Transport	HCFC-141b, HCFC-141b/-22	HFC-245fa, HFC-365mfc/227ea	HCFC-141b
Boardstock	HCFC-141b, HCFC-141b/-22	Hydrocarbons, HFC-245fa, HFC 365/HFC 227ea	N/A
Panels – Continuous	HCFC-141b, HCFC-22, HCFC-22/HCFC-142b	HFC-134a, hydrocarbons , HFC 365mfc/HFC 227ea, HFC-245fa	HCFC 141b
Panels – Discontinuous	HCFC-141b,	HFC-134a, hydrocarbons, HFC 365mfc/HFC 227ea, HFC-245fa	HCFC 141b
Spray	HCFC-141b	CO_2 (water), HFC 245fa, HFC 365mfc/HFC227ea	HCFC 141b
Blocks	HCFC-141b	Hydrocarbons, HFC 365mfc /HFC 227ea, HFC-245fa	HCFC 141b
Pipe	HCFC-141b	CO_2 (water), cyclopentane	HCFC 141b
One Component Foam	HCFC-22	HFC-134a or HFC-152a/ Dimethylether/propane/butane	HFC-134a or HFC-152a/ Dimethylether/propane/butane
Polyurethane: Flexible			
Slabstock and Boxfoam	HCFCs are not technically necessary for this end use	CO_2 (water, LCD), methylene chloride, variable pressure, LCD, special additives	CO_2 (water), methylene chloride, variable pressure, LCD, special additives
Moulded	HCFCs are not technically necessary for this end use	Extended range polyols, CO_2 (water, LCD, GCD)	CO_2 (water, LCD, GCD)
PU Integral Skin	HCFC-141b, HCFC-142b/-22	CO_2 (water), HFC-134a, -245fa, -365mfc/227ea, hydrocarbons	CO_2 (water), HFC-134a, hydrocarbons
PU Miscellaneous	HCFC-141b, HCFC-22/CO2	CO_2 (water)	CO_2 (water)

Table ES1 – Alternatives for Polyurethane Foams

Foam Type	**CFC Alternatives**		
	Currently in Use (2000/2001)	**Anticipated in 2005-2010 period**	
		Developed Countries	**Developing Countries**
Phenolic	HCFC-141b	Hydrocarbons, 2-chloropropane, HFC-365mfc/227ea, HFC-245fa	HCFC-141b, hydrocarbons
Extruded Polystyrene			
Sheet	Primarily hydrocarbons, HCFCs are not technically required for this end use	CO_2 (LCD), hydrocarbons, inert gases, HFC-134a, -152a	Hydrocarbons, CO_2 (LCD)
Boardstock	HCFC-22, HCFC-142b	CO_2 (LCD) or with HC blends, hydrocarbons (Japan only), HFC-134a, HFC-152a and HC blends	HCFC-142b, HCFC-22
Polyolefin	HCFC-22, HCFC-142b		

Table ES2 – Alternatives for Other Foams

ISSUES AFFECTING TRANSITION

The issues affecting transition are reviewed in detail within Chapter 2 of this Report. They encompass factors in both Article 5(1) and non-Article 5(1) environments. There are several common elements and these often focus on SMEs. Key points to highlight at this stage are:

- There is concern in some specific sectors about whether HFC technologies can be validated, including safety considerations with “non-flammable” blends, in time to support HCFC phase-out within the existing regulatory frameworks because of extended approval times and changing product requirements

- The financial constraints of SMEs remain key factors in many transition strategies, both in developing and developed countries

- There remains concern among users about the possibility of a supply/ demand imbalance for HCFC-141b once the phase-out in developed countries takes place. This extends to the maintenance of adequate geographic supply chains.

- The sustained availability of CFC-11 at low prices continues to hinder phase-out.

OTHER SIGNIFICANT ISSUES

The long historic use of CFCs in rigid foams, the long product lifetimes and the slow release rates of blowing agents continue to point to the existence of a significant bank of future CFC and HCFC emissions. As noted under the Transition Status review earlier in this Summary, this is not only an issue arising from earlier practices, but is also impacting decisions about current and future product use. This may result in a greater consideration of insulation product design in buildings to facilitate removal at end-of-life and to encourage re-use of the building element wherever possible. These issues have been identified previously by the Foams Technical Options Committee (FTOC) both in its own reports and those of relevant TEAP Task Forces and are addressed in Appendix 4 of this Report.

For the first time in this Report, and in the interests of information dissemination, Appendix 2 gives a comprehensive overview of the physical and chemical characteristics of the blowing agents together with issues that need to be considered when handling them. The Technical Options Committee hopes that this will be a valuable further dimension for readers.

Finally, unless otherwise stated, all graphs in the main report relate to 2001 data. Since this continues to be a period of rapid transition, there could be significant further changes by the time of reading of this report.

CHAPTER 1: TRANSITIONAL STATUS

POLYURETHANE FOAMS

RIGID POLYURETHANE FOAM

NON-CONSTRUCTION APPLICATIONS

This sector includes domestic refrigerators and freezers, commercial refrigeration units, water heaters and refrigerated transport applications. It does not include miscellaneous non-insulating applications.

DOMESTIC REFRIGERATORS AND FREEZERS

Current Technology

In developing countries there is still some use of CFC 11, particularly by the smaller producers. Many of these are likely to transition to HCFC-141b because economies of scale are not sufficient to justify other alternatives.

The most widely applied technology globally is hydrocarbon and, specifically, cyclo-pentane. This is used in all regions except for South Africa, where the blowing agent itself is not available, and in North America where HCFC-141b has remained dominant. Hydrocarbon technology has evolved from the initial 100% cyclo-pentane to blends with other hydrocarbons. Blends of cyclo-pentane with iso-pentane are emerging as the favoured blowing agent in the market because of better cost effectiveness. The initial density increase of cyclo-pentane is reduced because the blend offers improved flow and a more uniform and lower average density distribution. In 2001 some 60% of European production was based on this blend. Its use has been long established in Australia and is also increasing in the Chinese market. Blends of cyclo-pentane with iso-butane have grown in use for similar reasons to the cyclo-pentane/iso-pentane blend but the difficulty of using a liquid/gas blend has slowed its growth. Energy standards are met by use of thicker foam and cooling system improvements.

In North America there is additional use of a blend of HCFC-141b with HCFC-22 because this gives better foam stability. It also lowers the average ODP and could stretch HCFC availability under a cap. In addition, the use of HFC-134a as the blowing agent for some models is expected to continue.

Future Technology Trends

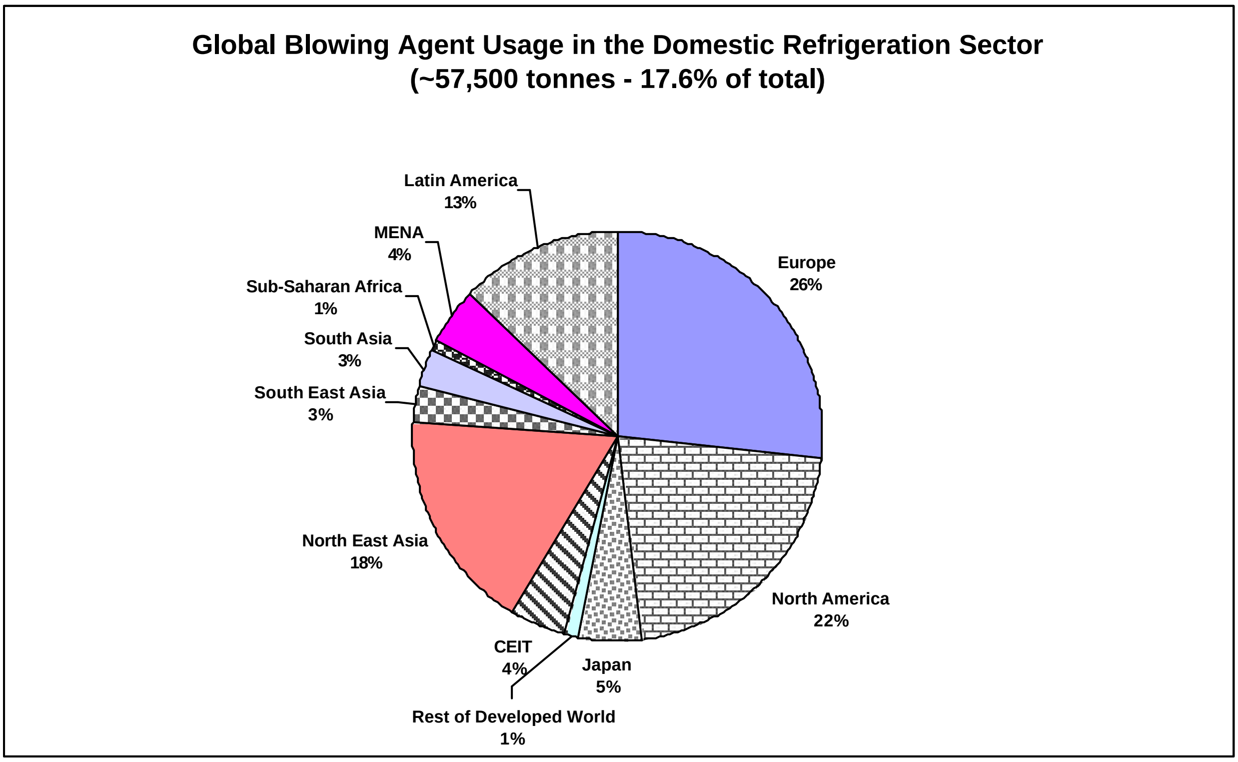
In developing countries there will be further conversion to HCFC 141b from CFC 11 and use of cyclo-pentane with further progression to blends will continue in both developed and developing countries. The next round of European Union energy requirements is likely to be met with the current blowing agent technology.

After HCFC-141b is phased out, the majority of North American appliance manufacturers will use HFC-245fa to meet the energy efficiency standards. One manufacturer will continue using HFC -134a.

The use of HFC 245fa and HFC 365mfc may be considered in other markets, too, if energy consumption requirements become more stringent.

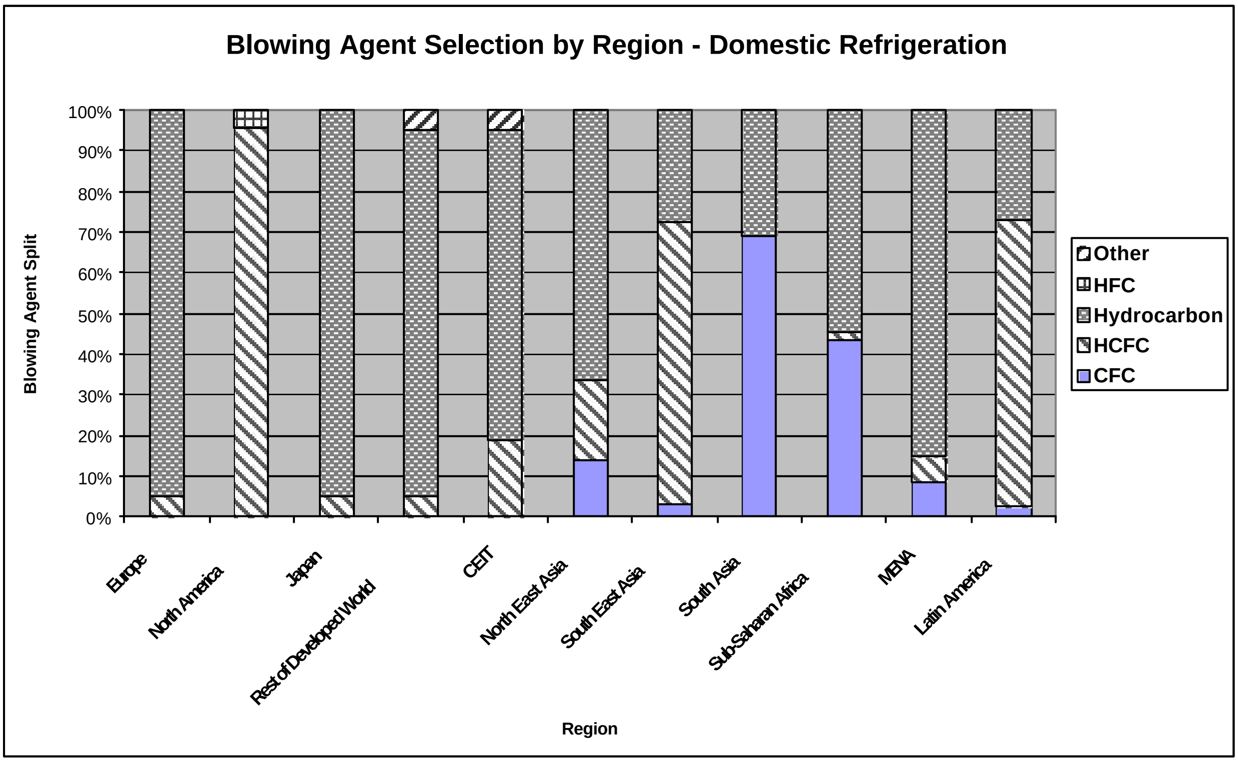
Data Summary

The current global distribution of blowing agent use in the domestic refrigerator and freezer sector is shown below:



It can be seen that the majority of production of domestic refrigerators is in the non-Article 5(1) countries. However, production in China is growing extremely rapidly and this is likely to become the single biggest market within the next five years. Production elsewhere in the world is fairly widely spread in contrast to many of the construction applications where climatic factors have more influence.

The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

In general terms, those regions supported under the Multilateral Fund have benefited from access to hydrocarbon technologies and the larger plants have already been converted as a priority. However, slower conversion in regions such as South Asia and Sub-Saharan Africa is indicative of the smaller-scale of many of the plants in the region. Nonetheless, many are still targeted to switch to cyclo-pentane with the balance transitioning to HCFC-141b.

OTHER APPLIANCES

Current Technology

CFC-11 is still in use by enterprises in developing countries.

The main option, in both developed and developing countries, to replace CFC-11 in these sectors is HCFC-141b. This is because of the low capital investment required by the manufacturers - many of these are small enterprises with limited production capacity

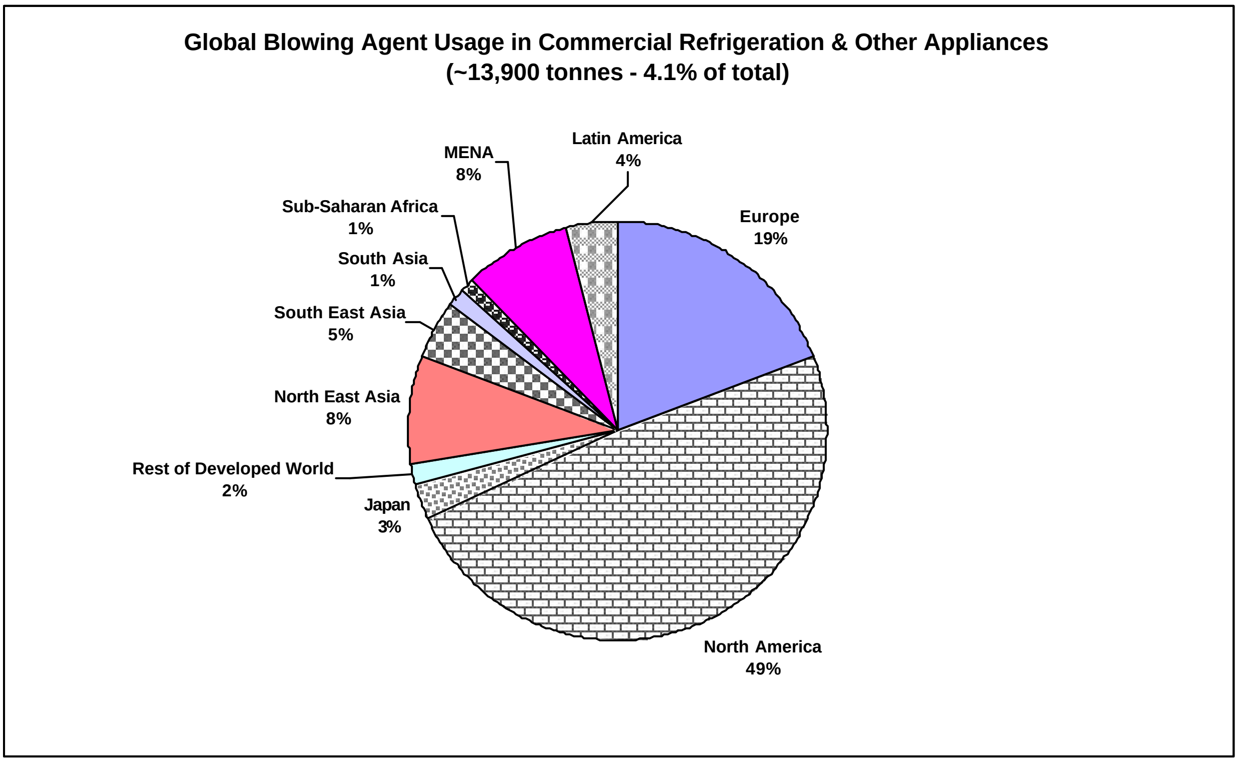
Cyclo-pentane is used for commercial refrigerators and freezers in those areas where the market demands a zero ODP, low GWP option. Some vending machines and water heaters are produced with CO_2 (water). For water heaters the comparatively poor thermal insulation properties of the foam can be compensated by increased thickness in some cases.

Future Technology Trends

For the replacement of HCFC-141b the blowing agents being evaluated are HFC-245fa and HFC-365mfc. The various forms of pentane are also technically suitable, but the cost of appropriate safety measures and the difficulty in supplying pre-blended formulations may rule out wide scale use.

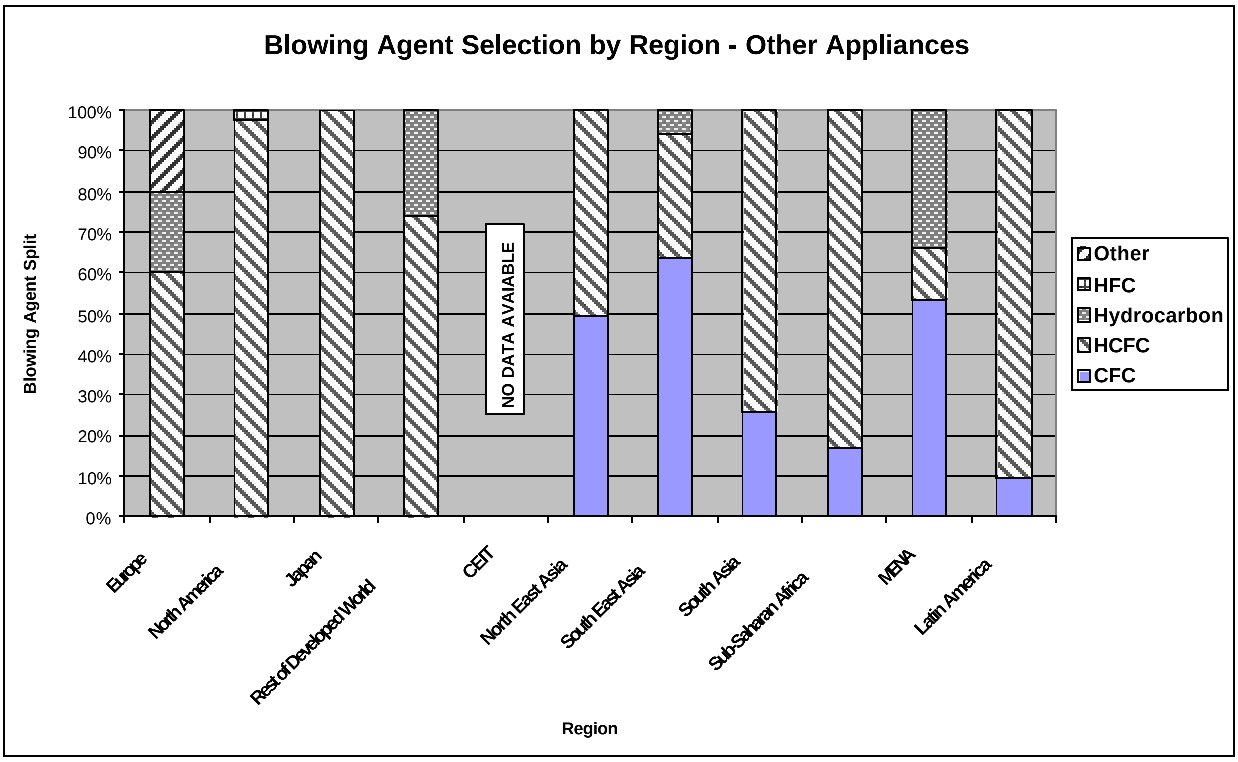
Data Summary

The current global distribution of blowing agent use in the commercial refrigeration and other appliances sector is shown below:



The North American demand for commercial refrigeration represents the largest single element of the blowing agent market, partly based on population, but also because of the propensity for drinking dispensers in public places and the size of the cabinets involved. It can also be seen that the regional manufacture of commercial refrigeration units and other appliances is fairly widely spread.

The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

As noted earlier, the ‘Other’ blowing agent used in Europe is CO_2 (H_2O). Otherwise, it can be seen that, where conversion from CFCs has occurred, HCFCs have been the favoured replacement. This is partly because of the smaller size of commercial refrigeration companies and the more widely varying product range being manufactured.

REEFERS & REFRIGERATED TRANSPORT

Current Technology

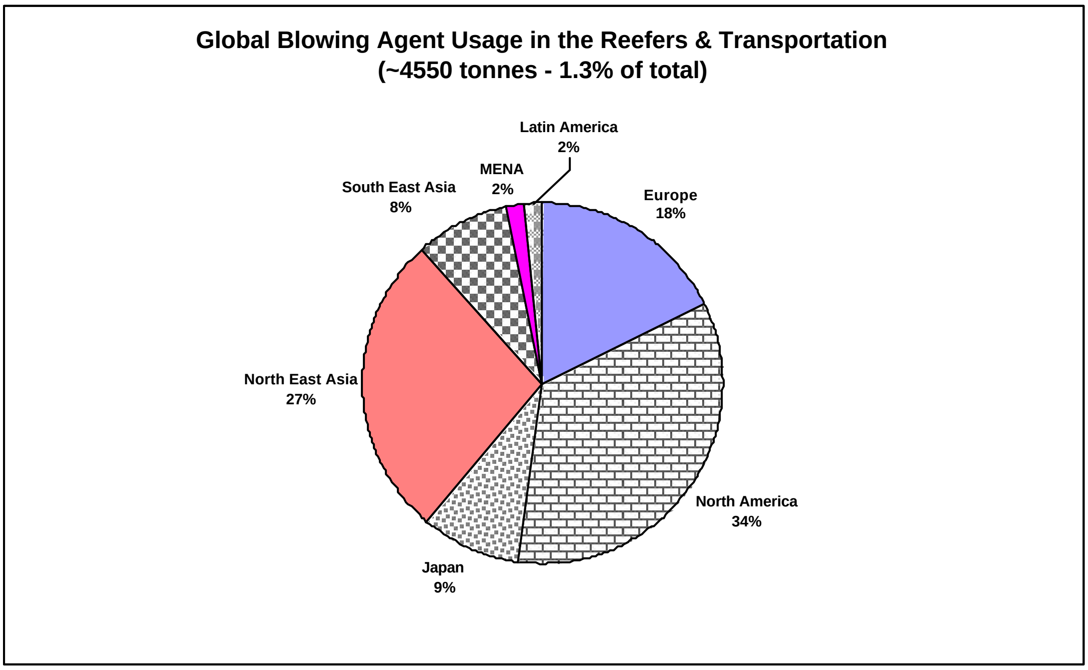
The most widely used technology is HCFC-141b and, with the transfer of much of the global manufacture to Article 5(1) countries such as China, the use of HCFC-141b is likely to be maintained for a considerable time to come.

Future Technology Trends

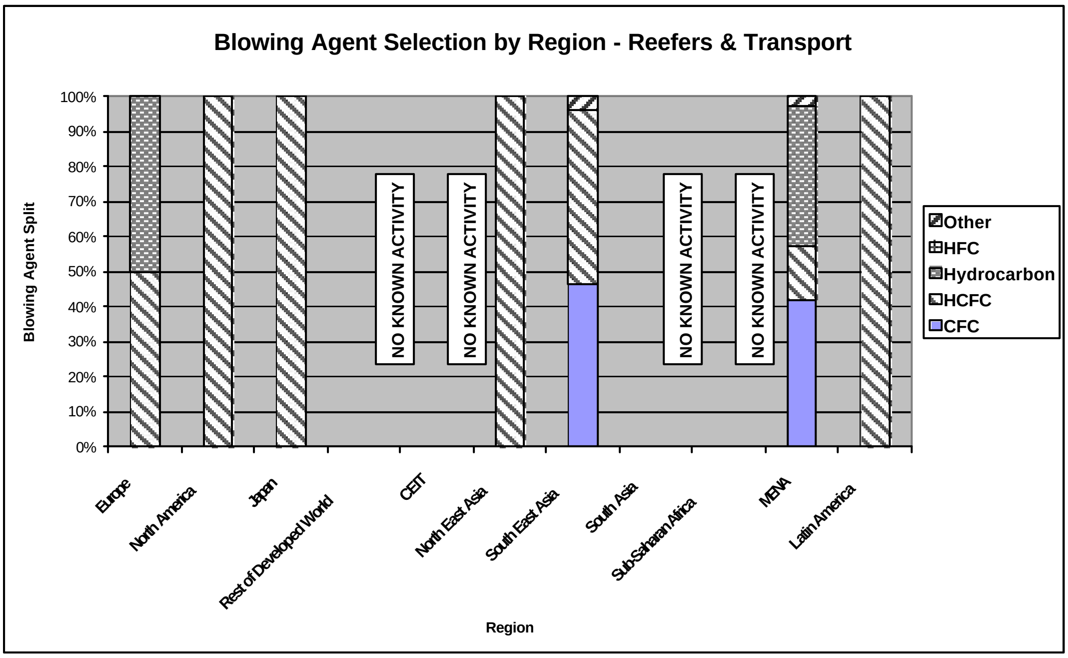
In developed countries the manufacturers are evaluating the use of foam systems based on hydrocarbons. These are usually based on linear pentanes and other similar blowing agents. HFC-245fa and HFC-365mfc are also likely candidates.

Data Summary

The current global distribution of blowing agent use for reefers and other PU transport applications is shown below:



The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

The growth of China as a producer of reefers is well illustrated in the graphs and this is expected to continue. The development of hydrocarbon technology for other transport applications in Europe and its transfer into some MENA areas is also highlighted.

CONSTRUCTION APPLICATIONS

This sector covers all applications of rigid polyurethane foams in building and construction, including the use of foamed panels in large-scale walk-in cold storage facilities, which are typically considered as temporary buildings.

BOARDSTOCK

Current Technology

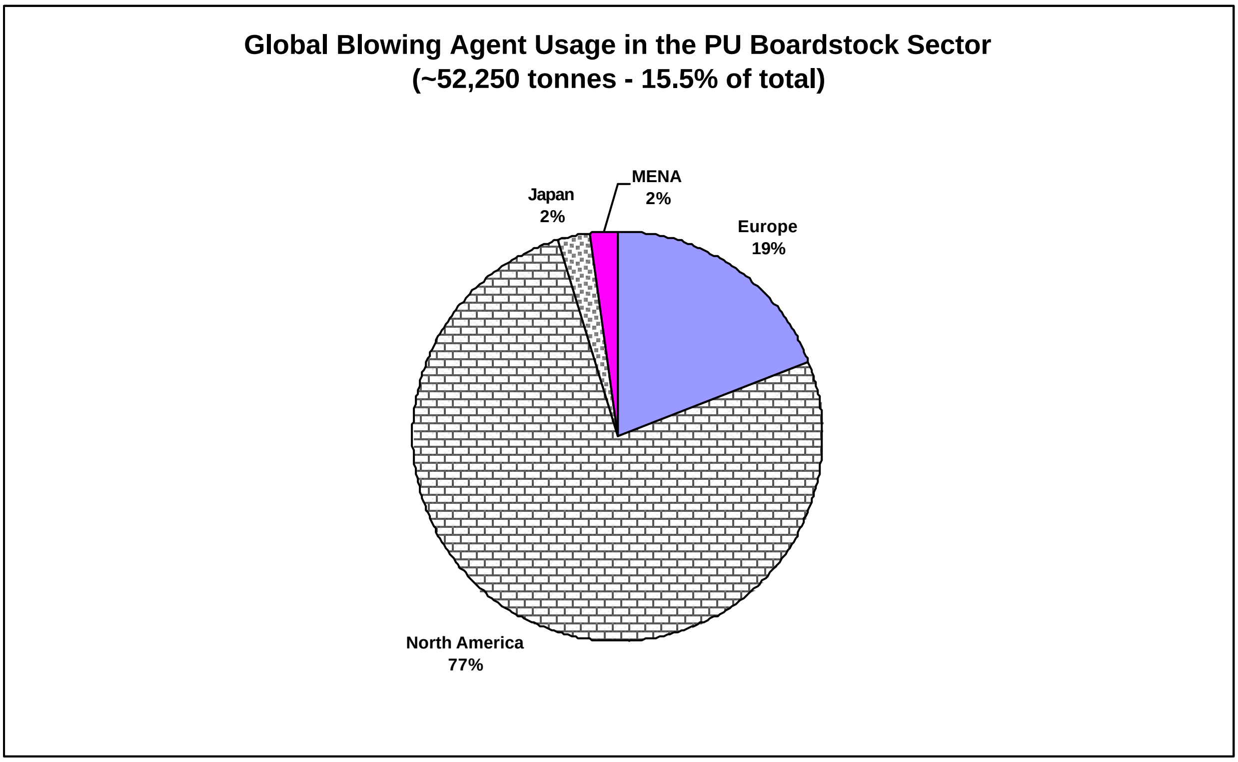
This is currently predominantly a developed country technology. Both HCFC-141b and n-pentane (or iso-pentane) have been in use since 1992. In Europe, the use of HCFC-141b has reduced significantly to a few niches where the best foam fire performance has been required. Technology based on n-pentane has taken it place and has achieved about 95% of the market. In North America HCFC-141b (and HCFC-141b/HCFC-22 blends) have been dominant but manufacturers have been evaluating hydrocarbons, including cyclo-pentane, with a view to their introduction when the use of HCFC-141b is phased out.

Future Technology Trends

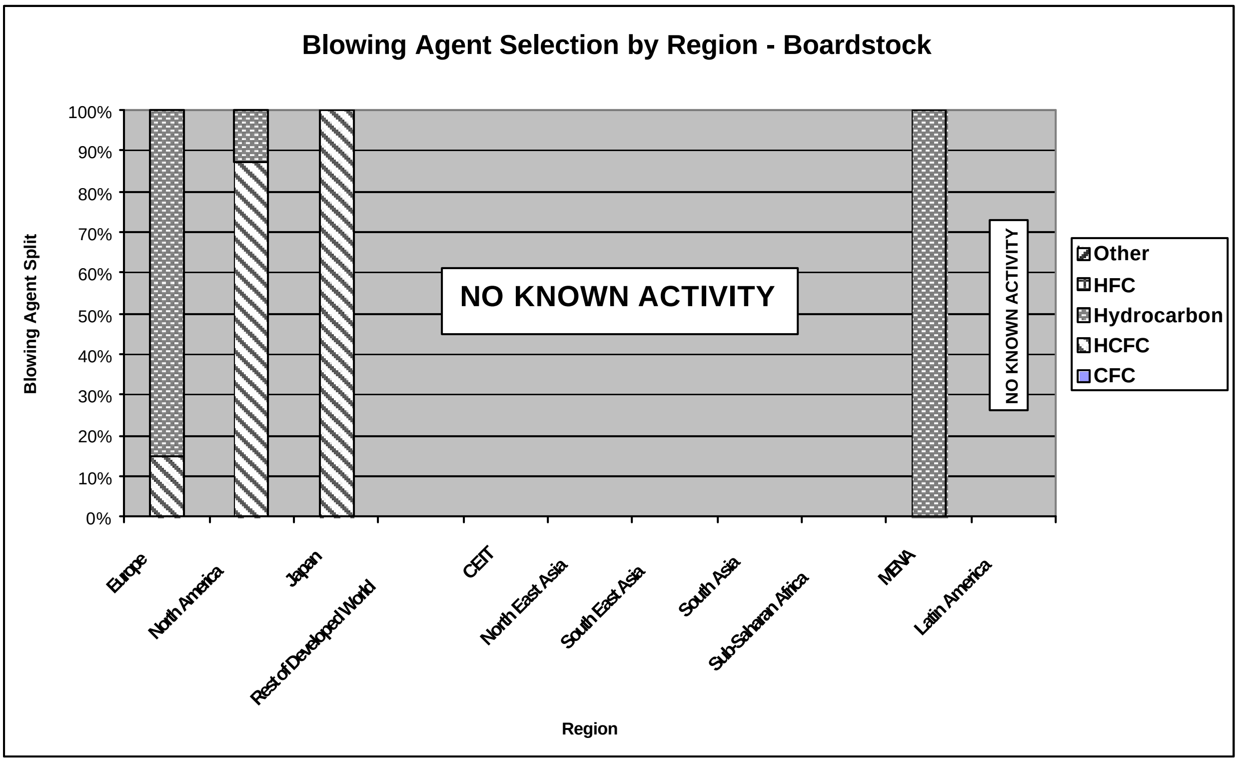
It is likely that hydrocarbons will be the long term blowing agents in this sector but the use of HFC-245fa and HFC-365mfc (and blends based on them) are likely to find niche applications for end uses where the most stringent foam flammability standards are required. Cost considerations are likely to inhibit their wide-scale use.

Data Summary

The current global distribution of blowing agent use in the boardstock sector is shown below:



The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

The only Article 5(1) activity identified is situated in the MENA region and relates to an operation in Iran which is believed to operate with flexible facings. The predominance of PU Boardstock use in the United States is illustrated bearing in mind that the respective sizes of the overall insulation markets in Europe and North America are similar.

PANELS - CONTINUOUS

Current Technology

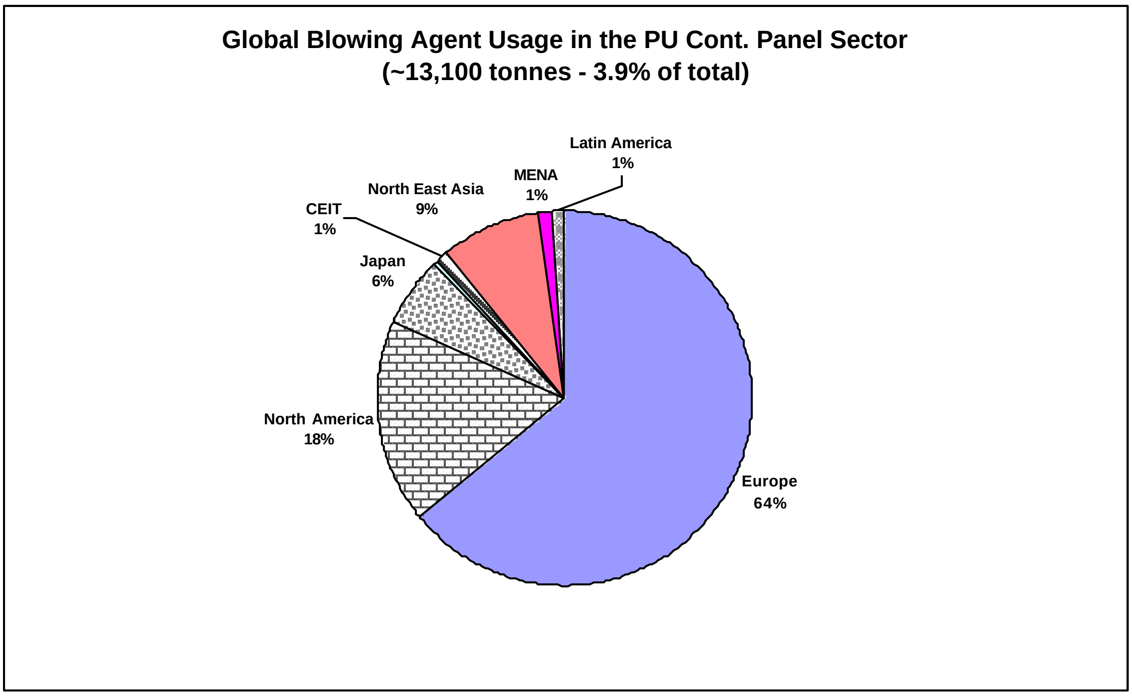
The use of CFC-11 has been replaced in nearly all developing country enterprises. The main blowing agent in this sector, in all countries, is HCFC-141b with additional use of n-pentane, HCFC-142b/HCFC-22, HCFC-22 alone and HFC-134a.

Future Technology Trends

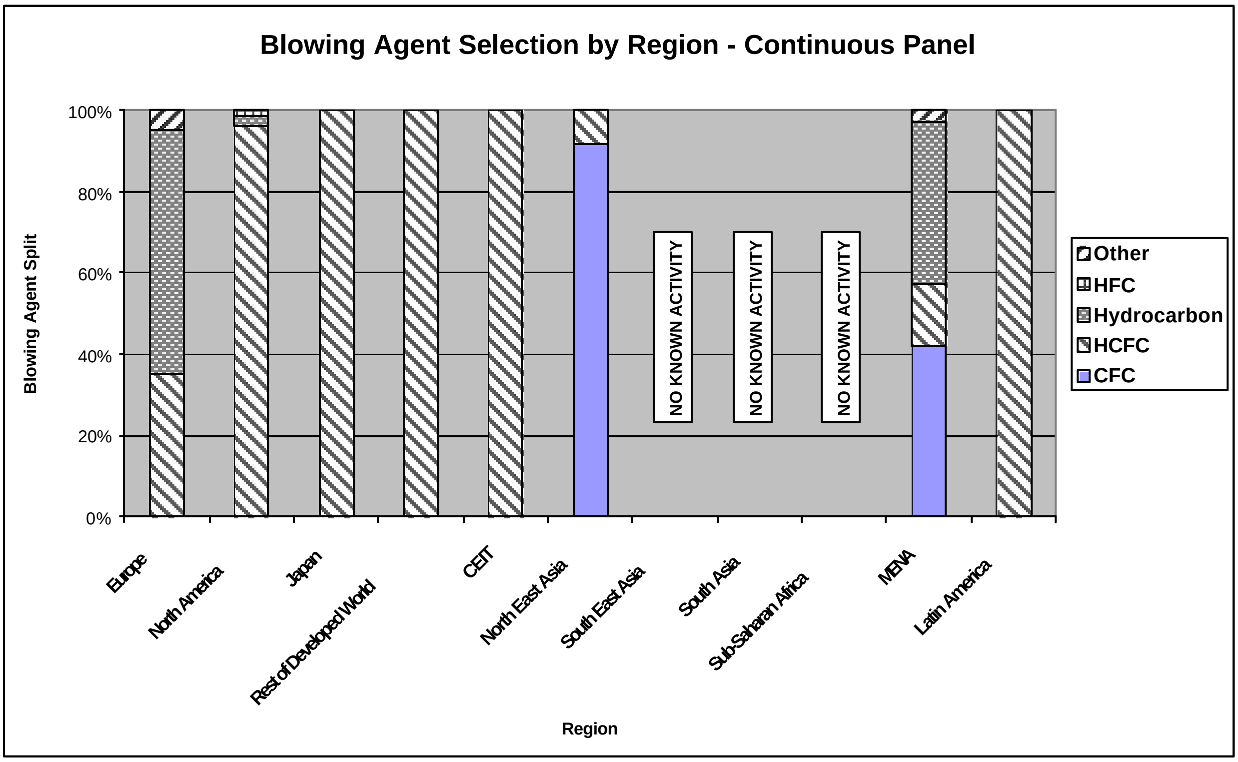
With the phase-out of HCFC 141b the European manufacturers are mainly converting to pentane. The option to use HFCs will be necessary for end applications where the most stringent end product flammability requirements are needed. In the USA and elsewhere a wider variety of blowing agents will be used with most of them based on HFC blends. In developing countries the use of HCFC-141b is projected to continue for many years.

Data Summary

The current global distribution of blowing agent use in the continuous panel sector is shown below:


Global Blowing Agent Usage in the PU Cont. Panel Sector (~13,100 tonnes - 3.9% of total)

The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

Again the linkage between European and MENA technology selection is shown here. However, with fire concerns continuing to pressurise the European market in certain countries, the introduction of HFCs in place of the remaining HCFC use is likely.

PANELS - DISCONTINUOUS

Current Technology

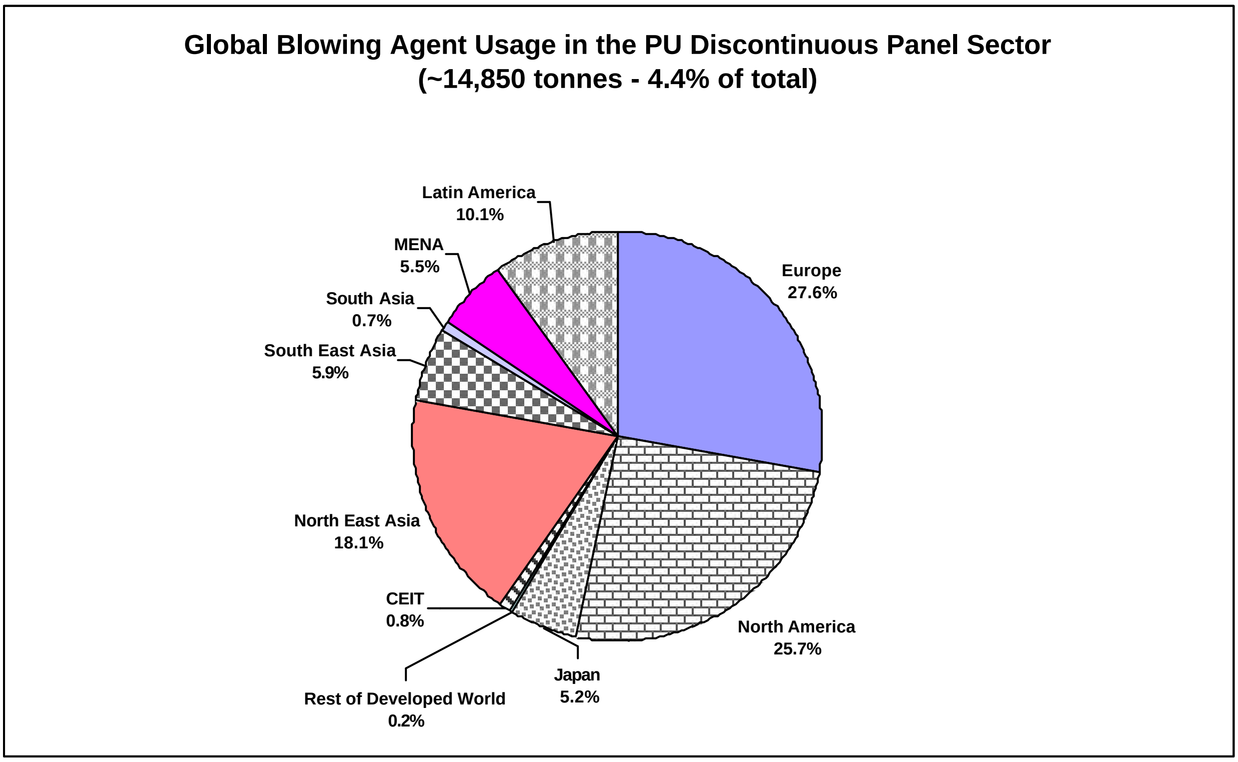
The use of CFC-11 in developing countries is continuing with several of the smaller enterprises options. The most widely used blowing agent in this sector is HCFC-141b and there have been significant challenges in its replacement in a cost-effective manner. Pre-blended HFC-134a formulations have been introduced in the European market and both cyclo-pentane and n-pentane have been used in the European and some developing country markets for several years.

Future Technology Trends

There will be some extension of the use of pentane but blends based on HFC-134a, HFC-245fa and HFC-365mfc are likely to emerge as the main replacements for HCFC-141b.

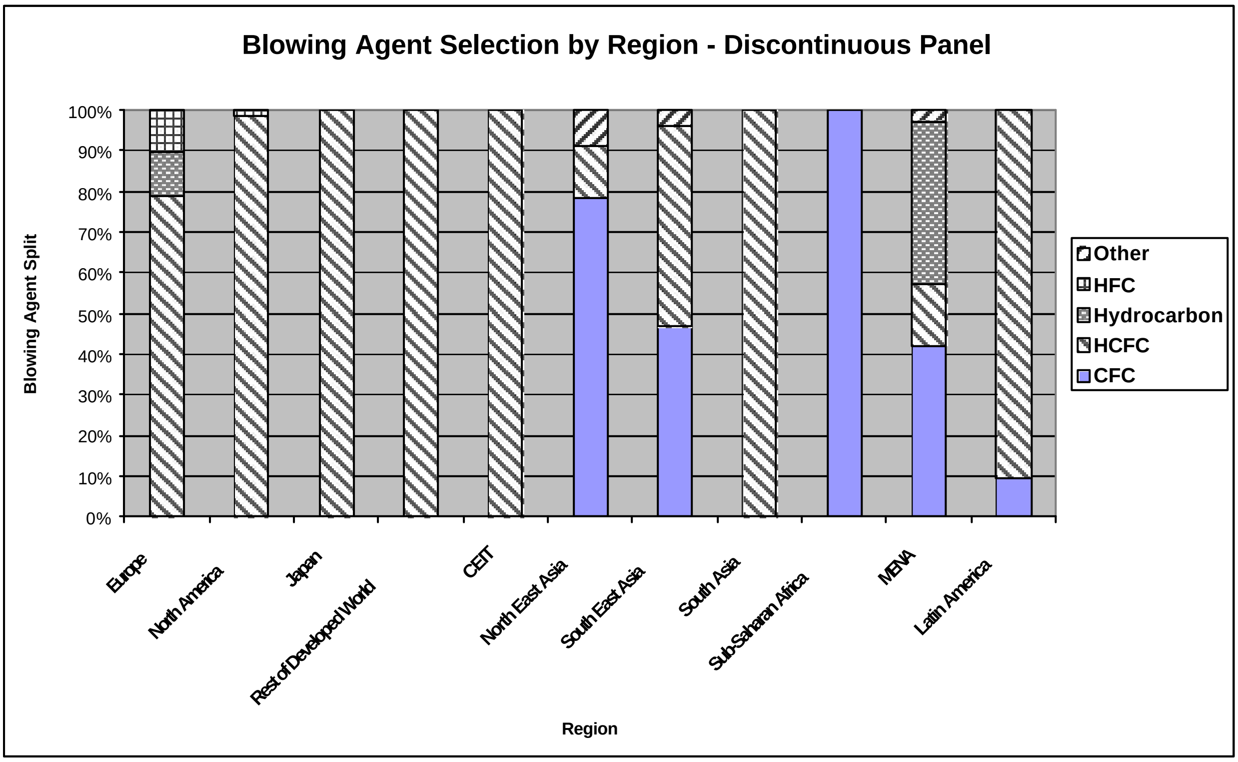
Data Summary

The current global distribution of blowing agent use in the continuous panel sector is shown below:


Global Blowing Agent Usage in the PU Discontinuous Panel Sector
(~14,850 tonnes - 4.4% of total)

This graph illustrates the widespread operation of discontinuous panel operations around the world. With the exception of the South Asia region, the production levels seem to be related primarily to population levels.

The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

The continuing reliance on HCFCs in this sector is self-evident, although hydrocarbon technologies are beginning to break through, particularly where the capital costs can be addressed under the Multilateral Fund.

SPRAY FOAM

Current Technology

CFC-11 remains in use with the foam applicators in some developing countries. The most commonly used blowing agent, in all countries, is HCFC 141b. However, CO_2 (water) is used in some cases. Neither gaseous HCFCs and HFCs, nor the pentanes are suitable for this sector. All formulations are pre-blended and a gaseous blowing agent would not give the required foam quality because of frothing and would result in unacceptable losses of the blowing agent. The flammability of pentanes would make their on-site applications unacceptable.

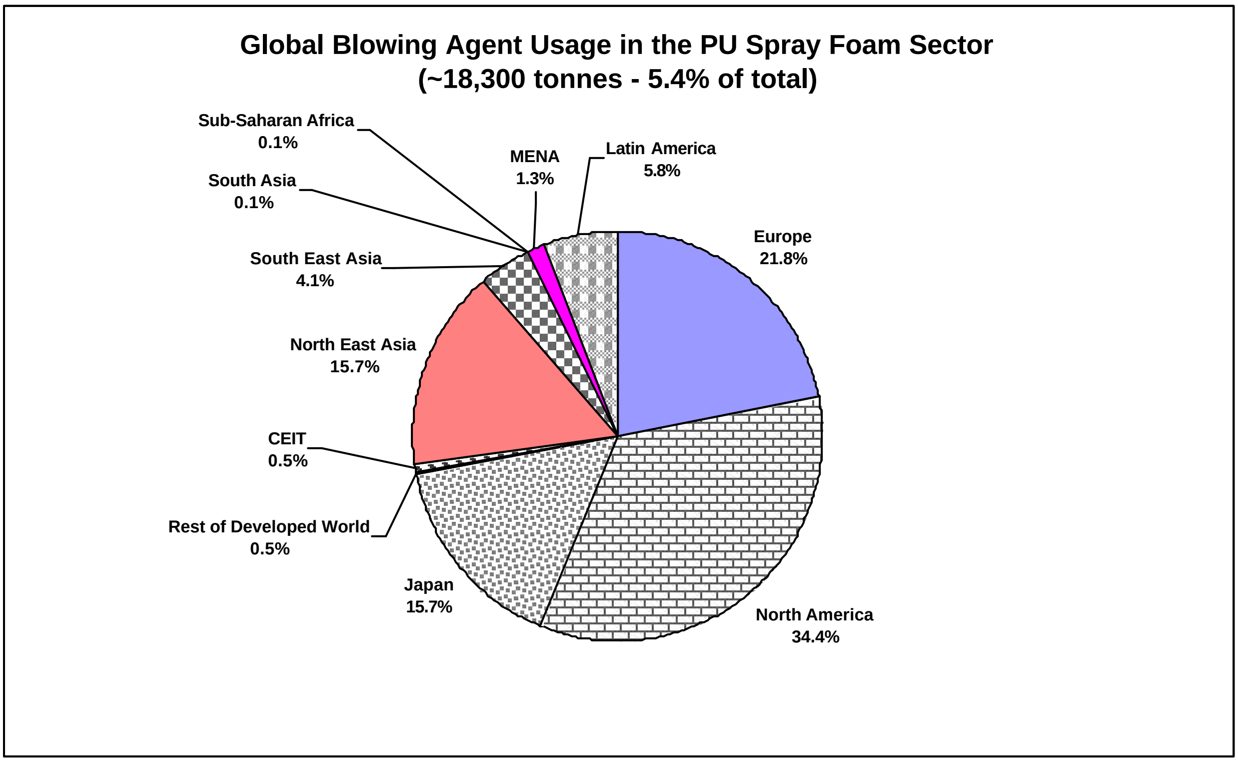
The use of CO_2 (water) is in applications where the higher (about 50%) foam thickness to give equivalent insulation value can be accommodated.

Future Technology Trends

Systems based on both HFC-245fa and HFC-365mfc are being developed as replacements for HCFC-141b. These include systems based on HFC-245fa and water CO_2 (water) and on HFC-365mfc and HFC-227ea. There continues to be considerable further development activity regarding hydrocarbons, particularly in the United States. However, concerns over process and product fire risks are limiting progress, especially in regions where fire regulations are most demanding (e.g. Japan).

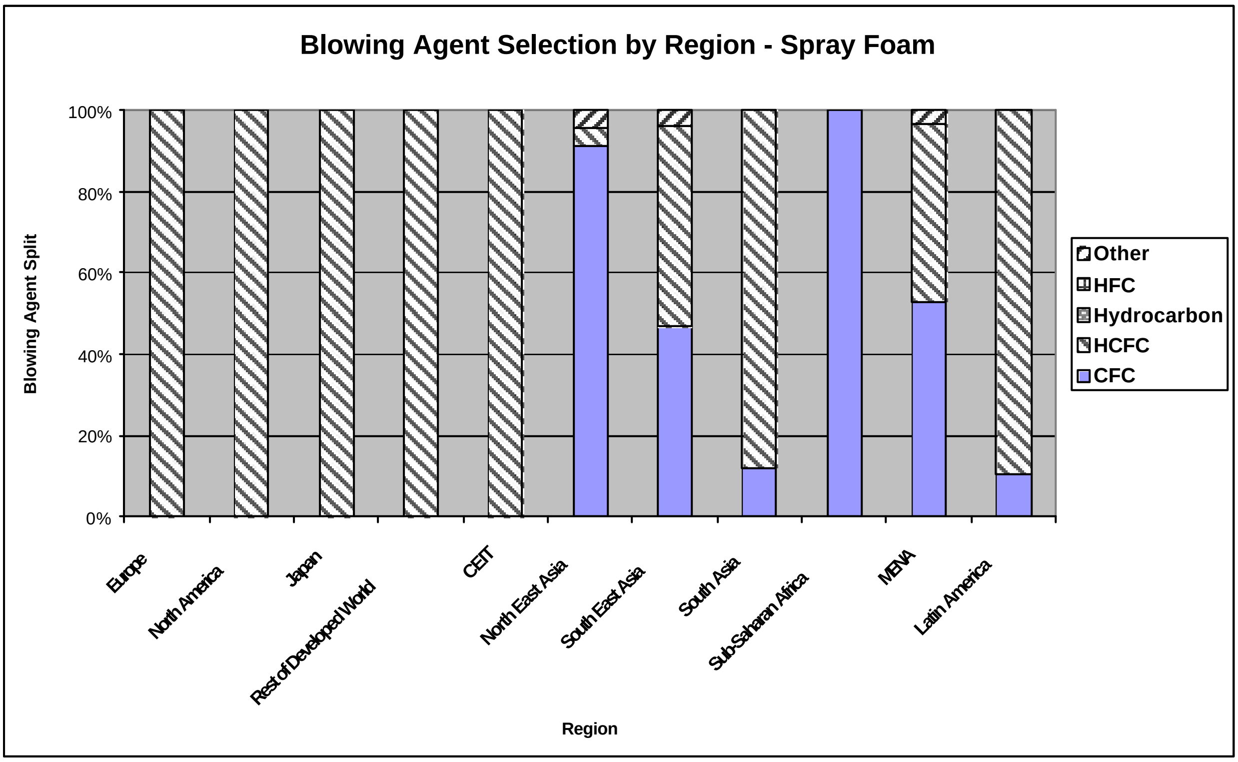
Data Summary

The current global distribution of blowing agent use in the PU Spray Foam sector is shown below:



As before, the widespread use of spray foam technologies is demonstrated with well-established markets in both North America and Japan. Markets are growing rapidly in Europe and in some Article 5(1) regions, where the utility of spray foams is assisting in the retrofit of many existing buildings.

The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

Again, the dominance of HCFC-based technologies is self-evident where transition has already occurred. With non-Article 5(1) countries reaching the transition phase from HCFCs, this sector is expected to become one of the most significant users of HFCs.

ONE-COMPONENT FOAM

Current Technology

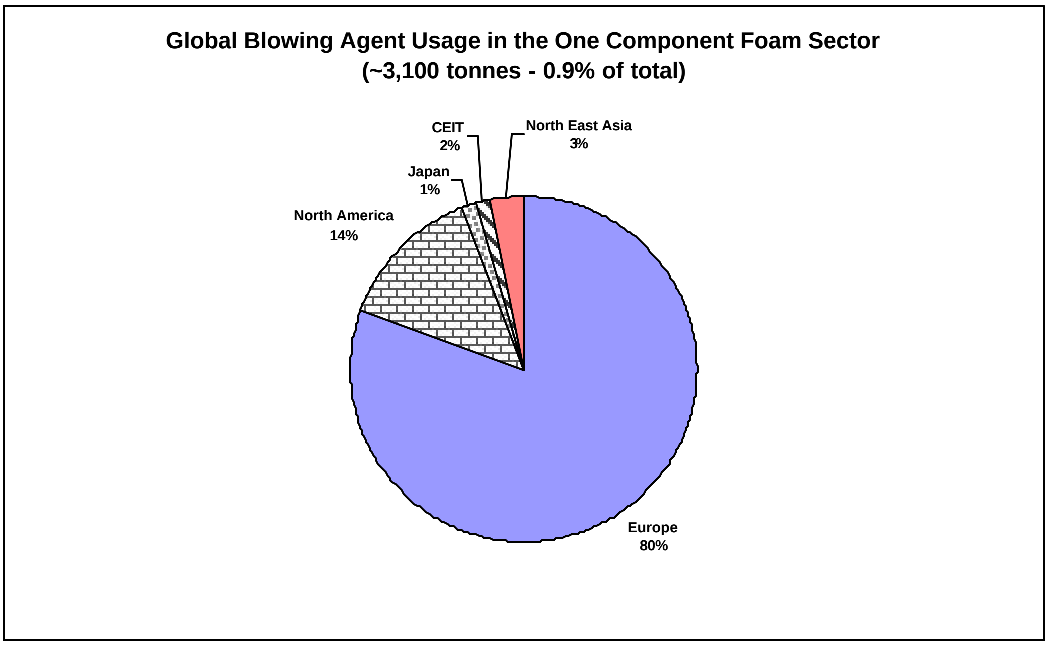
The current blowing agents in wide scale use are HCFCs, HFC-134a and HFC-152a, the hydrocarbons, propane and butane plus dimethyl ether (DME). They are frequently used in blends and, for example, a blend of HFC-134a/DME/propane/ butane is widely used in Europe. Flammable blends are used in about 80% of the total European market for cost-effectiveness reasons.

Future Technology Trends

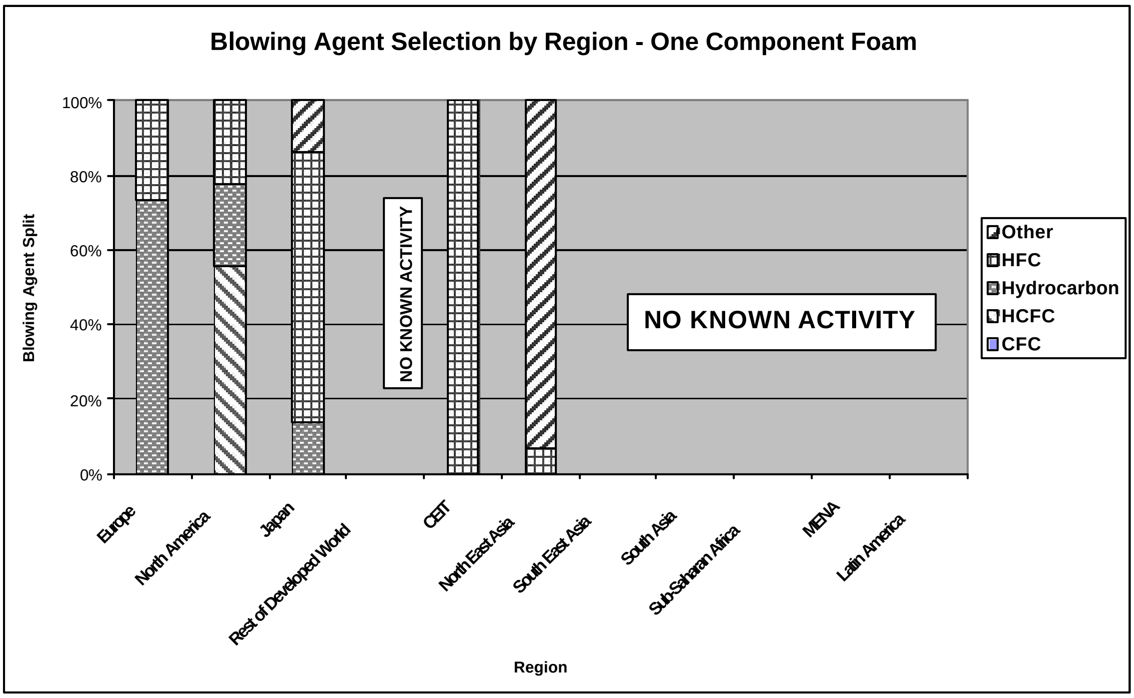
Legislative pressures against HFCs will limit their use in Europe. One the wider scale, the most cost effective blends are likely to gain market share.

Data Summary

The current global distribution of blowing agent use in the One Component Foam sector is shown below:



The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

Although the composition of OCFs in the North East Asian region stands out as unusual, it needs to be recognised that most gaseous propellants/blowing agents can be used in this application. In addition, the volume of OCFs produced in China is generally low, as indicated in the preceding graph.

PIPES

Current Technology

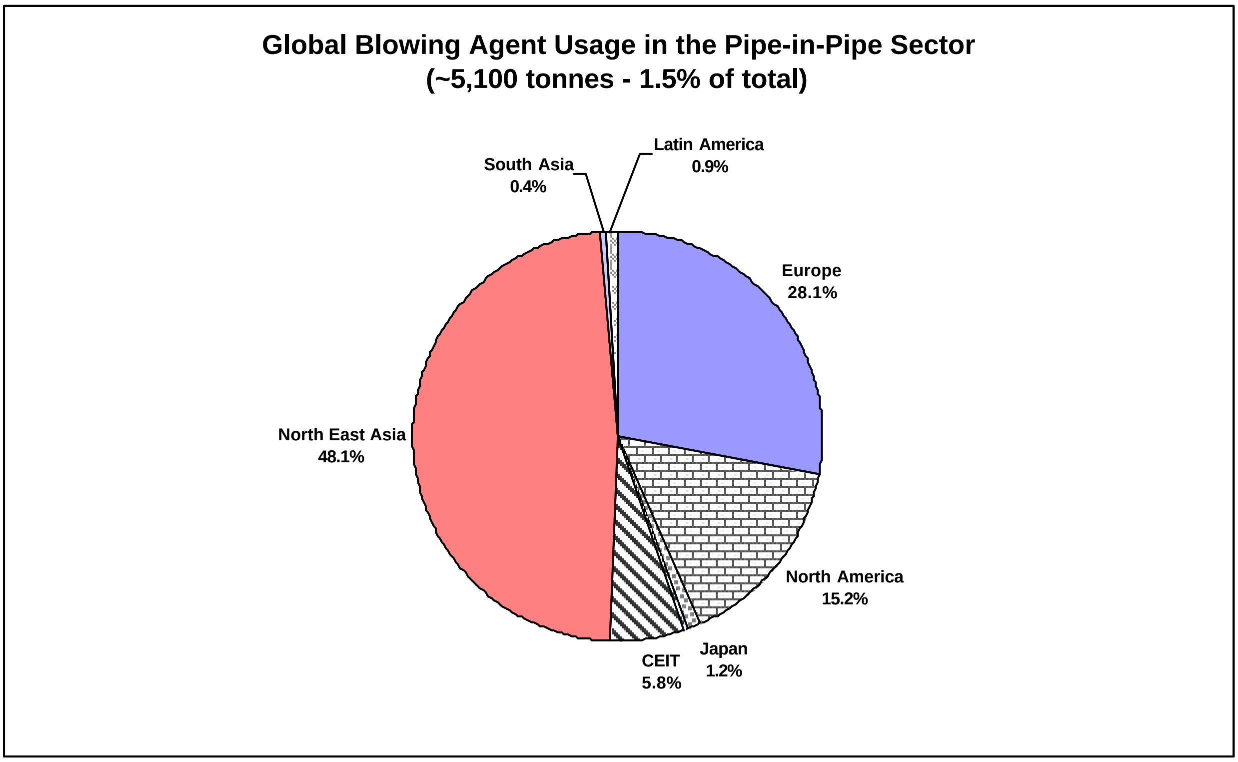
The main blowing agents in use are HCFC-141b, cyclo-pentane and CO_2 (water). In Europe cyclo-pentane is an industry standard.

Future Technology Trends

The replacement of HCFC-141b could be by cyclo-pentane or by HFC-245fa or HFC-365mfc.

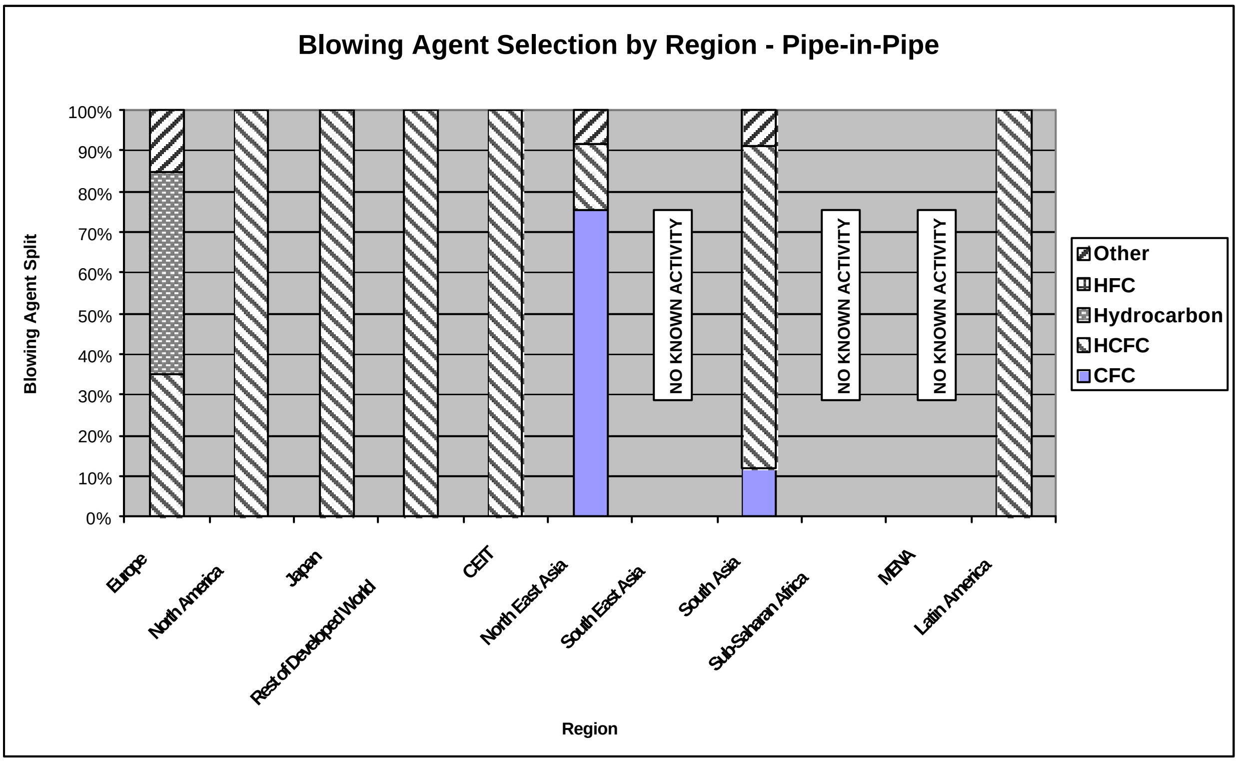
Data Summary

The current global distribution of blowing agent use in the pipe-in-pipe sector is shown below:



It can be seen that the utilisation of district heating in the centralised Chinese system has a major effect on the overall blowing agent consumption in this sector. Indeed, as shown below, the phase-out of CFCs in this application was still not fully implemented by 2001, leaving a considerable on-going usage.

A summary of the transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

The anticipated technology in the North East Asian market will be predominantly HCFC-141b, although some consideration may also be given to hydrocarbons as the technology in Europe matures.

BLOCKS

Current Technology

CFC-11 is still in use by some smaller developing countries enterprises.

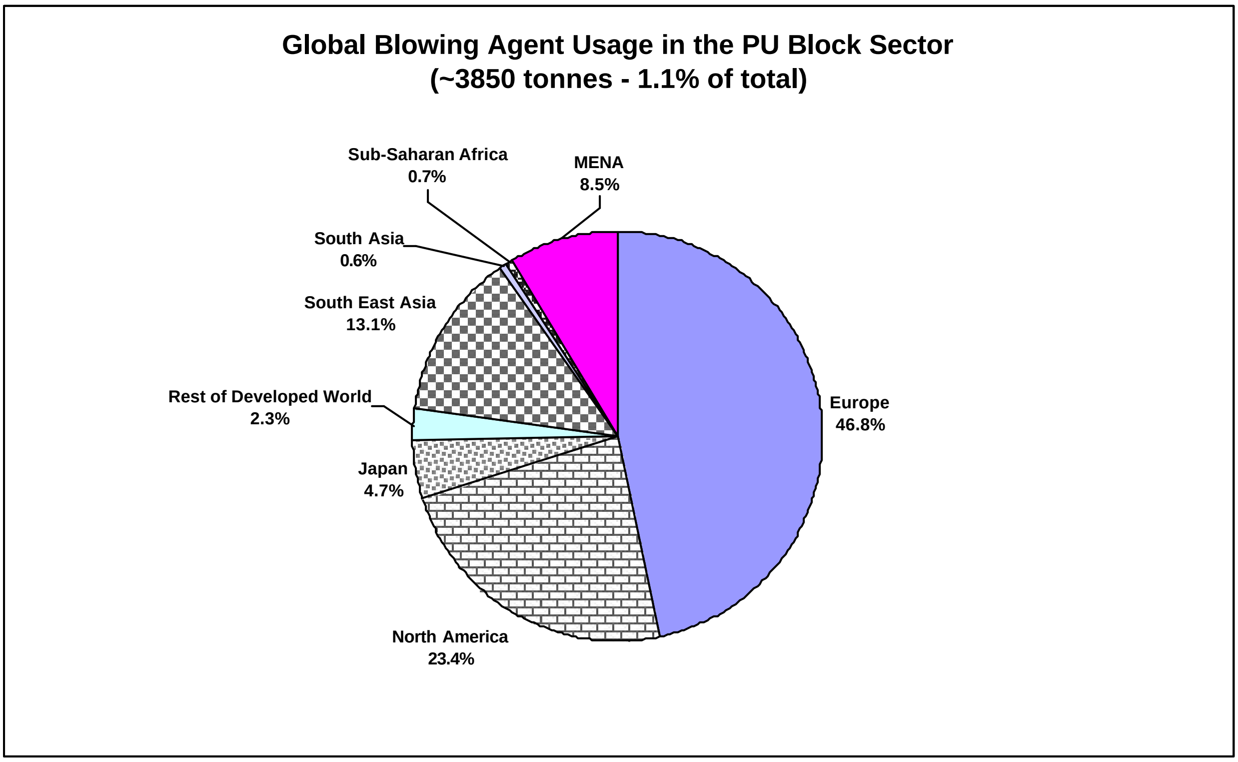
The main blowing agent in use is HCFC-141b and there is minor use of pentane and CO_2 (water). Several European enterprises are converting to pentane which can only be used after process development to ensure safe operation despite the propensity for high temperature exotherms being generated in this application. Similarly, use of CO_2 (water) also has the penalty of difficult processing because of the high exotherm temperature.

Future Technology Trends

Both HFC-245fa and HFC-365mfc have been evaluated for this sector and process well and give acceptable foam properties. Their use is likely to develop together, in Europe, with the wider scale use of pentane.

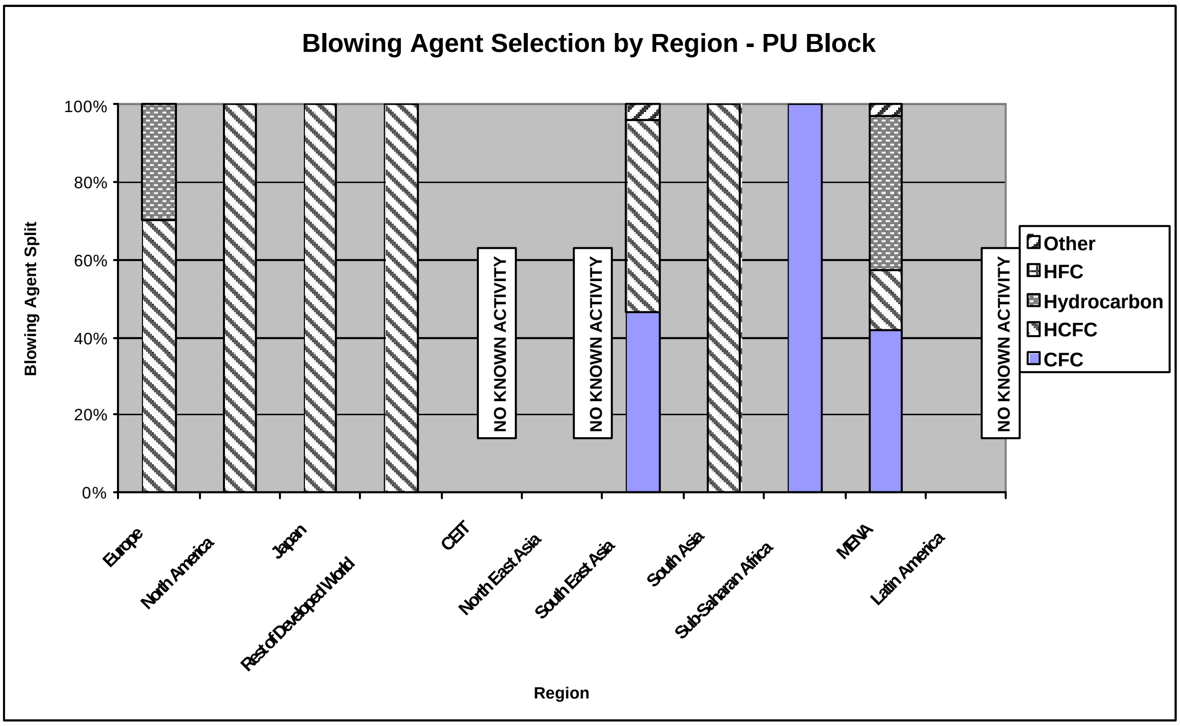
Data Summary

The current global distribution of blowing agent use in the PU Block Foam sector is shown below:



The differences in development of the PU block foam market in Europe and North America is interesting, bearing in mind that both insulation markets are roughly the same size. This seems to relate to the dominance of the mineral fibre lobby in the pipe insulation sector of the North American market. It can be seen that the versatility of process and relatively low investments costs has allowed it to get a foothold in most regions of the world to a greater or lesser degree.

The transitional status for each of these regions and choice of technologies is shown in the following graph:



Additional Regional Observations

There are some surprising omissions in the regions although we have recorded these under the heading ‘no known activity’, they could equally read as ‘no data available’. The Technical Options Committee will continue to research these regions and will hope to provide clearer picture in its 2004 Update.

FLEXIBLE POLYURETHANE FOAM

SLABSTOCK

Current Technology

The remaining use of CFCs in flexible PU slabstock is becoming more limited and technically there is no justification for its use. The numerous replacement technologies cover all applications but processing is sometimes more challenging and in some cases more expensive. This is specifically the case for low density/high hardness foams where the high process temperature (“exotherm”) limits the effectiveness of current replacement technologies.

The most widely applied technology is methylene chloride. However, the use of this substance is increasingly limited through regulatory restrictions and is therefore itself subject to replacement. Other significant current replacement technologies are liquid carbon dioxide, variable pressure technology and acetone. On a smaller scale, special additives are used—frequently as co-technology to limit the amount of methylene chloride required. There is also very limited use of n-pentane, formic acid and MDI based foams—the latter generally for speciality products. Forced cooling, a previously popular technology in the USA has virtually disappeared because of perceived increased emissions of TDI and fire risk. There is no use of HCFCs in this sector.

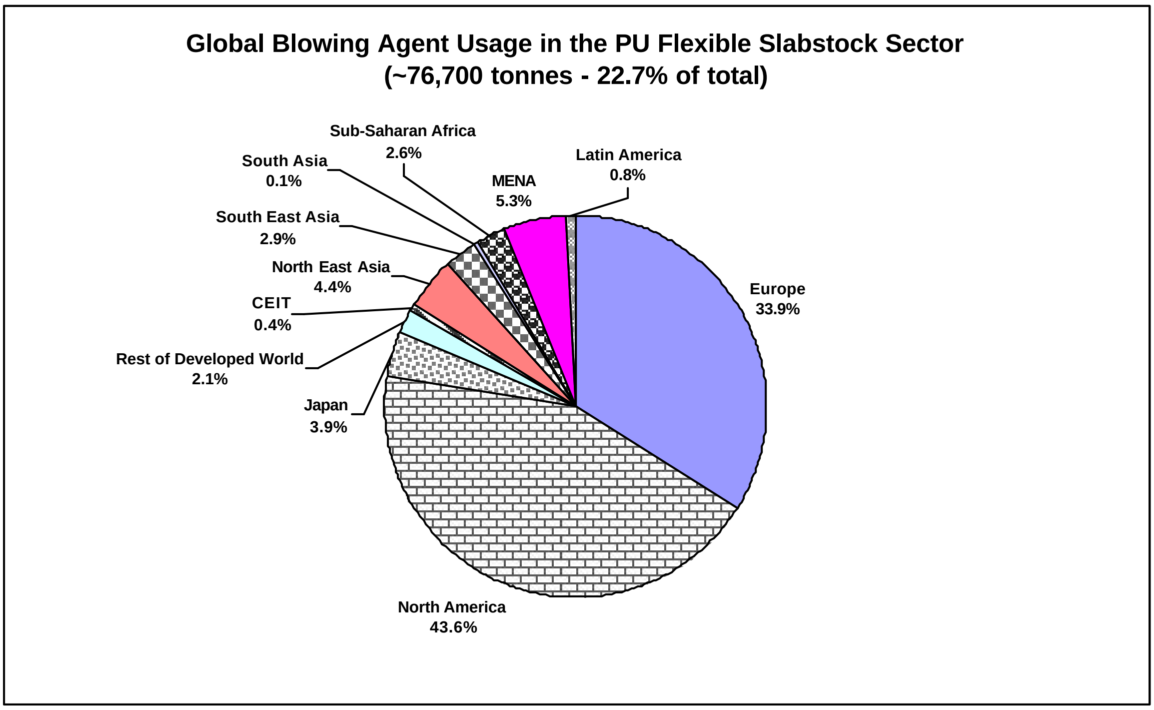
Future Technology Trends

Flexible foams are open-celled foams. This implies that all blowing agent will be emitted in over a rather short period (>90% within 24 hours). The acceptability of process emissions is therefore a critical factor. Organic vapour emissions are increasingly restricted and it can therefore be predicted that the application of organic blowing agents will be more and more limited. This will lead to more emphasis on technologies that can limit or avoid the use of these chemicals. The application of existing industrialized technologies such as variable pressure, liquid carbon dioxide and special additives will therefore grow over-proportionally. The demise of organic blowing agents will be gradual and most pronounced in industrialized countries. Because of their relative ease in processing and cost-effectiveness, they may continue to be used to the allowable limit as a co-blowing agent.

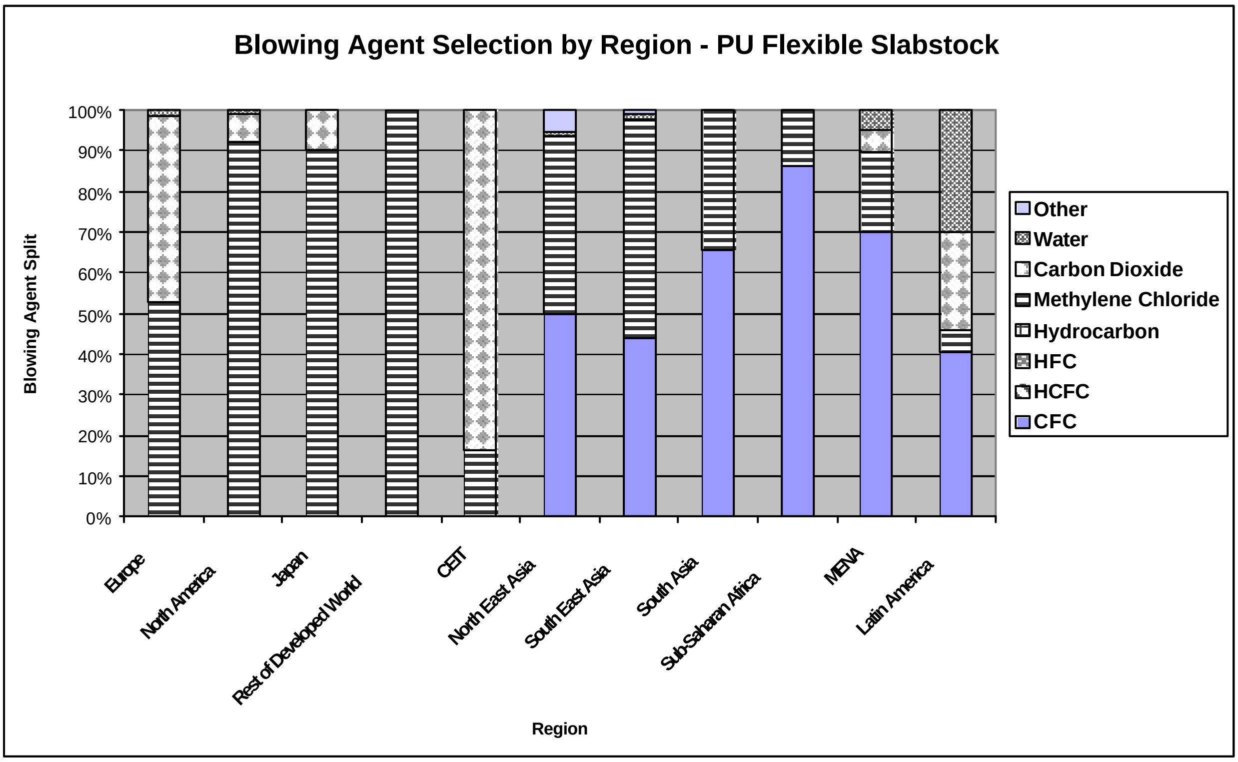
Of special interest is the recent emergence of the so-called Exotherm Management Technology (EMT), allowing for all-water based foams at acceptable process temperatures. Because the technology combines cost-effectiveness with low conversion costs and is most easily applied in boxfoam applications, it is the most potent "third generation" technology.

Data Summary

The current global distribution of flexible slabstock foam production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

The use of replacement technologies other than methylene chloride in developing countries may be overstated. While many enterprises have installed LCD technology (CO_2 (LCD)) and some variable pressure technology, the actual use may be far less. The use of these technologies is technically challenging and many enterprises use methylene chloride alongside.

Boxfoam production is more pronounced in developing countries. LCD technology cannot be used for this type of production and variable pressure requires a large investment. EMT will therefore be for many SMEs the only recourse if methylene chloride were to be disallowed.

MOULDED

Current Technology

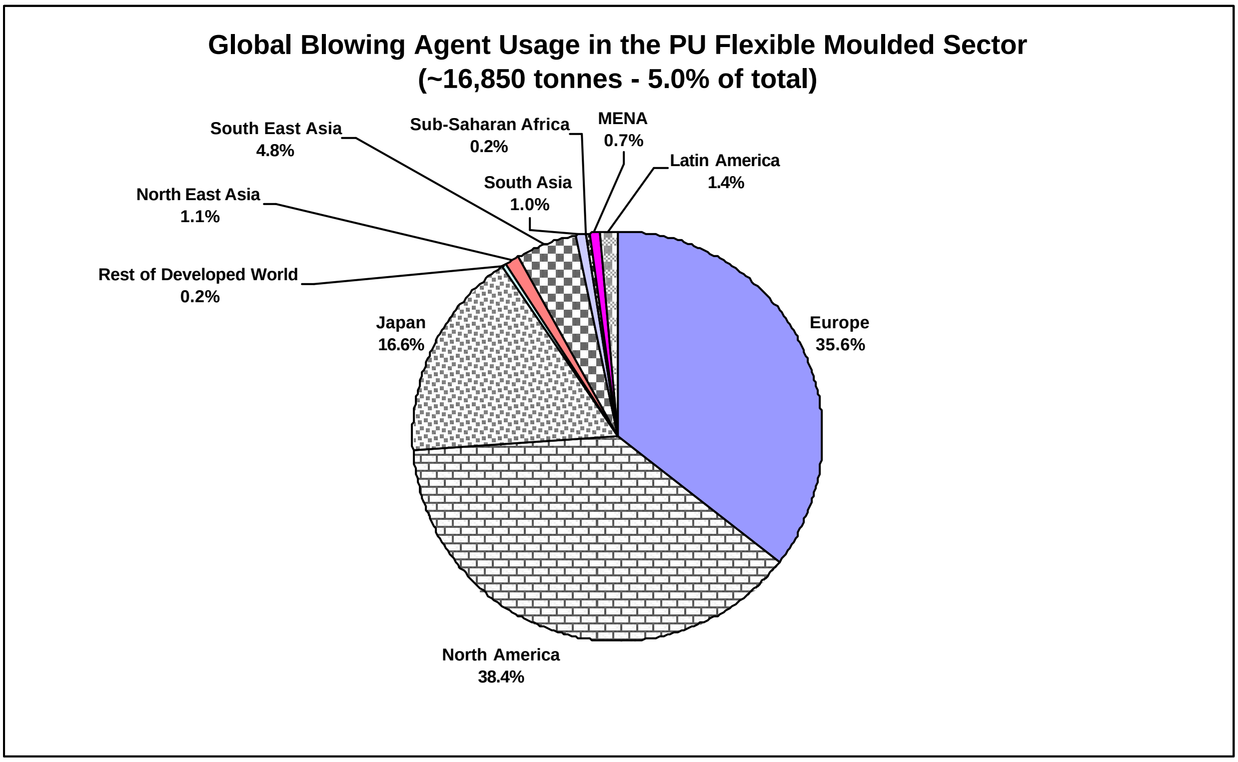
All-water-based technology is predominant in cold cured foams. In hot-cure applications there is also use of methylene chloride. In very low density/soft foams (e.g pillows) there is some use of LCD or GCD but generally, this technology did not get the same attention as in slabstock applications—most likely because there is no exotherm problem and water-based technology performs well in most cases. In developing countries there is still some use of CFC-11—often by adding to industrially available all-water-based systems to decrease densities. HCFC-141b is used in exceptional circumstances such as highly filled acoustical foams but is not essential as replacement in this industry. The use of HCFCs in this industry is not allowed in most industrialized countries.

Future Technology Trends

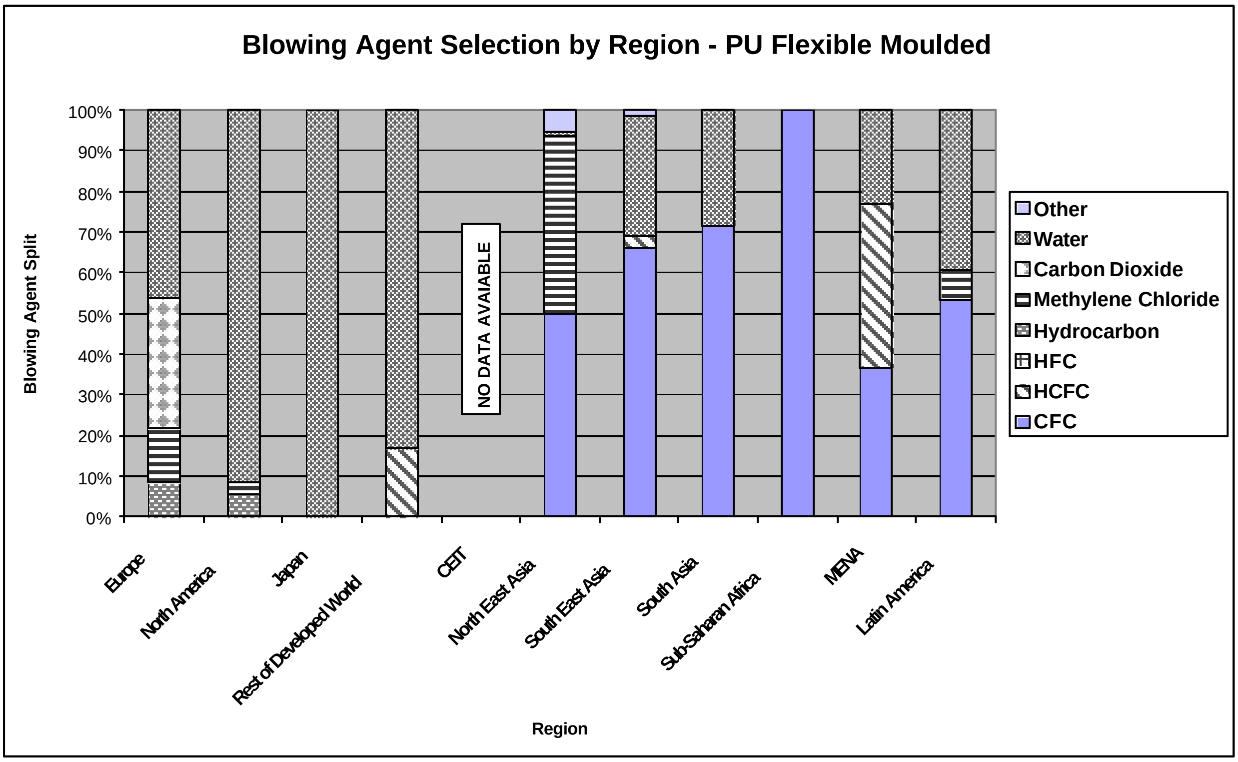
There are no significant technology trends in this industry related to blowing technology. The remaining CFC and HCFC use can be phased out without any technical challenges, without major investments, but with a cost penalty for low density applications.

Data Summary

The current global distribution of flexible moulded foam production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

As mentioned, the remaining CFC use is related to low density or highly filled applications in developing countries. The conversion to CFC/HCFC-free systems may carry a density penalty or require the use of foams with a high TDI content. These systems would require strict control of workplace emissions.

INTEGRAL SKIN AND MISCELLANEOUS FOAMS

This sector includes both rigid and flexible integral skin applications and also non-insulating rigid foam applications for packaging, leisure (e.g. surf boards), floatation and floral foams.

Integral Skin

Current Technology

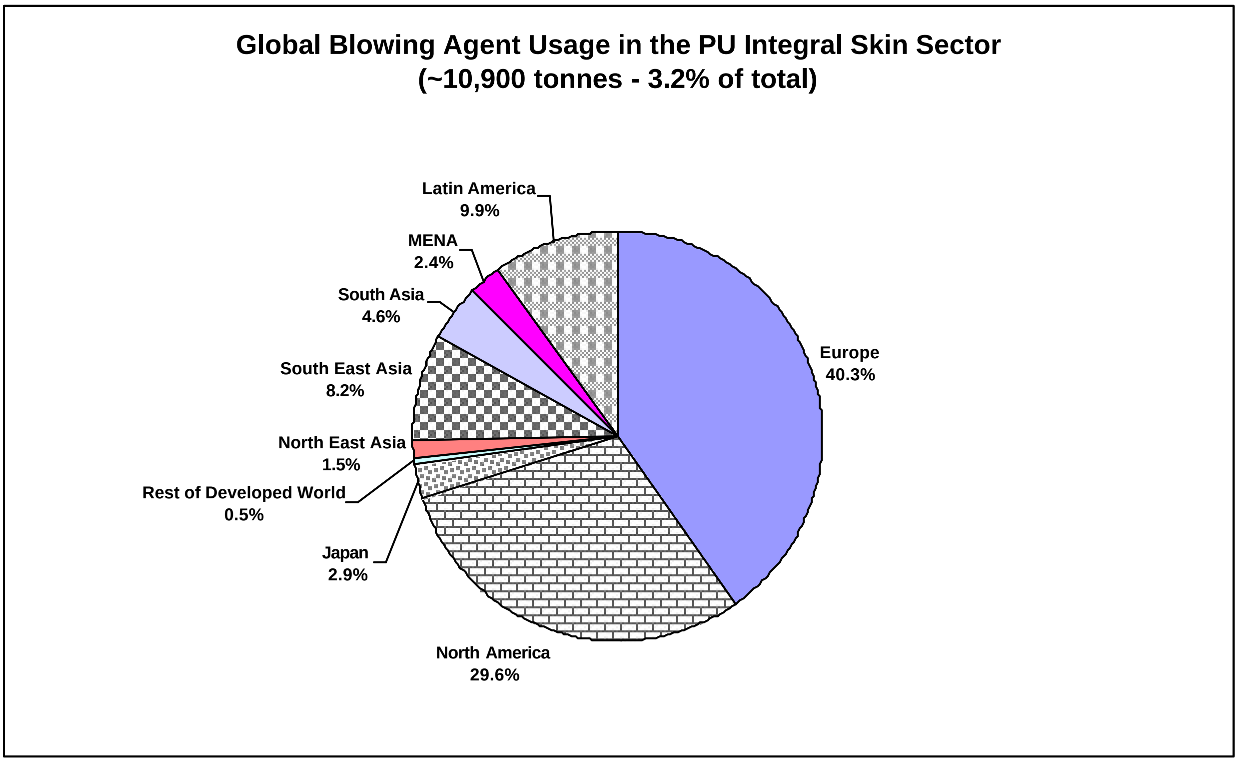
Zero ODP technologies have been developed for every application. While rigid foams have almost universally converted to all-water-based systems—sometimes in a two-step process—this has not been the case in flexible and semi-rigid foams. The related cost penalty related to sometimes significantly increased densities made the use of pentane and HFC-134a technology attractive in industrialized countries and caused continuous use of CFC-11 and conversion to HCFC-141b in developing countries. Other issues are availability in developing countries and acceptable physical properties such as abrasiveness and skin development. One of the drivers in the technological development was early legislation in the USA and the EU, which prohibited the use of HCFCs in all non-thermal insulation applications (except, initially, in safety related automotive products).

Future Technology Trends

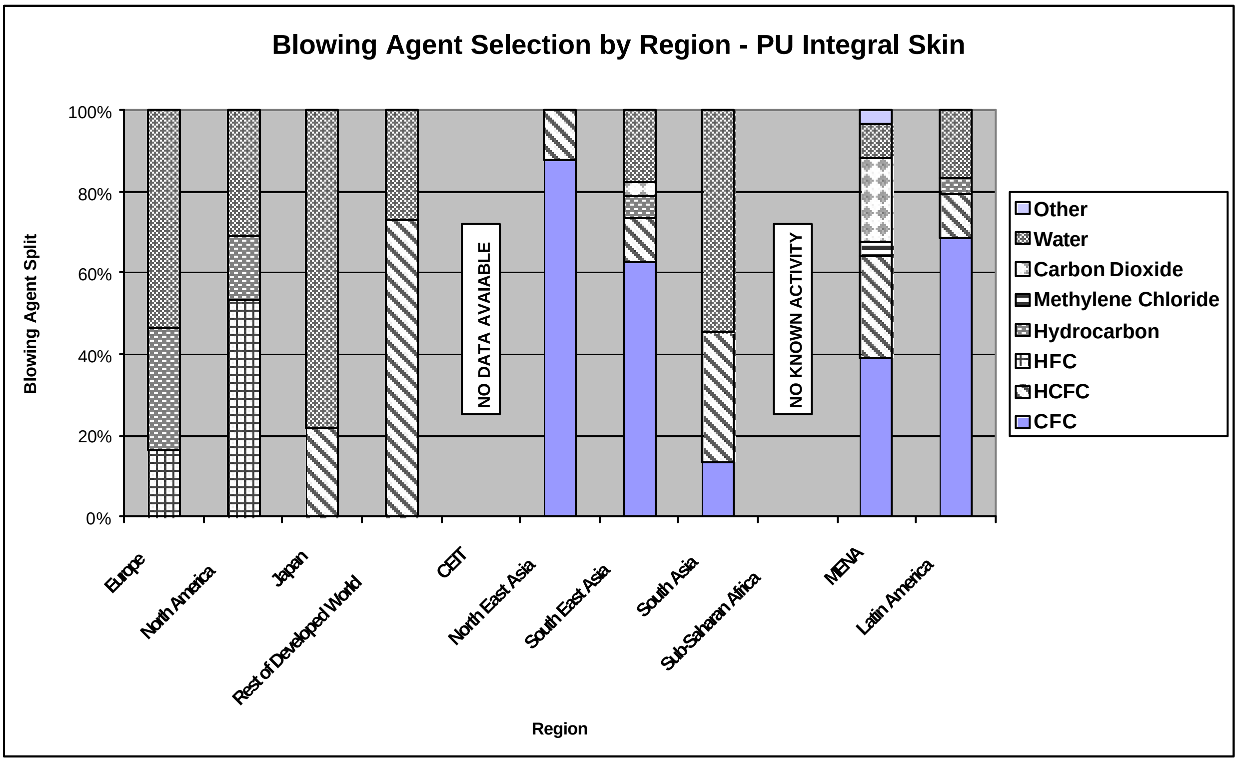
As water-based systems improve in performance, it is expected that its use will increase. In those cases where water-based systems do not perform, there will be continued use of hydrocarbons and HFCs. It is expected that liquid HFCs—HFC-245fa and HFC365mfc/227ea—will also emerge as suitable technologies for high performance applications.

Data Summary

The current global distribution of PU Integral Skin foam production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

Because of the relatively small market for integral skin foam products and the wide variety of technical requirements the development of suitable non-ODS alternatives in this sector has been a low priority for chemical suppliers. This is specifically the case for developing countries where densities in general are lower and technologies that are acceptable in industrialized countries do not always perform. The introduction of adequate—cost-effective and technically acceptable—non-ODS technologies in these countries is a concern. While future introduction of liquid HFCs will allow the entire range of technical requirements, the related costs may be prohibitive and the availability a concern.

POLYOLEFIN FOAMS

There are three prime product types in the polyethylene foam sector: sheet, plank and tubular. All of these have used CFCs in the past. This is in contrast to cross-linked polyethylene foams which are produced for specialist applications and have typically been blown with inert gases such as nitrogen. The transition issues facing sheet, plank and tubular products are broadly similar and these are therefore considered together in the review.

Current Technology

With the use of HCFCs phase-out in several non-Article 5(1) countries as early as 2000, the primary technologies currently in use are based on various hydrocarbons. However, there is some use of HFCs, particularly in the major market of Japan.

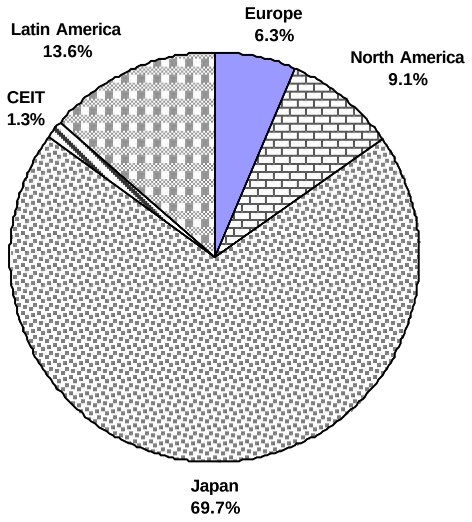
Future Technology Trends

Hydrocarbons are expected to remain long-term substitutes in this sector, unless their use contributes to, as yet, unforeseen problems with fire performance. In early developments with hydrocarbons there were problems with the entrapment and slow release of hydrocarbons in storage and shipment. However, these were overcome by the use of various perforation techniques.

Data Summary

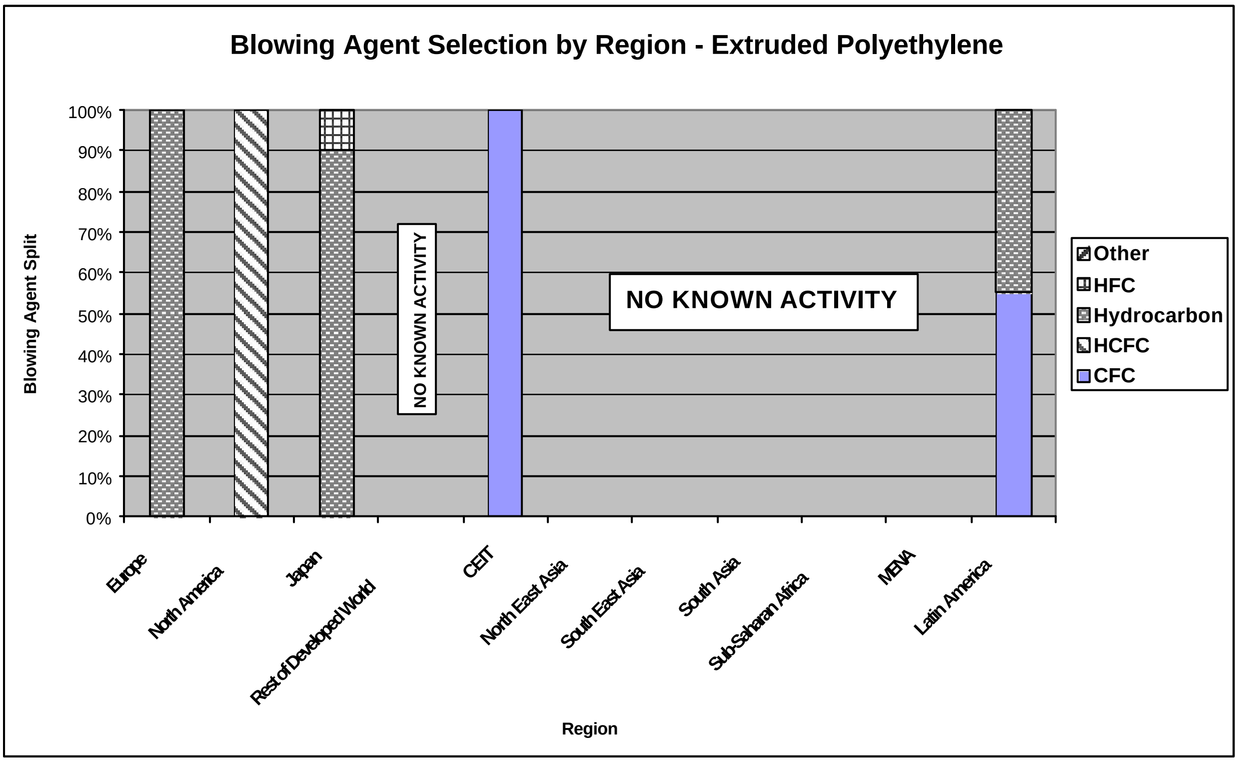
The current global distribution of extruded polyethylene foam production is shown below:

Global Blowing Agent Usage in the Extruded Polyethylene Sector
(~5,275 tonnes - 1.6% of total)



The dominance of the Japanese market in the global consumption of extruded polyethylene came as something of a surprise to Committee members. It may result from the inconsistent consideration of packaging and technical foams across the major global markets. As with previous issues, the TOC will seek to clarify this when it produces its next Update.

The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

It is assumed in this resume that the polyethylene market in the United States of America continues with the use of HCFCs in similar fashion to the XPS sector, bearing in mind that the availability of HCFC-142b and HCFC-22 will continue until 2010 under the current Allocation Rule. However, currently, SNAP limits HCFC use to insulation applications only and future SNAP provisions may lead away from HCFC use altogether prior to the phase-out in availability.

EXTRUDED POLYSTYRENE FOAMS

SHEET

Use of CFCs or HCFCs, is considered technically unnecessary in both Non-Article 5(1) and Article 5(1) Countries and have been banned by a significant number of countries. A wide range of alternative blowing agents have been evaluated for use in polystyrene sheet foam including: atmospheric gases (CO_2 (LCD), nitrogen); hydrocarbons (butane, isobutane, pentane, isopentane), HFCs (HFC-134a, HFC-152a); and hydrocarbon / CO_2 (LCD) blends.

Current Technology

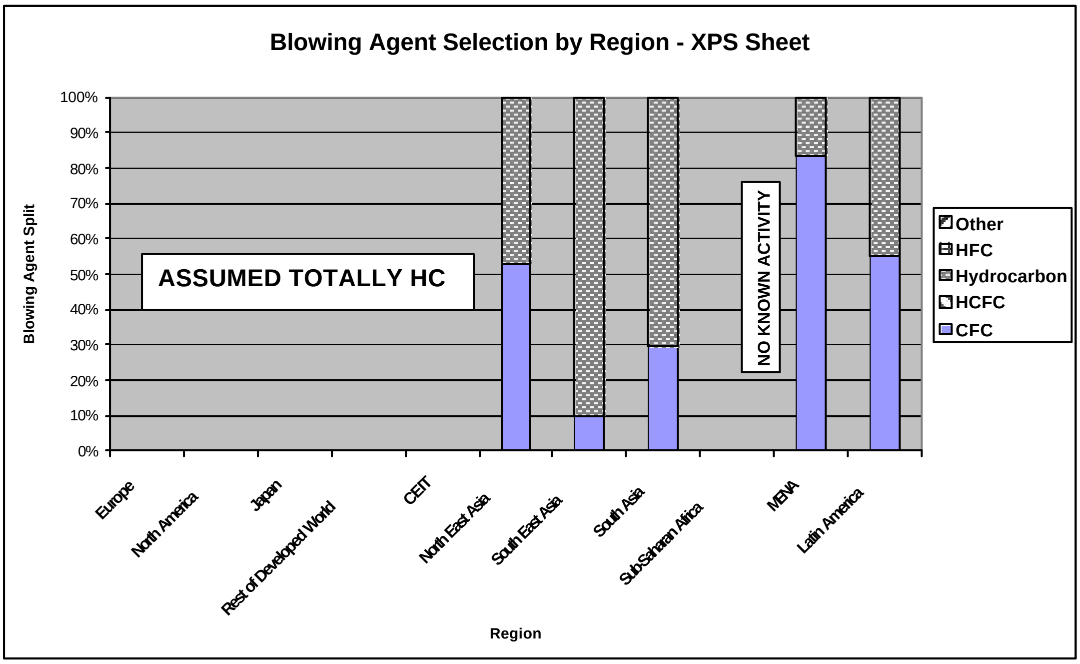
Hydrocarbons (butane, isobutane, pentane, isopentane), HFCs (HFC-134a, HFC-152a); and hydrocarbon / CO_2 (LCD) blends, have found a range of commercial use in roughly that order of volumes used. Capital investments required for handling flammability issues and VOC emissions will be the limiting factor in further expansion of hydrocarbon containing systems.

Future Technology Trends

Few future developments are expected.

Data Summary

A global assessment of blowing agent quantities in use within the XPS sheet market has not been conducted for this sector because of difficulties in collecting information from a very diverse ands diffuse packaging industry. However, an assessment of the transition technologies has been made and is shown below:



Additional Regional Observations

MLF funding must continue to support ultimate conversion to hydrocarbon systems as HFC based processes will prove commercially nonviable over time.

BOARDSTOCK

Current Technology

CFC's have not been a significant factor in this segment since the early 1990's. HCFCs 142b and 22 have found widespread use even in Article 5(1) Countries. Conversion to HFCs 134a and 152a blends occurred as early as 1997 in Sweden, but with severe impact on product and process performance.

The divide between European and North American technologies and markets is becoming increasingly clear as national and European-wide regulations on HCFC phase-out are implemented.

HCFCs have not been used in Europe since January 1, 2002. The conversion in 2002 has been to either CO2 of HFC based systems albeit with significant penalties in production performance capacity (throughput) and process efficiencies. CO_2 and CO_2/alcohol systems have gained market acceptance, except where traditionally heavy focus is put on thermal conductivity performance. Technological limitations on thickness (i.e. currently no greater than 120 mm) still exist either in actual production or in post-production performance vis-à-vis dimensional stability. HFC-134a, in particular, is the alternative blowing agent preferably selected for those markets and applications where high thermal insulation performance is demanded. Its low polymer solubility is offset by blending either with HFC- 152a or an organic solvent.

In North America, the XPS industry has not yet identified a way to transition from HCFCs owing to the particular challenges of the North American market. The market and subsequently the manufacturing processes have evolved around lower density products emphasizing thermal performance over structural. The preponderance of thin (12mm) and wide (1200mm) products for sheathing applications presents severe process constraints which are not present in Europe. In some cases the required fire performance within the existing building codes in use across the USA cannot be met at high densities because of the higher fuel loadings. This prevents the adoption of either of the CO_2 or HFC-134a technologies currently making progress in Europe without significant modification.

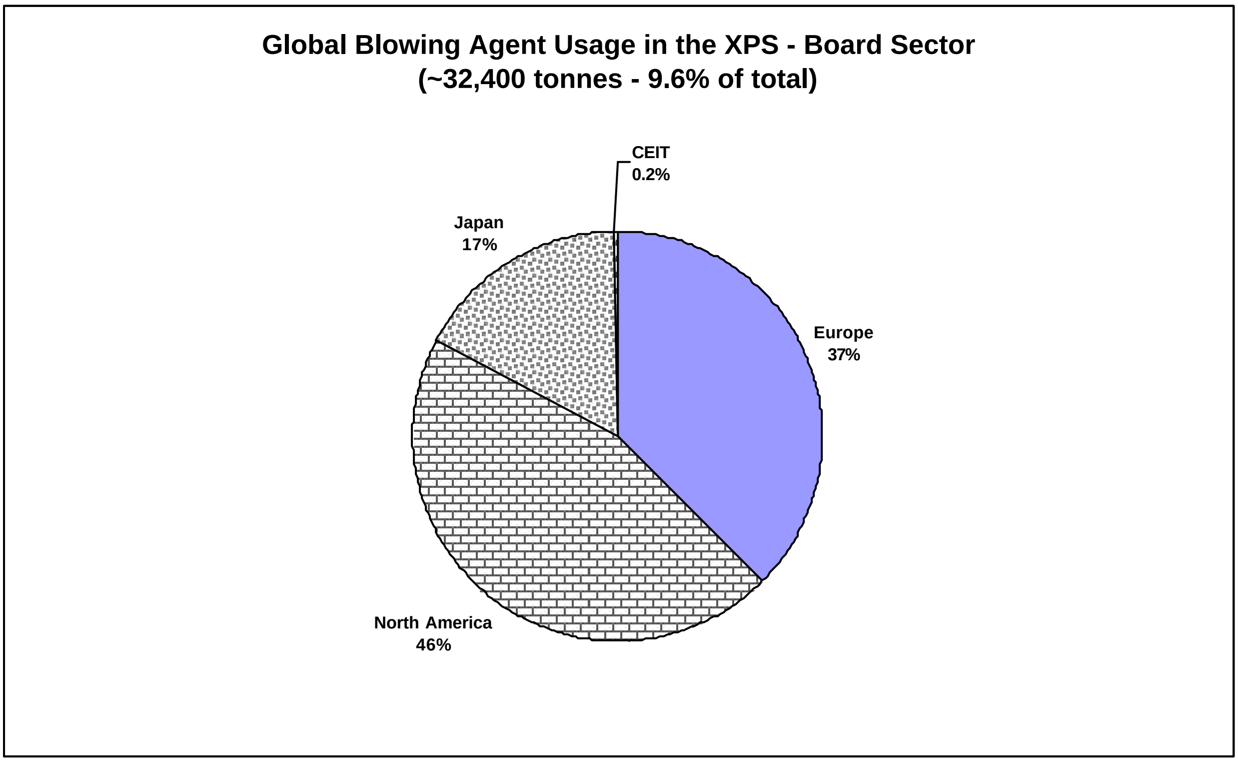
Future Technology Trends

The European Market will likely see a significant rationalization occur in the Industry with only the largest manufacturers able to make the capital investments required to profitably run the non ozone depleting blowing agent systems. CO_2 is clearly the system of economic choice if problems with dimensional stability can be overcome.

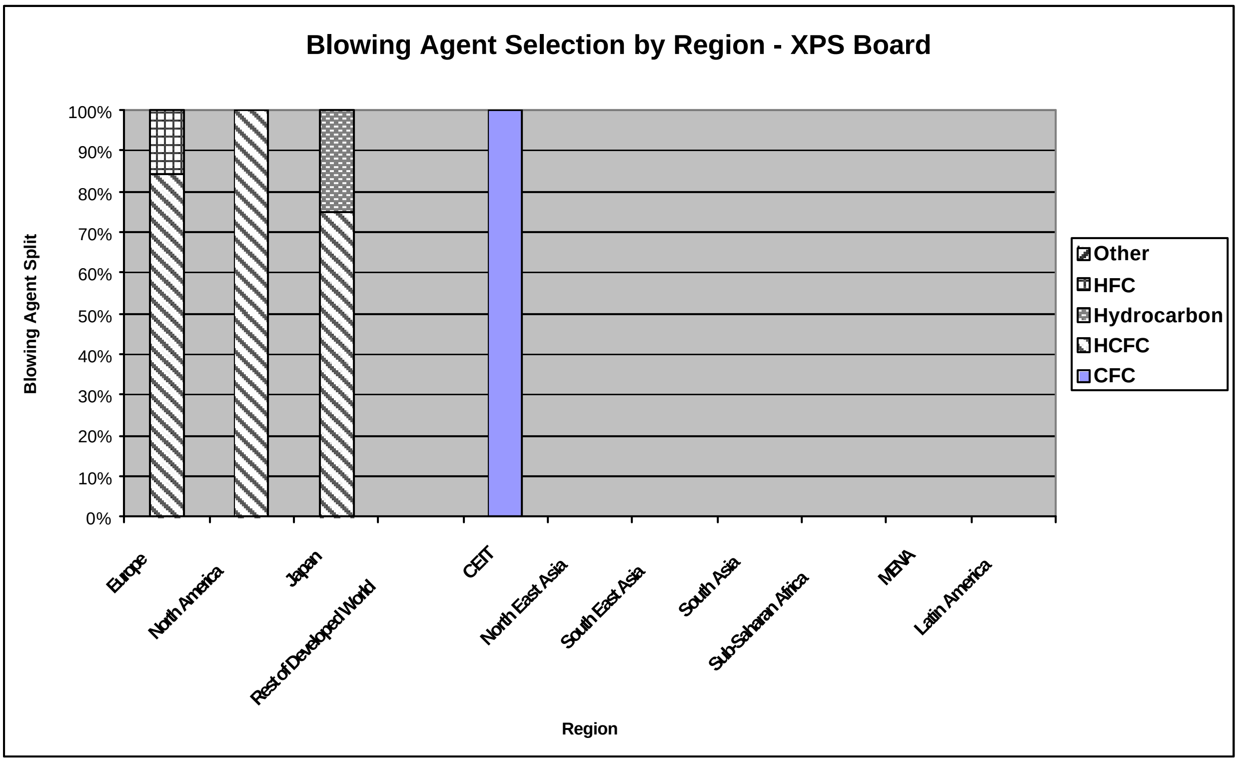
North American manufacturers are devoting significant resources to research and development and will solve the problems associated with HFC use prior to the 2010 phase-out currently imposed by the USEPA.. It is less clear that CO2 systems will ever be viable in the North American markets due to the significant loss in thermal performance. Without a breakthrough in the manufacturing costs associated with HFCs, the use of XPS boardstock will increasingly be restricted to niche markets which put a premium on the combination, of high moisture resistance, high thermal efficiency, and dimensional stability.

Data Summary

The current global distribution of extruded polystyrene boardstock foam production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

As can be seen, in Japan there is some hydrocarbon use in XPS. Typically a mixture of n-butane and iso-butane is used in conjunction with methyl chloride or ethyl chloride to produce a Grade 1 product, albeit with relatively poor insulating properties. While this may suggest that the hydrocarbon diffuses out of the foam before use, there is evidence that iso-butane has slower permeation rates than n-butane. Nonetheless, even when hydrocarbon is retained, it has a higher gas thermal conductivity than fluorocarbon alternatives. However, more recently, one manufacturer has announced that it will be able to make a Grade 3 product with a thermal conductivity of lower than 0.028 W/mK. This is made with pure iso-butane and relies on maximum retention of the blowing agent and specific cell structure for its performance. Although this immediately raises concerns over the release of blowing agent in a fire as the thermoplastic melts, the producer claims that the use of a novel fire retardant system suppresses any ignition process. The ultimate resolution of these concerns can, of course, only be gained from the successful commercialization of these systems.

PHENOLIC FOAMS

BOARDSTOCK

Current Technology

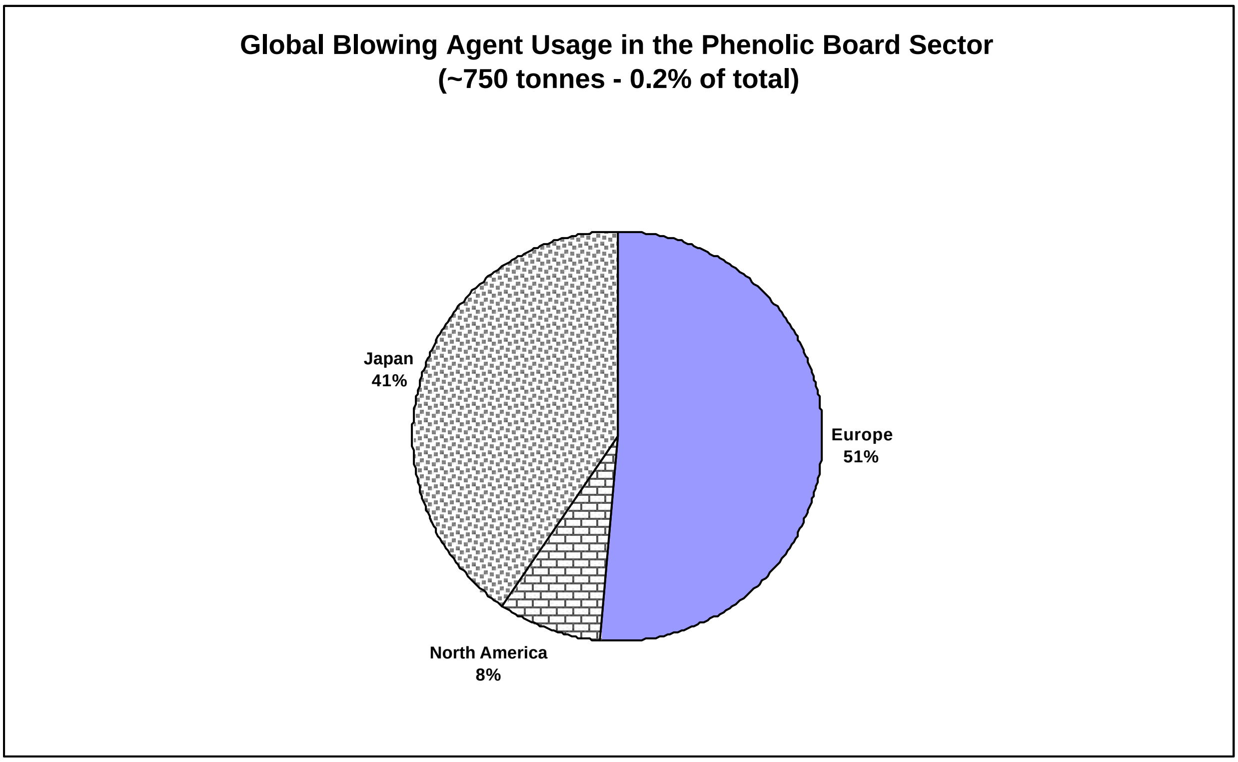
In the main global phenolic foam markets, the primary blowing agent remains HCFC-141b, although progress is being made with hydrocarbons in some regions (e.g. Japan). There is also preliminary use of HCFC-365mfc/HFC-227ea in Europe. One European producer continues to use 2-chloropropane for its production.

Future Technology Trends

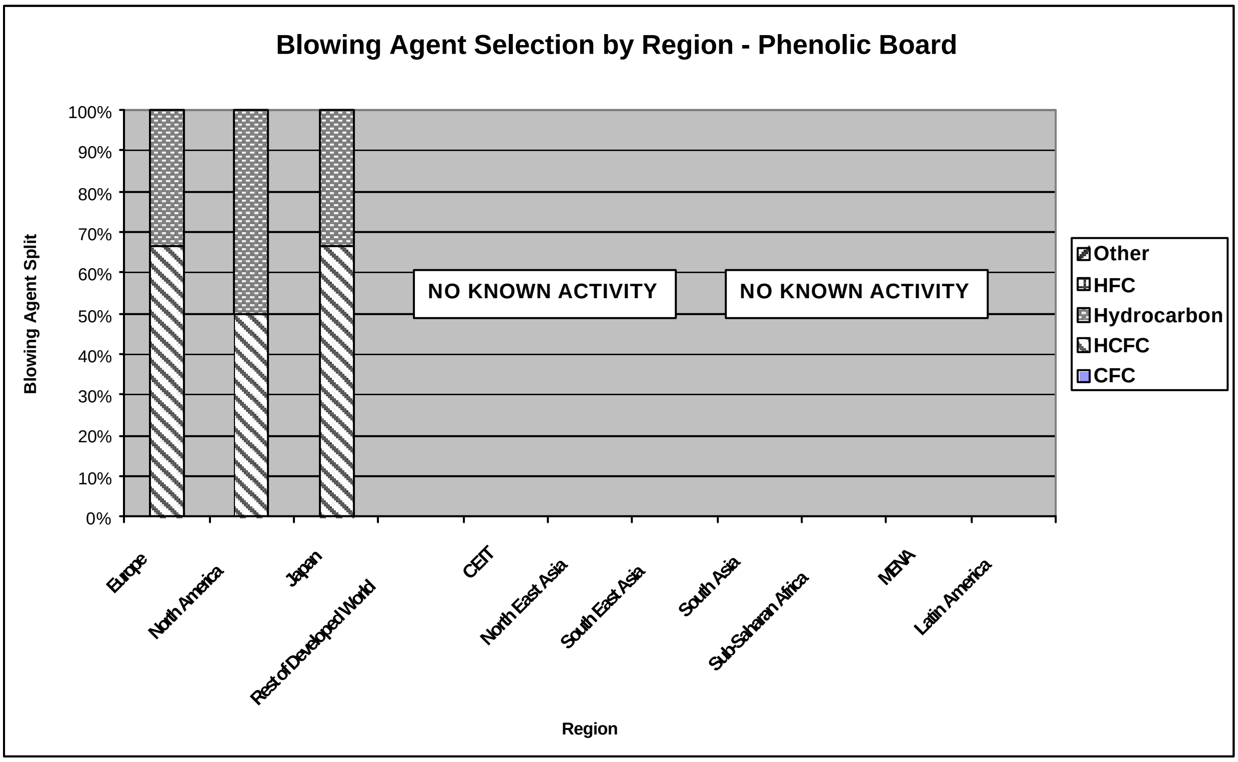
The key decision to be made for most producers is whether the fire properties of phenolic foams can be retained when using hydrocarbons. This decision rests mostly with the fire standards and classifications being adopted in the various regions of the world. Blends of HFCs and hydrocarbons may emerge as a key substitute for HCFCs when the time comes.

Data Summary

The current global distribution of phenolic boardstock production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

The production of phenolic foam board is concentrated in the main non-Article 5(1) markets and is unlikely to develop a wider regional spread in the short-term because of the significant investments required to control the process technically.

PIPES AND BLOCKS

Current Technology

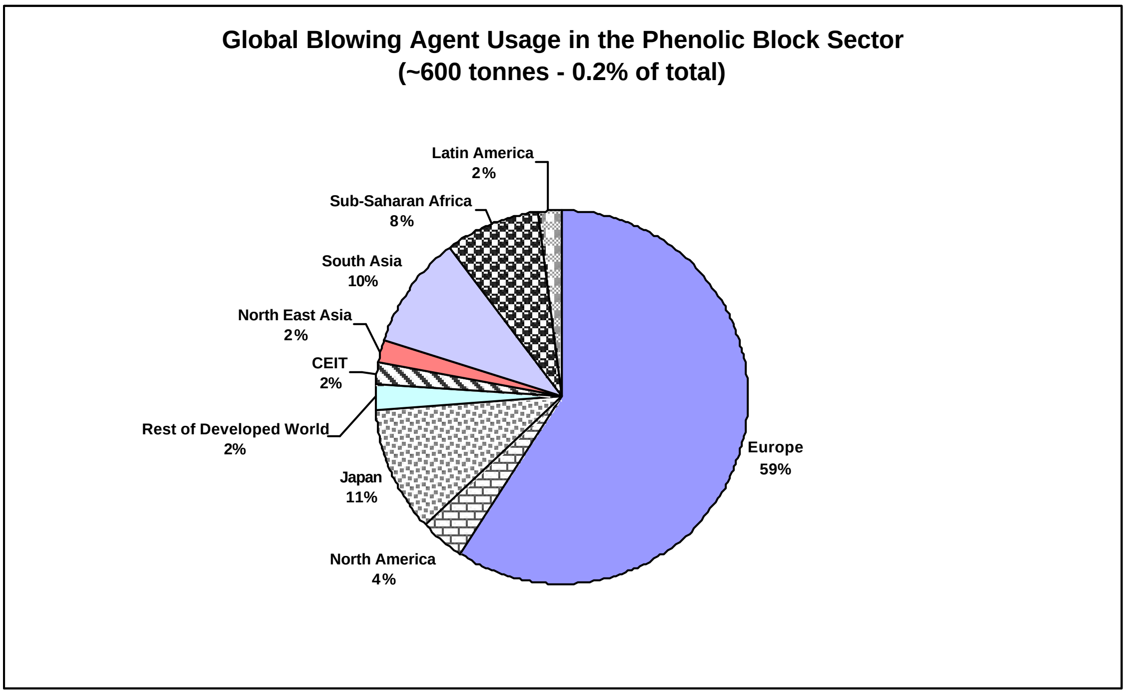
As with phenolic boardstock, the main current blowing agent is HCFC-141b. Bearing in mind that the block process is discontinuous and therefore more difficult to flame-proof satisfactorily, it is less likely that hydrocarbons will play a significant role in this sector.

Future Technology Trends

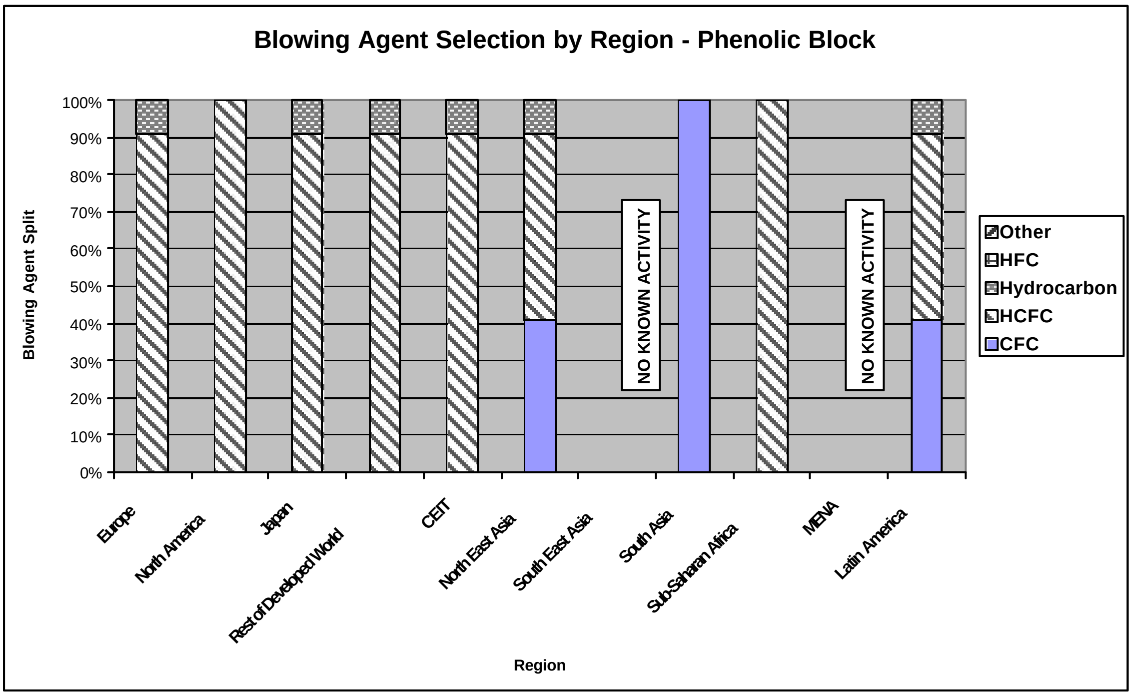
The main blowing agent option for block foams is expected to be HCFC-365mfc/HFC-227ea or possibly other combinations utilising HFC-245fa. Blends of any of the above with hydrocarbons may also emerge if flashpoints can be controlled satisfactorily.

Data Summary

The current global distribution of phenolic block foam production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

As with other discontinuous block foam processes, it can be seen that the genuine versatility of the technique and its relatively low investment cost has caused fairly widespread uptake of the technology. However, with a further blowing agent transition pending, there may be some rationalisation.

PANELS

Current Technology

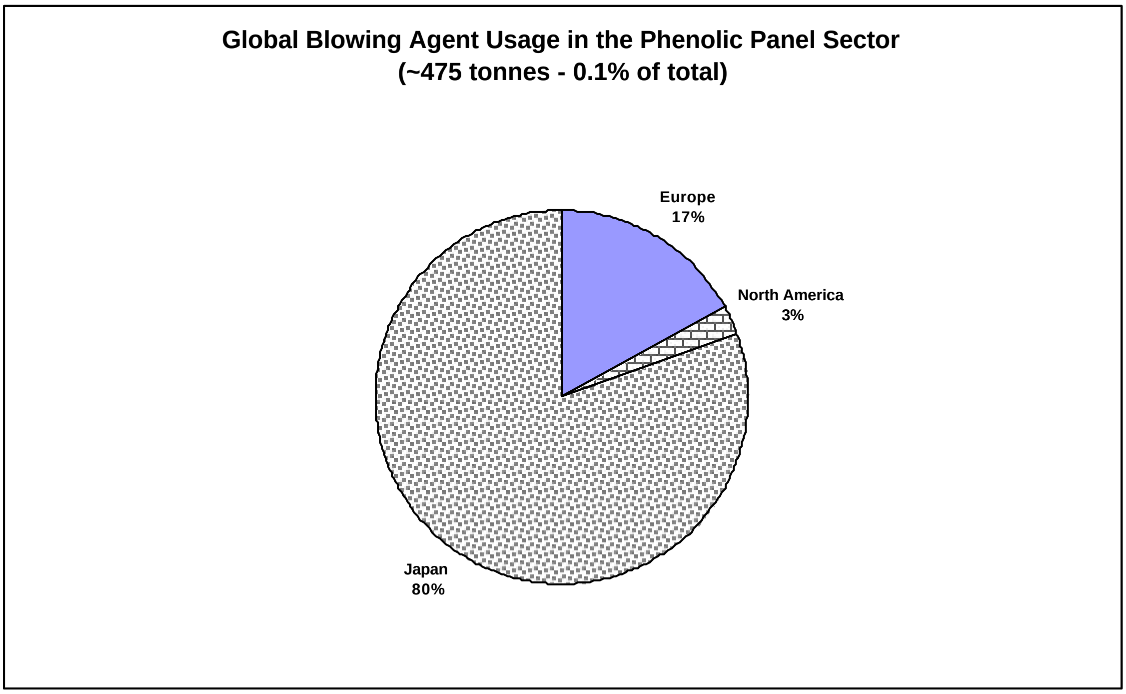
This is an emerging market in Europe, primarily for cold storage facilities. In Japan, however, phenolic foam panels have been produced as office partitioning for some years. Currently, the primary blowing agent is HCFC-141b.

Future Technology Trends

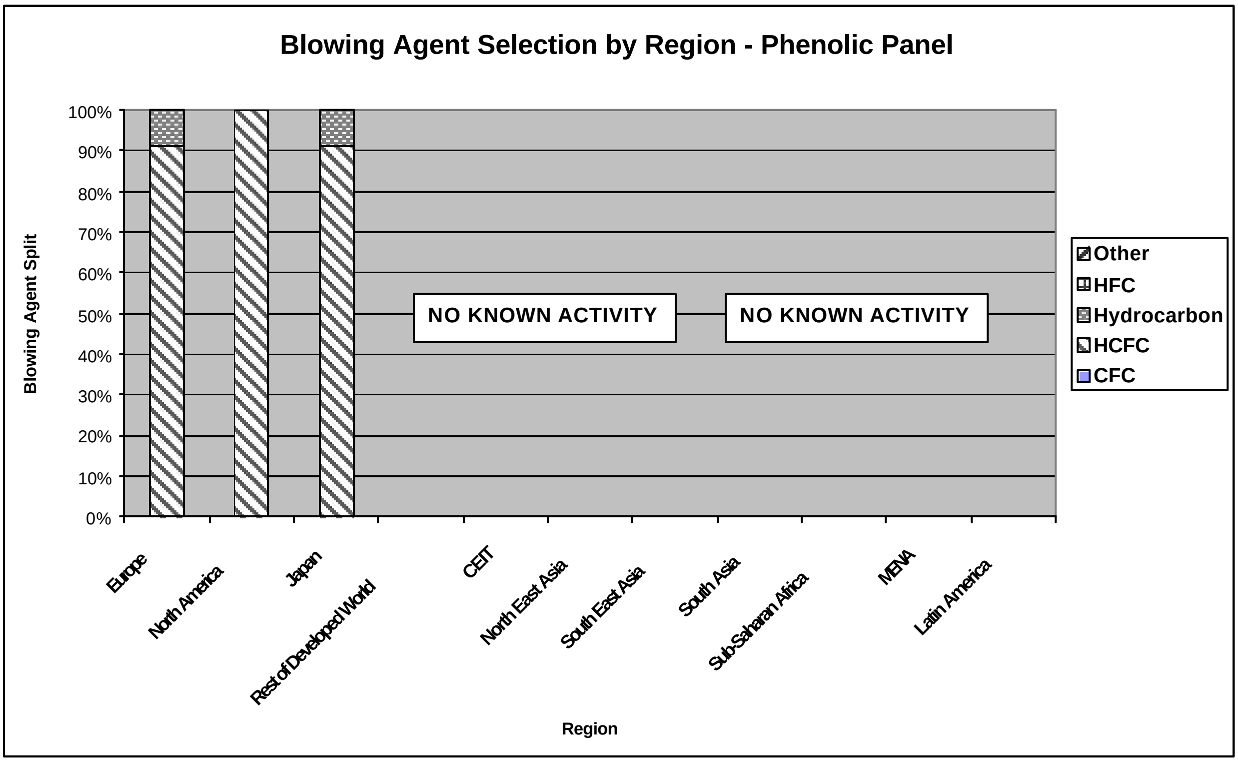
With regulatory requirements forcing a transition in Europe by 2004, the main replacement, as with the other phenolic foam sectors, is expected to be HFCs or HFC/hydrocarbon blends. The fire requirements of the cold store panel market are expected to eliminate the possibility of using hydrocarbons as a sole blowing agent.

Data Summary

The current global distribution of phenolic foam panel production is shown below:



The transitional status and choice of technologies is shown in the following graph.



Additional Regional Observations

The fact that panel production technology is based on a discontinuous process may lead to the more widespread production of phenolic panels in future. Should this occur, there is likely to be an increased burden on HFC requirements in the regions affected.

CHAPTER 2: ISSUES AFFECTING TRANSITION

Progress in the phase-out of ODS usage in the foam sector has been hampered by a variety of both process and product-related factors. Some of the product-related factors, have been particularly problematic since issues such as building code revision and fire standard development are usually slow processes and unlikely to be hurried by single issues such as ODS phase-out.

This section provides a review of the factors influencing phase-out in both Article 5(1) and non-Article 5(1) countries. Interestingly, it has been found that there are often common barriers in both environments, many of which are focused around the particular constraints of small & medium sized enterprises (SMEs). Ironically, the SME-related factors can be more severe in non-Article 5(1) countries than in their Article 5(1) counterparts, where support funding is available through the Multilateral Fund. A selection of examples of common barriers and SME-specific issues is shown below. The drivers behind these issues are explored in more detail in subsequent paragraphs.

- *Common Barriers*

- Expanding the technical acceptability of hydrocarbons, for example, in fire tests (e.g. FM 4450) and in processing (particularly discontinuous processes)
- There is a need for HFC-blown foams to be fully characterised to confirm that they meet stringent fire codes such as LPC 1181
- In the United States, and elsewhere, there is uncertainty about the potential of import/export of HCFC-containing polyol pre-blends and finished articles that would fall outside of any phase-out regulation and destabilise markets
- Uncertainty about precise phase-out regimes at regional and country level and the effects of these regimes on the availability of favoured blowing agent choices

- *SME Issues*

- There is a need to avoid the cost of multiple transitions. In the EU and other European countries there is uncertainty about regulatory acceptance/early phaseout of HFCs
- There is a need to make cost-effective technology selections. Uncertainty continues regarding optimum HFC technology/operating costs per sector. Time is required to define these and to seek certification
- There is a need to ensure local availability of blowing agent. Producers have clarified the availability of the "new" HFCs and systems houses have to clarify the availability of systems based on them. This includes delivery to all regions and includes SMEs
- There is a need to minimise capital investment. The use of HCs in SMEs limited by conversion economics and is likely to result in other non-ODS technologies such as HFCs

COMMON BARRIERS

Although regulatory phase-out mechanisms have been in-place for many years in some regions, the reality of achieving phase-out requires the coincidence of four key factors:

- The availability of suitable technology
- The potential for cost-effective transition and on-going use of the technology
- Market acceptance of the technology and products manufactured by it
- A ‘level playing field’ for all suppliers to the market

Experience has shown that regulation alone does not ensure any of the above and that appropriate motivation to innovate needs to be present. This usually arises from the long-term need to satisfy market requirements and this will often be sufficient to support substantial investment (e.g. in the appliance sector). However, other markets may be much less secure and may not have the critical mass to support significant investment. This is often the case in specialist, niche applications or in markets where there is strong competitive pressure and price sensitivity is a major component.

Where barriers are significant it will be inevitable that the final on-set of regulation will force a change, but this may drive certain segments or manufacturers from commercial practice to the detriment of the overall market and/or economy. When lower energy efficiency is the result even global environmental objectives are compromised. This is a ‘balanced call’ and regulators need to be vigilant to ensure that they understand the dynamics of transition in each case, since these can vary dramatically from sub-sector to sub-sector. This is one of the reasons why this report continues to contain a comprehensive description of the sectors (see Appendix 1).

It is interesting that, for the most part, these principles apply as much in non-Article 5(1) countries as in Article 5(1). Indeed, it can be argued that barriers of the type outlined are more acute in the non-Article 5(1) environment, since they are often being tackled for the first time there. A good example of such difficulties lies in the recent experience of the US administration, with the phase-out of HCFC-141b from the PU systems house sector (spray and poured in place foams). In this instance, local constraints on the availability of alternatives have put immense pressure on the transition process, causing the regulators to need to re-consider phase-out strategies and timings.

SME ISSUES

The common barriers outlined above are even more accentuated at SME level. Depending on the definition of SME applied, it is important to note that the majority of foam producers, even in non-Article 5(1) countries fall into the SME category. Only the largest of the producers fall outside, as do most of the raw material suppliers. There is therefore considerable reliance on the supply-side to develop and support the introduction of new technologies. This leaves SMEs feeling vulnerable, even if their predicament is no worse than larger players in the market.

One of the over-riding requirements of the SME scenario is the need to avoid multiple transition steps. This has inevitably made SMEs more cautious than most in considering future technologies. In many cases, there are periods of innovation when there can be as many as 5-10 credible options available. However, as the innovation 'curve' moves towards maturity, there are usually two or three technologies that emerge as the true front-runners. SMEs are less concerned about being technology followers than the larger manufacturers and are much keener to avoid expensive mistakes. Accordingly, the transitions in these sectors will be naturally slower.

Overall transition costs are another major factor and these have two distinct components:

(1) Capital costs
(2) On-going operational costs

Because of a lack of financial resources, SMEs are often not as well placed to take advantage of long-term operational cost benefits, where they are attached to greater up-front capital costs. Accordingly, a transition process often leads to an overall weakening of their competitive position. This aspect has been largely negated in Article 5(1) countries where the Multilateral Fund can assist enterprises in respect of investment. However, investment constraints still exist in this environment, particularly in low-usage scenarios where cost-effectiveness criteria are often not met. Some of these developing country aspects are explored more fully in the next section.

DEVELOPING COUNTRY ISSUES

ACCELERATORS

Advanced (sector) phase-out dates in several Article 5.1 countries

Several developing countries are approaching final phase-out in the foam sector. Ahead of the 2010 Montreal Protocol deadline, some Article 5.1 countries, like Brazil, China, Nigeria, Thailand, Malaysia, have established sectoral CFC-11 phase out programmes where technology options permit.

Voluntary advances in ODS phase-out have also been encouraged by the presence of multinational producers and customers, particularly in the domestic refrigeration sector (Electrolux, Whirlpool, General Electric, Bosch, LG, etc.). Specifically, foam producers with significant export potential have needed to be aware of the demand for ODS-free and sometimes HFC-free products. These factors have applied to domestic refrigerator and freezer imports from developing countries into the European Union and to drink vending cabinets (e.g. as required by Coca Cola).

Key role of Multilateral Fund

The funding and technology transfer provided by the Multilateral Fund have played a significant and positive factor to speed up ODS phase out. The assistance has been extended to those countries that combine a developing country status with a low ODS use.

DECELERATORS

Lack of economic incentives because of low price and ready availability of CFC 11

The ready availability and lower price of CFC-11, manufactured in Article 5(1) countries (China, India, Argentina, Mexico, Venezuela, etc) with a shut down deadline of 2010, continue to slow down the conversion programs in some countries. Differences as high as U.S. $ 1.20/kg in landed cost between CFC-11 and HCFC-141b have been reported. This situation is particularly critical in the case of SMEs and has seriously aggravated by illegal trade.

Limited R&D Capacity

The limited research and development (R&D) capacity of local suppliers and manufacturers, a common feature in most of Article 5(1) countries, make them strongly dependent on developed countries technology. Trade barriers which make more advanced technologies from external suppliers too expensive to apply are another factor. These points, combined in some countries with insufficient information on new viable options and frequent delays in availability of non-ODS technologies, negatively affects the on going phase down programs.

Coordination of Government regulatory programmes

The Government regulatory action programs are frequently not well coordinated with the industry or other public dependencies. In one country, as a result of an unplanned CFC-11 imports prohibition, the suppliers switched to HCFCs without informing their customers, which generated severe product quality problems.

Safety related issues

The introduction of hydrocarbons (c-pentane, butanes, LPG), a non-ODP option for PU and polystyrene foam, has been negatively impacted by the safety factors taking into account the increased investment cost and a poor operating discipline. This issue is specifically applicable for SMEs, where, along with economic constrains, limited the use of HCs, likely to result in other non-ODS technologies such as HFCs.

POTENTIAL INBALANCE BETWEEN SUPPLY AND DEMAND FOR HCFC-141B

From the data presented in the chapter one it is remarkable the significant role that HCFCs, especially HCFC-141b, are playing during transition period in Article 5.1 countries. There remains concern among users about the possibility of a supply/ demand imbalance for HCFC-141b once the phase-out in developed countries takes place. This extends to the maintenance of adequate geographic supply chains

Long term ODS replacement

The MLF policy of one time funding for CFC replacement may create problems for the implementation of long term solutions in countries where phase out technology has been or is being focused on transitional options, like HCFCs.

APPENDIX 1: DESCRIPTION OF SECTORS

RIGID PU FOAM PRODUCTS AND APPLICATIONS

Polyurethane foams are generally based on the exothermic reaction of isocyanates and polyols. By itself, the polymerisation reaction produces a solid polyurethane. During a process known as foam blowing, polyurethane foams are made by forming gas bubbles in the polymerising mixture. The "blowing agent" can be either a gas chemically formed by water or formic acid reacting with the isocyanate, or a physical blowing agent such as low boiling inert organic compounds separately introduced into the reaction.

Used in a large variety of products, polyurethane foams can be classified into three major categories: rigid, flexible and integral skin/expanded elastomers. Product applications include insulating materials for buildings and appliances, cushioning products for furnishings and automobiles, packaging for protection of high-value products, automobile instrument panels and steering wheels and shoe soles.

RIGID DOMESTIC REFRIGERATOR AND FREEZER INSULATION

Rigid polyurethane foams continue to be the dominant insulation used in refrigerators and freezers. In these products the foam serves as a key element in the structure of the appliance, as well as a very effective insulation. The foam must have adequate compressive and flexural strength to ensure the integrity of the product under extreme temperature conditions during shipping, as well as heavy loading during usage of the appliance. It must maintain both its insulation effectiveness and structural properties throughout the design life of the product. Using CFCs, foam manufacturers were successful in developing formulations which met all of these requirements. As substitutes are developed, care must be taken to ensure that properties are not compromised to the extent that the overall performance of the appliance is degraded.

Although the basic requirements for refrigerator/freezer foam insulation are similar for most manufacturers, unique manufacturing facilities, local market conditions and regulatory requirements result in a situation where unique requirements exist for specific markets. For example, the importance of energy consumption in the US and Japanese markets has influenced manufacturers to use formulations with higher levels of CFCs to achieve lower conductivities than are required in the European market.

Production Process

Liquid chemicals are injected between the outer shell and the interior liner of an appliance cabinet where they react, flow and expand to form rigid polyurethane foam throughout the cavity. Substantial fixtures are provided to support the walls which are under pressure from the foam. Typically, a few percent of the blowing agent escapes from the chemical mixture and is vented during the foaming process. Production systems do not readily lend themselves to recovery of this lost blowing agent, so it has generally been vented directly to the atmosphere.

Over time, foam suppliers have developed formulations (using CFCs) which have properties (viscosity, reaction speed, exotherm, etc.) that meet the needs of production processes. With any new blowing agent, these properties must be maintained in order to produce quality products and control costs.

OTHER APPLIANCES

This category encompasses all "appliance" applications other than domestic refrigerators and freezers. The main applications are :

- **Water Heaters** -- Where foam insulation leads to a significant saving in energy consumption, particularly in designs where the space for insulation is limited.
- **Commercial Refrigerators and Freezers** -- Which are typically much larger then domestic units and includes open top display units.
- **Picnic Boxes (Coolers)** -- With a premium on insulation value and strong lightweight structures.
- **Flasks and Thermoware** -- Several types of articles require the same characteristics as picnic boxes.
- **Refrigerated Containers (Reefers)** -- A very stringent application with emphasis on durability and minimum wall thickness whilst maintaining insulation value.

Production Process

All the listed applications are produced by direct pour or injection of the foam chemicals between the inner and outer surfaces of the article. Most are held in moulds or jigs during the foaming process. Refrigerated containers are also produced by foaming section by section into a large pre-assembled jigged structure.

CONSTRUCTION – BOARDSTOCK/FLEXIBLE-FACED LAMINATION

Polyurethane (PUR) and polyisocyanurate (PIR) foam can be continuously laminated to various facing materials, such as aluminum foil, paper, glass roofing felts, and plasterboard. These products are primarily used as insulation in buildings, with some also used as tank and solar collector insulation.

In buildings, the largest use is in commercial roof insulation. Other uses include insulation for walls, cavities, internal linings (including agricultural buildings), exterior ventilated facades (Europe) and sheathing for residential construction (North America).

Rigid laminated PUR and PIR foams have penetrated many building insulation markets because these products offer the following properties:

- **Low thermal conductivity** -- High values of energy efficiency can be achieved by using comparatively thin layers of foam insulation. Laminated foams with impermeable facers offer the highest degree of long-term insulation value. The low thermal conductivity was originally derived from the fine, closed-cell polymer structure combined with CFC-11 as the main blowing agent. Retention of low thermal conductivity is a key concern when considering alternatives.

- **Fire performance** -- PIR and fire retarded PUR foams provide excellent fire test results under a variety of test procedures;

- **Compressive strength** -- This property is very important in roofing applications because of the construction and maintenance traffic that a roof system, including the insulation, must bear;

- **Ease of processing** -- One advantage of the product is its ease of manufacturing combined with its excellent adhesion to a whole range of facing materials; and,

- **Ease of use and handling** -- Laminated products are lightweight, offered in a variety of thicknesses, provide excellent structural rigidity, and, in the case of PIR when used on roofs, can be sealed with hot bitumen and be used without separation technology.

Production Process

There are two principal types of continuous laminating machines:

- The continuous horizontal laminator used to produce products with two flexible facers, e.g., aluminum foil, paper or roofing felt; one flexible facer and one rigid facer; and,

- The inverse laminator variation used to produce one rigid facing in sheet form. The chemical components are metered and mixed from the mixing head onto the pressure conveyor where external heat may be applied to promote faster curing before the foam is moved to the cut-off saw area. This product can also be produced using slabstock production methods.

The two main centres of manufacture are Europe and North America. In Europe, mostly PUR foam is used with added fire retardant to obtain the desired fire properties and the term flexible faced lamination is commonly used. In North America, boardstock is a PIR product and no fire retardants are normally used. There is little production by this technique in developing countries.

CONSTRUCTION AND TRANSPORT: SANDWICH PANELS

Products and Applications

Sandwich panels have foam cores between rigid facings. The facings are often profiled to increase rigidity. Facing materials are typically steel, aluminum or glass fiber reinforced plastic sheet.

The panels are increasingly being used in the construction industry for applications such as:

- **cold stores**: for frozen and fresh food storage;
- **doors**: entrance and garage;
- **retail stores**: including the cold rooms for food storage within them; and
- **factories**: particularly where hygienic and controlled environments are required such as in electronics, pharmaceuticals, and food processing.

The panels are also used in the transport industry for the manufacture of insulated trucks and reefers.

In all applications, the insulating property of the foam is used in conjunction with its strength and self-adhesive capability. The panels are components of high quality modular construction techniques and their use is growing rapidly in developed and developing countries.

Production Processes

The panel thickness, depending on application, varies from 30 to 200 mm and products over the entire range can be made by either continuous or discontinuous processes.

- Continuous Process

The continuous process uses a horizontal laminator similar to that used for the production of boardstock/flexible-faced laminates. However, additional equipment is installed to convert coiled sheet steel to profiled facings which are fed into the laminator.

- Discontinuous Process

In the discontinuous process, pre-profiled or flat facings are assembled, with appropriate spacers, in single- or multi-daylight or in oyster presses. The foam is injected at multiple ports or a lance withdrawal technique is used.

SPRAY POLYURETHANE FOAM INSULATION

Products and Applications

Sprayed foams are used for in situ application of rigid thermal insulation. Their major use is in roofing applications, especially in North America. Worldwide, sprayed foams are used for residential and commercial buildings, industrial storage tanks, piping and ductwork, and refrigerated transport trailers and tanks. Spray foam is applied by contractors in the field in accordance with the instructions of manufacturers of spray foam systems.

Production Process

Spray foam is applied using a hand-held pressurized spray gun, in which separate polyol and isocyanate liquids are metered under pressure, mixed and then dispensed. Different formulations or processing parameters impart specific properties to the foam, such as increased compressive strength, good dimensional stability at high heat and humidity, and greater high temperature stability. The ability of the formulator to adjust foam properties is beneficial, considering the foam is applied in a variety of climatic conditions.

The foam is sprayed directly from the mixing head onto the substrate. This method of application facilitates coverage of large and complex surfaces. For those applications where a thick layer of foam is needed, multiple thin layers of foam, of not less than 10 mm, are applied to create the thick layer. The sprayed foam needs to be highly reactive, especially for adhering to vertical surfaces during application. Pipes can also be insulated with spray foam by using a fixed spray gun and rotating and traversing the pipe.

OTHER RIGID POLYURETHANE FOAM APPLICATIONS

Other rigid polyurethane foam applications include slabstock, pipe-in-pipe, and one component foams.

Slabstock

Product Applications

Rigid polyurethane slabstock is used as insulation for pipes and storage tanks, as insulation boards in construction, and can be the insulating material for refrigerated transport containers. Rigid slabstock can be fabricated into a variety of product shapes and forms.

Production Process

Rigid slabstock is produced using either the discontinuous or the continuous manufacturing process. Traditionally, CFC-11 has served in both processes as the blowing agent, although water and/or CFC-12 are sometimes incorporated into the foam mixture. During 1993, partial conversion to alternate blowing agents took place.

- Discontinuous Process

In the discontinuous method, the chemical components of a slow-reacting foam system are weighed and hand or machine-mixed, after which they are poured into a wooden or cardboard mould. Fitted on top of the foam, a floating lid rises with the expansion of the foam. The lid serves to level the top surface of the foam block that is being produced. The output of the discontinuous method can be increased by using mechanical stirrers and agitators to replace the hand-mixing stage, or by machines that both mix and dispense the foam reaction mixture into the mould.

- *Continuous Process*

In the continuous process, the foam reaction mixture is dispensed continuously into a trough lined with paper or polyethylene film and located on a moving conveyor belt. The foam expands as it moves forward on the conveyor belt. Some belts are fitted with equipment that produces a foam with a flat top surface, similar to the floating lid used in the discontinuous process.

In production by either method, the foam rises due to the expansion of the blowing agent and cures. Then it is cut into sections for use in the applications and products listed above. In general, rigid slabstock has neither a facer nor an impermeable liner attached to it.

PIPE-IN-PIPE/PREFORMED PIPE

Products and Applications

Foam-insulated pipe-in-pipe sections typically have an inner steel pipe which is surrounded with foam insulation which, in turn, is protected by a plastic outer skin. These pipes are installed underground and are used to transport hot water from a central boiler to surrounding dwellings. Similar pipes and others insulated with preformed pipe sections are used in production units and chemical plants for the transport of hot or cold fluids. Large diameter insulated pipes may have post-applied elastomeric or bituminous coatings to provide a permanent water barrier.

Production Processes

Pipe-in-pipe sections are produced by injecting the foam chemicals into the cavity between the inner and outer pipes. Preformed pipes are produced by pouring or injecting the foam chemicals into half-section moulds.

Continuous processes have been introduced in which the foam is injected onto the inner pipe, cured and the outer plastic cover is then extruded onto the foam through an annular die.

ONE COMPONENT POLYURETHANE FOAM

One component foams are used by both the building industry and the do-it-yourself market in a variety of applications. These include draft-proofing around pipes, cable runs, doors, and windows; sealing doors and window frames; and joining insulating panels, roofing boards, and pipe insulation. One component foams are preferred because they are portable and easy to apply, and offer both thermal and sound insulation properties.

Production Process

One component foams are polymeric MDI-based prepolymer compositions that historically contained dissolved CFC-12. CFC-12, which has a lower boiling point than CFC-11, has been used because it acts as a propellant and because it produced "frothed" foam, thereby preventing the material from flowing away from the site of its application. Additionally, one component foams do not generate enough heat to volatilise CFC-11.

One component foams are supplied in pressurized cylinders and aerosol cans fitted with a nozzle through which a thin strip of material is extruded. After application, the foam expands at room temperature and cures by reacting with moisture in the air. This characteristic is unique to one component foams. The foam continues to cure internally after becoming dry to the touch as moisture from the air diffuses into the foam. The total time needed for foam cure depends on temperature and relative humidity.

FLEXIBLE POLYURETHANE FOAMS

SLABSTOCK FOAMS

Products and Applications

Slabstock foams include both polyether and polyester-based foams of varying densities and firmness, in each of the generic categories; conventional, high-resilience (HR), and combustion modified high resilience (CMHR). They are widely used in comfort applications such as furniture, bedding, carpet underlay, and automotive interiors and technical applications such as sound dampening, air filters, fuel cells, and packaging. Available in a range of densities and firmness, the foams are produced in large blocks, which are cut/shaped for use in individual application. In applications requiring combustion-modified foams to meet fire safety standards, the foams include melamine, graphite, chlorinated phosphoric esters, or alumina trihydrate to improve the foam's fire resistance. Greater amounts of auxiliary blowing agents are normally used in these foams to offset changes in hardness and density resulting from the introduction of these solid additives. Applications are mainly in upholstered furniture and bedding. In some countries, this is limited to institutions and mass transit; however, in other countries, such as the UK, their use is compulsory for all domestic applications of upholstered furniture and bedding.

Production Processes

While the choice of process chemicals provides the basis for the resulting foam properties and costs, the production process has also a profound impact. A foam operation can be divided into a “wet part” and a “dry part”. The wet part ranges from the chemical storage/blending to the metering/mixing of the chemicals, while the dry part constitutes of all the subsequent equipment used to process the chemical blend and the resulting foam.

Slabstock foams can be produced following a continuous process or a discontinuous process.

- Continuous Processes

In a typical continuous production line, the wet part consists of a storage/conditioning and metering system through which the liquid chemicals are metered to a mixing head. Feed formulation varies for different foam grades and between different foam producers. The metered stream from the mixing head is dispensed to a nozzle with a traversing pattern across the width of an inclined portion of the conveyor belt: this is termed the "laydown". The dry part consists of an enclosed continuous conveyor belt, called a "foam tunnel", that can be over 60 meters long. The conveyor belt is lined with paper or polyethylene film to make a "U" shaped retainer for the rising foam mass as it descends the slope. In the wet part, the laydown can be effected in different ways:

- Transfer directly on the conveyor: “Liquid Laydown Technology”,
- Transfer through a pre-expansion device: “Trough Technology”
- Transfer through a direct expansion device: “Froth technology”

The dry part can be:

- An inclined conveyor
- A horizontal conveyor with fallplate
- A vertical three-dimensional conveyor system

The equipment industry frequently offers certain combinations such as:

- Maxfoam/Varimax - Trough technology with horizontal conveyor/fallplate
- Vertifoam - Trough technology with vertical conveyor system

These different processes are described in more detail below:

Traditional Slabstock Method

In a typical continuous slabstock foam production line, the slabstock foam is produced on an enclosed continuous conveyor belt, called a "foam tunnel", that can be over 60 metres long.

Liquid chemicals are metered to a mixing head. Feed formulation varies for different foam grades and between different foam producers.

The metered stream from the mixing head is dispensed to a nozzle with a traversing pattern across the width of the initial inclined portion of the conveyor belt: this is termed the "lay down". The conveyor belt is lined with paper or polyethylene film to make a "U" shaped retainer for the rising foam mass as it descends the slope.

As the polymerisation reactions proceed and cells form, the foam rises and the blowing agents are volatilised due to internal heat generation. Within six metres of the lay down, the foam mass generally reaches its point of maximum expansion.

The foam can be as high as 1 to 1.25 metres and up to 2.5 metres wide. From its maximum expansion, the foam starts to release its blowing agents and some unreacted chemicals. A ventilated tunnel, typically covering the first section of the conveyor system, exhausts these emissions and thereby controls workplace concentrations.

The continuous slab of foam moves through the production tunnel to a cut-off saw which slices it into blocks for curing and storage. These blocks can be as short as 1 meter or as long as 60 metres. The exothermic chemical reaction continues within the foam mass while in the curing area. The natural insulating qualities of the foam maintain the heat for a period of several hours. Slowly, the heat dissipates while air penetrates the block and replaces the blowing agent.

The traditional traversing slabstock process is less economical than newer methods; consequently, the use of this process is on the decline. In addition, processing is generally more critical, and the introduction of CFC alternatives is more problematic. However, the process is still the primary choice for polyester foams and many other specialty products where cell size and cell uniformity are critical.

Maxfoam/Varimax

Developed in the early 1970s, the Maxfoam/Varimax process differs from the traditional method in lay down and foam expansion. The metering from the mixing head is discharged directly into the bottom of a trough, which is nearly level with the ultimate height of the foam slab.

The rising foam mass expands and spills over the front edge of the trough and is drawn away on a series of sloped fall plates. This slope is kept similar in shape to the rise profile of the foam, thus allowing a downward expansion, giving the resulting foam slab a nearly rectangular shape.

Currently the process of choice for most manufacturers, the Maxfoam/Varimax process for flexible foam production is less complicated and more efficient that conventional foaming (higher blocks, more density control and firmness control).

Vertifoam

The Vertifoam process produces foam vertically rather than horizontally. This results in full-sized blocks at a far lower foam chemical throughput rate and a slower production rate than conventional equipment. This more controllable rate is suited to small to medium manufacturers, since it allows efficient operation from 500 to 3,000 tonnes per year.

In addition, the foam blocks produced are accurately shaped and trimming losses are low. All the skins on Vertifoam blocks are thinner and less dense than conventional blocks and have none of the heavy top and bottom skin. These thin skins allow rapid diffusion for cooling or recovery. Both square blocks and round blocks can be produced.

The Vertifoam process differs substantially from conventional horizontal foam machines that need high chemical throughput rates to produce large foam blocks. The high chemical throughput rates of conventional foam machines result in high capital costs and large heating and ventilation requirements.

The reductions in floor area achieved with the Vertifoam process are very substantial -- up to 85% reduction has been reported. The lower chemical throughput of the process means that a large reduction in the extraction system is possible, which in turn means heating and ventilation costs are reduced.

In countries where legislation may in the future require blowing agent recovery and/or fume scrubbing, the low air extraction rate substantially reduces the capital and running costs of recycling and/or scrubbing equipment.

- Discontinuous Processes

Box Foam

In many developing countries where manpower is abundant, two pre-batched liquid components are mixed together and then literally poured into a lined box, which then expands and cures into a final block.

The pressure to switch to the use of alternative blowing agents has led to the development of vacuum assisted box foam processes which, in contrast to their predecessors can have a high degree of sophistication.

MOULDED FOAMS

Products and Applications

Moulded Foams are mainly used in transportation applications such as seat cushions, back cushions, armrests, and headrests. A specialty market is the sound dampening in cars by back-foaming of carpets and firewall (shared with slabstock). Together, transportation uses account for at least 90% of the flexible moulded foams used worldwide. The other 10 percent used for furniture and a range of miscellaneous applications. Flexible moulded foam can be produced by either "hot cure" or "cold cure" with cold cure being the predominant process worldwide. Hot cure foams are used for automotive seating and headrests. Cold cure moulded foams are used in both automotive (seating, headrests, carpet ticking backing) and non-automotive (furniture) uses.

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Production Processes

Moulded Foams

In the production of moulded flexible foams, chemicals are dispensed (usually a pre-blended two component system) to an open mould of a desired shape and size. Following mould cleaning and application of a release agent, the moulds are filled, sometimes manually, and then closed.

As the foam reaction occurs within the mould, the polymer forms and simultaneously expands to fill the mould cavity. Many moulded products are manually flexed and/or crushed by rollers upon removal from the mould, which opens the remaining cells. In some cases, the newly-demoulded part is heat-treated to further cure and harden the skin.

Generally, within the automotive field, flexible moulded foam can be produced by either "hot cure" (approximately one third of production) or "cold cure" (approximately two-thirds of production) on a worldwide basis. Hot cure foam production is used exclusively for automotive seating and headrests. Cold cure moulded foams are used in both automotive (seating, headrests, carpet ticking backing) and non-automotive (furniture) uses.

CFC-11 has typically been used in supersoft grades (for back cushions) and in the low-density grades (25 kg/m^3). In 1986, approximately 10% of all moulded foam production used CFC-11 in manufacture. In formulations using high resilience foam, auxiliary blowing agents are essentially phased out.

INTEGRAL SKIN AND MISCELLANEOUS FOAMS

Products and Applications

This section includes the many types of polyurethane foams which do not fall into the rigid or flexible category. The list of applications is long and varied.

Integral skin and miscellaneous polyurethane foams include:

Integral Skin

- flexible (or semi-rigid) integral skin foams for steering wheels, headrests, armrests, shoe soles, beer barrels, etc;
- rigid integral skin foams for computer cabinets, skis, and tennis rackets;

RIM

- microcellular high-density foam for exterior body parts of automobiles;

Non-Insulation Rigid

- low-density packaging foam;
- floatation foam;
- floral foams; and,
- energy absorbing foams for side impact in automobiles.

The principal benefits of polyurethane use for these applications are physical performance, ease of processing, and cost. CFCs have essentially been eliminated in these foams in most developed countries.

Production Process

Integral skin foams are molded foams, manufactured either by injection into closed vented molds (i.e. steering wheels) or by pouring into open molds (i.e. skin soles). These foams are characterized by a high density outer skin and a low density, softer core. The density gradation results from (a) blowing agent condensation at the mold surface compacting the cells of the urethane foam, and (b) overpacking of the mold.

Microcellular high density foams (RIM) are manufactured via injection into closed molds, in many cases using large presses to maintain clamping pressure and produce parts within dimensional tolerances. The microcells form air nucleation and also from small amounts of CO_2 (resulting in most cases from residual water).

Non insulation critical rigid foams are manufactured via a variety of processes including spray, moulding or rigid slabstock, using conventional or high pressure urethane dispensing equipment.

Most integral skin and miscellaneous foams are open cell, where the blowing agents used in manufacture are emitted to the atmosphere during the foaming reaction or soon thereafter. Rigid integral skin and flotation foams are closed cell, but low thermal conductivity is unnecessary in these products.

EXTRUDED POLYSTYRENE

EXTRUDED POLYSTYRENE SHEET

Products and Applications

Extruded polystyrene foam sheet is a thermoformable material used primarily to manufacture food service and food packaging products, such as hinged carry-out containers, single-service plates, cups, egg cartons and food trays. Other applications include dunnage, laminated sheets, and wrap-around labels.

- *Food Service and Packaging*

Food service applications for extruded polystyrene foam sheet include the manufacture of cups, plates, bowls, and hinged-lid containers, while food packaging applications include the production of meat trays, egg cartons, and produce trays. In 1986, food service and packaging applications consumed about 83% of the CFCs used for rigid polystyrene foam packaging.

CFCs were attractive blowing agents for some foam food service products because they contributed to the products' ability to insulate food and beverages at the proper temperature and to provide appropriate moisture resistance. In food packaging, CFCs also contributed to the products' moisture resistance; therefore, the end products eliminate the need for frequent in-store rewrapping.

- *Dunnage*

Dunnage is loose fill packaging materials such as foam "peanuts," pellets, and chips. This foam is used to protect products during transit and, thus, reduce the amount of breakage. Foam dunnage is reusable, sanitary, lightweight, and moisture resistant.

- Laminated Foam Sheets

Laminated foam sheets are used as art board and in insulated packages. Providing aesthetic versatility when used art board, laminated foam sheet is rigid yet lightweight, and readily accepts printing inks. In insulated packaging applications, laminated foam sheets are lightweight, rigid and moisture resistant, in addition to providing thermal insulation.

Production Process

Extruded polystyrene foam sheet is produced by a process that mixes polystyrene resin with additives and melts the mixture to a low viscosity in a two-stage screw extruder. During the process, blowing agents are injected into the extruder under high pressure and dispersed into the polymer melt.

Then, this mixture is cooled and forced through a die under controlled pressure. As the molten polymer exists the die, the dissolved blowing agent vaporises and expands. This reaction causes the plastic to foam. An annular die is used to form a tube, which is subsequently slit to make foam sheets.

Final production stages involve cooling, shaping, cutting or winding the foam into the desired form. Extruded foam sheet is normally aged two to four days prior to thermoforming into the desired form. Approximately 80% of the extruded polystyrene foam sheet produced consists of foam sheet that is thermoformed into a variety of products.

The thermoforming step typically generates a substantial amount of foam scrap. In some cases, 30% to 40% of the extruder feed becomes scrap. Manufacturing processes commonly include grinding and repelletising steps after final cutting and thermoforming.

The pelletised foam scrap recovered from thermoforming is recycled back to the extruder feed. The typical extruder feed mixture is 65% virgin polystyrene and 35% recycled polystyrene.

EXTRUDED POLYSTYRENE INSULATION BOARD

Products and Applications

Polystyrene foam boardstock was invented in Sweden in the early 1940s but was further developed to the extrusion process in the United States. It is a rigid foam with a fine closed-cell structure. The original blowing agent was methyl chloride, not CFCs. Extruded polystyrene foam insulation made with CFC-12 was introduced to the market in the early 1960s.

Globally, approximately 90% of extruded polystyrene rigid foam boards are used for thermal insulation purposes. The cellular products consist almost entirely of polymer and blowing agent. The type of blowing agent used determines the character of the cellular structure formed during the manufacturing process.

There are two main types of foam boards available:

- boards with a smooth skin covering the two principal heat transfer surfaces,

- the main application of the self-skinned material includes insulation for roofs, floors, and walls in dwellings, commercial and agricultural buildings. In some northern countries, another major application is the protection of roads, airport runways and railways against frost-heave by laying the insulation boards in the earth below the pavement and rail permanent way;

- boards with a planed or cut cell surface that provides grip for plaster, adhesive, and pour-in-concrete -- the main application for this product includes wall insulation of concrete buildings, tile and plaster backing, core material for sandwich panel construction, and low temperature space. There are a number of small specialty applications in most geographical markets as well.

High moisture resistance combined with mechanical strength makes extruded polystyrene insulation both an economical and practical material for below-ground building applications, such as basements, foundations and earth-sheltered homes, and inverted roof applications, where the waterproofing membrane is below the insulation material.

Other properties of extruded polystyrene foam include:

- low thermal conductivity;

- resistance to freeze-thaw deterioration;

- excellent compressive strength and dimensional stability (low shrinkage);

and

- good handling properties, including low toxicity and low insulating gas diffusion loss with time.

Production Process

The manufacturing of extruded polystyrene foam board for insulation purposes involves an extrusion process similar to that described for sheet. Polystyrene resin is mixed with additives, then continuously fed into an extruder where it is melted. Blowing agent, continuously injected under high pressure, is dispersed in the resin to form a foamable gel. The gel is then cooled and extruded through a rectangular cross section die where the blowing agent volatises, causing the plastic to assume a foam structure.

After the foam has been formed, it is transported away by a continuous conveyer belt and cut into appropriate lengths and widths. This cutting section can also include equipment to remove the skin (i.e., make planed boards). Internally generated scrap is recycled within the plant. In order to be recycled the scrap has to be reground with consequential release of cell gases.

In closed-cell insulation foams, such as extruded polystyrene, the blowing agent performs two functions:

- it makes the gel foam

and

- it contributes insulation value to the foam.

The blowing agent which stays in the foam to provide insulation value, the primary blowing agent, is sometimes called the insulating gas. A second, or auxiliary, blowing agent is sometimes used to support the foaming process; another proprietary technology uses vacuum foaming. In all processes the primary blowing agent must be present to provide characteristic high level insulation performance.

POLYOLEFIN FOAMS

Products and Applications

The general category of polyolefin foams includes products made from either polyethylene or polypropylene resins. These general foam types sometimes include other olefinic constituents, such as ethylene/vinyl acetate or ethylene/acrylic acid copolymer resins, as modifiers. Several different manufacturing processes are used for polyolefin foams, which result in different product forms.

One type of processing, which involves the crosslinking of extruded resin sheet and its subsequent expansion, uses only decomposable blowing agents, such as azodicarbonamide, and, as such, *this process will not be considered further here*. These products have different properties and are typically more expensive than polyolefin foams manufactured with physical blowing agents. They are not generally considered to be substitutes for most non-crosslinked polyolefin foam applications.

Polyethylene and, more recently, polypropylene resins are used in expandable bead products**,** which may be subsequently shape-moulded. These foam products are used primarily as moulded cushion packaging and automotive bumper systems. CFC-11 and CFC-12 were previously used as blowing agents. All bead producers now use hydrocarbons or carbon dioxide. Consequently*, no further comments will be made regarding these products.*

- Sheet products

Both polyethylene and polypropylene resins are extruded into sheet products. These sheet products are commonly used as protective packaging for furniture, electronic devices, and other goods. Other applications include flotation devices (such as life vests), construction materials, and gaskets. CFC-11, CFC-12, and CFC-114 have historically been used for most of these sheet products.

- Plank products

Polyethylene resins are used in the manufacture of extruded plank products. Their most frequent application is designed cushion packaging of electronic or other high-value goods. Some plank products are also used in military packaging, flotation, construction, aircraft seating and other applications. CFC-12 and CFC-114 were generally used in the manufacture of plank products.

- Tubular products

Polyolefin foam is also extruded in an annular shape i.e. as a tube, for use as thermal insulation for pipe. Applications include residential hot and cold water pipe insulation and similar near-ambient temperature applications. Historically CFC-12 or CFC-114 were used as blowing agents.

In most polyolefin foam applications, products are used because of specific properties. The most important of these properties is the material's ability to provide insulation from mechanical, vibrational, thermal and/or other environmental stresses.

Production Processes

In the case of extruded products, the resin is melted and mixed with the blowing agent(s). The resin and blowing agent are then passed through a die, where the product rapidly expands and cools.

- Sheet products

For sheet products, a circular, annular die is used to form a thin-walled hollow cylinder of foam. This foam tube is subsequently slit to produce a flat sheet that can then be rolled for storage or shipment. Sheet products are normally no thicker than 6 mm, and most are no thicker than 3 mm.

- Plank products

Typically, plank products are made using a specific die, which produces the particular cross-section desired. Each cross-section requires a different die. The plank is then cut to length and, if necessary, the edges are trimmed. Plank products can be from 12 to over 100 mm thick, are made up to 1200 mm wide, and are occasionally made in circular or other non-rectangular cross-sections. One process injects the foaming materials into a closed cavity to help dimension the product.

- Tubular products

Tubular pipe insulation also uses an annular die but one producing a reasonably small diameter, relatively thick-walled foam product. The inside diameter of the tubing ranges from 6 mm to 125 mm with wall thicknesses of 5 to 50 mm.

All three foam types are closed cell products. Thus, most of their blowing agents are initially trapped within the foam. With very thin sheet products, a significant portion of the blowing agent may be lost at or near the die. For extruded plank, tubing and thicker sheet products, very little is lost at the die although some will be lost in trimming operations, which open the cells.

PHENOLIC FOAMS

Products and Applications

Phenolic foams represent only a small proportion of the foamed insulation materials used world-wide. However, their generic fire properties (particularly their extremely low smoke emission) have established the product in many applications previously served by other insulation products. Phenolic foam products have particularly gained acceptance in public and commercial buildings where fire concerns are often more significant. Cost usually rules against phenolic foams when considered for the domestic environment.

There is a significant level of substitution against fibrous products where cleanliness and moisture resistance can be offered without unnecessary loss of fire performance. This is particularly the case in the building services sector, where insulation is often exposed. Pipe laggings are an example. Uptake of the product has, however, been heavily dependent on local building methods and fire codes. In some Member States in Europe, laminate products are widely used for wall and roofing applications, particularly within the growing single-ply roofing market. However, in others, there is very little usage. Phenolic foam is making particular in-roads in Japan, where the building methods and population density create a ready market. However, mixed experiences with phenolic technologies in North America have led to a virtual de-selection in several applications. More recently, activity in Europe has increased in the use of phenolic foams in rigid faced paneling for cool-rooms, doors and partitions.

There is still some residual usage of open-celled phenolic foam for specific market requirements. A prime example of this is its use for floral arrangements. The unique wetting properties of this particular product make it virtually irreplaceable. However, these properties are not reliant on the use of CFCs and most production had already switched to hydrocarbons on the basis of cost. Accordingly, floral foams are not considered further in this report.

More orthodox open-celled phenolic foams are still used in some countries, most notably the former Soviet Union, as prime insulation. As these foams exhibit poorer insulation characteristics than those made from the more recently developed closed-cell technologies outlined above, there has been pressure to transfer these technologies under license or other co-operative agreement.

Production Processes

- Discontinuous Processes

Several discontinuous processes have been developed for closed-cell foams, but undoubtedly the most prevalent is the Block or Bun process. This has been particularly dominant in Europe where the process lends itself to the varied requirements of Building Services market. Complex computer-controlled cutting equipment optimises yields from blocks when cutting pipe sections. Despite this, yields can be as low as 50% for the more awkward shapes.

Other discontinuous processes include the manufacture of rigid faced panels by injection (normally referred to as "pour-in-place"). Multi-daylight and oyster-press routes have been followed, but investment in these sectors has only re-emerged following the development of thermally efficient CFC-free technology.

Most, if not all, discontinuous processes have used CFC-11 and/or CFC-113 to obtain their high thermal efficiencies historically. Accordingly, most plant technologies, and their associated installed units, are unable to handle low boiling blowing agents. Additionally, few plants are flame-proofed. These factors have inhibited the move to alternative blowing agents, particularly the low boiling HCFCs and HFCs.

- Continuous Processes

Within the range of continuous processes, lamination with flexible facings is the most common. There has been less focus on rigid faced lamination and continuous block to date, although these may follow as and when ODS-free technologies become established. The machines used for continuous lamination are, in the main, more capable of processing low boiling blowing agents than their discontinuous counterparts and, accordingly, CFC-114 has been a common constituent within several technologies historically. It should be stressed that it is the process rather than the machinery per se which facilitates the use of these materials. Therefore, it is unlikely that much of the associated technology will be transferable to the discontinuous operations.

APPENDIX 2: REVIEW OF BLOWING AGENT OPTIONS

This Appendix has been produced specifically to provide relevant information to potential users on the characteristics and availability of the blowing agents referred to in this document. Efforts have been made to provide as much information as possible. However, commercial concerns about the disclosure of the locations of specific plants have made it impossible to provide a comprehensive review of potential geographic constraints. To avoid misleading anecdotal comments, the Committee has elected to omit any comments related to geographic limitations, except where their use is legally defined by patents. The Committee would refer the reader to the suppliers listed under each blowing agent cited for further information.

In addition, the UNEP Technical and Economic Assessment Panel (TEAP) will address the issue of supply and demand of HCFCs in Article 5(1) countries in a forthcoming Task Force Report scheduled for publication in mid-2003. Again, readers are encouraged to reference this document directly for further information on the on-going availability of HCFCs is various geographic regions.

The major blowing agents being commercially used in the foam sector, or being considered for commercial introduction in the short-term, are shown in Table A-2.1 overleaf. This, table and the subsequent descriptive paragraphs, provide technical information on the blowing agents themselves and some information on usage patterns and commercial availability. It should be noted that there are no references to regulatory constraints in this Appendix. While, the impact of ODS Regulations is probably well known to the reading audience and does not require further iteration here, it might be useful to note, for example, that all fluorocarbons in the United States are not treated as Volatile Organic Compounds (VOCs) for regulatory purposes.

TABLE A-2.1 PHYSICAL AND ENVIRONMENTAL PROPERTIES OF MAJOR BLOWING AGENTS

	CFC-11	CFC-12	HCFC-22	HCFC-142b	HCFC-141b	Methylene Chloride	HFC-134a	HFC-152a	HFC-245fa	HFC-365mfc	Isopentane	Cyclo-pentane	n-pentane	Carbon Dioxide	Isobutane	n-butane
Chemical Formula	$CFCl_3$	CCl_2F_2	$CHClF_2$	CH_3CClF_2	CCl_2FCH_3	CH_3Cl_2	CH_2FCF_3	CHF_2CH_3	$CF_3CH_2CHF_2$	$CF_3CH_2CF_2CH_3$	$CH_3CH(CH_3)CH_2CH_3$	$(CH_2)_5$	$CH_3(CH_2)_3CH_3$	CO_2	C_4H_{10}	C_4H_{10}
Molecular Weight	137	121	86	100	117	85	102	66	134	148	72	70	72	44	58.12	58.12
Boiling point (°C)	24	-30	-41	-10	32	40	-27	-25	15.3	40.2	28	49.3	36	-139	-11.7	0.5
Gas Conduct. (mW/m°K at 10°C)	7.4	10.5	9.9	8.4	8.8	N/A	12.4	14.3”	12.5**	10,6**	13.0	11.0	14.0	14.5	15.9	13.6****
Flammable limits in air (vol.%)	None	None	None	6.7-14.9	7.3-16.0	None	None	3.9-16.9	None	3,8-13,3	1.4-7.6	1.4-8.0	1.4-8.0	None	1.8-8.4	1.8-8.5
TLV or OEL (ppm) (USA)	1000	1000	1000	1000	500	35 to 100	1000	1000	N/A	N/A	1000	600	610	N/A	800	800
GWP (100 Yr.) ***	4000	8500	1700	2000	630	N/A	1300	140	820	840	11	11	11	1		
ODP	1.0	1.0	0.055	0.065	0.11	0	0	0	0	0	0	0	0	0	0	0
Producers (major)	Honeywell	Honeywell	Atofina Honeywell, Solvay DuPont	Honeywell Atofina, Solvay	Honeywell Solvay Atofina		Atofina, DuPont, INEOS, Honeywell Solvay	DuPont, Solvay	Honeywell Central Glass	Solvay	ExxonMobil Haltermann Phillips Shell	ExxonMobil Haltermann Phillips	ExxonMobil Haltermann Phillips Shell		Chevron Bayer Huntsman Phillips	Bayer DuPont Huntsman Phillips

“	Measured at 25°
*	Measured at 40°C
+	Measured at 20°C
**	Measured at 24°C
***	IPCC-Report 1996
****	Measured at 0°C

HCFC-22

Description & Usage

HCFC-22 is a non-flammable gas liquefied under pressure. One main application is as a non-flammable mixture with HCFC-142b for PU and XPS foams. In rigid PU foam it has been used in combination with HCFC-141b.

Physical and Chemical properties

Chemical name:	Chlorodifluoromethane
Formula:	$CHClF_2$
Molecular Weight:	86.5
EC Number (EINECS):	200-871-9
CAS Number:	75-45-6
Density/Specific gravity	1.22
Boiling Point (°C)	- 40.8
Vapour pressure	9.08 bar (20°C), 19.33 bar (50°C)
Gas Conductivity (mW/m. °K at 10 °C)	9.9
Gas Conductivity (mW/m. °K at 30 °C)	11.0
Vapour density (air=1)	3.65 (20°C)
Solubility (20°C, 1bar)	Slightly soluble in water (0,42 %) Soluble in most organic solvents
Decomposition temperature	480°C

HSE properties

Toxicological data:	TLV (ACGIH-USA) 2001 TWA = 1,000 ppm TWA = 3,540 mg/m^3 TLV or OEL (USA, ppm) = 1000
VOC	No
GWP[*] (100 years)	1700
ODP	0.05

Commercial Status

Producers:	Atofina, Honeywell, Solvay, DuPont, Daikin, Mitsui-DuPont, Asahi Glass

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[*] IPCC – Report 1996

HCFC – 141b

Description & Usage

HCFC-141b is a liquid at room temperature and does not have a flash point. HCFC-141b has been used as a foam blowing agent in almost all rigid and integral skin foam sectors.

Physical and Chemical properties

Chemical name:	1,1-dichloro-1-fluoroethane
Formula:	CH_3CFCl_2
Molecular Weight:	117
EC Number (EINECS):	404-080-1
CAS Number:	1717-00-6
Density/Specific gravity	1.22
Boiling Point (°C)	32
Vapour pressure @ 25 °C (bar)	0.78
Gas Conductivity (mW/m. °K at 10 °C)	8.8
Gas Conductivity (mW/m. °K at 25 °C)	9.7
Vapour density (air=1)	4,86 (25°C)
Solubility	approx. 4,8 % (20°C)
Decomposition temperature	> 200°C
Flammable limits in air (vol. %)	5,6-17,7

HSE properties

Toxicological data:	
TLV or OEL (USA, ppm)	500
WEEL, 8 hr. TWA, ppm	500
VOC	No
GWP* (100 years)	630
ODP	0.11

Commercial status

Producers:	Atofina, Honeywell, Solvay, Hangzhou First Chemical Co. Ltd. Zhejiang Sanhuan Chemical Co. Ltd., Central Glass, Daikin

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* IPCC – Report 1996

HCFC – 142b

Description & Usage

HFC-142b is a gas at room temperature. It is used as a foam blowing agent for both polyurethane and extruded polystyrene foams. It can be used alone or as a blend with HCFC-22. A blend of 60/40 HCFC-142b/HCFC-22 (60/40) is non-flammable.

Physical and Chemical properties

Chemical name:	1-chloro-1,1-difluoroethane
Formula:	CH_3CF_2Cl
Molecular Weight:	100.5
EC Number (EINECS):	
CAS Number:	75-68-3
Density/Specific gravity	1.22
Boiling Point (°C)	-9.6
Vapour pressure @ 25 °C (bar)	3.4
Gas Conductivity (mW/m. °K at 10 °C)	8.4
Gas Conductivity (mW/m. °K at 25 °C)	11.5
Flammable limits in air (vol. %)	6-18
Vapour density (air=1)	4,18 (25°C)
Solubility	0,14 %
Decomposition temperature	no data

HSE properties

Toxicological data:	
TLV or OEL (USA, ppm)	1000
WEEL, 8 hr. TWA, ppm	1000
VOC	No
GWP[*] (100 years)	2000
ODP	0.066

Commercial status

Producers:	Atofina, Solvay, Honeywell, Daikin

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[*] IPCC – Report 1996

METHYLENE CLORIDE

Description & Usage

Methylene chloride, or dichloromethane, is a clear, colourless liquid with a penetrating ether-like odour. Pure, dry methylene chloride is very stable and will not produce corrosion in mild or galvanized steel, copper, nickel, lead or tin. In the presence of water, however, it may undergo very slow hydrolysis to produce small quantities of hydrogen chloride, which can lead to corrosion. This process is accelerated by elevated temperatures and the presence of alkaline or metals. Commercially available methylene chloride is normally inhibited with small quantities of stabilizers to avoid this process. Typical stabilizers are propylene oxide and cyclohexane.

Methylene chloride's combination of properties, such as a low boiling point, relative inertness, low toxicity and non-flammability have led to its use as an auxiliary blowing agent in the foam industry. Its low photochemical ozone creation potential (PCOP) and lack of ozone depletion potential (ODP) has increased its use dramatically in the recent years, making it a significant CFC-replacement in the manufacture of polyurethane foam. The U.S. EPA has recognized this by mentioning methylene chloride under the Agency's Significant New Alternatives Program (SNAP) as an acceptable alternative to ozone depleting solvents.

Physical and Chemical properties

Chemical name:	Dichloromethane
Formula:	CH_2Cl_2
Molecular Weight:	84.9
CAS Number:	75-09-2
Density/Specific gravity	1.32
Boiling Point (°C)	40
Freezing Point (°C)	- 95
Viscosity, 25 °C, cp	0.41
Refractive index (25 °C)	1.421
Vapour pressure @ 25 °C (bar)	...
Ignition temperature in air, °C	615 - 932
Vapour density (air=1)	...
Solubility	...
Decomposition temperature	...

HSE properties

TLV or OEL (USA, ppm)	35 - 100
Flash point (closed cup)	none
LEL (25 °C, %)	15
UEL (25 °C, %)	20

Methylene chloride is considered non-flammable but under certain circumstances it may propagate a flame. In the vapor phase and under abnormal conditions (elevated temperatures, flame, sparks etc.), it may be decomposed to give off small amounts of hydrogen chloride, carbon monoxide, and phosgene.

The most likely routes of human exposure will be inhalation and skin contact. Methylene chloride is absorbed through the lungs and through the skin. It can, however also be absorbed through the intestines upon ingestion. It is quite rapidly excreted, mostly through the lungs, without any chemical change. The remainder is metabolised to carbon monoxide (CO), carbon dioxide (CO2) and inorganic chloride. There are two pathways for this metabolism: a cytochrome P450 pathway, also called "mixed function oxidise (MFO), generating CO and CO2, and a glutathione-S-transferase (GST) pathway, generating only CO2.

The MFO route is predominant at relatively low doses; saturation occurs at around 500 ppm. Increasing the dose above the saturation level does not lead to extra metabolism by this route. The GST route seems to be used very little in the human system. In other species (e.g. the mouse) this pathway can become the major route at sufficiently higher doses.
The generation of CO in the body is of significance. It can combine with haemoglobin in the blood, forming carboxy- haemoglobin (COHb) thus reducing the oxygen carrying capacity of the blood.

MC has a relatively low acute toxicity. High exposure (> 1,000 ppm) triggers anaesthetic effects and a depressant effect on the central nervous system (CNS). The CNS effect is additive with those from other CO sources, e.g. cigarette smoking. Some reversible effects on sensory and psychomotor function have been observed from acute exposures to 300-500 ppm, but not to lower concentrations. Little evidence is available on oral toxicity. Swallowing of small splashes is unlikely to have significant effect.

Liquid MC is a slight skin irritant, due to the removal of natural oils in the skin.

Long term behavioural and neurological studies have shown no significant adverse effects. There is no evidence that MC causes the irreversible chronic CNS damage sometimes diagnosed as "Danish Painters Syndrome" (solvent induced encephalopathy).

The potential carcinogenicity of MC is a controversial issue. There is one study, performed for the National Toxicology Program (NTP), that suggests carcinogenic effects of high lifetime doses in mice. Other bioassays with different animals (rat, hamster) and at lower concentrations did not confirm these findings, indicating that the association between MC exposure and carcinogenicity may be unique to mice and even then concentration related. This was supported by subsequent research, concluding that important species differences exist in metabolism between the mouse on one side, and rats, hamsters, or humans on the other side. Evidence was provided that the GST pathway of metabolism is linked to the carcinogenic response observed in mice. Since humans show a very limited ability to metabolize MC via the GST pathway, the mouse is a poor surrogate for assessing human hazard.

The above mentioned research efforts led to the development of a physiologically based pharmacokinetic (PB-PK) model to evaluate the carcinogenic risk to man from exposure to MC.

Application of this model on experimental animal data concludes to no significant risk for man under current hygiene standards.

The U.S. EPA has accepted the PB-PK model, and used in its draft Update to the Health Assessment Document (HAD) for methylene chloride. Also EPA's Science Advisory Board indicated approval. OSHA, however, indicated reservations, and has based its proposed revision of the occupational exposure standard for MC on the before mentioned NTP study. The industry has submitted critical comments to this proposal, and achieved reconsideration by the agency. The effected date for the new standard delayed accordingly.

Industrial mortality studies have shown no evidence of that methylene chloride, even at relatively high concentrations (100-350 ppm, with peaks of up to 10,000 ppm) represents a carcinogenic or cardiovascular ischemic risk to humans.

The US Occupational Safety and Health Administration (OSHA) in January 1997 adopted a comprehensive standard for workplace exposure to methylene chloride. The standard establishes permissible exposure limits (PELs) of 25 ppm as an 8-hour time-weighted average (TWA) and 125 ppm as a short-term exposure limit (STEL). The compliance dates vary by industry sector and size of business; all companies must be in compliance by April 2000 at the latest. The standard also requires medical surveillance and contains a number of other ancillary provisions. The ACGIH threshold limit value (TLV) is 50 ppm for an 8-hour TWA exposure. In 1987, the US Consumer Product Safety Commission (CPSC) published a Statement of Interpretation and Enforcement Policy for household products containing methylene chloride. This policy statement establishes labeling guidance for these products under the Federal Hazardous Substances Act. In addition, the use of methylene chloride in cosmetic and food products is restricted by the Food and Drug Administration (FDA).

The EU classification was established as Carc. Cat. 3 /Xn;R40 in the 23rd ATP in 1997. This classification was implemented by member states by December 1998.

Commercial status

Methylene chloride is a generic chemical and available from numerous manufacturing and trading sources. The use of recycled material in PU foam applications is discouraged because of a possible catalytic effect of dissolved trace metals. Several manufacturers such as Dow Chemical, Solvay and ICI offer product versions that have been specifically stabilized for the use in PU foam.

HFC-134a

Description & Usage

HFC-134a is a non-flammable gas at room temperature. It is the most widely used zero ODP fluorochemical and is an established refrigerant. HFC-134a has been used as a blowing agent in almost all foam sectors, particularly rigid and integral skin foam. It is also being used for extruded polystyrene foam in Europe.

Physical and Chemical properties

Chemical name:	1,1,1,2-Tetrafluoroethane
Formula:	CF_3CH_2F
Molecular Weight:	102,0
EC Number (EINECS):	212-377-0
CAS Number:	811-97-2
Density/Specific gravity	1.21
Boiling Point (°C)	- 26.3
Vapour pressure @ 25 °C (bar)	6.6
Vapour pressure	5,72 bar (20°C), 13,18 bar (50°C)
Gas conductivity (mW/m. °K at 10 °C)	12.4
Gas conductivity (mW/m. °K at 25 °C)	13.7
Vapour density (air=1)	4,32 (20°C)
Solubility (20°C, 1bar)	Slightly soluble in Water (0,15%) Soluble in many organic solvents
Decomposition temperature	no data
Flammable limits in air (vol. %)	None
Vapour density (air=1)	4,32 (20°C)

HSE properties

Toxicological data:	
TLV or OEL (USA, ppm)	1000
WEEL, 8 hr. TWA, ppm	1000
VOC	No
GWP[*] (100 years)	1300
ODP	0

Commercial status

Producers:	Atofina, DuPont, INEOS, Honeywell, Solvay, Showa Denko, Mitsui-DuPont

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[*] IPCC – Report 1996

HFC-152a

Description & Usage

HFC-152a is a flammable gas at room temperature. It has limited use in polyurethane foam because it is flammable, and it diffuses out of the foam quickly, preventing it from offering additional long term thermal insulation value. Yet, HFC-152a is widely used as a blowing agent for one component PU foam system where the foam is mostly used to fill a cavity and thermal insulation value is not the most critical parameter.

HFC-152a is used with HFC-134a in XPS boardstock. Although it does not offer long term thermal insulation value for the product, it is mainly used to reduce the foam density of HFC-134a foam, and improve processing conditions. It is also used as blowing agent for extruded polystyrene sheets, mostly used in food packaging applications. It is the only HFC that is approved by US food and drug administration (FDA) for this application.

Physical and Chemical properties

Chemical name:	1,1-Difluoroethane
Formula:	CH_3CHF_2
Molecular Weight:	66.0
EC Number (EINECS):	200-866-1
CAS Number:	75-37-6
Density/Specific gravity	0,886 (g/cm^3) at 30°C
Boiling Point (°C)	- 24.7
Vapour pressure @ 25 °C (bar)	6.1
Gas conductivity (mW/m. °K at 25 °C)	14.3
Flammable limits in air (vol. %)	3.8-21.8

HSE properties

Toxicological data:	
WEEL, 8 hr. TWA, ppm	1000
VOC	No
GWP[*] (100 years)	140
ODP	0

Commercial status

Producers:	DuPont, Solvay, Maruzen Petro Chem.

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[*] IPCC – Report 1996

HFC-245fa

Description & Usage

HFC-245fa is a non-flammable liquid having a boiling point slightly below room temperature. It is being actively considered for a wide variety of foam blowing applications.

Physical and Chemical properties

Chemical name:	1,1,1,3,3-Pentafluoropropane
Formula:	$CF_3CH_2CHF_2$
Molecular Weight:	134.0
EC Number (EINECS):	
CAS Number:	460-73-1
Density/Specific gravity	1.32
Boiling Point (°C)	15.3
Freezing Point (°C)	< -160
Vapour Pressure @ 20 °C (KPa)	123
Gas Conductivity (mW/m. °K at 20 °C)	12.05
Water Solubility in HFC-245fa, ppm	1600
Flammable limits in air[**] (vol. %)	None
Flash Point[***] (°C)	None

HSE properties

Toxicological data:

WEEL, 8 hr. TWA, ppm	300

HFC-245fa is currently listed on the US EPA TSCA inventory, the European EINECS inventory, and the Japanese MITI inventory. Extensive toxicity testing indicates that HFC-245fa is of low toxicity. Overall results from a series of genetic studies indicate that HFC-245fa is non-mutagenic. It was also not a teratogen. The American Industrial Hygiene Association has established a Workplace Environmental Exposure Level (WEEL) of 300 ppm.

VOC	No
GWP[*] (100 years)	820
ODP	0

HFC-245fa is a fluorinated hydrocarbon. Treatment or disposal of wastes generated by use of this product may be of concern depending on the nature of the wastes and the means of discharge,

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[**] Measured at ambient temperature and pressure using ASTM E681-85 with electrically heated match ignition, spark ignition and fused wire ignition; ambient air.

[***] Flashpoint by ASTM D 3828-87; ASTM D1310-86.

[*] IPCC – Report 1996

treatment or disposal. HFC-245fa is not considered a “hazardous waste ”by the Resource Conservation and Recovery Act (USA) if discarded unused. Care should be taken to avoid releases into the environment.

The US EPA has given SNAP approval for the use of the HFC-245fa blowing agent as a replacement in all foam applications. Based on a review of toxicity and food migration test results by Keller and Heckman, it was concluded, there is no impediment to refrigerator and freezer manufacturers adopting a self determined GRAS position on HFC-245fa.

Commercial status

Honeywell has supplied semi-commercial quantities of HFC-245fa since 1998. A world-scale commercial manufacturing facility, located in Geismar, LA, USA came on stream in Q3 2002. Central Glass has announced the construction of an HFC-245fa manufacturing facility in Japan. This plant is scheduled to come on-stream in mid 2003.

Current Producers:	Honeywell, Central Glass

HFC - 365mfc

Description & Usage

HFC - 365mfc is a liquid at room temperature with low gas phase thermal conductivity. It is being actively considered for a wide variety of foam blowing applications.

Physical and Chemical properties

Chemical name:	1,1,1,3,3-Pentafluorobutane
Formula:	$CF_3CH_2CF_2CH_3$
Molecular Weight:	148
EC Number (EINECS):	430-250-1
CAS Number:	406-58-6
Density/Specific gravity	1.25
Boiling Point (°C)	40.2
Vapour pressure @ 20 °C (bar)	0.47
Heat of vaporization at boiling point, (kJ/mol)	26.2
Gas conductivity (mW/m. °K at 25 °C)	10.6
Flammable limits in air (vol. %)	3.6-13.3
Minimum Ignition Energy (mJ) (25°C)	10.4
Flash point, °C	< –27
Auto flammability, °C	580
Vapour density (air = 1)	5.11
Solubility in Water, g/l	1.7

HFC - 365mfc has a flash point, but the flammability behaviour is much different to hydrocarbons. This is due to the high content of fluorine, which takes away much energy from the molecule. According to the manufacturer, the flammability can be managed by adding 5% of a non flammable HFC, e.g. HFC-134a, HFC-227ea or HFC-245fa. Non flammable blends have been developed to overcome the original flammability of neat HFC - 365mfc.

HSE Properties

Toxicological data:	
WEEL, 8 hr. TWA, ppm	N/A
Acute toxicity oral route, LD50 rat, mg/kg	> 2000
Acute toxicity inhalation, LC50, 4h, rat, mg/kg	> 2000
No mutagenic effect	
Comments: Not hazardous under normal conditions of use.	
GWP[*] (100 years)	840
ODP	0

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[*] IPCC – Report 1996

Commercial Status

HFC-365mfc has been produced since 1999 in a pilot plant of Solvay, and a commercial plant with a capacity of 15 000 t/year will be operational end of 2002.

Geographic Constraints

The use of HFC-365mfc might fall within the scope of European Patent 381 986 and its counterparts, all held by Bayer. Solvay has acquired from Bayer the right to sublicense its customers under these patents in all countries except in the USA and in Canada.

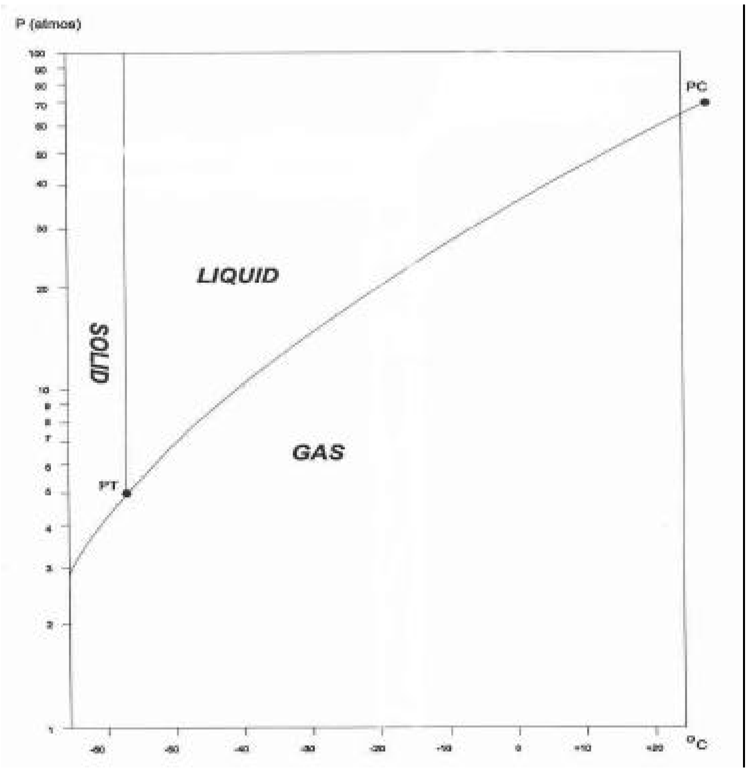
CARBON DIOXIDE

Description & Usage

Carbon Dioxide (chemical formula CO_2) is a gas in normal conditions and exist in the atmosphere in small concentrations. It is a colourless, odourless, non flammable gas, with very low chemical reactivity and toxicity.

Physical and Chemical Properties

Formula	CO_2	
Molecular weight	44.01	
Triple point pessure	5.11	bar.
Temperature	-56.6	°C
Critical point pressure	75.2	bar
Temperature	31	°C
Specific volume	2.156	l/kg
Density relative to air at 20 °C (air = 1)	1.521	
Latent heat of vaporisation at triple point	83.20	Kcal/kg
Latent heat of sublimation at atmospheric Pressure	136.40	Kcal/kg
Heat of formation of gas at 25 °C	2.137	Kcal/kg



Phase diagram for carbon dioxide

HSE Properties

Carbon dioxide is toxic only at very high concentrations (5000ppm = 9000 mg/m3).

Commercial Data

Carbon dioxide is a generic chemical with numerous suppliers and wide availability im most countries. There are two main supply sources :

- From mining sources (natural CO_2). Carbon Dioxide exist in the underground and is produced by the decomposition of carbonate compounds in presence of steam or by the sudden cooling of magma which release CO_2 as a gas.

- Chemically generated as a by-product of several chemical reactions in the main industrial processes. One of the main sources is the process to produce ammonia and urea. The main impurities are sulphurous products, inert gases and water.

Since CO_2 is normally utilized as an additive in the food industry, it is supplied at very high purity (some suppliers guarantee more than 99,9%).

CO_2 is liquefied to be stored and transported. There are two are systems to store carbon dioxide for industrial use: pressurized bottles for small consumption requirements and bulk tanks for high consumptions. All mayor suppliers of liquid gases provide rental contracts for the mentioned storage solutions.

- Pressurised bottles: Bottles of liquid CO_2 are at pressures of 70 to 100 bar at normal ambient temperature. Two types of pressure bottles are used – bottom feed, with an internal bottom-feed pipe for delivering liquid CO_2 or top-feed, for delivering gaseous CO_2. Avoid any heating of the bottles either by sun light or any heating source. Bottles must be handled with care using gloves and avoiding any hard contact.

- Bulk tanks: CO_2 is stored in insulated, pressurised tanks of capacity from 3 up to 50 m^3, at a pressure of about 16-18 bar and temperature about –30 to –24 °C. The tank is normally fitted with a CO_2 level detector and cooling system to control the pressure within the required limits. It is recommended that the tank is protected from adverse weather conditions and to erect around it a guard rail, to restrict access. Any parts of the electric installation should be placed under a roof or indoors.

Carbon Dioxide as blowing agent for polyurethane foams

In polyurethane flexible foam (slabstock or moulded) the main blowing agent is carbon dioxide generated chemically by the reaction between water and isocyanates.

CYCLOPENTANE

Description and Usage

Cyclopentane is a colorless and flammable liquid with a gasoline-like odor. It is a blowing agent for polystyrene and polyurethane foam processes.

Physical and Chemical properties[2]

Chemical name :	Cyclopentane
Formula	C_5H_{10}
Molecular Weight	70.134
EC Number (EINECS)	206-016-6
CAS Number	287-92-3
Density/Specific gravity (15°C)	0.745
Boiling Point (^{o}C)	49.3
Melting point (^{o}C)	-93.9
Vapour pressure	515 mmHg at 100 ^{o}F
Gas Conductivity (mW/m.°K @ 10°C)	11.0
Solubility in Water	Insoluble

HSE properties

Toxicological data (exposures limits)	TLV: 600 ppm; 1720 mg/m^3 (ACGIH 1993-1994). NIOSH REL: TWA 600 ppm (1720 mg/m^3)
VOC	Yes[3]
GWP (100 years)	11
ODP	0
Flammable limits in air (%)	1.4 – 8.0
Vapour density (air=1)	2.42 (20 ^{o}C)
Autoignition Temperature	350 ^{o}C

Commercial Status

Producers[4]	Chevron, ExxonMobil, Haltermann, Phillips

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[2] Specific data from http://ull.chemistry.uakron.edu

[3] Subject to regulations that can vary from country to country and within a country even from region to region

[4] http://www.chemchannels.com

ISOPENTANE

Description and Usage

Iso-pentane is a colorless and flammable liquid with a gasoline-like odor. It is a blowing agent for polystyrene and polyurethane foam processes.

Physical and Chemical properties[5]

Chemical name :	2-Methylbutane
Formula	C_5H_{12}
Molecular Weight	72.15
EC Number (EINECS)	201-142-8
CAS Number	78-78-4
Density/Specific gravity (15°C)	0.625
Boiling Point (°C)	27.8
Melting point (°C)	-159.9
Vapour pressure[6]	595 mmHg (20.4 psi) at 21.1 °C
Gas Conductivity (mW/m.°K @ 10°C)	13.0
Solubility in Water	< 0.1 g /100ml at 23°C

HSE Properties

Toxicological data (exposures limits)	TWA = 600 ppm (ACGIH 1996), OSHA 1995 PEL (8Hr. TWA) for isopentane = no listing (n-pentane =1,000 Molar PPM).
Odor threshold	10 ppm
VOC	Yes[7]
ODP	0
GWP (100 years)	11
Flammable limits in air (%)	1.4 – 7.6
Vapour density (air=1)	2.48 (20 °C)
Auto-ignition Temperature (°C)	420

Commercial Status

Producers[8]	ExxonMobil, Haltermann, Phillips, Shell

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[5] http://ull.chemistry.uakron.edu

[6] http://chemfinder.cambridgesoft.com

[7] Subject to regulations that can vary from country to country and within a country even from region to region

[8] http://www.chemchannels.com

n-PENTANE

Description and Usage

N-pentane is a colorless and flammable liquid with a gasoline-like odor. It is a blowing agent for polystyrene and polyurethane foam processes.

Physical and Chemical properties[9]

Chemical name :	n-pentane
Formula	C_5H_{12}
Molecular Weight	72.15
EC Number (EINECS)	203-693-4
CAS Number	109-66-0
Density/Specific gravity (15°C)	0.632
Boiling Point (^{o}C)	36.1
Melting point (^{o}C)	-130.0
Vapour pressure [10]	400 mmHg at 18.5 ^{o}C
Gas Conductivity (mW/m.°K @ 10°C)	14.0
Solubility in Water	0.04 g /100ml at 23^{o}C

HSE Properties

Toxicological data (exposures limits)	OSHA PEL: TWA 1000 ppm (2950 mg/m^3) NIOSH REL: TWA 120 ppm (350 mg/m^3) C 610 ppm (1800 mg/m^3) 15-minute NIOSH IDLH: 1500 ppm LEL
VOC	Yes[11]
ODP	0
GWP (100 years)	11
Flammable limits in air (%)	1.4 – 8.0
Vapour density (air=1)	2.48 (20 ^{o}C)
Autoignition Temperature (°C)	285

Commercial Status

Producers[12]	ExxonMobil, Haltermann, Phillips, Shell

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[9] http://ull.chemistry.uakron.edu

[10] http://chemfinder.cambridgesoft.com

[11] Subject to regulations that can vary from country to and from region to region

[12] http://www.chemchannels.com

ISOBUTANE

Description and Usage

Isobutane is a colorless gas with a faint petroleum-like odor. It is a blowing agent for polyethylene and polyurethane foam processes.

Physical and Chemical properties[13]

Chemical name :	Isobutane
Formula	C_4H_{10}
Molecular Weight	58.12
EC Number (EINECS)	200-857-2
CAS Number	75-28-5
Density/Specific gravity	0.557
Boiling Point (^{o}C)	-11.7
Melting point (^{o}C)	-255.3
Vapour pressure	3723 mmHg at 100 ^{o}F
Gas Conductivity (mW/m.°K @ 20°C)	15.9
Solubility in Water	Slightly soluble

HSE properties[13]

Toxicological data (exposures limits)	NIOSH REL: TWA 800 ppm (1900 mg/m^3)
VOC	Yes[14]
ODP	0
Flammable limits in air (%)	1.8 – 8.4
Vapour density (air=1)	2.01 (20 ^{o}C)
Flash Point (°C)	-107
Autoignition Temperature (°C)	460

Commercial Status

Producers[15]	Chevron, Bayer, Huntsman, Phillips

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[13] http://ull.chemistry.uakron.edu

[14] Subject to regulations that can vary from country to country and within a country even from region to region

[15] http://www.chemchannels.com

N-BUTANE

Description and Usage

N-butane is a colorless gas with a faint disagreeable odor. It is used It as blowing agent for polyethylene and extruded polystyrene processes.

Physical and Chemical properties[16]

Chemical name :	n-butane
Formula	C_4H_{10}
Molecular Weight	58.12
EC Number (EINECS)	203-448-7
CAS Number	106-97-8
Density/Specific gravity	0.6
Boiling Point (^oC)	0.5
Melting point (^oC)	-138.4
Vapour pressure (mmHg)	760
Gas Conductivity (mW/m.°K @ 0°C)	13.6
Solubility in Water @ 20 ^oC	0.0061g/100mL

HSE properties[17]

Toxicological data (exposures limits)[18]	ACGIH TLV 800 ppm, OSHA PEL 800 ppm
Odor threshold	50,000 ppm
VOC	Yes[19]
ODP	0
Flammable limits in air (%)	1.8 – 8.5
Vapour density (air=1)	2.046
Flash Point (°C)	-60
Autoignition Temperature (°C)	405

Commercial Status

Producers	Chevron, Bayer, Huntsman, Phillips, DuPont

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[16] http://ull.chemistry.uakron.edu

[17] http://ull.chemistry.uakron.edu

[18] http://www.cpchem.com/specialtychem/products/MSDS/nBUTANEpuregrade.pdf

[19] Subject to regulations that can vary from country to country and within a country even from region to region

APPENDIX 3: DESCRIPTION OF TECHNICAL OPTIONS

RIGID PU FOAM TECHNICAL OPTIONS

DOMESTIC REFRIGERATOR AND FREEZER INSULATION

Performance Requirements

Rigid polyurethane foam is the dominant insulation material used in refrigerators and freezers. The foam serves as a key element in the structure of the appliance, as well as a very effective insulation. It must have adequate compressive and flexural strength to ensure the integrity of the product under extreme temperature conditions during shipping, as well as heavy loading during usage of the appliance. It must maintain both its insulation effectiveness and structural properties throughout the design life of the product. Using CFCs, foam manufacturers were successful in developing formulations which met all of these requirements. As substitutes are developed, care has been taken to ensure that properties are not compromised to the extent that the overall performance of the appliance is degraded.

Although the basic requirements for refrigerator/freezer foam insulation are similar for most manufacturers, unique manufacturing facilities, local market conditions and regulatory requirements result in a situation where unique requirements exist for specific markets. For example, the importance of energy consumption has influenced manufacturers in the USA to use foams giving lower conductivities than those required in the European market. Nevertheless, energy regulations control the energy consumption of the complete unit and the foam thermal conductivity is only one of several factors.

In the EU stringent energy consumption requirements have now been put into place since September 1999. Developments to reduce energy consumption have continued. For example, the ability of some of the current European models to surpass the current best rating of class A by a considerable margin has been highlighted in a report[20] prepared for the European Commission in 2001. This level of performance has been achieved with hydrocarbon blowing agents. The report recommends a new labeling and minimum energy performance system from 2005/6 in which the minimum energy performance allowed would be today's class A.

New and more stringent US energy efficiency standards set by the DOE were implemented in July 2001. These require, on average, a 30% reduction in energy consumption compared to existing models. Cabinet design, flammability, capital conversion cost, and potential liability issues moved the industry towards a HFC solution in contrast to the hydrocarbon solution preferred in most other regions.

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[20] COLD II 'The revision of energy labelling and minimum energy efficiency standards for domestic refrigeration appliances'

Technical Options

There are two main technology streams in use. Hydrocarbon technology has been in use since 1993 and has been under continuous development to deliver improvements in foam properties. This technology stream is seen as a long-term option. The other current technology is an intermediate one based on HCFC-141b, also in wide scale use since 1993, and is expected to be replaced by, mainly, "liquid" HFC blowing agents. There is some use of the HCFC-141b/HCFC-22 blend and minor use of the HCFC-142b/HCFC-22 blend and of HFC-134a.

- *Low ODP Technologies*

The foams based on HCFC-141b show the best insulation performance of any CFC 11 substitute used so far. The increase in initial thermal conductivity is about 7-10% relative to an optimised full CFC-11 foam (measured at 10°C) or equivalent to slightly lower than for a 50%-reduced CFC-11 foam. There has been an increase in density because of the solvent effect on the foam matrix of the blowing agent - this amounts to 4-7% on overall density compared to a full CFC foam. Work with blends containing up to 50% HCFC-22 shows that this effect can be reduced (see below).

There are many solutions in use to counter the solvent effect of HCFC-141b on the plastic liner. Most show an economic penalty of up to 15 % on the cost of the liner material depending on product design and foam system characteristics. For those designs where voids (which contain pockets of HCFC-141b) can be avoided, there may be no need to take special measures to protect "standard chemically resistant" grades of HIPS. For other designs, a barrier layer may be required to protect the liner or a special grade of ABS may be used with an economic penalty that can be a major issue for all producers. High-pressure dispensers are recommended to obtain the best foam quality.

The thermal insulation properties of foams based on HCFC-142b/HCFC-22 are about 5% poorer than for HCFC-141b but this blowing agent combination is less aggressive to the plastic liner. Pre-blenders capable of blending-in the gaseous blowing agent mixtures are required.

The technology based on blends of HCFC-141b with HCFC-22 has been extended up to 50/50 blends. These give advantages in terms of reduced density and cost, reduced effect on liners, good dimensional stability and minimal effect on thermal conductivity and energy consumption.

Another blowing agent being considered is HCFC-124 but little information is available on its performance in appliance foams.

- *Zero ODP Technologies*

Hydrocarbon technology has been mostly based on cyclopentane, either "pure" grade (95%) or "technical" grade (75%). There is no significant difference in their performance in practice. Both are easy to process in formulations that have been developed around them. Because of their flammability, extensive but now well established modifications to the foaming part of the factory to meet appropriate safety requirements are essential.

These include a dedicated storage tank for the cyclopentane, pre-mixers, adapted high pressure dispensers, suitable moulds (often water-cooled) plus process exhaust, hydrocarbon detectors, appropriate classification of electrical equipment, avoidance of static electricity and, above all, training of operating staff. See Appendix 4 for a more detailed outline of standard hydrocarbon process safety procedures. These requirements make economic conversion to this technology, particularly in the cases of small factories, a difficult issue. However, in this sector most of the production units, even in developing countries, are large enough to make conversion to hydrocarbons an economic proposition. To extend the use of this technology to some areas, including some regions in the USA, precautions would be necessary to comply with limits on the emissions of VOCs.

Conventional liner systems, as used with CFC-11, are suitable for use with any of the hydrocarbon blowing agents.

The conventional cyclopentane-based foams show an overall density of, typically, 38 kg/m^3 or 15-18% above the 50%- reduced CFC-11 foams which they replaced and, typically, the initial thermal conductivity is increased by 12-13% to about 20.8 mW/m°K (at 10°C). Optimisation of the foam systems has reduced these deficiencies to 36 kg/m^3 (an increase of 10-13%) and 20.2 mW/m°K (an increase of 7-10%) respectively. The latter figure equates to an increase of cabinet energy consumption of about 5% relative to the reduced CFC- 11-based foams.

Further development of hydrocarbon systems involves the use of blends which reduce the economic density penalty without affecting the insulation performance and may even enhance it at refrigerator and, particularly, at freezer operating temperatures. For example, an optimised cyclo/iso pentane-based foam shows the overall density reduced to about 35 kg/m^3 (an increase of 6-8% compared to 50%-reduced CFC 11-foams) with similar thermal insulation performance to the best cyclopentane systems. Another approach, using cyclopentane/isobutane blends, achieves the same improvement plus improvement in low temperature thermal insulation because of the higher gas vapour pressure in the foam cells. There is minor use of iso/normal pentane blends. This is in markets where cyclopentane is not available locally and the iso or normal isomers are used despite their deficiencies in terms of thermal conductivity.

The technologies that have been actively evaluated as non-hydrocarbon replacements for the HCFCs are those based on HFC-134a and HFC-245fa.

Foams based on HFC-134a are seen as a safeguard against the non-availability of liquid HFCs. They have been used in appliances, for short periods, already and are being used in a few production lines today. The main issues are: processing because HFC- 134a is a gas and has poor solubility in polyol formulations; and the thermal conductivity penalty of the foam - which is 15-20% compared to CFC-11-based foam.

In contrast, the evaluation of HFC-245fa shows it to be a technically viable blowing agent for this application, giving similar densities to those of CFC-11-based foams. The thermal conductivity of the foam, at about 18.5 mW/m°K (at 10°C) and the energy consumption of the appliance are equivalent to those of HCFC-141b-based products and up to 10% lower than for current hydrocarbon-blown foams. The boiling point of 15.3°C may mean that pressurised blending equipment will be necessary for its use, although evaluations reported to date suggest that HFC-245fa can be processed through foam equipment designed for use with CFC-11 and HCFC-141b in many cases. The very good solubility in polyol formulations is a significant factor in its use. The liner materials used with CFC-11 are suitable for use with HFC-245fa with the exception of some ABS compositions.

To date, there has been little evaluation of HFC-365mfc in this application.

Vacuum insulation panels continue to be developed and are used in limited quantities. They are not, strictly, CFC-11-replacement technologies but allow insulation efficiency to be maintained or improved when using foam technologies of inferior insulation compared to that based on CFC-11. There is now production of refrigerators and freezers using open-celled polyurethane rigid foam-based vacuum panels. These allow, for example, a reduction of either 20% in energy consumption or, in another example, an increase of 25% in internal volume at the same energy consumption. Such advances are obviously strongly dependent on model design.

OTHER APPLIANCES

Performance Requirements

This category encompasses all "appliance" applications other than domestic refrigerators and freezers. The main performance requirements are:

- **Water Heaters** - Where foam insulation leads to a significant saving in energy consumption, particularly in designs where the space for insulation is limited. There is a trend towards energy consumption controls in some regions. For example, the US DOE has implemented energy efficiency standards for water heaters that will require approximately a 15% improvement in energy efficiency beginning in 2004. There are also controls on energy consumption in the EU.

- **Commercial Refrigerators and Freezers (including display units)** - These are typically much larger than domestic units and include open top display units. Vending machines are also included and there have been requirements for zero ODP and low GWP blowing agents from large manufacturers of soft drinks. Basic performance requirements are as for domestic refrigerators.

- **Picnic Boxes (Coolers)** - With a premium on insulation value and strong lightweight structures.

- **Flasks and Thermoware** - Several types of articles which require the same characteristics as picnic boxes.

Technical Options

- *Low ODP Technologies*

The main option to replace CFC-11 in these sectors is HCFC-141b. This is because of the low capital investment required by the manufacturers - many of these are small enterprises with limited production capacity. The "drop-in" nature of this liquid blowing agent is of paramount importance. In addition, for the reefer application, the excellent thermal insulation performance of HCFC-141b-based foams is important for this application in which there are stringent requirements in terms of wall thickness and energy efficiency.

- Zero ODP Technologies

Cyclopentane is used for commercial refrigerators and freezers in those areas where the market demands a zero ODP, low GWP option.

Some vending machines and water heaters are produced with CO_2 (water). For water heaters the comparatively poor thermal insulation properties of the foam can be compensated by increased thickness in some cases.

For the replacement of HCFC-141b the blowing agents being considered are HFC-245fa and HFC-365mfc. The question of whether HFC-245fa can be supplied pre-blended into formulations will be an important factor in its wide scale use in temperate and tropical climates and this issue is being studied.

The various forms of pentane are also technically suitable, but the cost of appropriate safety measures and the difficulty in supplying pre-blended formulations may rule out wide scale use as many of the manufacturers in this sector are comparatively small enterprises.

INSULATED TRUCKS AND REEFERS

Performance Requirements

This is a very stringent application with emphasis on durability and minimum wall thickness whilst maintaining insulation value. Most products for this market are produced by the discontinuous sandwich panel technique (see below) although reefers can also be produced by foaming section by section into a large pre-assembled jigged structure.

Technical Options

The technical options available for insulated truck bodies are the same as for discontinuous panels for other applications and these are dealt with later in this section. For the manufacture of reefers, the situation is rather different since the skins are much thicker and are often jigged differently. The basic technologies can be set out as follows:

- Low ODP Technologies

Historically, HCFC-141b has been widely used in this sector and with the transfer of much of the global manufacture to Article 5(1) countries such as China, the use of HCFC-141b is likely to be maintained for a considerable time to come.

- Zero ODP Technologies

Although thermal insulation requirements can be onerous, there is sufficient leeway in the design of reefers to allow the use of foam systems based on hydrocarbons. These are usually based on linear pentanes and other similar blowing agents.

BOARDSTOCK/FLEXIBLE-FACED LAMINATION

Performance Requirements

Rigid laminated PUR and PIR foams have penetrated many building insulation markets because these products offer the following properties:

- **Low thermal conductivity** - High values of energy efficiency can be achieved by using comparatively thin layers of foam insulation. Laminated foams with impermeable facers offer the highest degree of long-term insulation value. The low thermal conductivity was originally derived from the fine, closed-cell polymer structure combined with an ODS as the main blowing agent. Retention of low thermal conductivity is a key concern when considering alternatives.

- **Fire performance** - PIR and fire retarded PUR foams provide excellent fire test results under a variety of test procedures. The impact on fire performance is another factor when considering alternative blowing agents;

- **Compressive strength** - This property is very important in roofing applications because of the construction and maintenance traffic that a roof system, including the insulation, must bear. Some alternatives can plasticise the foam and reduce the compressive strength and result in the need to increase density;;

- **Ease of processing** - One advantage of the product is its ease of manufacturing combined with its excellent adhesion to a whole range of facing materials; and,

- **Ease of use and handling** - Laminated products are lightweight, offered in a variety of thicknesses, provide excellent structural rigidity, and, in the case of PIR when used on roofs, can be sealed with hot bitumen and be used without separation technology.

Technical Options

There are two main blowing agent technologies in use. Both HCFC-141b and n-pentane (and isopentane) have been in use since 1992. HCFC-141b (and the HCFC-141b/HCFC-22 blend) provide the best insulation value of the CFC-11 replacements, and these boards satisfy a wide range of building codes. N-pentane, iso-pentane and cyclopentane plus blends are used in markets, which require a zero ODP option.

- Low ODP Technologies

HCFC-141b processes in a very similar fashion to CFC-11. There are two main differences in terms of foam properties. The density is usually increased by up to 10% in order to obtain a satisfactory dimensional stability and the initial and aged thermal conductivities of the foam are increased by up to 5% and 10% respectively.

The dimensional stability problem arises because of the plasticisation effect of the blowing agent and its higher boiling point (32°C) compared to CFC-11 (24°C). There have been problems in both US and European markets with dimensional instability of roof boards based on HCFC-141b (also with n-pentane in Europe). These effects were not predicted by the then existing standard dimensional stability tests. Some manufacturers had also reduced density, for economic reasons, to a borderline level. There have been several actions to ameliorate the problem. Foams based on HCFC-141b/HCFC-22 blends with, typically, 10% of the gaseous blowing agent are in use - these give an increase in cell vapour pressure and hence avoid shrinkage. New, more severe, test methods have been introduced and adopted by the industry.

Boards/foam based on HCFC-141b can be produced to meet the same flammability requirements as were achieved with CFC-11. However, changes in building codes in both the USA and the EU are constantly introducing new challenges.

- Zero ODP Technologies

N-pentane/isopentane requires changes in the processing area of the factory to ensure safe operation because of its flammability. In addition, there are issues of dimensional stability, thermal conductivity and formulating to satisfy fire codes.

There have been dimensional stability problems in the European market with shrinkage of installed roof boards, particularly in winter conditions. This has arisen because of the high boiling point (36°C) of the n-pentane and is similar, in some respects, to the problems seen with HCFC-141b. Industry has addressed the issue by assuring that the density is maintained and through the introduction of the new test methods mentioned above.

The initial and aged thermal conductivities are about 10% higher than with CFC-11 but the rate of aging is no more than with CFC-11 and with isopentane it is slower than with CFC-11. Some code standards, such as the DIN 020 classification, cannot be met. This is a considerable penalty in the market.

The need to meet fire codes means that the potential economic advantage of using a cheap blowing agent is not realised in practice. The inherent flammability of the blowing agent is counteracted, in practice, by the use of flame retardants. Preferably, these are of the reactive type because non-reactive fire retardants can lead to plasticisation of the foam matrix. By these means most small scale tests can be met, as can some of the larger scale tests. However, the increasing stringency of both the developing EU harmonised tests and those of the insurance companies' results in pentane-based boards being unable to meet all market requirements. However, progress is being made and recent developments in the USA have achieved ASTM E-84 Class 1 and FM Calorimeter ratings.

For several markets the HCFC-141b replacement options are HFC-245fa and HFC-365mfc. Current evaluation indicates that processing, insulation, physical property and most flammability requirements would all be met by these blowing agents. Initial insulation properties would be similar to those of HCFC-141b with the advantage of reduced rates of aging.

The key issue relating to the acceptance of these blowing agent in this sector are their prices and the resulting costs of the boards in an extremely cost sensitive market in which there are several potential substitution products. This is currently an open question.

CONSTRUCTION: SANDWICH PANELS

Performance Requirements

These panels are increasingly being used in the construction industry for applications such as:

- light industrial steel construction
- residential buildings
- cold stores - for frozen and fresh food storage;
- doors entrance and garage;
- retail stores - including the cold rooms for food storage within them; and
- factories - particularly where hygienic and controlled environments are required such as in electronics, pharmaceuticals, and food processing.

Similar panels are also used in the transport industry for the manufacture of insulated trucks and reefers.

In all applications, the insulating property of the foam is used in conjunction with its strength and bonding capability. The panels are components of high quality modular construction techniques and their use is growing rapidly in developed and developing countries.

There has been particularly strong growth for continuously produced sandwich panels in Europe. This market has grown at the expense of built-up wall and roof systems with mineral fibre insulants. By developments such as the use of PIR foam and attention to edging and joint detail the fire performance of these panels has improved to a level close to those of panels based on mineral fibre core materials.

Technical Options – Continuous Panels

The main CFC-11 replacement blowing agent in this sector is HCFC-141b with additional use of n-pentane, HCFC-142b/HCFC-22, HCFC-22 alone and HFC-134a. This sector does not sell on thermal conductivity alone and this results in a range of options being used.

Low ODP Technologies

HCFC-141b gives most of the property and processing advantages of CFC-11 with few penalties. The dimensional stability is not an issue because the core density is about 40 kg/m^3 to endow the panel with adequate structural properties. Flammability performance is also similar to that obtained by CFC-11.

HCFC-142b/HCFC-22 and HCFC-22 alone are also in use. The processing equipment has to be modified to include pre-blenders. These can be of the in-line type. The impervious steel facers counteract the rather more rapid diffusion out of the foam cells of HCFC-22.

Zero ODP Technologies

N-pentane is used where a zero ODP-blowing agent is required. The production equipment has to be modified to counter its flammability.

HCFC-134a is also in use in markets where a zero blowing agent is required. The poor solubility of HFC-134a in polyols is less of an issue in this application. This is because of the low level of blowing agent required at the higher density of the foam used in structural panels. Another factor is that the HFC-134a is used as a co-blowing agent with CO_2 (water), thus reducing the amount of HFC-134a required.

This market is facing ever more stringent flammability requirements and this has, so far, favoured HCFC options, particularly HCFC-141b, and it inhibits the wider scale use of n-pentane.

This sector also sees HFC-245fa and HFC-365mfc as the most significant future options (together with n-pentane). Evaluations have shown them to be technically suitable but, as in the case of boardstock, the industry is uncertain about the economics of their use.

Technical Options - Discontinuous Panels

The options and market requirements are basically similar to those for continuously produced panels. There is often the requirement for non-flammable pre-blended systems for the smaller producers in both developed and developing countries.

- Low ODP Technologies

The most widely used alternative is HCFC-141b. It gives a performance almost equivalent to CFC-11 and is usually supplied in pre-blended formulations.

- Zero ODP Technologies

Pre-blended HFC-134a formulations have been introduced in the European market. The latter is possible despite the low solubility of this blowing agent in polyol formulations because the mixed CO_2 (water)/HFC-134a systems only require about 2% of the gaseous blowing agent.

HFC-245fa and HFC-365mfc are seen as replacements for HCFC-141b.

Because of safety considerations, there is a strong reluctance to market pre-blends containing pentane. Accordingly, these systems are virtually not marketed. However, both cyclopentane and n-pentane have been used in the European and some developing country markets for several years where direct supplies of blowing agent can be handled.

SPRAY POLYURETHANE FOAM INSULATION

Performance Requirements

Sprayed foams are used for in situ application of rigid polyurethane foam thermal insulation. Worldwide, sprayed foams are used for residential and commercial buildings, industrial storage tanks, piping and ductwork, and refrigerated transport trailers and tanks. A major use is in roofing applications, especially in North America. There are strongly growing markets in other countries such as Spain and in several countries in the Asia Pacific region. Spray foam is generally applied by contractors in the field in accordance with the instructions of manufacturers of spray foam systems. In view of these requirements, spray foams have to demonstrate the following characteristics:

- High resilience (e.g. to foot traffic)
- Low moisture absorption and transmission (closed cell requirement in some cases)
- Good thermal properties
- Sufficient fire performance to meet relevant building codes
- Application capability in a variety of climatic conditions
- Ease of use and operation
- Multi-layering capability

Technical Options

The main CFC replacements in current use are HCFC 141b and CO_2 (water). Neither gaseous HCFCs and HFCs, nor the pentanes are suitable for this sector. All formulations are preblended and a gaseous blowing agent would not give the required foam quality because of frothing and would result in unacceptable losses of the blowing agent. The flammability of pentanes would make their on-site applications unacceptable.

- Low ODP Technologies

The major CFC-11 replacement is HCFC-141b. It gives equivalent processing and foam properties to its predecessor. There may be a density penalty depending on the choice of the system.

- Zero ODP Technologies

The use of CO_2 (water) is in applications where the higher (about 50%) foam thickness to give equivalent insulation value can be accommodated. There is also a penalty of a density increase of about 30% for the lower, 32 kg/m^3 density, foams but this penalty does not apply to those higher density foams used for example in roofing applications. The processing equipment can be modified to cater for stream ratios of about 1.5:1.

Systems based on both HFC-245fa and HFC-365mfc are being developed as replacements for HCFC-141b. These include systems based on HFC 245fa and water (CO_2).

PIPE-IN-PIPE

Performance Requirements

These pipes are used, mostly underground, to transport hot water over long distances.

The foam in this sector has a high density of 70-80 kg/m^3 and is well protected by a thick high density polyethylene cover. However, it must last for a specified 50 years (CEN 253) at an operating temperature of 80°C. The main markets are in Northern Europe and in China.

Technical Options

In the pipe-in-pipe sector, the main CFC-11 replacements are HCFC-141b, cyclopentane and CO_2 (water).

All the above options meet the performance requirements of the application. The only significant difference is that thicker walls are required with CO_2 (water) to achieve the same insulation value.

The two "liquid" HFC options, HFC-245fa and HFC-365mfc, have not yet been evaluated in this application.

SLABSTOCK/PREFORMED PIPE

Performance Requirements

The performance of foam required will depend heavily on the application envisaged. Slabstock production tends to be the method of producing foam for many low-volume standard and non-standard applications. In many cases, these niche markets can be highly demanding and hence the potential range of performance criteria needs to be kept in mind when selecting blowing agent alternatives. A significant application is for the low volume manufacture of panels in which the metal or other facing materials are glued onto the foam. These are used for trucks and other applications.

In the case of preformed pipe section, it is common that these are used in exposed internal and external environments and particular care needs to be taken in ensuring that fire properties and moisture performance requirements can be met.

Technical Options

The options to replace CFC-11 are the same as those in the boardstock sector. The major replacement blowing agent is HCFC-141b and there is minor use of pentane and CO_2 (water). The options tend to be similar for both continuous and discontinuous processes, although particular care is required in designing plant for hydrocarbon use (see below).

Low ODP Technologies

Because of the thick sections and range of densities required the processing requirements in this sector are quite stringent and HCFC-141b gives equivalent processing to that obtained with CFC-11.

Zero ODP Technologies

Pentane can also be used but only after process development to ensure safe operation despite the propensity of the high temperature exotherms being generated in this application.

The use of CO_2 (water) also has the penalty of difficult processing because of the high exotherm temperature. Care has to be taken to ensure safety, especially in the post application storage phase.

Both HFC-245fa and HFC-365mfc have been evaluated for this sector and process well. The foam properties are acceptable.

ONE COMPONENT POLYURETHANE FOAM

Performance Requirements

One component foams have rather unusual performance requirements which are associated with its prime end-use (gap filling) and the fact that its usage is shared between the DIY sector and the professional building industry. Accordingly, the following characteristics become important:

- Rapid foaming and curing characteristics independent of climatic conditions
- Safety in use (low level of flammable blowing agents/propellants)
- Low surface spread of flame for cured foams (a legal requirement in some markets)
- Good foam adhesion

Technical Options

A gaseous blowing agent/propellant is required to replace CFC-11/CFC-12. The thermal conductivity of the foam is not a critical requirement. The gaseous HCFCs, HFC-134a and HFC-152a, the hydrocarbons, propane and butane plus dimethyl ether (DME) are all technically suitable and are in use. These are frequently used in blends, for example, a blend of HFC-134a/DME/propane/ butane is widely used in Europe. Flammable blends are used in about 80% of the total European market for cost-effectiveness reasons.

Considerable modifications are required in the production and storage areas to ensure safe operation with hydrocarbons.

FLEXIBLE PU FOAM TECHNICAL OPTIONS

SLABSTOCK

Performance Requirements

The use of ODS technologies in this sub-sector has been driven historically by the need to generate lower density and hardness combinations and, by providing a heat sink, to lower the process heat generation. The majority of the foams are TDI-based—which is relatively volatile at prevalent process temperatures (80-150 ^{0}C)—and virtually all blowing agent is released within twenty-four hours after production. This makes control of process emissions together with potential flammability and toxicity issues a major factor in the choice of CFC replacement—which is inert, non-toxic and non-flammable. However, while these issues limit the replacement choices, the fact that there are no requirements for thermal insulation, allows more latitude and makes it feasible to select from non-ODP/non-transitional substances alone.

Technical Options – Slabstock (Continuous)

Available technologies can be classified into

- Conservation Methods
- Alternative Substances
- Chemical Modifications
- Process Modifications

- Conservation

Conservation techniques are those technologies and procedures, understood to reduce the use of CFCs through best management practices, reformulation and recovery/recycling. Proper housekeeping and formulation management can save a plant up to 10 % of its use of ABAs. Some recommendations—not only for CFCs, but for any blowing agent:

- Use closed loop unloading systems
- Do not leave drums open
- Store at reduced temperature and out of the sun
- Avoid using CFCs for non-essential applications (flushing, viscosity adjustments)

Recycling/Recovery: Has been practiced in several foam plants but lost in significance after because of costs, low efficiencies and unwanted side effects. In this process, the ABA is first adsorbed to activated charcoal, and subsequently desorbed through steam or nitrogen. Precondition is a reduction of the process ventilation, which can lead to exposure problems for production workers. Recovery of curing emissions is hardly feasible, reducing the obtainable overall efficiency to less than 50 %. Investment and operational costs are high.

"E-MAX"™: The E-Max process combines the production and curing steps by encapsulating the developing foam in a mold as the foaming mixture is introduced to the foam line. The foam mold allows all emissions from the process to be captured and collected, using relatively low airflow. The costs are high; retrofitting is not possible and the enclosure of the lay-down and expansion process complicates process control. Only one facility has been constructed and is believed not to be in operation anymore.

- Alternative Substances

Methylene Chloride (MC): Methylene chloride's combination of properties, such as a low boiling point, relative inertness and virtual non-flammability have led to its use as an auxiliary blowing agent in the foam industry. It does not contribute significantly to atmospheric pollution through formation of tropospheric ozone, to the depletion of stratospheric ozone, or to global warming. MC is a widely used industrial chemical and its health effects have been studied extensively both in animals and through epidemiological studies. It is considered "possibly carcinogenic to humans" (Group 2B) by the International Agency for Research on Cancer (IARC). MC's volatility can result in high concentrations in the production area, requiring careful handling to avoid overexposure. Local and regional exposure and emission regulations vary and may affect the use of this auxiliary blowing agent. MC is capable of replacing CFCs without any significant limitations, at lower costs. The "learning curve", however, can be considerable, as the process is less forgiving. Also, contamination of MC with metals can cause severe scorching. It is recommended to use only a stabilized version ("Urethane Grade"). MC is currently the preferred replacement technology in many countries. However, some countries limit its use based on toxicity concerns.

Acetone: Acetone has been proven fully capable in replacing CFC-11. Precautions must be taken in view of its flammability. Only about 60% is needed compared to CFC-11. Capital outlays and license fees may put the costs close or equal to those of MC.

AB Technology: This technology utilizes the reaction between TDI and formic acid to create an ABA, consisting of equal amounts of carbon monoxide (CO) and CO_2. As this reaction is exothermic, a complete replacement of CFCs is not feasible. Substantial equipment adjustments are needed and monitoring of CO is highly recommended. This technology has been used in a few European plants, but has found no acceptance elsewhere, due to safety concerns and limited applicability. It is believed that most users have in the mean time changed--or are in the process of changing--to other technologies.

Pentane: While proven capable, the flammability of pentane would require extensive safety precautions when used in flexible polyurethane foam. There is currently very limited use of this technology.

Liquid Carbon Dioxide (LCD) Technology: The basic principle of LCD technology is the blending of liquidized CO_2 with other foam components under pressure prior to the initiation of the chemical reaction. This blend is then released and, triggered by the decompression, releases the CO_2, resulting in froth. This froth further expands because of the CO_2 released from the water/isocyanate reaction. While the "wet end" (storage, metering and blending of chemicals) of the process requires considerable modifications to allow the storage and processing of liquefied/pressurized CO_2, the "dry end" (conveyor) remains essentially unchanged. The application of LCD requires the resolution of a number of challenges, which include limited solubility in the PU chemical mixture, controlled decompression, and distribution of the unavoidable froth. Several approaches—ranging from pre-blending to co-blending—are offered. All LCD equipment suppliers have developed patented technologies to manage these issues. Three distinct, proprietary technologies through four manufacturers are currently offered. LCD technology has proven to be commercially viable for a significant variety of foam grades in the 15-35 kg/m^3 density range and applicability to densities as low as 10 kg/m^3 has been claimed (albeit a density associated with high exotherms and not recommended by industry trade associations). Each individual foam manufacturer faces challenges specific to equipment design and product range. Typical problems include achieving high hardness at low density, control of cell structure (pinholes), achievement of optimum block profile, and producing foams with solid particles. Storage can also be an issue and bulk facilities will generally be more appropriate for slabstock processes than bottled supplies. Economically, the use of LCD offers potential savings compared to the use of CFCs based on a lower cost price and higher blowing index. These advantages are to an extent negated by higher cost of other chemicals, energy and maintenance as well as license fees. In addition, a significant learning curve can be expected when introducing this technology. About 100 slabstock production units are currently operating with LCD technology with about 20-30 more in planning or in construction stages. LCD is also widely used where toxicity controls inhibit methylene chloride use.

- Chemical Modifications

Chemical modifications allow water technologies to be more widely used. These modifications have been effectively applied in foam softening, but fall short in density reduction.

Extended Range Polyols: These polyols are able to provide a larger range of foam hardness, and consequently, partially replace CFC-11 as a softening agent. Some do also allow the use of lower TDI indexes, and will therefore lower the exotherm. This allows in addition a reduction of the foam density. However, a complete replacement of CFC-11, while maintaining the full production range is not (yet) possible. Additional metering systems and tanks are needed, and the price of an extended range polyol is higher than conventional polyol. Application is relatively limited.

Additives: Several additives have been developed to modify the chemistry of the flexible PUF production process. These additives are predominantly for softening and do not allow very low densities. Some additives can be used in addition with extended range polyols and reduced TDI index. A special variant of additive technology is the so-called “Low Index/Additive (LIA)

Technology", in which the use of certain additives is combined with a lower TDI index. The application of additive technologies is limited by the relatively high price.

Exotherm Modifiers: one of the functions of an auxiliary blowing agent (ABA) is to reduce the process temperature, in other words, act as a heat sink. Accelerated Cooling technology aims at the same purpose. Recently the use of an organic additive with excellent heat sink properties have been presented (PFA Congress, October 2002, Salt lake City). The powderized additive allows up to 25 ^{0}C reduction in process temperature and allows therefore all-water-based formulations in all densities over 15 kg/m^3 and significant reduction of the use of ABAs in densities lower than that.

The technology provider claims:

- Formulation costs matching or lower than MC as well as LCD technology
- Relatively low related conversion costs
- Improved safety
- Good environmental performance – No organic emissions

The technology provider has applied the technology for more than three years in its own facilities before offering it in the market and produced thousands of tons product. While no other enterprises have yet applied this technology on production scale, many have initiated test programs. The technology is regarded as the most significant recent development in this sector. The technology is offered under license as "Exotherm Management Technology" (**EMT**).

MDI Technology: Water-blown MDI technology is widespread in the manufacture of molded flexible foam because of its inherent softness and lower exotherm, which allows higher water formulations. Several chemical suppliers offer MDI-based flexible PUR systems also for slabstock. Some interesting environmental features are:

- no need for auxiliary blowing agents to achieve softness,
- significant lower isocyanate emissions,
- rapid curing,
- lower exotherm, allowing higher water formulations.

The technology is, however not capable to produce low densities without sacrifices to physical performance. Its use is therefore more focused on achieving better hardness combinations.

- Process Modifications

Several technologies have surfaced, that could be classified as "mechanical" replacement technologies for the use of CFCs in flexible PUR, predominantly slabstock. The "mechanical" technologies allow the integration of the curing area in the emission control, or allow elimination the use of auxiliary blowing agents altogether.

Accelerated Cooling Systems: The process is based on an accelerated dissipation of process energy, which allows increasing the amount water up to a level that permits complete elimination of the use of ABAs for the purpose of density reduction. The chemical costs are reported to be very close to those of MC-blown foams. Capital costs are highly dependent on local layout. There are several proprietary systems on the market that apply this technology in several variations, sometimes including treatment of process emissions. The emergence of LCD technology has decreased the attractiveness of forced cooling technology considerably and the application of this technology is on the decline.

Variable Pressure Systems: It is well known that the blowing efficiency increases with decreased atmospheric pressure. This allows at higher altitudes the manufacture of lower density foams with less or no ABAs through a higher effectiveness of the water/TDI generated CO_2. This principle can be applied at lower altitudes by encapsulating the foam production line and then reducing process pressure. Conversely, the increase of pressure reduces the effectiveness of the water/TDI induced gas generation and in this way allows the generation of higher urea levels (a by product of this reaction). Two equipment manufacturers market this technology as proprietary technology. Six production units are currently in operation with good results and several more in the planning. The capital requirements are high - approximately 2 to 5 million U.S. dollars, depending on the configuration.

Technical Options (Slabstock – Discontinuous)

Chemically, slabstock foams made through a discontinuous process—also called "Boxfoams"—are identical to product made through the continuous process and application of the previously mentioned CFC replacement technologies is only limited by different—more simple—manufacturing equipment.

Methylene chloride is the prevalent CFC replacement technology applied in boxfoam operations. In cases where the use of MC is subject to regulatory limitations or poses process problems, additive technologies are applied, often with a restricted production program, as these technologies do not provide for a full range replacement and are less economical.

LCD technology, while theoretically capable of being applied in boxfoam operations is not (yet) offered for this production process.

The use of forced cooling has been applied but the prevalent production of rather close-celled foams—a method to provide an initial increase in hardness—interferes with the cooling operations and has rendered the introduction of forced cooling in boxfoam operations less than successful.

Several variable pressure technology (VPT) systems target the boxfoam market following essentially the same technology as described before—but in a drastically reduced complexity. There are currently VPT facilities in the USA, Spain, Brazil and several African countries. In total, in excess of 25 plants are installed, but some of the earlier ones may not be operating. VPT provides the only option in boxfoam application to avoid the use of methylene chloride—a substance that is increasingly under regulatory scrutiny and restrictions. Capital outlays are considerable—US$ 300,000-500,000. The process provides significant operational savings because of the elimination of the need for an auxiliary blowing agent, without replacing this by other chemicals.

MOULDED FOAMS

Performance Requirements

Densities of moulded foams are higher than slabstock foams, and there is consequently no concern of excessive process heat. This reduces the need for ABAs and facilitates the application of CFC-free options. Moulded foams can be produced using either "hot cure" or "cold cure" technology. In hot cure and cold cure/primarily TDI-based formulations, CFCs reduce the hardness. In cold cure/MDI-based formulations, CFCs perform also a function in density reduction.

Technical Options – 'Hot Cure'

For hot cure molded PU foams, established replacement technologies include methylene chloride systems, water-blown systems (with the use of an additive) or substitution by water-blown cold cure foams. The use of HCFCs, although technically feasible, is not considered necessary as sufficient technically feasible zero ODP options exist.

Technical Options – 'Cold Cure'

For cold cure foams, established technologies include water-blown systems and auxiliary carbon dioxide. The use of HCFCs, although technically feasible, is not considered necessary, as sufficient technically feasible zero ODP options exist.

The advantages of CO_2 (water) based systems include superior environmental performance (no ODP or GWP), no health and safety hazard, almost unlimited commercial availability and low/no capital outlays. Disadvantages include the potential of increased densities and reduced flow properties of the foam mixture due to higher viscosity. These disadvantages can be overcome by equipment, chemical and process modifications.

Technology based on carbon dioxide—liquefied (LCD) or gaseous (GCD)—as an auxiliary blowing agent is the most important replacement option to have recently emerged. Whilst there are 20-30 LCD units in operation, only a few GCD plants are known to be in operation. This technology provides significant economic and environmental benefits (no ODP, very low GWP or health hazards) and lower foam densities, while essentially maintaining quality. Disadvantages are relatively high initial investment and more complicated process control. The technology can be applied in two ways:

- First, directly through injection in or just prior to the mixing head. This allows instantaneous formulation change and in this way very flexible manufacturing. The maximum amount of CO_2 that can be injected is 3% of the foam mixture. This is equivalent to almost 10% CFC-11 replacement and sufficient to cover most replacement scenarios. The technology is only offered as LCD.

- Second, indirectly through premixing in one of the foam components. This is done preferably in the isocyanate to avoid potential hydrolysis that would occur in the polyol component. As this is in principle a "batch" system--even when effected in the day-tank on a continuous base, no instantaneous formulation change is possible. The tank has to be emptied and refilled with another CO_2 concentration. Also, the control on the CO_2 concentration is more critical as this concentration has to be maintained over a longer period against a tank atmosphere. LCD as well as GCD can be applied. The maximum amount of CO_2 that can be added to the foam formulation is restricted--less than 1%--and this may reduce the technology co-replacement option.

The application of LCD/GCD in flexible molded foams has not shown the rapid development seen in slabstock. This may be related to the fact that the current major CFC replacement technology—the use of CO_2 (water)—does not face regulatory restrictions and requires significantly lower investment.

INTEGRAL SKIN FOAMS

Performance Requirements

This category can be sub-divided in

- Flexible Integral Skin Foams
- Rigid Integral Skin Foams

The major performance requirements in both sectors relate to the following:

- Processability
- Skin formation
- Density
- Cost of processing (e.g. pre-mould coating)

Technical Options – Flexible Integral Skin

The choice of technology is frequently regulation and specification driven. Zero ODP technology is mandated in most industrialized countries, despite drawbacks in performance such as skin quality and density. In countries where no regulations limit the choice, the use of HCFCs (mainly HCFC-141b, which mirrors closely the performance of CFC-11) remains important.

Several specifications, particularly in the EU, favor water-based formulations. Such technology is now available for all applications but may require in-mold coatings (IMC) to be first injected into the mold.

HFC-134a is also used in this application and may also require the use of an IMC to give the required skin quality.

There is also use of n-pentane blown foams for applications such as shoe soles, exercise equipment and steering wheels/instrument panels in trucks, where a very durable skin is required.

Technical Options – Rigid Integral Skin

Water-blown systems are available and commonly used where available. There is minor use of HCFC-141b where water-based systems are not commonly available or where water-based systems do not perform—mostly based on skin problems.

NON-INSULATING RIGID FOAMS

These applications are met by foams manufactured from a variety of processes including spray, pour-in-place, moulding and slabstock. Accordingly, it is difficult to categorise specific alternative technologies for each application.

Performance Requirements

For similar reasons, technical categorization is challenging and difficult in view of the many different and highly individualized requirements. The following breakdown is an approximation:

- Semi-Rigid Foam
    - Packaging Foam
    - Floral Foam
    - Energy Absorbing Foam
- Rigid Foam
    - Low Density (i.e. floatation devices)
    - Medium Density (i.e. cornices)
    - High Density (i.e. wood imitation)

Technical Options

All applications have moved predominantly to all-water-base systems with minor applications of HCFCs in low-density rigid foams for floatation devices (HCFC-22) and floral foam (HCFC-141b), and some methylene chloride in packaging foams.

SUMMARY

The following table provides a summary of the current status and future trends for technologies in the Flexible PU Foam sector.

SECTOR	TECHNOLOGIES	
	CURRENT	TREND
SLABSTOCK	MC, Acetone, VPT, LCD, LIA	LD, VPT
BOXFOAM	MC, VPT, LIA	MC, VPT
MOLDED FOAM – HOT CURE	MC, Water/CO_2	Water/CO_2
MOLDED FOAM - COLD CURE	Water/CO_2, LCD/GCD	Water/CO_2
INTEGRAL SKIN – RIGID	Water/CO_2, HCFC-141b	Water/CO_2
INTEGRALSKIN – FLEXIBLE	Water/CO_2, HCFC-141b, HFC-134a, Hydrocarbons	Liquid HFCs, HFC-134a, Water/CO_2
NON-INSULATION RIGID	Waer/CO_2, HCFC-22, -141b, MC	Water/CO_2

EXTRUDED POLYSTYRENE

EXTRUDED POLYSTYRENE SHEET

Performance Requirements

The major uses of extruded polystyrene sheet are in the food packaging sector, where there is a requirement for basic thermal insulation and resilience. However, as these are not difficult to attain with extruded polystyrene sheet, there is little dependence on the blowing agent to contribute in final product performance. Accordingly, if processing characteristics can be maintained, there are several other blowing agents available for use.

Technical Options

Use of CFCs or HCFCs, is considered technically unnecessary in both non-Article 5(1) and Article 5(1) Countries and have been banned by a significant number of these countries. A wide range of alternative blowing agents have been evaluated for use in polystyrene sheet foam including atmospheric gases (carbon dioxide, nitrogen), hydrocarbons (butane, isobutane, pentane, isopentane), HFCs (HFC-134a, HFC-152a), and hydrocarbon/CO_2 (LCD) blends.

- Zero OPD Technologies

Atmospheric Gases--CO_2 (LCD) is considered a technically proven, licensable technology and remains as a viable alternative. Some have claimed it to be a higher cost alternative to hydrocarbons when the license package costs are included. Nitrogen gas is very insoluble, produces small-celled, high density foam that is not dimensionally stable. It is difficult to process and very difficult to make high quality foam. For these reasons, nitrogen is not recommended as a viable zero-ODP option.

Hydrocarbons (butane, isobutane, pentane, and isopentane)--Hydrocarbons produce good quality foam sheet and are relatively low in cost. Due to their high flammability, stringent safety precautions in manufacturing, storage, handling, transport and customer use are imperative. These safety measures should include periodic safety audits to ensure continued compliance by all. Hydrocarbons are volatile organic compounds (VOCs), contribute to ground level ozone and smog and are regulated in many regions. Capital (emission control, safety equipment) is a usual requirement to convert to this category of alternative.

Hydrofluorocarbons (HFC-134a, HFC-152a)--HFCs have been implemented by some foam sheet manufacturers. HFC-152a is flammable requiring equipment modification and safety precautions. No VOC emission controls are necessary. This classification of alternative is significantly higher in cost than CO_2 or hydrocarbons.

Hydrocarbon / CO_2 (LCD) blends -- Although blends are definitely viable, few manufacturers are employing them. Difficulties of additional equipment for storage, transfer and emission control are a few of the drawbacks of this alternate technology.

EXTRUDED POLYSTYRENE BOARD

Performance Requirements

As the major application for extruded polystyrene board is in thermal insulation for buildings, there is a distinct requirement to optimise thermal conductivity at all times. This is particularly the case in the highly competitive domestic markets served by the product in the United States. As an additional challenge, the blowing agents are of much greater processing significance in board production and the right solubility characteristics are a key factor in successful production. Finally, density needs to be carefully controlled to avoid undue influence on cost and fire loading. All in all, the performance requirement of a blowing agent in extruded polystyrene board is greatly contrasting to that in its ‘sheet’ counter-part.

Technical Options

- Low ODP Technologies

HCFC-142b and HCFC-22 remain the primary transitional blowing agents for extruded polystyrene boardstock insulation across most of the world because of their important contribution as insulating gases in the product. The high insulation value obtained helps to reduce and mitigate the amount of carbon dioxide (CO_2) produced from fossil fuel combustion in the home and commercial heating contribution sectors of the global climate change challenge. Although some zero-ODP alternatives are commercially available, performance requirements, inability to produce a wide enough product mix, loss of insulation value, poor processability, dimensional instability, low density foam capability, economic viability and commercial availability cannot be met for all products in all markets at this time.

- Zero ODP Technologies

Potentially viable zero-ODP alternatives for extruded polystyrene boardstock are the following: HFC-134a, HFC-134, HFC-152a, HFC / CO_2 (LCD) blends, CO_2 (LCD)/ Organic Blowing Agents (i.e. ethanol), 100% CO_2 (LCD) and hydrocarbons in limited applications.

Technical advantages / disadvantages of each of these systems include:

HFC-134a--Availability and comparative economic viability versus other zero-ODP alternatives will cause HFC-134a to be seriously considered as an HCFC replacement. Lack of solubility during manufacture (causing inability to produce a full product mix along with higher densities), along with higher raw material prices compared to other HCFC alternatives will be deterrents. Flammability is of little concern during manufacture, storage and use. Equivalent insulation performance to HCFCs can likely be maintained. Work continues on processability and the ability to make cost effective insulation.

HFC-134--As an isomer of 134a, HFC-134 possesses greater solubility in polystyrene. It diffuses from the foam more rapidly than HFC-134a, consequently greater starting concentrations must be used to achieve equivalent long-term insulation values. HFC-134 is more expensive to produce and when coupled with the need for higher concentration makes this option unattractive economically. No producer has planned to commercialise this product at this time.

HFC-152a--HFC-152a as an alternative in extruded polystyrene boardstock holds no technical advantages over HFC-134a. Limited producer activity will cause this alternative to be higher cost than HFC-134a. HFC-152a is flammable, requiring capital expenditure for storage, processing and safety considerations.

HFC / CO_2 blends--CO_2 (LCD) when combined with either HFC-134a or HFC-152a has potential to reduce overall blowing agent system costs. CO_2 itself has poorer solubility than HFCs in polystyrene consequently production of a wide-enough product mix at low densities is even further challenged. It will however continue to be explored by industry because of its' potential as an attractive economic zero-ODP alternative.

CO_2 / Organic Blowing Agent blends (i.e. ethanol)--Organic blowing agents combined with CO_2 (LCD) produce lower density, full cross-section products. The organic blowing agents (i.e. ethanol) are usually flammable (requiring capital electrical upgrades), are volatile organic compounds (VOCs), requiring emission controls in many regions and produce foam having 10-15% lower R-values than those containing HFCs.

100% CO_2--While this option is the most environmentally preferred, it is the most difficult technically to perfect and commercialise. Today, product mix breadth is limited and foam densities are higher than producers can tolerate economically. Significant capital investment is required to convert to CO_2 (LCD) capability. In addition to capital investment, heavy research and development time is needed to work on these formulation disadvantages. Thermal efficiency is also reduced by 10-15% over conventional HCFC technology.

Hydrocarbons (butane, isobutane,)--Hydrocarbons produce exhibit good processability, because of their solubility in polystyrene and are relatively low in cost. Due to their high flammability, stringent safety precautions in manufacturing, storage, handling, transport and customer use are imperative. These safety measures should include periodic safety audits to ensure continued compliance by all. Hydrocarbons are volatile organic compounds (VOCs), contribute to ground level ozone and smog and are regulated in many regions. Capital (emission control, safety equipment) is a usual requirement to convert to this category of alternative. Their largest drawback resides in product performance; - namely flammability and loss in thermal efficiency.

HFCs will likely remain an important option for parts of the product mix where flammability, dimensional stability constraints and thermal performance are key properties that must be met.

POLYOLEFIN FOAM

Performance Requirements

One of the primary criteria in blowing agent selection is the ability to match the diffusion rate of blowing agents out of the foam with the diffusion rate of air into it. This match is necessary because the polyolefin resins are resilient. If the diffusion rates are not sufficiently matched, the foam will either shrink or expand while ageing. This is unacceptable in all three product types: sheet, plank and tubular. Permeability modifiers can sometimes be used to help match these diffusion rates where they are reasonably close but not acceptably so.

Technical Options

- Low ODP Substitutes

Initially the sole option for polyolefin foam producers was to move to hydrocarbons either via HCFC-142b or HCFC-142b/22 blends, in an attempt to preserve, especially in the cushion packaging area, traditional physical properties, or, as typically the case for new entrants to the market, directly. With the experience which now exists, it is possible to convert directly from CFCs to hydrocarbons. This will be further discussed in the next section.

- Zero ODP Substitutes

The usual choice is a blend of normal and isobutane. Some pentane is also used.

Hydrocarbons are flammable. For example, isobutane flammability limits are about 1.8 to 8.4 volume percent in air with an extremely low energy of ignition. This situation requires the careful consideration of proper processing equipment upgrades along with appropriate safety procedures and equipment in manufacturing, storage, handling, and shipment of the product. Periodic safety audits should be performed to ensure full worker compliance. Removal of flammable gases (e.g. through perforation) from the foam in order to ensure safe transport, storage and use in an economically viable time period represents “best available technology” that is patented and licensable. In addition, hydrocarbons are volatile organic compounds (VOCs) that are regulated in certain regions. Emission controls would be required in these areas.

It is very difficult to make extruded polyolefin foams using HFCs 152a and 134a alone. To facilitate meeting VOC emission requirements, HFC-152a is sometimes used in combination with hydrocarbons.

- Other Theoretical Options

Carbon dioxide, nitrogen and other inorganic gases have very low solubility in the resins and have only very limited use in extruded polyolefin foams. In addition, process pressures will be very high, typically beyond the capability of most processes without significant or prohibitive capital expenditure. These volatile gases are, however, being used in some mouldable bead products where the process pressure problem can be overcome.

Carbon dioxide diffuses rapidly out of polyolefin foams and causes massive dimensional stability problems. Without some, as yet unidentified, enabling technology, carbon dioxide, except as a very minor component of the blowing agent system, is simply not an option.

CO_2, nitrogen and other inorganic gases thus remain theoretical options only for the bulk of today's polyolefin foams applications.

PHENOLIC FOAM

Performance Requirements

Phenolic foams are differentiated by three key criteria:

- Good reaction to fire properties
- Very low thermal conductivities (arising from the use of emulsion technologies)
- Extremely low inherent smoke generation.

The selection of alternative blowing agent therefore has to maintain these properties in both continuous and discontinuous processes.

Technical Options – Continuous Processes

- Low ODP Technologies

HCFC-141b continues to remain the predominant blowing agent in use for the continuous lamination of phenolic insulation foams. In some technologies it needs to be used with a small proportion of perfluorocarbon to stabilise the cells in view of the increased solubility of HCFCs in the foam matrix. It looks unlikely that this approach will be required for the future use of HFCs in phenolic foam because their solubilities are already lower.

One European continuous laminate technology makes use of 2-chloropropane as the blowing agent. Although this does not provide such good thermal conductivity properties as HCFC-141b it has a significantly lower ozone depletion potential of 0.002. This technology has been in the market place since the early 1990s and is not likely to be more widely used in future because of a trend towards stricter fire requirements in the sector served by laminated products.

- Zero ODP Technologies

Liquid HFCs and blends thereof

In previous FTOC reports, the key zero-ODP options for the phenolic sector were defined as liquid HFCs and hydrocarbons. In the intervening period more attention has focused on HFC-245fa and HFC-365mfc as both products are now becoming more readily available. HFC-365mfc is being particularly paired with HFC-227ea for flammability and processing reasons. However, significant confirmatory work on continuous processes using these blowing agent options is still required. Of course, the eventual commercial price of the materials will be an additional critical factor for the industry.

One further option that has also been assessed is the blending of liquid HFCs with small quantities of hydrocarbon (n- or iso-pentane). However, to maintain the non-flammable performance of the blend, the level of hydrocarbon used has to remain below 8% by weight. Even at this level the blowing contribution is significant (around 15%) because of the higher efficiency associated with hydrocarbons.

Hydrocarbons

End-product fire performance continues to be the chief concern for closed cell hydrocarbon phenolic foams and the uncertainties surrounding the future harmonisation of European fire regulations have only served to heighten this. Additional concerns are also arising from strengthening VOC legislation in certain parts of Europe and North America that are pressuring existing hydrocarbon users in related industries.

A significant additional factor in the selection of hydrocarbons as a blowing agent for phenolic foam remains their poorer thermal efficiency. Current estimates show a 5-20% reduction in thermal efficiency over existing HCFC-141b blown foams and this has, to some extent, been transferred also to the HFC comparison. Obviously, such thermal efficiency differences are at their most influential in applications where thickness is restricted. Nonetheless, the lower cost of hydrocarbons can offset many of these drawbacks where performance requirements are less restrictive and some producers have already adopted this option.

This is specifically the case in Japan where one producer has invested substantially in a new ‘state-of–the-art’ facility to produce hydrocarbon-blown foams for the domestic housing market. As with all such investments, the key to success is a comprehensive understanding of the prevailing standards and classification requirements and a full knowledge of product performance against these.

Finally, a mention of 2-chloropropane is appropriate. Although the blowing agent has a finite ozone depletion potential of 0.002, it is not a controlled substance under the Montreal Protocol and is, therefore, considered a long-term substitute. This treatment is consistent with that given to other very low ODP materials. On this basis, it is likely that the blowing agent will continue to be used by at least one continuous laminate producer in Europe. However, as noted previously, it is unlikely that 2-chloropropane will ever have widespread use in the phenolic or other foam sectors.

Technical Options – Discontinuous Processes

- *Low ODP Technologies*

The situation is the same as for continuously laminated foam.

- *Zero ODP Technologies*

Again, the situation is the same as for continuously laminated foams. However, the possibility of using blends of HFC-245fa, HFC-365mfc and other HFCs or hydrocarbons will be more important in this sector because of process sensitivity to boiling point.

For hydrocarbons, the comments are as for continuously laminated foam with the exception that the fire issues are even more critical. Foam fabricated from blocks is often used for heating and ventilating applications in exposed locations within public buildings or for petrochemical plants. The maintenance of product fire properties is therefore critical.

APPENDIX 4: END-OF- LIFE PRODUCT CONSIDERATIONS

BASELINE EMISSIONS ESTIMATES FROM FOAMS

Although the Montreal Protocol is fundamentally a consumption-based control, it is recognised that the rate of emission of CFCs and HCFCs from applications is the key factor in assessing the impact of these ozone-depleting substances on the stratospheric ozone layer. While many applications lead to immediate emission (e.g. aerosols), the nature of rigid insulation foams is such that, in many applications, the blowing agent remains in the foam for extended periods. Depending on the lifetime of the application, this can be upwards of 50 years in some cases. Accordingly, much of the foam manufactured using CFCs in the period 1960-1995 is likely to be still in use today. This provides a substantial opportunity for recovery of blowing agent at end-of-life. However, to assess this opportunity and to focus recovery activities in the most appropriate places, it is important to be able to model anticipated retention levels in differing product types.

In assessing emissions from foams, it is recognised that there are three prime phases in which emissions can occur. These are:

- Foam production and installation (first year losses)
- Installed foam during its use phase
- Decommissioning at end of life

Depending on the application and product type in question, these areas of emission (known as emission functions) can vary substantially. In view of the increasing importance being placed on quantifying emissions (particularly under the operation of the Kyoto Protocol), there has been increased interest over the last few years to develop appropriate emission functions for a variety of product types and end uses.

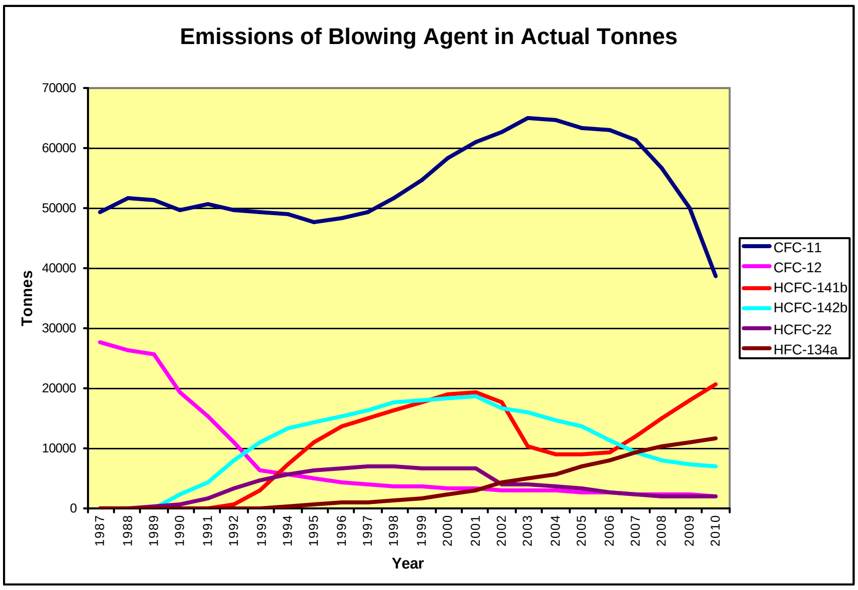
As part of an on-going study carried out for AFEAS over the past five years, the following emission functions for various foam applications have been derived and refined:

Table A4-1: Emission functions derived for various foam types and applications

Foam Type	First year release (%)	Release Rate (%/yr)	Time to Total Release[1] (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 applications where there are significant amounts of ozone depleting substances to recover at end-of-life are shaded yellow in Table A4.1. The retention within domestic appliances is particularly high because of the metal/plastic encapsulation of the foam. These retention levels have been verified by the appliance industry through cross checks on 25 year-old units blown with CFC-11. Using these basic emission functions and the historic usage patterns of CFCs and HCFCs within the various foam types and applications, it is possible to create a projected emission pattern of the type shown in *Figure A4:1* below:

Figure A4:1: Projected emissions estimates for various CFCs and HCFCs to 2010



*Figure*Figure A4.1 should, however, be used with caution because it assumes that, at the end of design life, release of the encapsulated CFC is instantaneous which, in reality, it certainly is not. There are two categories of reason why this is not the case:

(1) Incidental outcomes of non-intervention at the end of design life

(2) Specific initiatives to reduce emissions at the end of design life

In essence, these two categories summarise two alternative strategies best defined as ‘leave well alone’ and ‘manage all end-of-life processes’. At their extremes, both of these routes can be highly effective in minimising emissions. In reality, however, even the processes of landfill and other apparently non-interventionist approaches have impacts on emissions because of poor handling and the damage resulting. Similarly, interventionist approaches such as mechanical recovery need to be highly engineered to avoid accelerating emissions unduly. These issues are addressed in more detail in the next section. Suffice it to say for the moment, that the emission profile shown in Figure A4:1 represents a genuine ‘worst case’ scenario at end-of-life. Nonetheless, the graph provides a good indication of the potential scale of the emissions challenge over the next eight years. Even in 2010, there is still likely to be well over 1 million tonnes of CFC-11 remaining in rigid foams globally even assuming that most blowing agent in refrigerator foam in developed countries has been either dealt with or released by that time. The distribution of this CFC-11 is indicated in FigureA4:2 below:

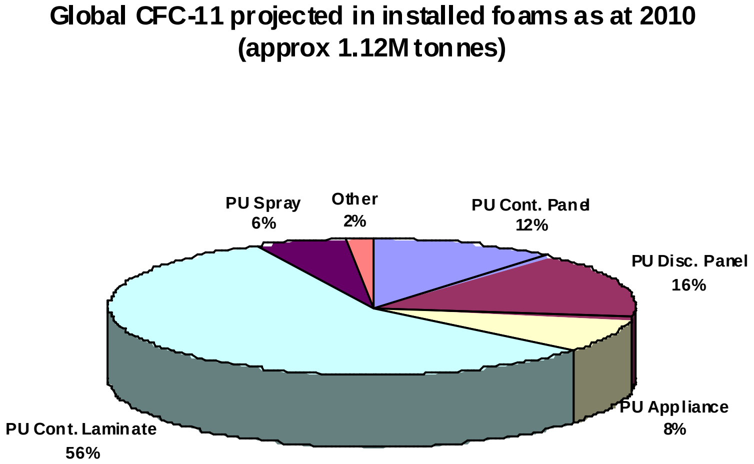


Figure A4:2: Remaining CFC-11 in installed foams at 2010

Although this is a very significant quantity, it is worth reflecting that, at their peak CFCs were being sold into the rigid foam sector at over 200,000 tonnes per annum. Accordingly, the projected CFCs remaining in 2010 represents around 5 years worth of peak supply.

An interesting further fact is that the burden of recovery, particularly in the appliance sector, will have switched from developed to developing countries. Figure A4:3 illustrates the likely split of CFC-11 banks in 2010. This split does not take into account any trade which may have taken place in second-hand refrigerators exported from developed to developing countries for re-use. The picture illustrates the importance of phasing out the use of CFC-11 in refrigerator plants in developing countries at the earliest possible opportunity. The current data set was compiled in 1998 on the basis of the best available information on transitioning at that time. Further work is now required to determine how these projected CFC-11 banks in 2010 might be altered by the latest projections for CFC phase-out.

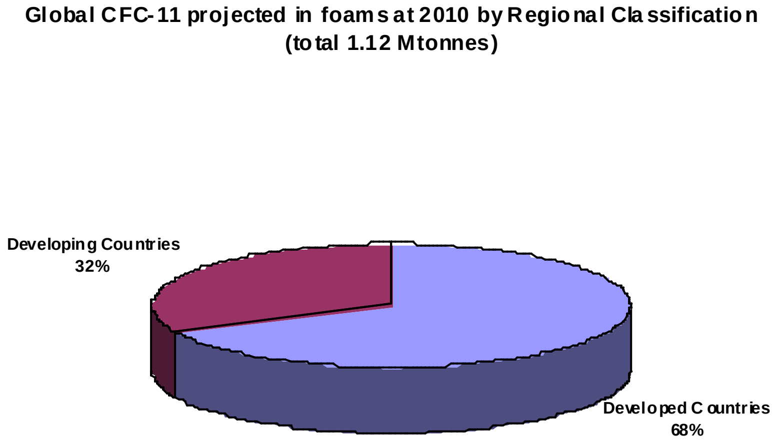


Figure A4:3: Remaining CFC-11 in foams by Regional Classification

OPTIONS AT END OF DESIGN LIFE

Blowing agent recovery, while not mandated under the Montreal Protocol, has been recognised by many Parties as worth pursuing and several initiatives have been taken at national and regional level to take advantage of the excellent blowing agent retention of many rigid foam applications. However, the physical challenge of retrieving the installed foams from within structural building projects and other equally inaccessible locations has led to some severe questions about the practicality and cost effectiveness of such initiatives. In contrast, foams within domestic and small commercial refrigerators and freezers are considerably more accessible, particularly where units are already collected for recovery of refrigerant or for other material recycling reasons. Nonetheless, the potential for recovery of blowing agents from any foam source depends on the following factors:

- Quality of the foam cell structure and resulting diffusion rates
- Solubility of the blowing agent in the matrix
- Thickness of foam sections
- Types of facing materials
- Other materials adhered to the foam or facing materials

It is important to note that blowing agent recovery need not necessarily be undertaken at the end of a product’s designed use, since secondary usage can be a serious option in some cases. In addition, any attempt to recover blowing agent, even when mandated by regulation, will not be 100% effective. The following flow-chart (Figure A4A4-4) illustrates the ‘real life’ material flows for foamed products, including continued losses through abandonment and landfill:

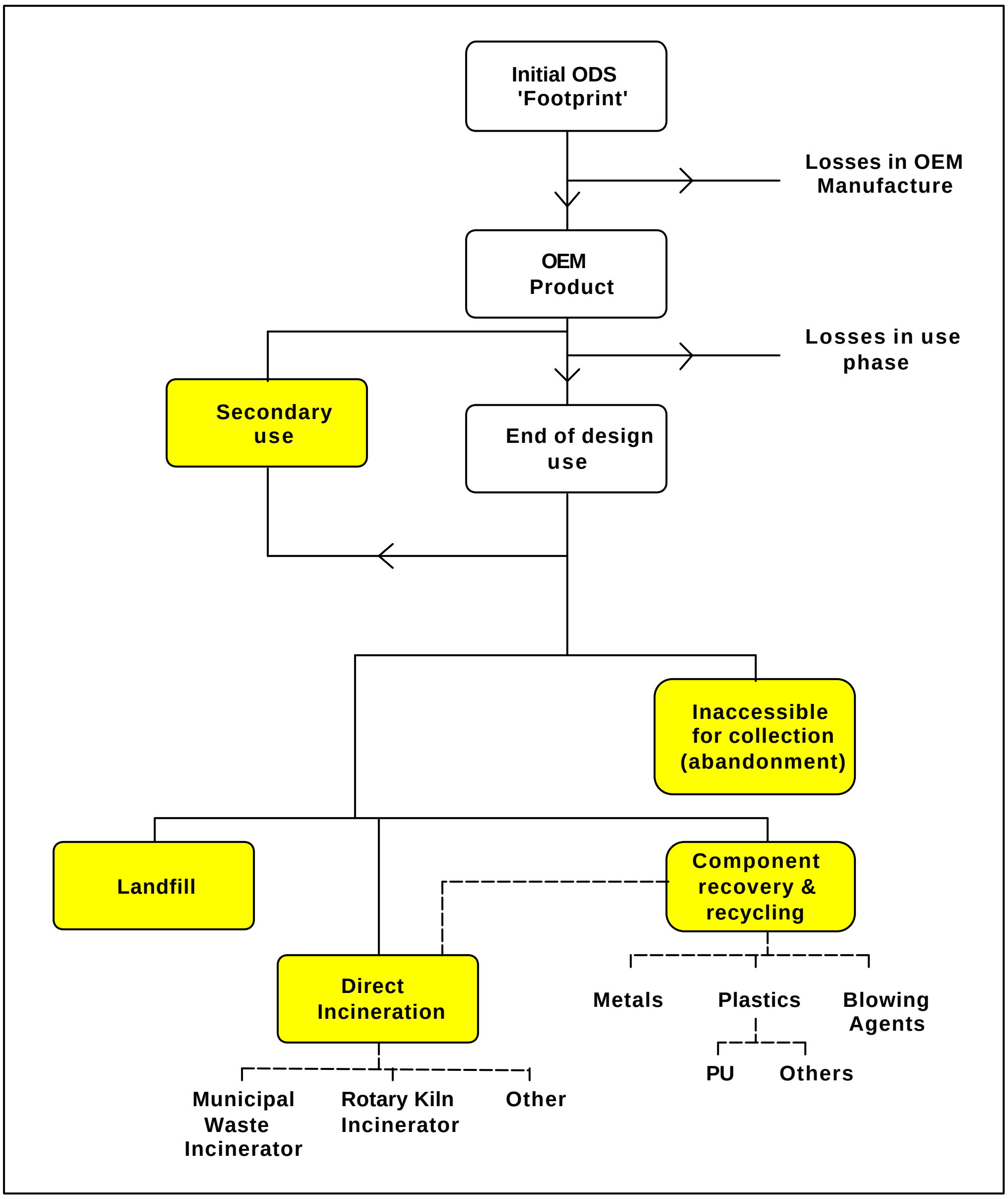


Figure A4:4: Typical Lifecycle and Disposal Routes for Foam Products

The flow-chart illustrates that there are five prime end-of-life scenarios for foams (shaded yellow). These are:

- Abandonment
- Secondary use
- Landfill
- Direct incineration (with energy recovery)
- Component recovery and recycling/destruction

Each of these scenarios is dealt with in turn in the next paragraphs.

ABANDONMENT

Abandonment is a fact of life and will continue to be so, even within the most stringent regulatory framework. In general terms, there are two sources of the problem:

Accidental : – This arises when the foam in question is inaccessible or in cases where its presence is unknown and/or undetected

Deliberate : - This occurs when, for reasons of economy or social irresponsibility, the foam in question is disposed of in an uncontrolled fashion.

Quantifying the amount of foam abandoned in any application or region is extremely difficult because, by its very nature, it is uncontrolled. The only known method of gaining some insight into the practice is from the experience of local authorities called to clear up 'fly tips' and other impromptu collections of disposed waste. Even in these cases, it is seldom that the collection is either systematic or quantitative. Accordingly, it is typically necessary to make an assessment of abandoned foam products by inference from other data sources. However, this is inevitably an approximation because the precise amount of foam being decommissioned either accidentally or deliberately is never completely known.

While absolute values are difficult to specify, trends can be easier to spot. In some, but not all, societies, the tendency towards 'fly tipping' increases with the regulatory and, most importantly, financial burden placed on the individual disposing of the foam in question. Thus, if some sort of disposal tax is charged, there can be a reaction from the general public and individual corporations against incurring these costs resulting in the disposal of the foam in an uncontrolled manner. However, this is less the case in more disciplined and responsible societies such as Japan, where charges for disposal can be made to work.

To avoid such behavioural effects, the more widely used approach is to incorporate any element of disposal taxation into the purchase price of a replacement unit. This works particularly well if the tax can be sufficiently well targeted to apply only to the products leading to a disposal problem. However, more typically it will not be possible to focus taxation measures so tightly and the tax may only act as a general disincentive to replace existing products. This can be environmentally counter-productive if less energy efficient products are currently in use.

As developed later, much of the current regulation governing disposal is driven not only by consideration of ODS recovery but also by more comprehensive resource recovery targets for recycling. In this case, more widespread taxation is justified.

SECONDARY USE

The ability to re-use a foam-based product depends on the way it is manufactured and installed in the first instance. The prime requirement for such a product is that it can be transposed from one application point to another without disrupting the integrity of the product itself. Historically, such characteristics have been the preserve of genuinely self-contained items such as refrigerators and, indeed, a significant trade in second-hand refrigerators has developed across regions of the world. Additionally, there is a significant trade within a country where units are sold on to poorer sections of the population. Nonetheless, the most common occurrence with refrigerators is their continuing use within a household after a new unit has been purchased.

Where units are traded between the Article 2 and Article 5(1) or CEIT countries, this practice has created a dilemma for regulators under the Montreal Protocol. On the one hand, the units provide access to improved standards of living for many residents in developing countries at affordable prices. In addition, the practice is a classic example of extending the use period of a product and avoiding premature obsolescence. On the other hand, the practice often extends the use of less energy efficient equipment and effectively exports a future disposal problem to a developing country. This latter problem is of particular significance in the case of refrigerators using CFC refrigerants where rapid fugitive emission is more likely than with the foams themselves. In general, the Ozone Regulators in developing countries have come down against the practice of such trade and this position has now been supported by the prohibition of exports of used refrigerators from the European Union under the recent Regulation 2037/2000. The decision, however, remains a controversial one and even some environmental NGOs consider that it would be better to maintain the trade and install suitable recovery equipment for end-of-life management. The practicality and cost of so-doing remains the key barrier.

Another opportunity for life extension is the potential for re-use of building insulation elements. The growth of use of PU composite panels in Europe points strongly to the cost-effectiveness of this approach in the first instance with the added value of being able to dismantle these elements from the supporting structure and re-using them at the end of the building's life. Obviously, such practice assumes that the effective lifecycle of the insulation element itself will be longer than the building in which it is used. With the performance standards of these elements increasing progressively and the duration of practical building utility decreasing, the assumption is becoming ever more applicable.

LANDFILL

Landfill has been the traditional destination of most of the foam products decommissioned over the last 30 years, including many products containing CFCs and HCFCs. Although the regulations surrounding the location and management of landfills has improved considerably over this period, there is still little measurement or control of specific materials entering into a given site in many countries. The exception in this respect is where materials are determined to be hazardous or special waste (e.g. asbestos based). In these cases, regulatory controls have increased substantially. For example, regulations in several European countries prohibit the landfill of combustible materials. This is already the case in the Netherlands, Sweden, Denmark and Switzerland. Austria and Germany will follow in 2004 and 2005 respectively. The new EU Directive will prohibit the placing in landfills of materials of high carbon content, which will include foams.

One of the options for monitoring the movement of CFC and HCFC-containing foams onto landfill sites would be to classify the material as hazardous or special waste. In some countries, this has been done and with significant effect. In other countries, thresholds have been set for foams to qualify as hazardous or special waste (typically at 5% by weight of CFCs). However, because the composition of foam waste is not easily determined, and is not instantaneously recognisable from its exterior appearance, such thresholds are hard to apply in practice.

In general, the attitude of a Party to the prospect of landfilling foams is largely dependent on their wider approach to landfilling as part of their waste strategy. In the United States, for example, there is such substantial capacity for landfill that it is unlikely that alternative strategies will be pursued unless the case for better control of CFC emissions from landfill is compelling. Nonetheless, there are bans on the landfilling of refrigerators in 13 states. To further understand the effects of the landfilling of foams, the American Home Appliance Manufacturers (AHAM) commissioned a study at the Danish Technical University (DTU) in 2000 to investigate the rate of emission of CFCs from shredded foams[21]. The study has produced two key conclusions that are relevant to this discussion:

- That blowing agent releases from the shredded foam are not high during the first six weeks after cutting
- That the rate of release is highly dependent on the particle size of the shredded element

A further conclusion from a separate study conducted by the DTU shows that there are anaerobic mechanisms whereby CFCs can be largely broken down by enzymes and bacteria. This has the effect of restricting the ultimate release of CFCs to the atmosphere

These are important conclusions when considering the future role of landfill activities in the management of CFC and HCFC containing foam. However, issues such as the identification of the breakdown products resulting from the anaerobic degradation of the halocarbons needs to be addressed before this method of approach can be endorsed fully.

Of course, in the case of refrigerator cabinets, there is an even stronger argument for the disposal of the cabinet in its manufactured form rather than in shredded or crushed form, since in its manufactured form the rate of release in disposal will be no different to its rate of release in use. On the basis that the major issue influencing the recovery of the ozone layer is not specifically the total chlorine loading emitted but the rate at which it is emitted, there is a school of thought which suggests that it is better not to disturb the CFCs in disposed foams unless and until cost-effective techniques are available to recover the blowing agent *without any risk of fugitive emission*.

DIRECT INCINERATION (WITH ENERGY RECOVERY)

Direct incineration of foams is distinguished from other incineration options by the fact that, in the case of direct incineration techniques, no attempt is made to separate the foam matrix from the blowing agent prior to incineration. There may be some accidental separation in some facilities as pre-shredding takes place prior to feeding into the incinerator.

In the context of the Montreal Protocol, the destruction of blowing agents in this diffuse form has been less well studied than for concentrated and re-concentrated streams of ODS. This has led

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[21] 'Determination of the fraction of blowing agent released from refrigerator/freezer foam after decommissioning the product' *Kjeldsen & Scheutz (2002)*

to the TEAP Task Force on Destruction Technologies (TFDT) assigning a relatively cautious minimum Destruction and Removal Efficiency (DRE) of 95% for qualifying processes. Even with such a low threshold, only two processes have been shown to meet the requirements – namely Municipal Solid Waste Incineration and Rotary Kiln Incineration. These two stand out from the many other theoretical options because they have the ability to handle solid waste streams. Reactor cracking facilities may also provide potential in future, but there is little available data as yet on this process.

Despite the caution of the TFDT, work in Europe as early as 1993 indicated that destruction of diffuse CFC-11 in a Municipal Waste Incinerator was 99.95 ± 0.04% when processed in the temperature range of 800-1100C. This compared with a destruction efficiency of 99.97 ± 0.03% for concentrated and re-concentrated sources.

More recent studies such as that carried out at the Karlsruhe Facility (Tamara) used construction foams containing significant quantities of fire retardant to demonstrate the granulated foams up to 3% by weight of waste feed (30% by volume) could be disposed of at a rate of 146 to 225 kg/hr. Destruction efficiencies for other ODSs were observed to augment the original 1993 data on CFC-11. The results showed that the CFC-12 DRE exceeded 99.9% at 900C, while both HCFC-22 and HCFC-142b achieved 99.99% levels at 850C, reflecting the overall lower stability of the hydrogen containing ODSs.

In Japan there is also considerable experience with rotary kiln incinerators, which are often used destroy foam outputs from closed shredding units without prior separation of blowing agent from the foam matrix.

Figure A4:5 illustrates the process. Test reports on trials carried out in March 2000 by Matsushita (Panasonic) and Dowa Mining Company show destruction levels of better than 99.95%.

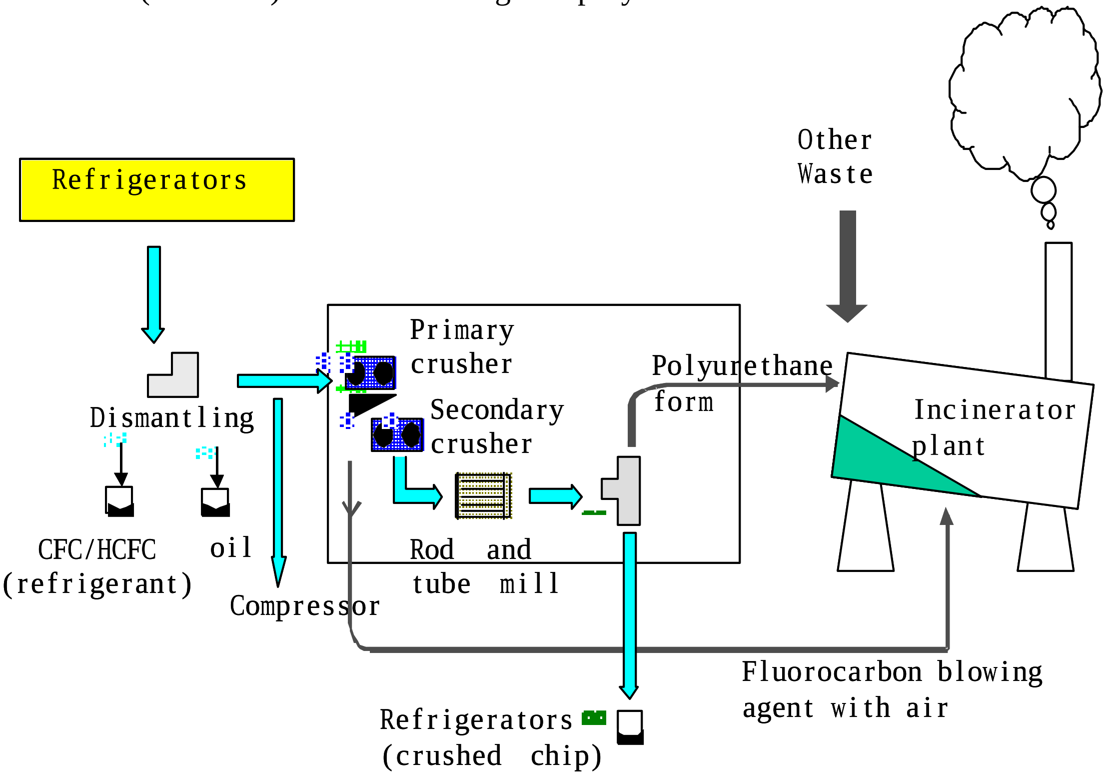

Figure A4-5: Direct Incineration from shredded foam

Direct incineration of complete refrigerators has been applied, both in the Netherlands and in Denmark.

Recent information suggests that one facility in the Netherlands has ceased processing refrigerators in this way because of the problems with slag build-up. Where the technique continues to be practiced (e.g. in Denmark), throughputs are kept at a low level.

In summary, therefore, direct incineration is seen as a viable method for the destruction of foams and is particularly effective where the foam can be separated from other components prior to incineration. Costs depend significantly on the available capacity for MSW incineration, but the technique can be highly competitive if the capacity is available.

COMPONENT RECOVERY AND RECYCLING/DESTRUCTION

This method of handling foam waste has grown in technical integrity and environmental acceptability during the 1990s as the demand for high levels of material recycling has increased. This is particularly the case for domestic refrigerators where the concentration of metals and other plastics is of significance to national recycling targets. Indeed, in Japan, the current legislation demanding the component recovery from domestic appliances is driven by material recovery and recycling targets rather than by the management of ODSs. Similar pressures are likely in Europe as the WEEE Directive is introduced within the next 2-3 years. A distinction between the regions is that, in contrast with Europe, ODS recovery from appliance foams in Japan remains voluntary. Nonetheless most responsible investments already include the facility to recover the blowing agents. It is likely that such recovery will become mandatory in Japan in the near future – at the very least for refrigerators. In Japan, there is also a project underway investigating the economic and technical feasibility of recovery from buildings. Such a step would be unique in the world, since most other regulators have viewed the economics of recovery from buildings as, at best, marginal. The current European Regulation (2037/2000) which is viewed as progressive in this area only calls for the mandatory recovery and disposal of ODSs in domestic and commercial refrigerators, leaving the recovery of blowing agents from building products only required 'if practicable'. This phrase carries with it both technical and economic connotations and provides an opt-out for most European Member States at this time. However, the growth in use of pre-fabricated elements in building construction could potentially increase the practicability of blowing agent recovery (and possibly product re-use) over time. Accordingly, the mechanisms for collection and recovery of building waste will become increasingly visible in the next 5-10 years.

The history of mechanical recovery technology development has not been an unqualified success, with prototype units achieving recovery levels of less than 30% in the early 1990s. Viewed in isolation, it is self-evident that it would have been better to have left many refrigerators untouched rather than to accelerate the release of 70+% of the blowing agent in this way. Nonetheless the early equipment short-comings led to further developments and the state-of-the-art units of today can reach levels of recovery well in excess of 90% routinely. A typical plant design is shown below in Figure A4:6.

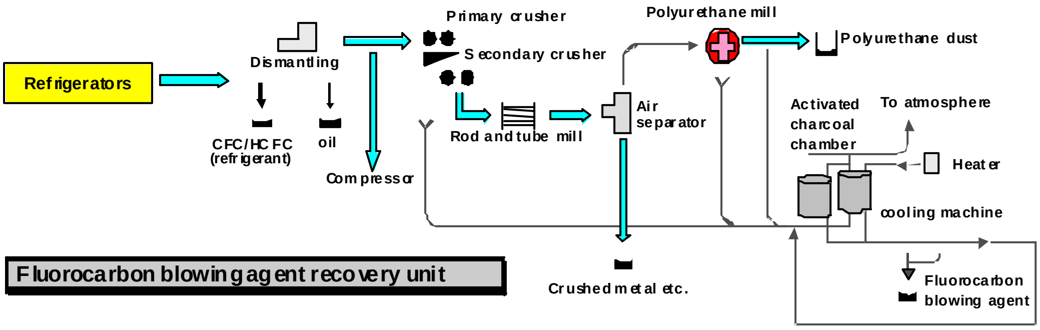

Figure A4:6: A typical mechanical recovery plant

Annex 1 of the TEAP Task Force Report on Collection, Recovery and Storage is dedicated specifically to the definition of current good practice and the reader is encouraged to look there for further information.

After mechanical recovery of the ODS, the PU foam material can follow several recovery routes. If the foam is pure enough it can be recycled into e.g. pressboards, light weight insulating mortar or re-used as oil-binder. If the foam cannot be mechanically recycled it can be incinerated for energy recovery (e.g. in MSW, cement kilns, etc) or used in feedstock recycling technologies such as gasification or in blast furnaces together with other organic rich fractions.

APPENDIX 5: ALLOCATION OF COUNTRIES TO REGIONS

Latin America and the Caribbean (LAC)

Antigua and Barbuda
Argentina
Bahamas
Barbados
Belize
Bolivia
Brazil
Chile
Colombia
Costa Rica
Cuba
Dominica
Dominican Republic
Ecuador
El Salvador
Grenada
Guatemala
Guyana
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and The Grenadines
Suriname
Trinidad and Tobago
Uruguay
Venezuela

Middle East/North Africa (MENA)

Algeria
Bahrain
Egypt
Iran, Islamic Republic of
Iraq
Israel
Jordan

	Kuwait Lebanon Libyan Arab Jamahiriya Mauritania Morocco Oman Palestine Qatar Saudi Arabia Syrian Arab Republic Tunisia Turkey United Arab Emirates Yemen
Sub-Saharan Africa (SSA)	Angola Benin Botswana Burkina Faso Burundi Cameroon Cape Verde Central African Republic Chad Comoros Congo Congo, Democratic Republic of Cote d'Ivoire Djibouti Equatorial Guinea Eritrea Ethiopia Gabon Gambia Ghana Guinea Guinea-Bissau Kenya Lesotho Liberia Madagascar Malawi Mali Mauritius

	Mozambique
	Namibia
	Niger
	Nigeria
	Rwanda
	Sao Tome and Principe
	Senegal
	Seychelles
	Sierra Leone
	Somalia
	South Africa
	Sudan
	Swaziland
	Tanzania, United Republic of
	Togo
	Uganda
	Zambia
	Zimbabwe
South/Central Asia (SCA)	Afghanistan
	Bangladesh
	Bhutan
	India
	Maldives
	Nepal
	Pakistan
	Sri Lanka
South-East Asia (SEA)	Brunei Darussalam
	Cambodia
	Indonesia
	Lao People's Democratic Republic
	Malaysia
	Myanmar
	Philippines
	Singapore
	Thailand
	Viet Nam
North-East Asia (NEA)	China (incl. Taiwan)
	Mongolia
	North Korea
	South Korea

Japan	Japan
Europe	Albania
	Andorra
	Austria
	Bosnia and Herzegovina
	Belgium
	Bulgaria
	Croatia
	Cyprus
	Czech Republic
	Denmark
	Estonia
	Finland
	France
	Germany
	Greece
	Holy See
	Hungary
	Latvia
	Iceland
	Ireland
	Italy
	Liechtenstein
	Lithuania
	Luxembourg
	Macedonia
	Malta
	Moldova
	Monaco
	Netherlands
	Norway
	Poland
	Portugal
	Romania
	San Marino
	Slovakia
	Slovenia
	Spain
	Sweden
	Switzerland
	United Kingdom

Yugoslavia

North America

Canada
USA

Australia, New Zealand & The Pacific (ANZP)

Australia
Cook islands
Fiji
Kiribati
Marshall Islands
Micronesia
Nauru
Niue
Palau
Papua New Guinea
Samoa
Solomon Islands
Tonga
Tuvalu
Vanuatu

Countries with Economies in Transition (CEIT)

Armenia
Azerbaijan
Belarus
Georgia
Kazakhstan
Kyrgyzstan
Russian Federation
Tajikistan
Turkmenistan
Ukraine
Uzbekistan

APPENDIX 6: UNEP FOAMS TECHNICAL OPTIONS COMMITTEE

Committee Member	**Affiliation**	**Country**
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Mr. Antonio Cristodero	Independent Consultant	Argentina
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* Denotes Lead Authorship in the preparation of the Report