2010 RIGID AND FLEXIBLE FOAMS REPORT

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EXECUTIVE SUMMARY

Executive Summary

E.1 Introduction

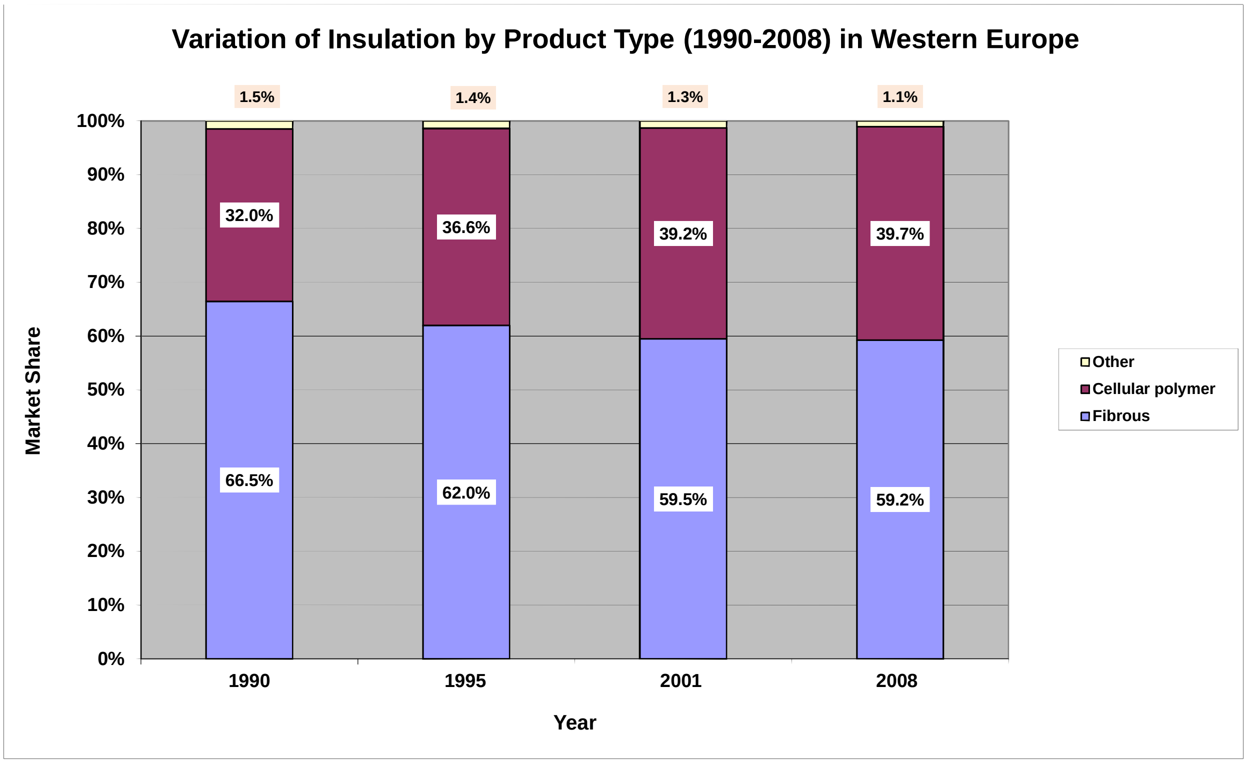
Not since the initial decision to phase-out CFCs in the early 1990s has the foam sector faced a period of such uncertainty. Although a large proportion of the industry has previously settled on hydrocarbons or CO_2 (water) as their blowing agent of choice, there are increasing pressures to improve the thermal performance of foams – primarily in the appliance sector, but also in some construction and transport applications. Coupled with this, there are pressures to limit future use of saturated hydrofluorocarbons (s-HFCs) because of their high global warming potential, and to phase these down where possible. Finally, there is the time-certain schedule for phasing out HCFC use in Article 5 countries, but substantial uncertainties remain about the optimal choice of alternatives. These three trends are placing unparalleled stresses on the sector and there is a significant divergence of opinion at this time about the most appropriate way forward, particularly as there are a growing number of emerging alternatives to consider. The following sections provide further background on the issues being faced.

E. 2 Foam Market Dynamics

Growth in thermal insulation foams continues to be driven by increasing energy efficiency requirements in appliances, transport and buildings. Space constraints in the built environment (e.g. cavity dimensions) have driven dramatic shifts from fibrous products to foam products in some localised markets to meet the required thermal performance. However, fibre has largely maintained its share through growth in the residential refurbishment sector where cost is a prime issue. An additional downward trend on foam use in non-Article 5 countries has been the on-going shift of appliance and refrigerated equipment manufacture to other regions where costs of manufacture are lower. The latest extension of a graph for Western Europe shown in previous reports (see overleaf) indicates that this combination of factors has led to only a small net shift to the overall foam/fibre balance despite the turbulence of individual sectors.

Nonetheless, the same region saw overall growth in thermal insulation sales to the domestic and commercial building sector of over 20% in the period between 2001 and 2008 despite the impact of the global downturn in 2008, thereby driving demand for appropriate blowing agents. This is likely to be representative of other non-Article 5 regions responding to the parallel drivers of climate change policy and energy security.

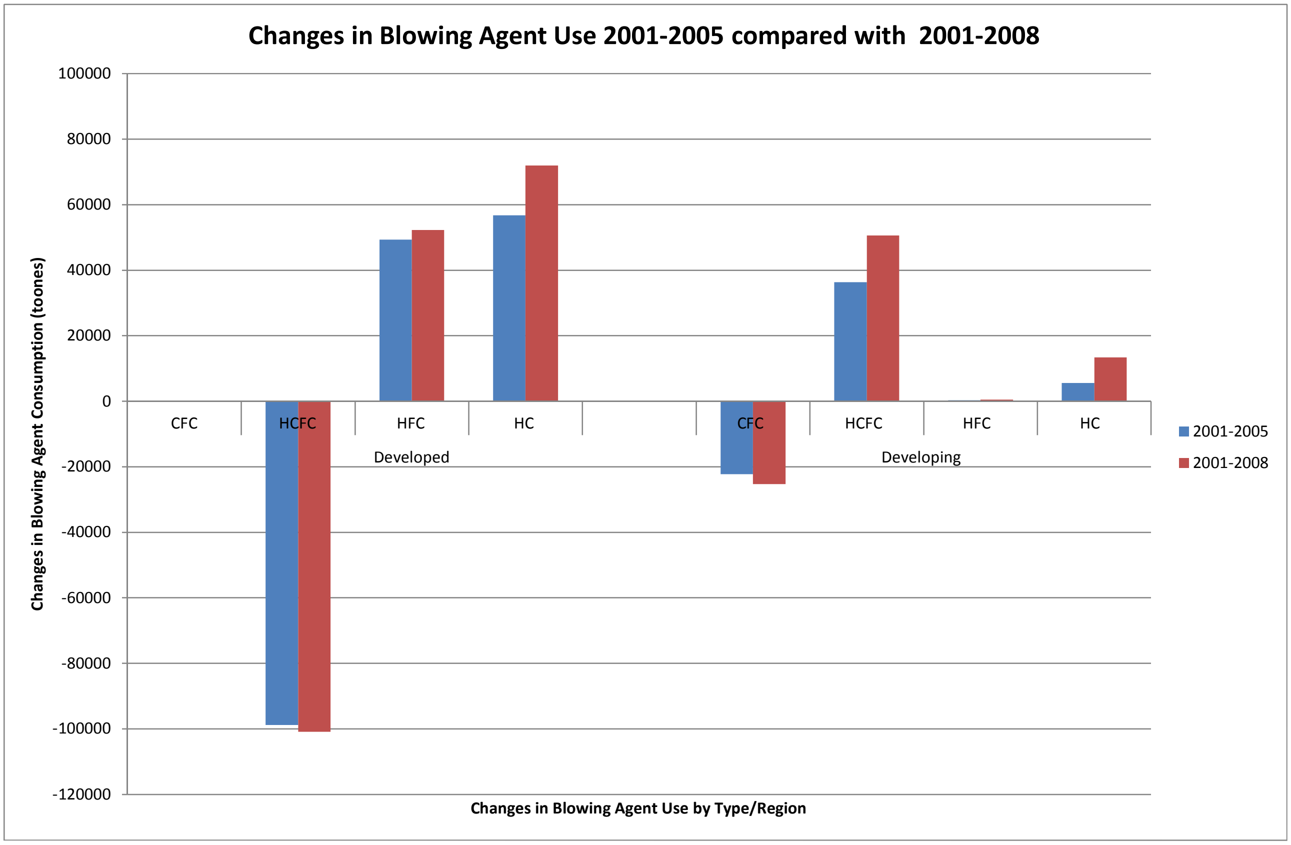
In Article 5 countries, the growth in demand for thermal insulation has been even starker than for non-Article 5 countries in view of the increasing manufacturing base for global appliances and the recognition that energy efficient buildings have a major contribution to make in combating climate change for Article 5 countries. As an example, the use of PU Spray Foam in China is understood to have grown to 70,000-80,000 tonnes, making it already the second largest market in the world for PU Spray Foam, with only the United States market larger.



Source; IAL

E.3 Transitional Status

As of 2010, HCFC phase-out is virtually complete in all non-Article 5 countries, with XPS in North America being the last major sector to make the transition. In this instance, the technology choice has been saturated HFCs, reflecting the demanding product range and process requirements that the XPS industry has in the region. Experience from this transition has made the industry wary about committing to any further transitions in the medium term, since proving emerging alternatives in these applications will involve substantial further effort. As shown in the graph below, the main growth in blowing agent use between 2005 and 2008 had occurred with hydrocarbons, although there was also some additional use of HFCs. By contrast, only a very marginal further decline in HCFC use had taken place, highlighting the fact that the XPS sector in North America was not able to address its usage of HCFCs in the period to 2008, but was able to do so prior to the phase-out deadline in 2010.



In Article 5 countries, the phase-out of remaining CFC use has been completed with the main replacement for these residual applications being HCFCs. Growth has also continued in hydrocarbon use, largely driven by a further increase in the appliance manufacturing base in these regions.

Overall, the comparison between 2001-2005 and 2001-2008 time periods illustrates that the changes in the last four years have been relatively moderate compared with those of the previous four years.

Although hydrocarbons continue to be the primary solution in non-Article 5 countries, there is pressure in some sectors to further optimise these solutions by blending. While cyclopentane continues to play an important role in optimising blend performance, other components such as unsaturated HFCs (u-HFCs or HFOs) and methyl formate are also being assessed at this time. Early work on unsaturated HFCs suggests that they deliver better thermal performance than their saturated counterparts, although toxicological work remains to be completed for those substances yet to be commercialised. In the interim, there is evidence that some enterprises manufacturing appliances in developing countries are already blending saturated HFCs with hydrocarbons to meet energy requirements.

Decisions need to be made at short notice within HCFC Phase-out Management Plans (HPMPs) on the choice of alternative to HCFCs in Article 5 countries. The prioritisation of ‘worst first’ embodied within Decision XIX/6 puts a strong focus on dealing with HCFC-141b applications in the early phases of implementation. Nevertheless, some countries are finding it easier to manage their compliance issues by phasing the foam sector transitions according to the ease with which projects can be implemented and the magnitude of their impact. Shortfalls are then being made up from other sectors.

E.4 Likely Future Scenarios

In general terms, the future technology selections in both Article 5 and non-Article 5 countries continue to be uncertain. This makes it particularly difficult to forecast the precise blowing agent mix in the period to 2020 and the impact that this may have on bank composition at that time.

As noted above, HCFC phase-out in Article 5 countries continues to be a serious source of unease. In several sectors, particularly in rigid PU foams, previously identified low-GWP alternatives to HCFCs have yet to be fully proven in the field or require high investments. This is particularly important since many of the enterprises expected to take up these technologies are small medium enterprises (SMEs) and have little, if any, internal capacity to optimise formulations. There is evidence that measures to manage flammability for methyl formate may require system houses to reformulate with more compatible polyols in order to reduce the risk. However, in a limited number of cases it may be more productive to blend methyl formate in the isocyanate component to obtain the required foam properties whilst avoiding flammable blends.

There continues to be a need to characterise the performance of foams made from low-GWP alternatives in the range of applications envisaged. This is an on-going exercise, but is particularly important for technologies that do not have a significant history of use in non-Article 5 countries. The role of the Pilot Projects sponsored under the Multilateral Fund are especially relevant here and the work of UNDP on methyl formate, for example, has already cleared the way for wider use in the flexible moulded and integral skin sectors with potential for others to follow.

In non-Article 5 countries, the primary future interest is in further improving energy efficiency. However, an additional pressure may arise from proposals to see the phase-down in use of saturated HFCs. Apart from initiatives signalled under the Montreal Protocol itself, there is growing interest in seeing such a measure as part of the re-cast F-Gas Regulation in Europe. This may serve to strengthen research efforts in non-Article 5 countries towards low-GWP solutions and, in particular, towards the intelligent use of blends. There may be added spin-offs for Article 5 countries from this work, but these are unlikely to emerge in time for incorporation within relevant HPMPs.

For the immediate challenge of phasing out HCFC-reliance in Article 5 countries, there are a number of obstacles. The time pressure to resolve these only serves to add to the complexity of the situation and it may be that a number of not fully proven solutions need to be adopted in the short-term, with the potential downside risk to enterprises and investors alike. Another consequence could be that enterprises choose to minimise their risks by choosing proven, but sub-optimal, technology solutions (e.g. high GWP or less energy efficient solutions) with the intent of making a second conversion when more appropriate solutions have become established.

E.5 Banks, Emissions and Destruction

The management of ODS banks in appliance foams is currently being addressed by a variety of regulatory and voluntary frameworks and using a range of fully automated, semi-automated and manual technologies. Although there is evidence to suggest that fully automated approaches provide the most comprehensive recovery potential, the relevant cost-abatement curves would suggest that some semi-automated processes will have a place in the on-going management of ODS banks, particularly in areas where population densities are low or investment is restricted.

Efforts have been made to further characterise foam inventories in a number of regions. The flow of ODS-containing foams into the demolition waste stream from buildings is currently low and is likely to remain so for at least the next decade for most product types. Although the economics of recovery vary by region and are influenced by wider demolition waste management frameworks, even the most favourable circumstances lead to costs of above $100 per tonne CO_2 saved on average. There will be a need for further innovation in the longer-term if recovery from this source is going to become economically feasible.

Considerations will continue into the most appropriate strategies for ODS bank management in foams, with particular focus on ensuring that CFC capture from existing appliance-based banks is optimised before those opportunities are lost. This may involve the need to look at efficient ways of transferring existing technologies from non-Article 5 to Article 5 environments. The most appropriate funding mechanisms for such action are still under discussion, but a conclusion needs to be reached soon if opportunities are going to be grasped.

Although less emissive than the refrigeration and air conditioning sector, the foam sector continues to represent a substantial bank of long-lived ODS which provide opportunities for future management. Time pressures for management initiatives vary by sector, but ultimate policy decisions will depend on the emerging cost abatement curves on a wide range of other ozone layer protection and climate measures. It remains to be seen whether or not the recovery of ODS from buildings will become a viable option given the scattered nature of the sources involved and the efforts required for recovery.

E.6 Specific Regional Messages

Developed Countries

- The growth of appliance foams and blowing agent use will continue broadly with general economic drivers, since markets are largely saturated. However, there may continue to be shifts in manufacturing location which will influence regional blowing agent consumption trends.

- Hydrocarbons are now almost fully optimised for appliances, but the relentless drive for energy efficiency is encouraging more focus on cyclo-pentane as a component of blends and, beyond that, interest in unsaturated HFCs (HFOs), which themselves are showing better potential thermal performance than current liquid HFCs. It may be that there is some switch from hydrocarbons to HC/u-HFC blends in future as well as a possible switch in North America from liquid HFCs directly to unsaturated HFCs over time depending on the future HFC policy in the United States.

- The growth in blowing agent demand for construction applications is driven by energy efficiency in new and existing buildings; there has been a slow-down in the construction of new buildings because of global recession but retrofitting continues with spray foam and other foam products (boards, etc). Nevertheless, growth in the demand for insulation foams has been dramatic over the last ten years with changes in market share between foam and fibrous insulation over that period, driven by the requirement for increased thicknesses and a relatively buoyant construction market.

- Hydrocarbons are the dominant blowing agent in the construction sector, with the exception of spray foam where s-HFCs continue to dominate due to safety issues, although there is likely to be a further proliferation of blends – perhaps with u-HFCs (HFOs) and/or methyl formate – particularly where the thickness requirements for insulation are perceived to be becoming unmanageable.

- In extruded polystyrene, the long-term future for blowing agent selection is still unclear, with a significant range of technologies in current use. The emergence of u-HFCs (HFOs) may prove of interest as a replacement for gaseous HFCs, particularly as a component of blends. Pressure for transition is likely to be greater in Europe where the F-Gas Regulation is currently under review. However, in North America there are no further plans to make transitions in the next 10 years since the transfer to gaseous s-HFCs has only just been implemented as of 2010.

Developing Countries

- Economic growth rates in several key developing countries are likely to drive demand for appliances and other consumer goods over the coming years which will be reflected in the expected growth in demand for blowing agents.

- Since the appliance market is becoming largely a globalised market, future blowing agent selection is largely expected to follow the same patterns as in developed countries.

- Some appliance manufacturers have been or are considering moving from cyclopentane to blends of cyclopentane and HFCs to meet emerging energy efficiency standards and to better meet existing energy standards for products exported to developed countries.

- Focus on insulation materials for the construction market and, in particular, foam products varies substantially by developing country region, influenced primarily by climatic aspects and the ability to invest in infra-structure.

- There is evidence of considerable effort to insulate both new and existing buildings in China and this has driven demand for PU spray foam as one of the most energy efficient options. Substantial growth in EPS/XPS has also been observed. However, in recent years, a few high profile fires in cities such as Beijing and Shanghai have resulted in stricter regulations that may limit the future use of organic insulation materials for residential buildings.

- There is much less clarity about the choice of blowing agent for the small/medium size enterprises in the construction sector and a variety of technology options (including pre-blended hydrocarbons, methyl formate, CO_2(water), liquid s-HFCs and u-HFCs) could all be used to some degree.

- Although methyl formate has SNAP approval by the US EPA for PU spray foam applications, it is still not clear whether the market will view the flammability issues as sufficiently differentiated from hydrocarbons to drive uptake. There is likely to be some use of methyl formate in those integral skin applications where CO_2(water) is not already established.

- Although commercialisation of the various u-HFCs (HFOs) under consideration is likely to occur slightly earlier than previously expected (perhaps 2013-2015), these technologies are still likely to be too late for the bulk of HCFC-141b transitions. Therefore two-step transitions may be necessary to take advantage of their properties. Since the investment costs are likely to be minimal for such technologies, a two-step strategy might be appropriate where the economics support it.

- Work on ‘three-stream’ technologies for spray foam (e.g. super-critical CO_2 and gaseous u-HFCs) may allow an earlier transition in some instances, although the investment implications are still being assessed.

FOREWORD

DATA AVAILABILITY

There is no single reference source for the consumption of blowing agents on a global basis. This is because most bottom-up quantitative assessments are carried out at country or regional level. However, supply-side information is available for some blowing agent types at the global level. For example, the fluorocarbon industry has published this data on relevant fluorocarbons at hemispherical level through the AFEAS project. However, this activity was recently discontinued. There has been an understandable reluctance by blowing agent manufacturers to provide supply-side information at greater levels of disaggregation because of disclosing valuable confidential information and ultimately the risk of contravening competition law.

Without a reliable, comprehensive source of data, the Foams Technical Options Committee (FTOC) has developed its own set of data based on information gained from a variety of the above sources over a period of years. From this a model has been assembled to characterise consumption – past, present and future. During each Assessment period, FTOC members are encouraged to research information at regional level. However, this is never expected to result in a comprehensive picture of usage patterns at any one juncture, but the information gained provides a cross-check on the projections contained in the existing FTOC model. Adjustments can then be made based on the robustness of the information obtained.

In this Assessment, the outputs of this process are reported for 2008, which is the latest year for which data could be accessed by the Committee. However, anecdotal qualitative information is conveyed for the subsequent period to 2010 where this is known.

The data is reported by blowing agent type and by region, with developed countries being divided into four regions and developing countries into the seven. The country allocation is provided in Appendix 3. It should be noted that ‘Russia and the Former Soviet countries’ is a new designation, which replaces ‘Countries with Economies in Transition (CEIT)’. Although not all of these countries would now be classified as ‘developing’ the allocation is maintained in order to provide continuity with previous Assessments.

LEVELS OF CONSENSUS

The Assessment has proved the most challenging to date in which to reach consensus for the FTOC. This is partly because there is a high level of uncertainty in the likely success of competing alternative blowing agents. This, in turn, arises from the fact that there is little previous experience with many of these alternatives in developed countries. With the future of some blowing agent options resting in the balance and pressures to make choices in a number of developing countries, there has been and understandable culture of claim and counter-claim. The FTOC has not been immune from these claims and counter-claims and, in the absence of sound scientific evidence or practical experience, it has been impossible to resolve some differences of opinion. However, in most instances a strong majority view has emerged. One of the focal points of these differences has been methyl formate technology, which has become something of a *'cause célèbre'*, since its promotion in some quarters has influenced the funding basis for many MLF projects. The FTOC remains sceptical about some of the claims made for the technology, but a minority believe that these claims either have been, or can be, substantiated. In dealing with this situation, the following statement has been agreed as an appropriate expression of the status:

> *Although the majority view of the Committee is that the use of methyl formate in rigid foam is unproven, a minority of members - particularly the protagonists of the technology - contest this view, arguing that usage is already occurring or has been sanctioned. A further aspect on which there is a discrepancy of view is over the significance of the flammability issue, with the majority aligning with the text of this report. Key areas of dispute are annotated by footnotes.*

The co-chairs of the FTOC advocate that readers approach the relevant sections of this report with this caveat in mind.

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.

REFRIGERATION EQUIPMENT AND APPLIANCES

Developed Countries

Domestic Refrigerators and Freezers

- Current market trends

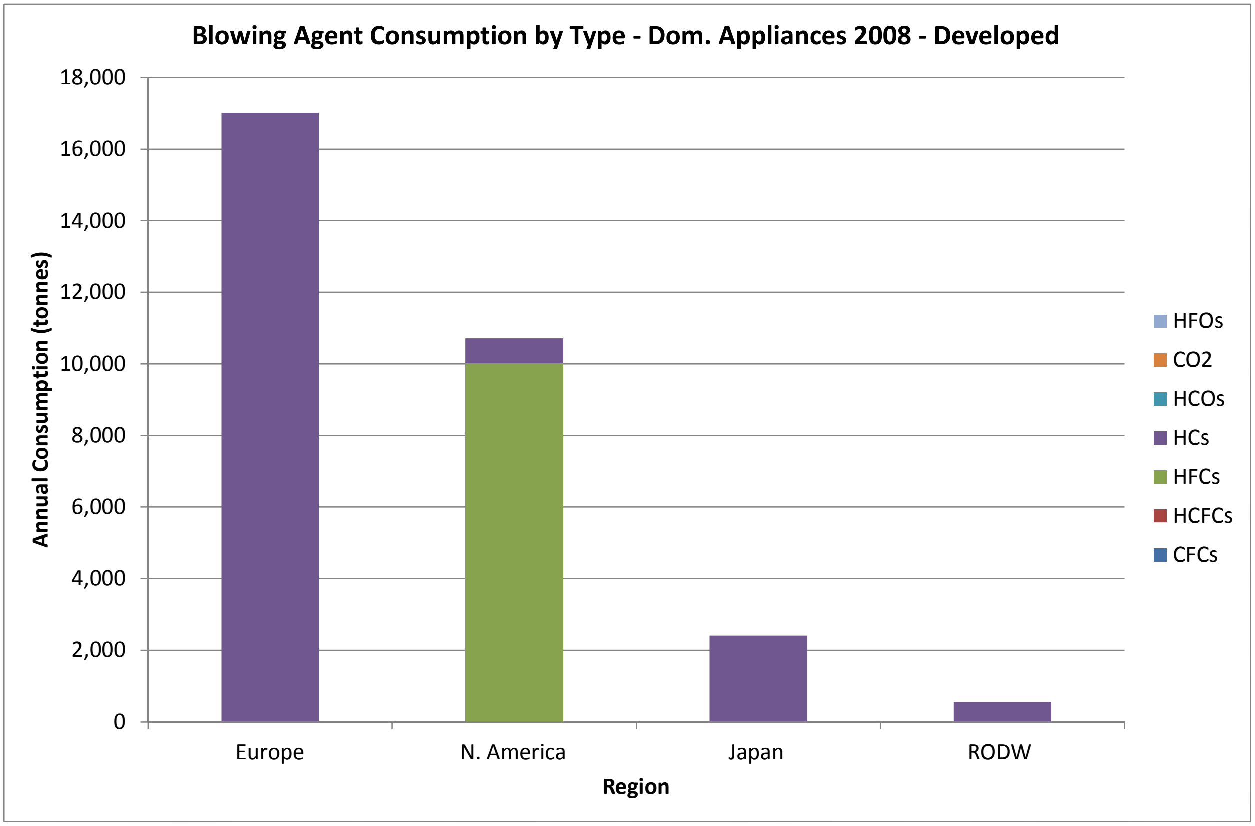
The manufacture of domestic refrigerators and freezers continues across most of the developed world, although there is an increasing shift of production from developed to developing countries. Current estimates suggest that the split is now 45%:55%.

Polyurethane foam continues to dominate the market for refrigerator and freezer insulation, with more sophisticated technologies such as vacuum panels still being limited to very specialist applications. However, it is noted that one manufacturer [Panasonic] has recently re-introduced a model containing such panels into Europe and there is also some continuing use of vacuum panels (based on open-celled foams) in Japan for the walls of some models. One of the short-comings observed with vacuum panels is that they have low thermal inertia when compared to foam, which leads to more rapid warm-up in the event of a power outage.

Further increases in the thermal performance of domestic refrigerators in Europe are expected to continue, but it is not yet clear whether this will lead to increased foam use, bearing in mind that space is usually at a premium. However, continued trends towards North American styles of cabinet refrigerator will permit increased foam usage per unit. In Japan the market is relatively static, although showing little sign of decline, partly because the country continues to be a net importer of white goods (1.9 million produced versus 4.5 million sold). As in Europe, North America will see further increases in energy efficiency requirements over the next five years. In the United States of America, the Department of Energy had already set a new rule for domestic appliances being manufactured in 2014 and onwards. These requirements are likely to be met by a combination of compressor efficiencies, increased foam use and potential changes to the blowing agent selection.

- Current blowing agent selection

The choice of blowing agent in developed countries as a whole is illustrated in the graph below.



The divide between the North American market and the rest of the developed world continues as the domestic appliance industry continues its use of HFC-245fa and, to a lesser extent HFC-134a in refrigerators and freezers. With the US Department of Energy continuing to demand increasing minimum energy standards across the industry it seems unlikely that the bulk of the industry will consider a move out of saturated HFCs until unsaturated HFCs (HFOs) such as 1234ze(Z) and 1336mzz and other still undisclosed molecules are commercially available. However, there are some US manufacturers who have gained experience of manufacturing with hydrocarbon in Mexico and may still consider a switch to HCs in the United States as their ultimate solution. Indeed, one is already reported to have switched one plant to hydrocarbons.

Meanwhile, in Europe and elsewhere, the experience with hydrocarbons is well established and increasing energy efficiency demands continue to be met, partly as a result of on-going improvements in hydrocarbon technologies. It is therefore likely that European manufacturers will stay with their choice for the foreseeable future, even though there is some interest in evaluating unsaturated HFCs – particularly where these are exhibiting superior thermal performance. In Japan, the market is fully settled on hydrocarbons with cyclo-pentane and cyclo/iso blends being amongst the blowing agents of choice.

Other Appliances

- *Current Market Trends*

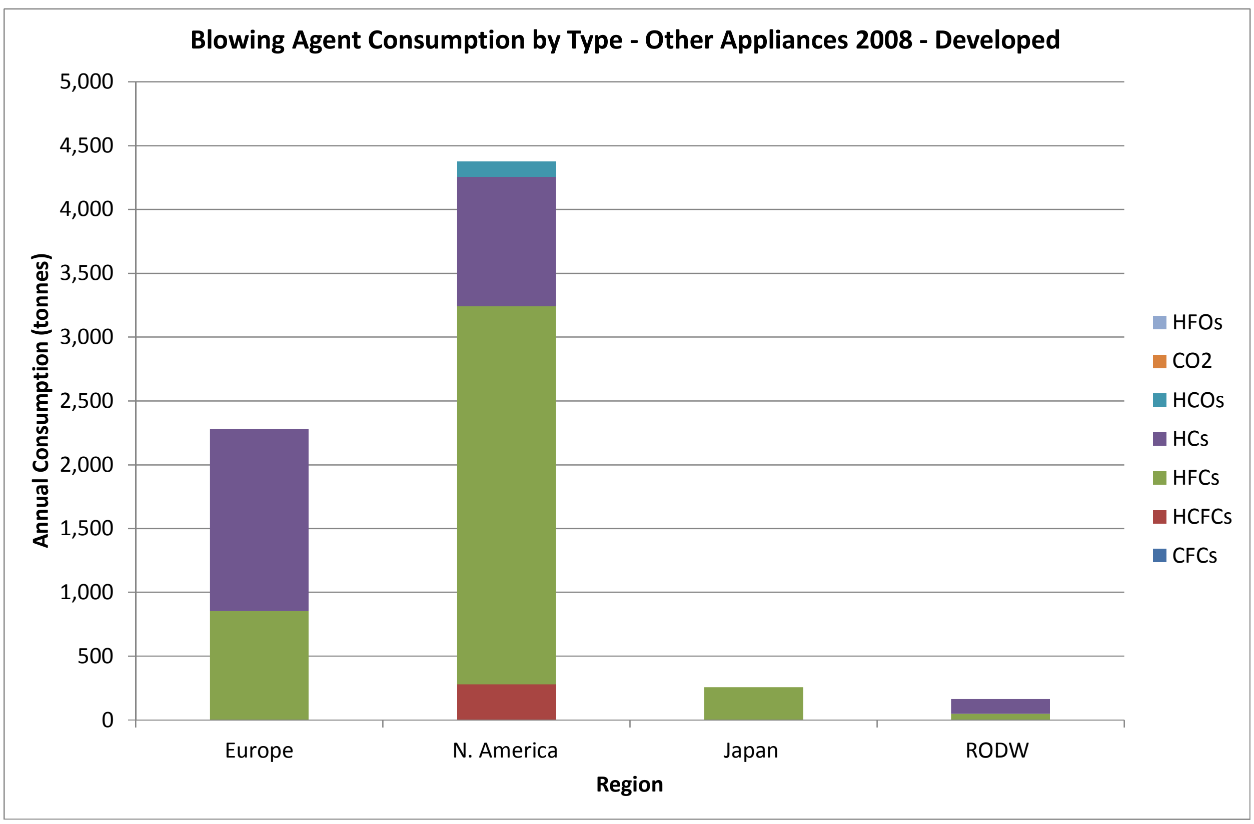
This sector covers a number of product types including water heaters, vending machines, display cabinets and commercial freezers. The widespread use of vending machines across the hotel industry in the United States and their relative size, makes the North American market for foams more significant than other regions.

Despite the drive for improved energy efficiency, the market is seen as relatively static from a technology perspective with size being a less significant constraining factor than it is in the domestic sector. This has allowed the use of less efficient insulation types and has made the choice of blowing agent less significant.

The situation is rather different for supermarket display cabinets, where occupied floor area is an important factor. Nonetheless, the energy efficiency of such supermarket systems is often dictated by the choice of refrigerant delivery system (distributed versus stand-alone). It is only in the stand-alone cases, where the foam technology choices are likely to be critical.

- *Current blowing agent selection*

The graph below illustrates the spread of blowing agent choice as at 2008:



At this point in time, there was some residual use of HCFCs in this sector in North America. This was partly as a result of the fact that regulatory requirements were only just taking effect in the US. However, there was also some continued use in Canada, since the phase-down there continues to progress on a tradable allowance system.

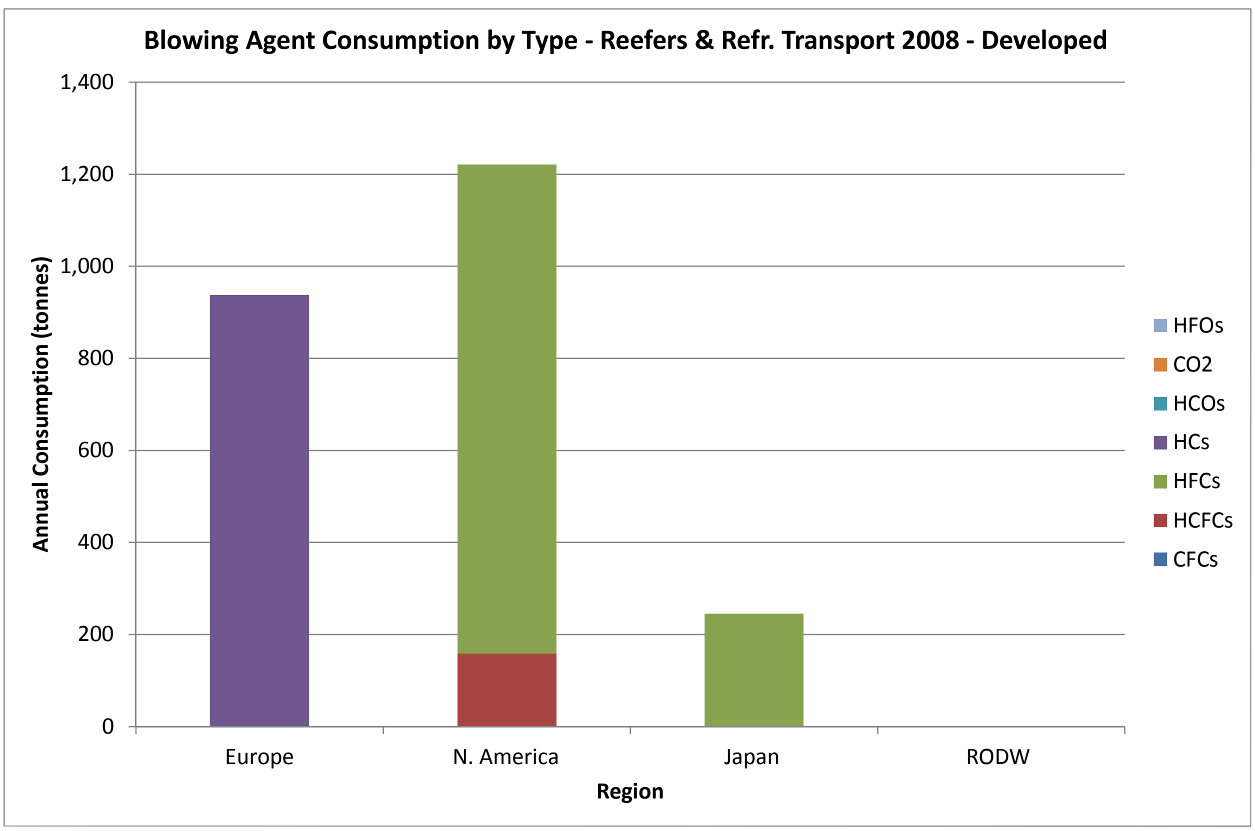
In the North American vending machine sector, there has also been some use of CO_2 (water) systems as well as some emerging acceptance of methyl formate in the application. In 2008, the use of methyl formate was nominal (perhaps 125 tonnes [3-4%]), but there is an understanding that it may have grown further since then to perhaps about 5%.

Reefers and Refrigerated Transport

- *Current Market Trends*

This sector covers both the manufacture of reefers (refrigerated containers) and the manufacture of other refrigerated transport bodies (e.g. insulated tanks and truck bodies). The sector is distinguished from others by the fact that the polyurethane foam system is injected into a cavity rather than constructed from pre-fabricated parts (e.g. discontinuous steel-faced panels). Over 50% of all foam in this sector is manufactured in developing countries indicating the dominant position that China holds in the global manufacture of reefers.

- *Current blowing agent selection*



The graph of consumption in developed countries shows the substantial variations in blowing agent choice across the regions, with the European region focusing on the use of hydrocarbons, whilst Japan and North America are largely reliant on HFCs. As with other appliances, there was some residual reliance on HCFCs in 2008 in North America – primarily in Canada.

Developing Countries

Domestic Refrigerators and Freezers

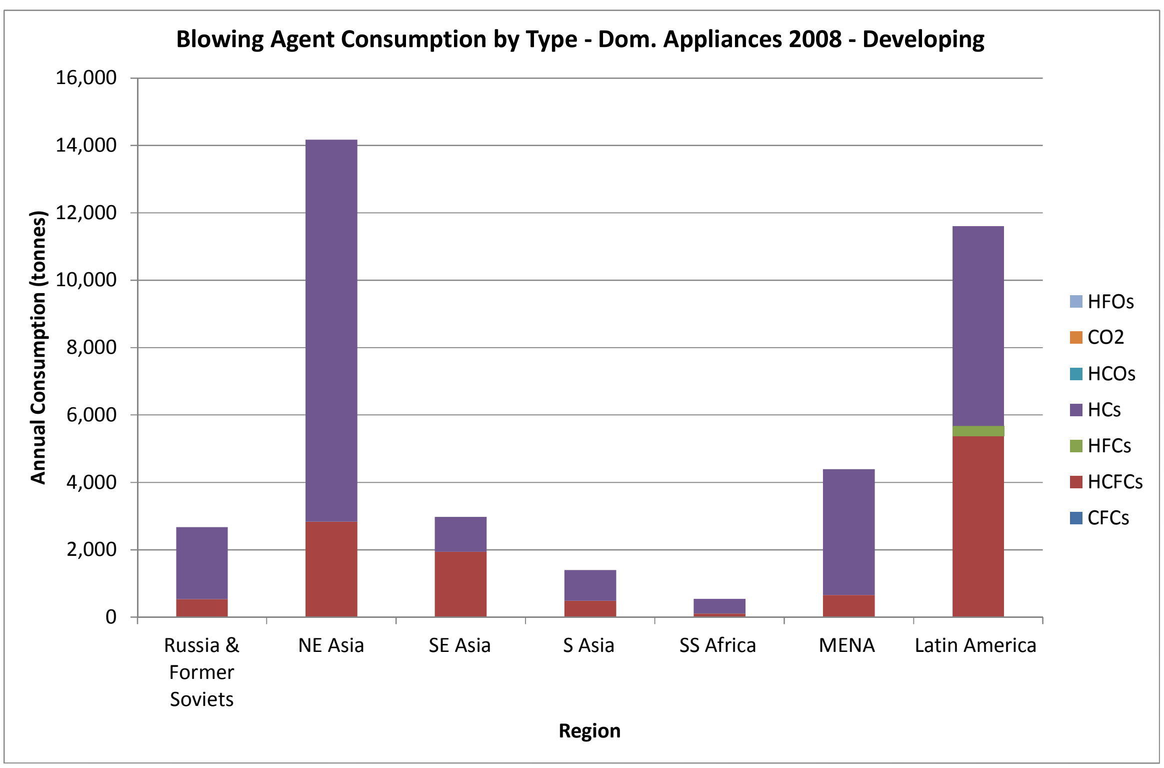
- *Current Market Trends*

The manufacture of domestic refrigerators and freezers in developing countries is dominated by production by North East Asia (including China and South Korea) and Latin America. In China alone it is estimated that more than 300,000 tonnes of PU foam was consumed in 2008 in the domestic refrigerator and freezer market alone. Growth rates are running at around 8% per annum based on both domestic growth and the shift of production capacity from other countries.

In Latin America, the market has been growing at 5-7% per year, but has been influenced in the post-2008 period by some Government intervention to increase refrigerator ownership and to catalyse the replacement of old, inefficient units. The market, particularly in Mexico and surrounding countries, also continues to be influenced by the relocation of production from the United States and the export demand that this provides.

- *Current Blowing Agent Selection*

The choice of blowing agent in developed countries as a whole is illustrated in the graph below.



The market in developing countries is split between the use of hydrocarbons and HCFCs. There is also a small amount of HFC use for the export market to North America in the Latin American region.

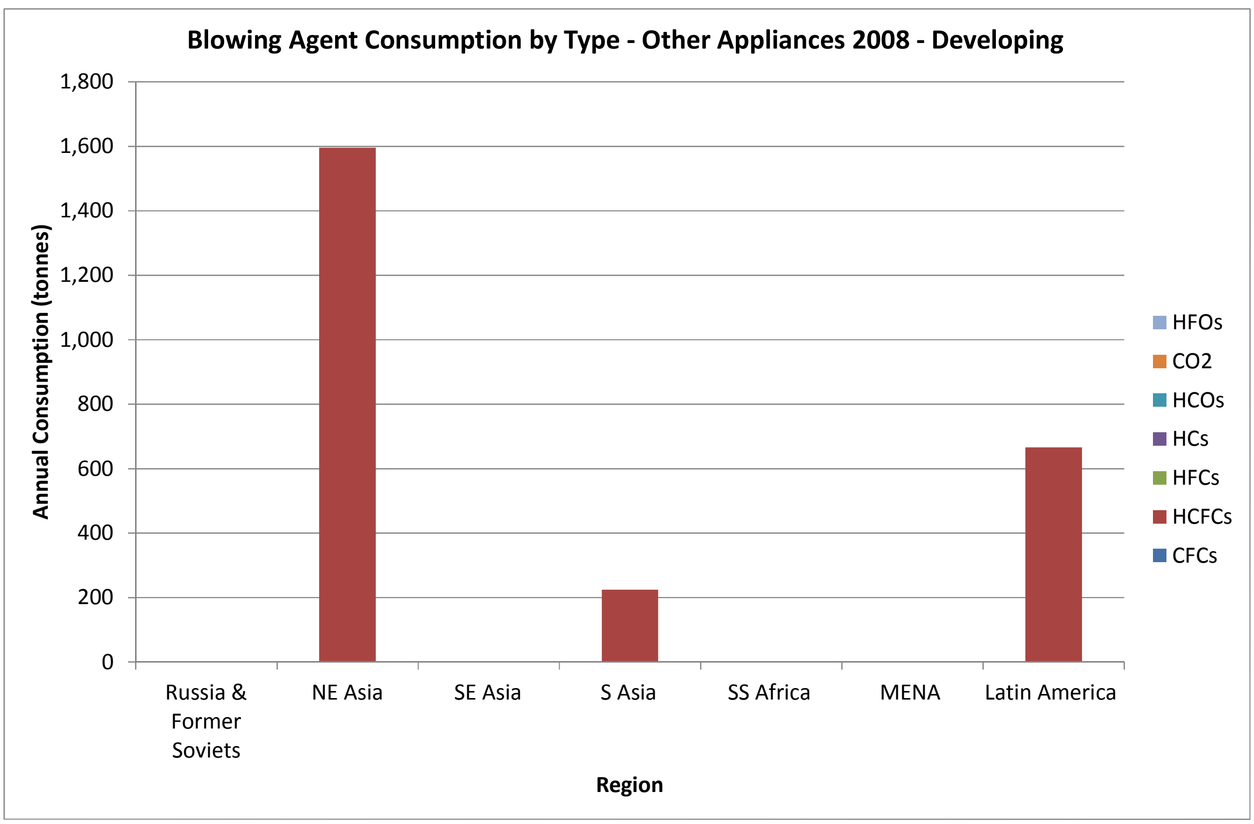
The original decision to invest in hydrocarbon technology was driven, in part, by the likely demand arising from large populations, which in turn led to perceived economies of scale. An additional factor in the direct transition from CFCs to hydrocarbons in the previous phase was the active promotion and encouragement provided under the Multilateral Fund, which offered additional support to leap-frog HCFCs in this sector.

<u>Other Appliances</u>

- *Current Market Trends*

In contrast with domestic appliances, only just over 25% of 'other appliances' manufactured globally are made in developing countries, with the bulk of these being in China. As noted for developed countries, the range of product types is very diverse. However, there is typically greater demand for small-scale display cabinets in developing countries driven by the size of retail outlets.

- *Current blowing agent selection*



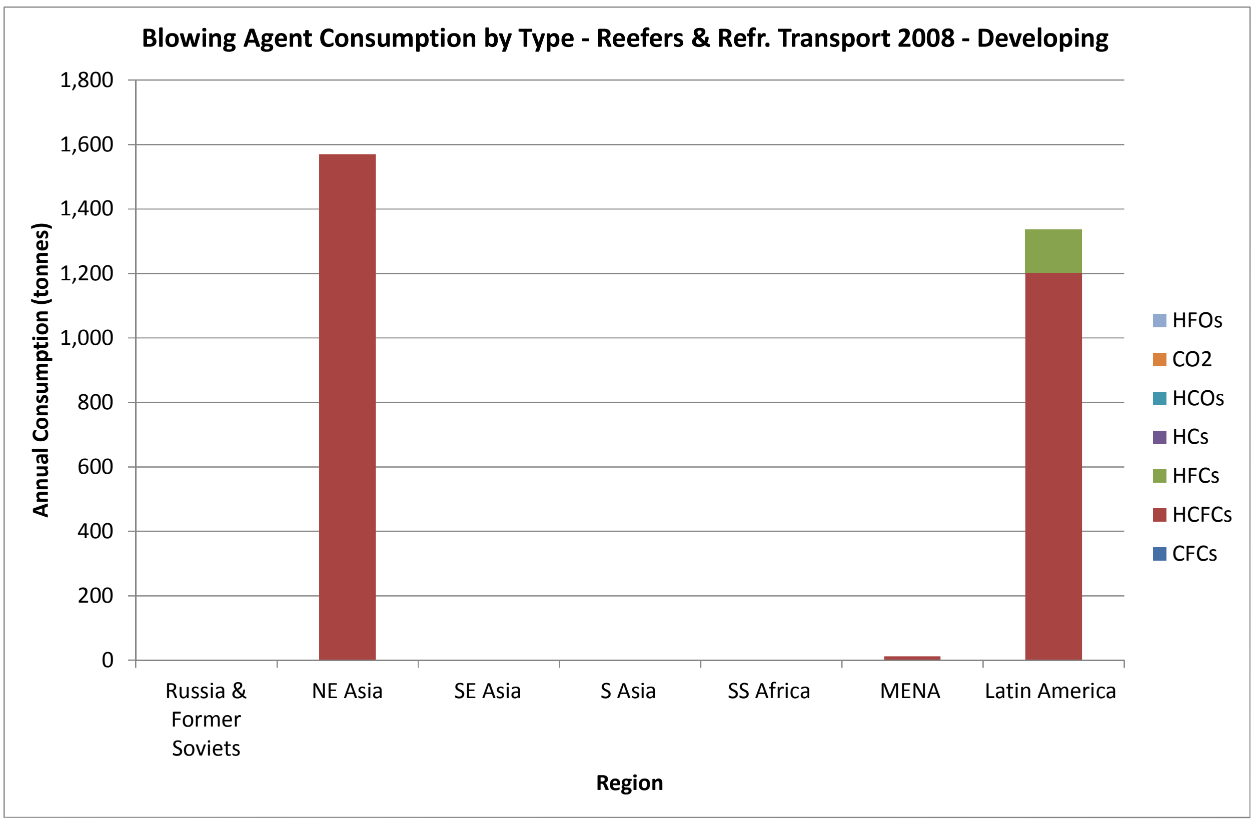
As can be seen in the graph above, virtually the total blowing agent demand in this sector in 2008 was for HCFCs. There is now interest in hydrocarbons and methyl formate. Accordingly, this sector is reliant on the delivery of HCFC alternatives under Decision XIX/6 initiatives. Options are discussed further in Chapter 2.

<u>Reefers and Refrigerated Transport</u>

- *Current Market Trends*

Although refrigerated transport units (e.g. insulated tankers and refrigerated truck bodies) are manufactured throughout the developed world for local use, the bulk of global refrigerated container manufacture has shifted to China based on unit pricing – partially derived from economies of scale. This market has grown relatively rapidly and, as an in-situ process has needed to be based on proven technologies for the most part.

- *Current blowing agent selection*



As can be seen from the graph above, main blowing agents currently in use are HCFCs, and this is almost exclusively HCFC-141b. There is also some reported use of HFC-134a in Latin America, although the precise application is not known. It is expected that a froth foaming process would be practised in this instance.

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.

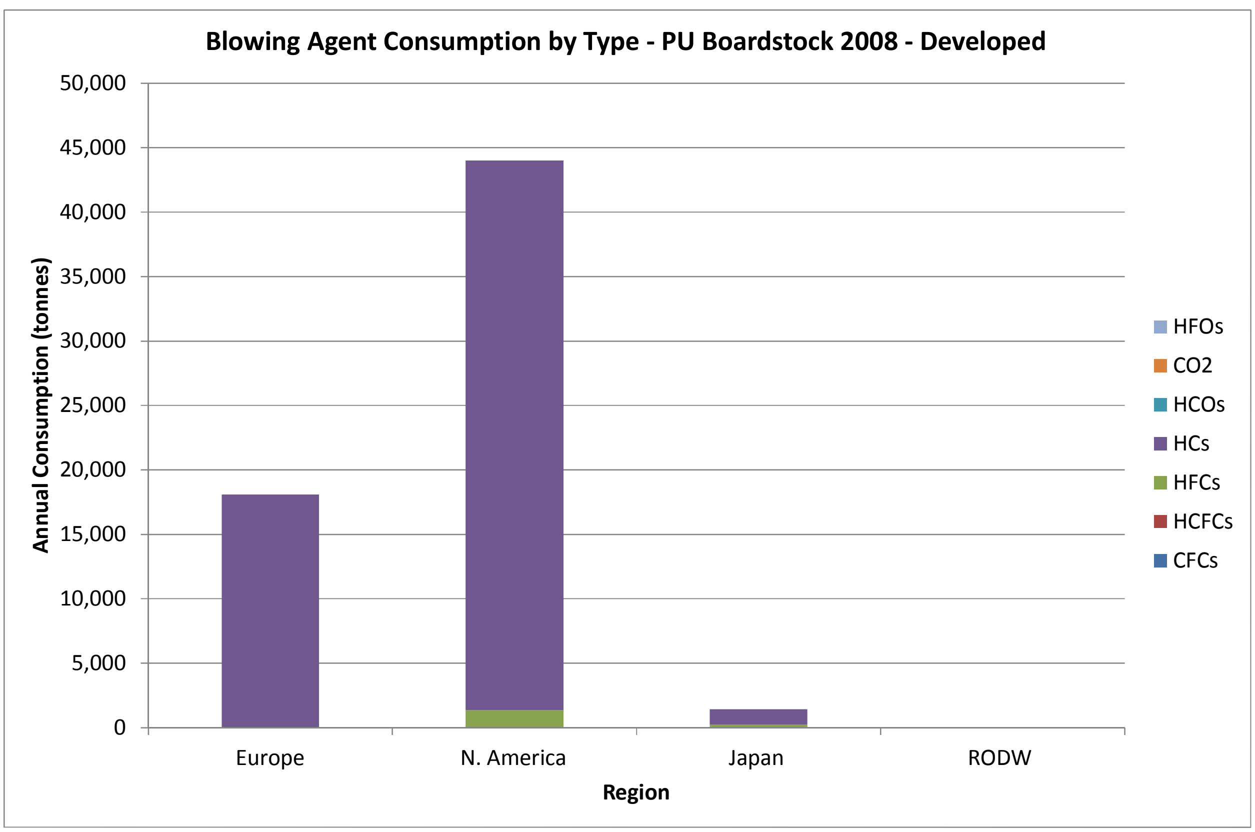
Developed Countries

PU Boardstock

- *Current Market Trends*

The growth in use of PU (incl. PIR) boardstock products has been dramatic in some markets, particularly where cavity wall constructions are common and the minimum energy efficiency requirements cannot be met with less efficient insulation types such as mineral fibre. There is a trend toward incorporating boardstock products in external thermal insulation construction systems (ETICS) for the refurbishment of solid walls. Although these typically have a payback within their lifetimes (i.e. net negative whole life cost), they are amongst the more expensive renovation options. Accordingly, fibre insulation has made ground in on-going residential loft insulation upgrades as a more cost-effective renovation strategy, where it can be applied.

- *Current blowing agent selection*



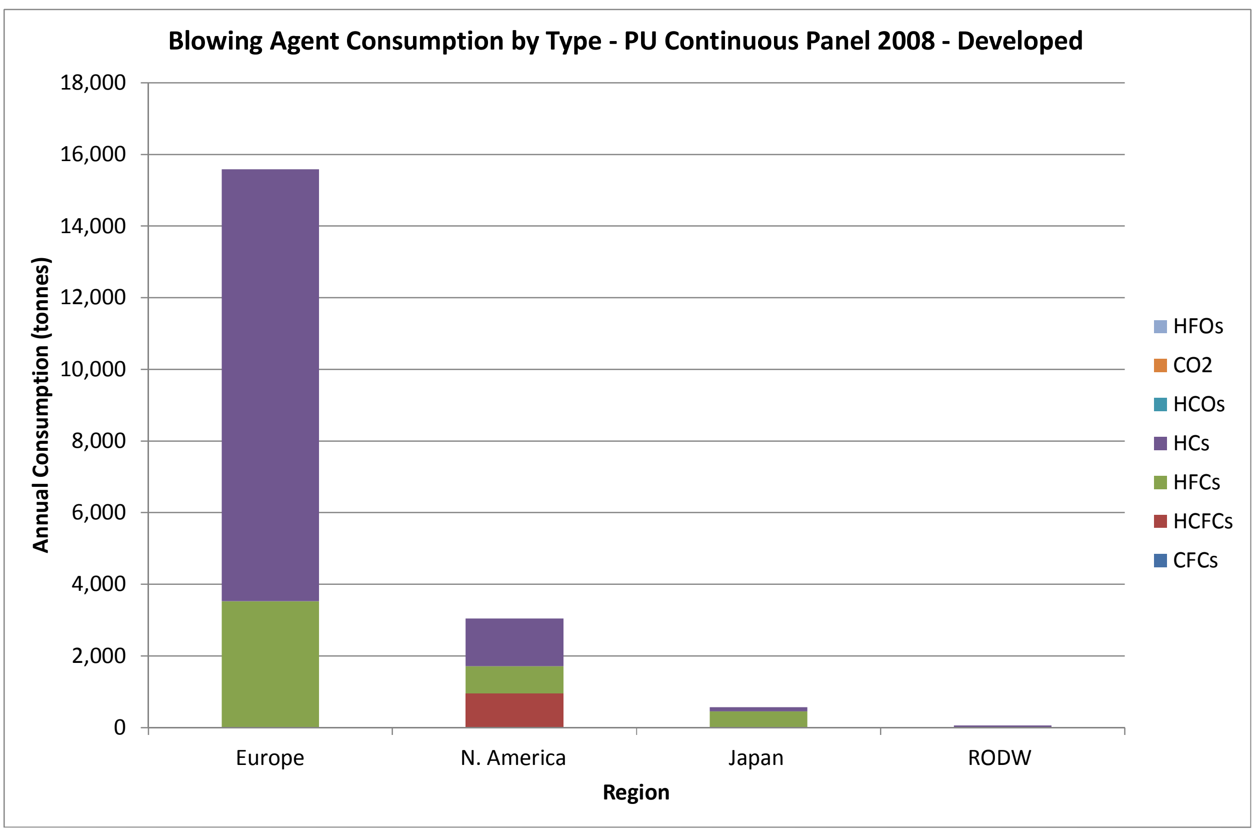
The bulk of the polyurethane boardstock market has transferred to hydrocarbon (initially cyclo pentane but now more typically n- or iso-pentane), with only very minor use of HFCs in North America. As can be seen, consumption levels in Japan are relatively low based on the fact that PU Spray systems are a more prevalent way of insulating than PU boardstock in that region. No further transitions are expected in developed regions in the near future.

PU Continuous Panels

- *Current Market Trends*

The growth of the polyurethane composite (sandwich) panel market has continued apace in the period since the last Assessment. These panels can typically be faced with steel, aluminium or other metallic surfaces and are increasingly being marketed as architectural panels. In some instances, they are now being designed to incorporate PV solar panels and offer the potential of contributing strongly towards zero-carbon building solutions now being demanded in some countries.

- *Current blowing agent selection*



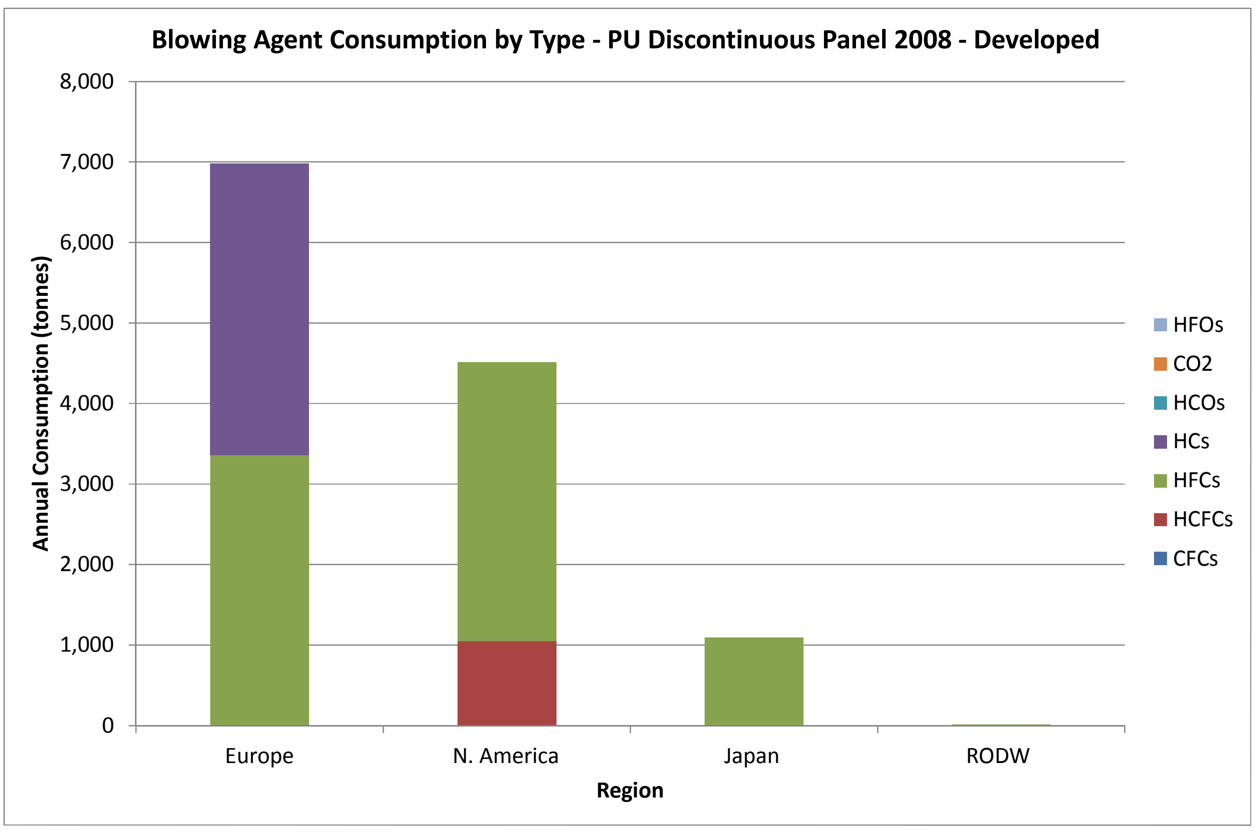
There has been retention of HFCs in some countries in Europe based on the requirements to meet certain regulatory and insurance criteria with respect to fire. However, increasingly, hydrocarbon is seen as the long term solution in this sector, since the thickness of foam requirements is driven more by panel strength requirements than it is by thermal performance per se. Typical panel thicknesses for new buildings can be in the 80-100mm range. As can also be seen from the relevant graph, this technology is far more established in Europe than elsewhere. However, growth rates are rapid in parts of North America and in the Rest of the Developed World (RODW). There was, in 2008, some residual use of HCFC technology in Canada.

<u>PU Discontinuous Panels</u>

- *Current Market Trends*

There has been a level of conjecture about the relative size of the discontinuous panel market sector as a proportion of the total metal-faced panel industry. Some projections have the absolute size of the discontinuous panel market staying relatively static – arguing that increased demand will be met exclusively by the continuous sector as investments respond to economies of scale. Others, including this Assessment, argue that, where market penetration is spreading geographically, fledgling production facilities will always start in a discontinuous fashion. In the end, it is the transport costs of finished products that probably dictates the final outcome and this will be further reviewed in subsequent Assessments.

- *Current blowing agent selection*



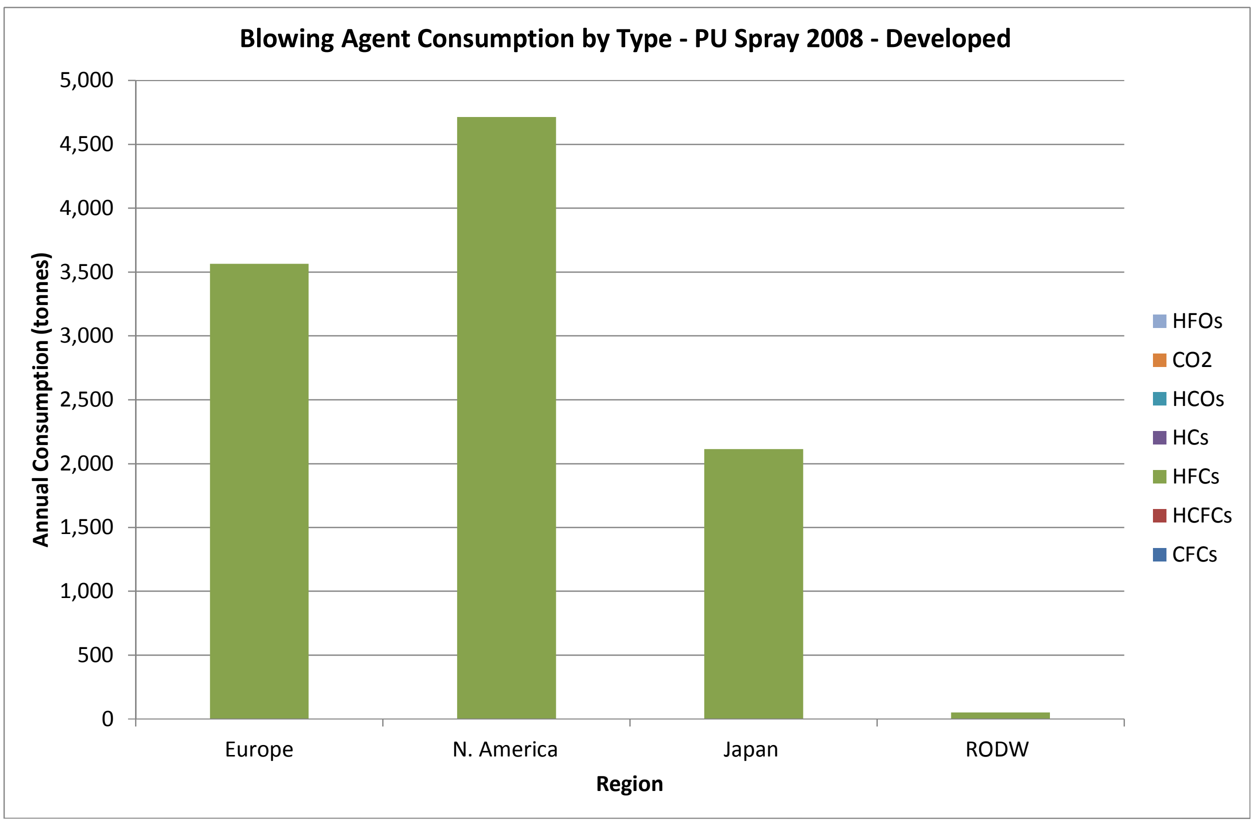
Again Europe has the bulk of this market with the blowing agent choice being split between HFCs and hydrocarbons depending on the prevailing response to the risk of handling hydrocarbons in discontinuous processes. As for the continuous panel scenario, there was some residual use of HCFCs in North America as at 2008.

PU Spray Foam

- *Current Market Trends*

As noted under the PU boardstock section, this technology is a major component of the Japanese insulation sector and spray foam remains the most significant market on a per-capita basis. In North America, there are two distinct product types: - a low density infill product for gap-filling between timber studs (primarily to avoid air infiltration) and a higher density thermal insulation material for more technically demanding applications such as commercial flat-roofing. In Europe, the product is typically used on flat-roofed residential buildings in Southern Europe (e.g. Spain and Italy). The technology is seen to have a particular role in cost-effective renovations in these regions.

- *Current blowing agent selection*



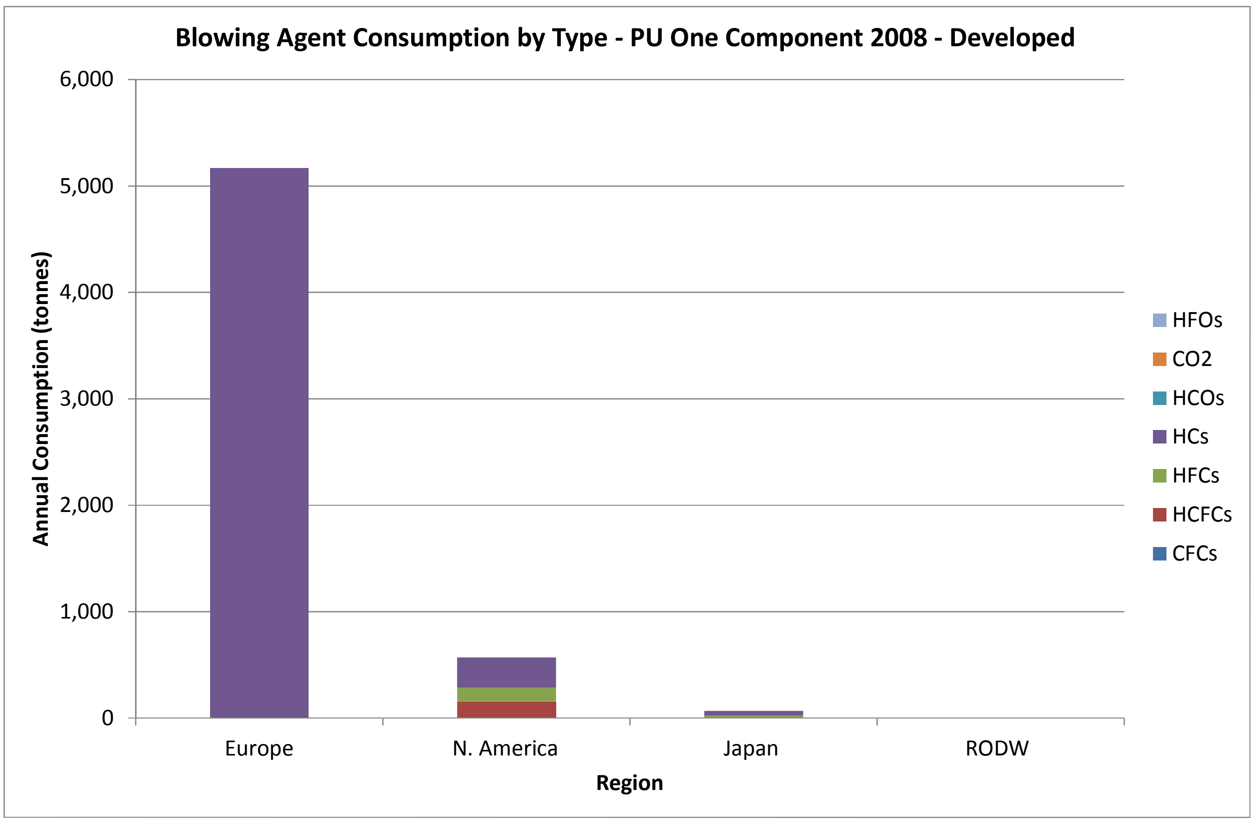
The primary blowing agent choices for this technology in developed countries are HFCs. This can be either HFC-245fa (primarily in the United States) or HFC-365mfc/227ea blends (more prevalent in Europe). The low density in-fill foams used in North America are typically CO_2(water) blown. There is also significant use of super-critical CO_2 in Japan, although this has not been graphed separately at this stage, since CO_2 consumption data has been harder to verify. Nonetheless, it is estimated that CO_2-based technologies as a whole represent the majority of consumption in the Japanese market.

PU One Component Foam

- *Current Market Trends*

This is a predominantly European market arising from the construction methods used with brick and block constructions. The product is based on a moisture-cured system (hence the term 'one-component') and is used primarily on site. The market is highly sensitive to construction activity, particularly in the residential sector, but is likely to benefit from renovation activities also.

- *Current blowing agent selection*



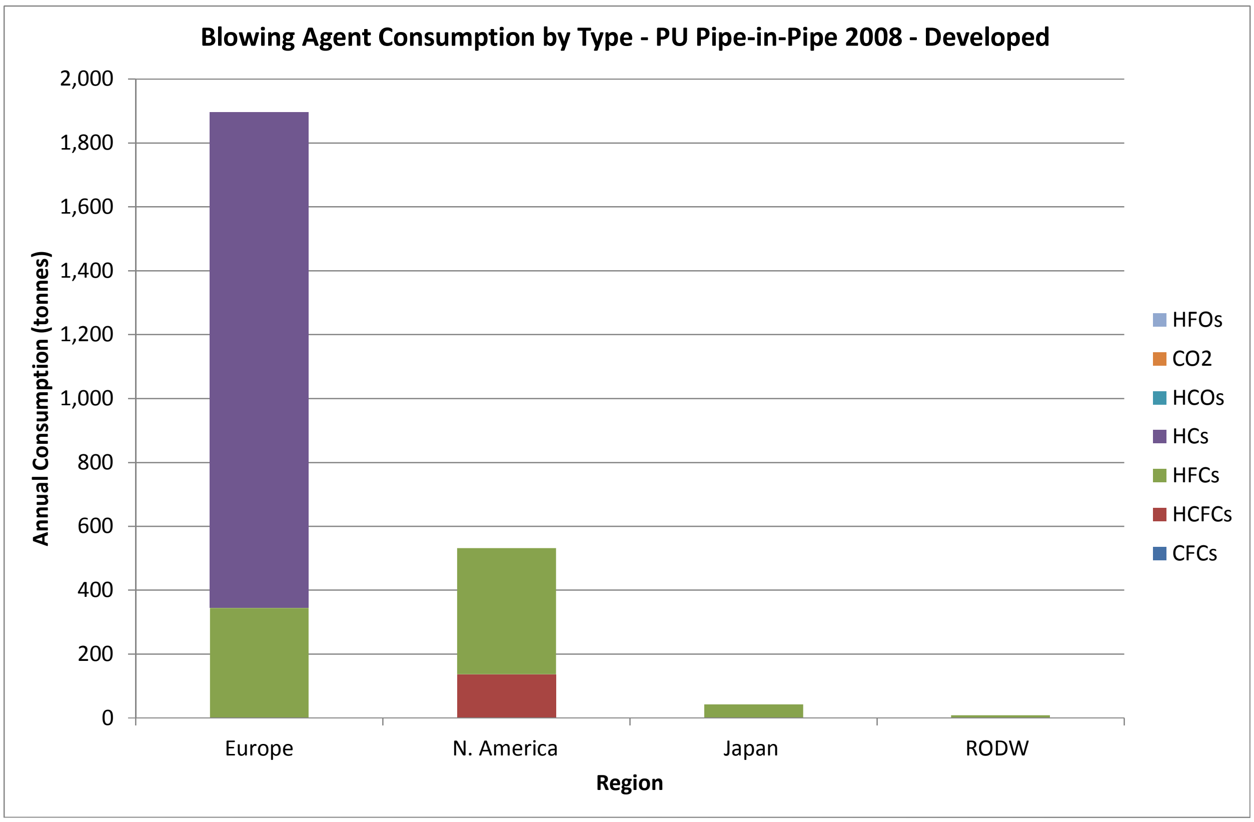
Although hydrocarbons are noted as the primary blowing agent in Europe, this analysis needs to be enhanced further in future Assessments since, although many formulations are based on blends, one of the principle components is believed to be dimethyl either (DME) and other similar products. Ethers would typically qualify as oxygenated hydrocarbons (HCOs) and would be accounted accordingly in future analyses.

PU Pipe-in-Pipe (including moulding of pipe sections)

- *Current Market Trends*

This market has historically been strong in centralised economies where the provision of heat to large residential complexes is delivered from a central heat source. These district heating systems have become more significant now in other regions where the advent of combined heat and power (CHP) systems has encouraged similar underground pipe solutions. Some of these systems can now be on quite a small-scale (so-called *micro-CHP*).

- *Current blowing agent selection*



The major market for this approach is in Europe where hydrocarbon technologies have proved fully operable for the pre-insulated pipes required. There is also some minor use of HFCs.

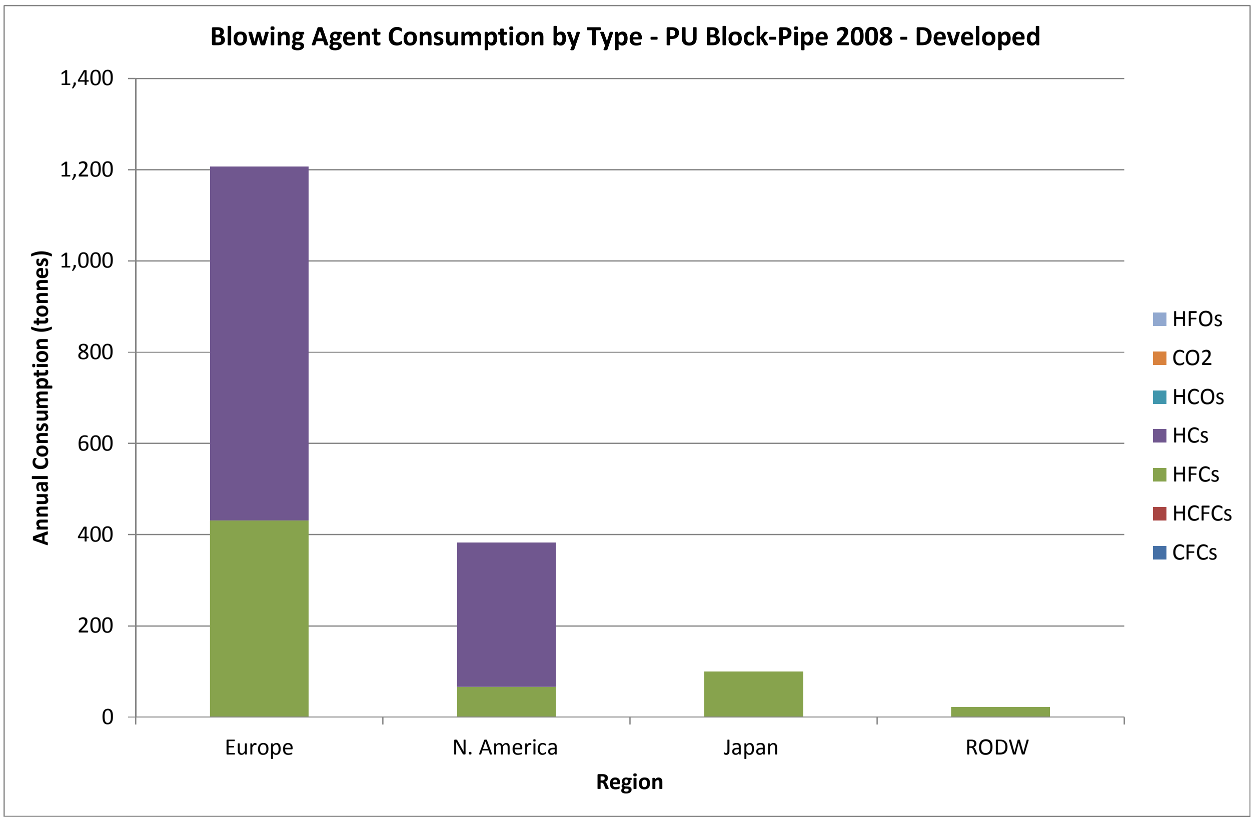
PU Block – Pipe Section

- *Current Market Trends*

Compared with other polyurethane markets, this sector remains fairly mature and tends to fluctuate mostly with process-based investments. Polyurethane pipe sections (particularly PIR) have a niche in cryogenic applications, where their resilience at these temperatures is important. In other parts of the market they are under more pressure from other products offering better fire performance (e.g. phenolic foam or mineral fibre).

- *Current blowing agent selection*

PU block can be made both continuously and discontinuous. Where market demand supports it, continuous block offers less waste. However, cutting pipe sections from blocks is always an inefficient process and the choice of blowing agent needs to reflect this, both economically and environmentally. Accordingly, there has been increasing pressure on the use of hydrocarbons in this sector despite the initial concerns over process safety. For the larger producers, the management of hydrocarbon technology has proved both possible and cost-effective – once the initial investment was made. For smaller manufacturers, HFCs have been a more obvious choice.



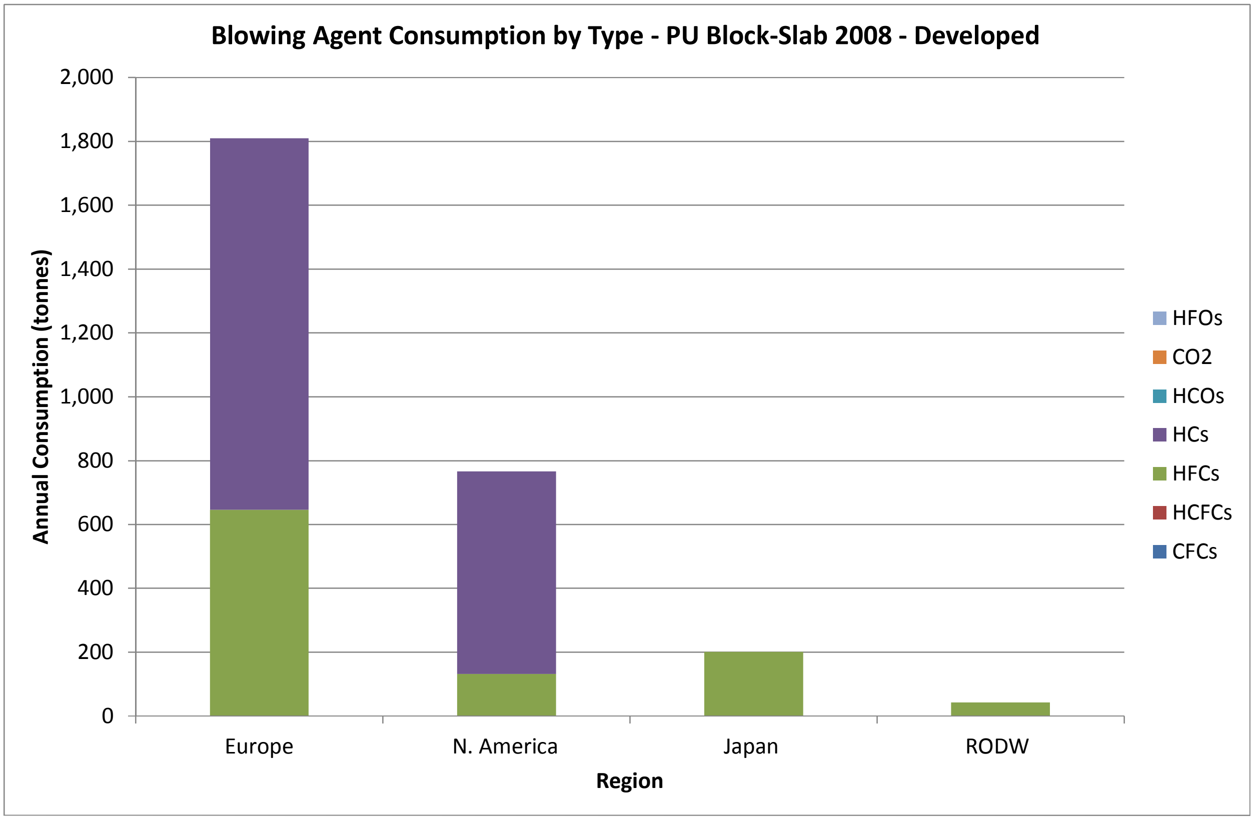
<u>PU Block - Slabstock</u>

- *Current Market Trends*

Again, this product type is relatively mature and is typically used for non-routine applications for polyurethane foams where a degree of fabrication is necessary. The market for slabstock products is typically higher than for pipe section – partly due to the lower losses resulting from the fabrication step. This can be passed on in more competitive pricing.

- *Current blowing agent selection*

The processing is precisely as described for PU Block-Pipe and the blowing choice is identical as a result. There are few applications for slabstock where the choice of a hydrocarbon blowing agent does not suffice. Therefore, the final blowing selection is broadly driven by process considerations.



Developing Countries

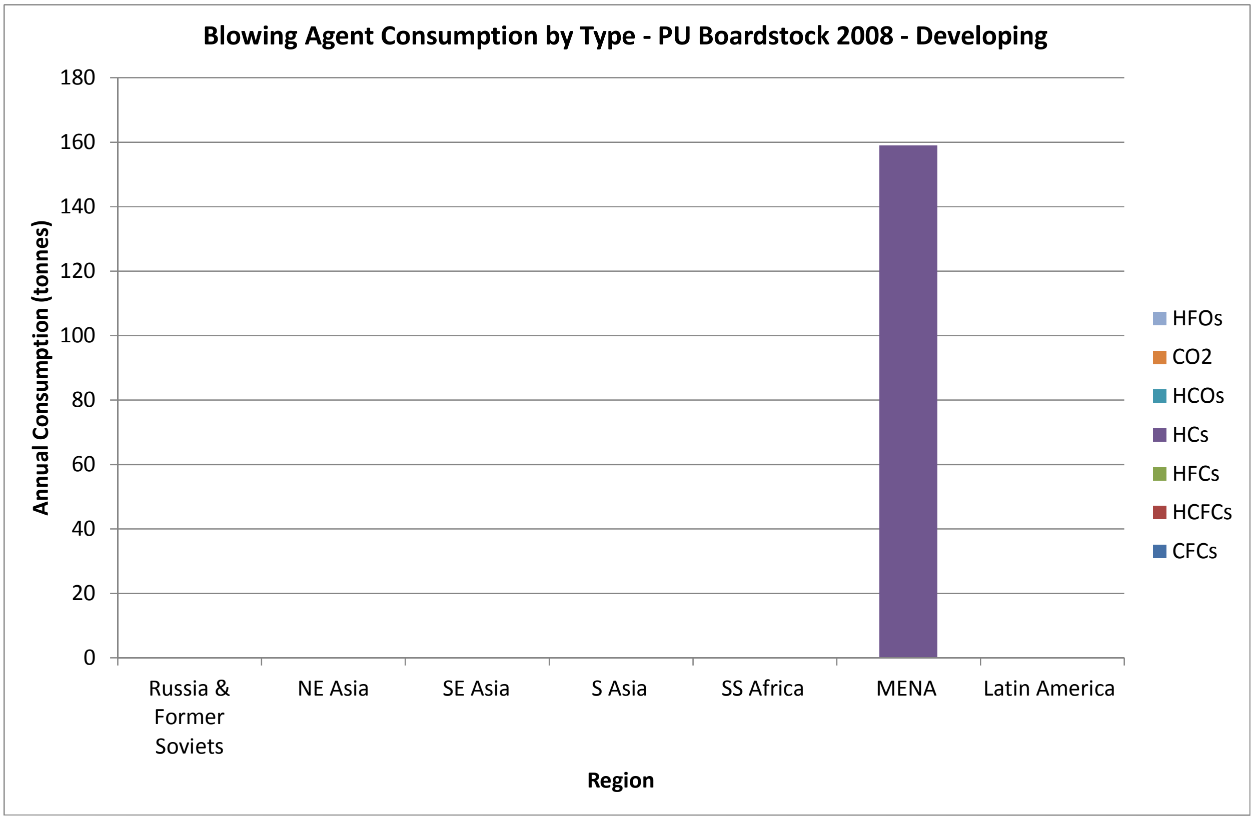
PU Boardstock

- *Current Market Trends*

PU Boardstock has not been an historic part of the product mix in developing countries and the only known production facility has been in Turkey (accounted for under MENA). This facility has broadly been supplying the European market and does not really reflect indigenous demand. That said, there is an increasing interest in all thermal insulation options for new buildings, particularly in colder climates as the demand for energy efficiency, driven both by energy security and climate change considerations, increases. It has been observed by the FTOC that technology transfer from developed to developing countries relating to energy efficiency solutions and standards has been on the increase during this Assessment period and may lead to the adaptation of more developed country insulation strategies for both timber-framed and brick/ block constructions.

- *Current blowing agent selection*

In the one known facility, the choice of blowing agent has been consistent with the market served (Europe) and no particular technological challenges have been observed.



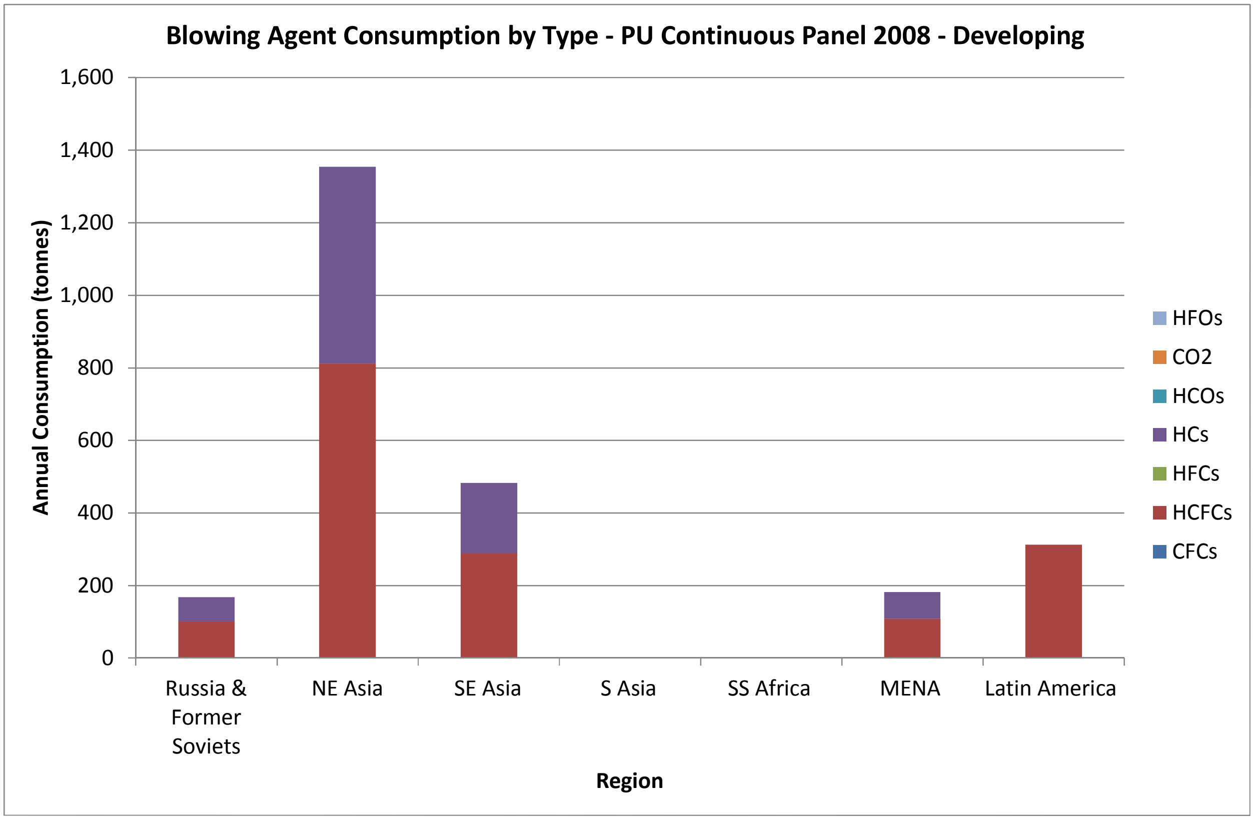
PU Continuous Panels

- *Current Market Trends*

In view of the pre-fabricated nature of these products and the reproducibility that this brings, this technology has been more transferable than others and multi-national interests have not been afraid to invest directly in continuous plants where the overall population size and potential economic growth are seen to justify it. One of the advantages of this type of construction is the speed at which the erection of new buildings can take place around a steel frame. The technology also has the advantage of having the thermal insulation characteristics in-built, thereby avoiding the risk of under-insulation which can be associated with systems built up on site.

- *Current blowing agent selection*

The choice of blowing agent has largely been a measure of the timing of the investment. Once the developed countries became comfortable with the use of hydrocarbons, it was inevitable that this would be adopted for new investments in developing countries. However, earlier plants were based on HCFCs (typically HCFC-141b) and will require conversion as part of the enactment of Decision XIX/6. The choice of alternative will is quite widespread with both hydrocarbons and HFCs being options.



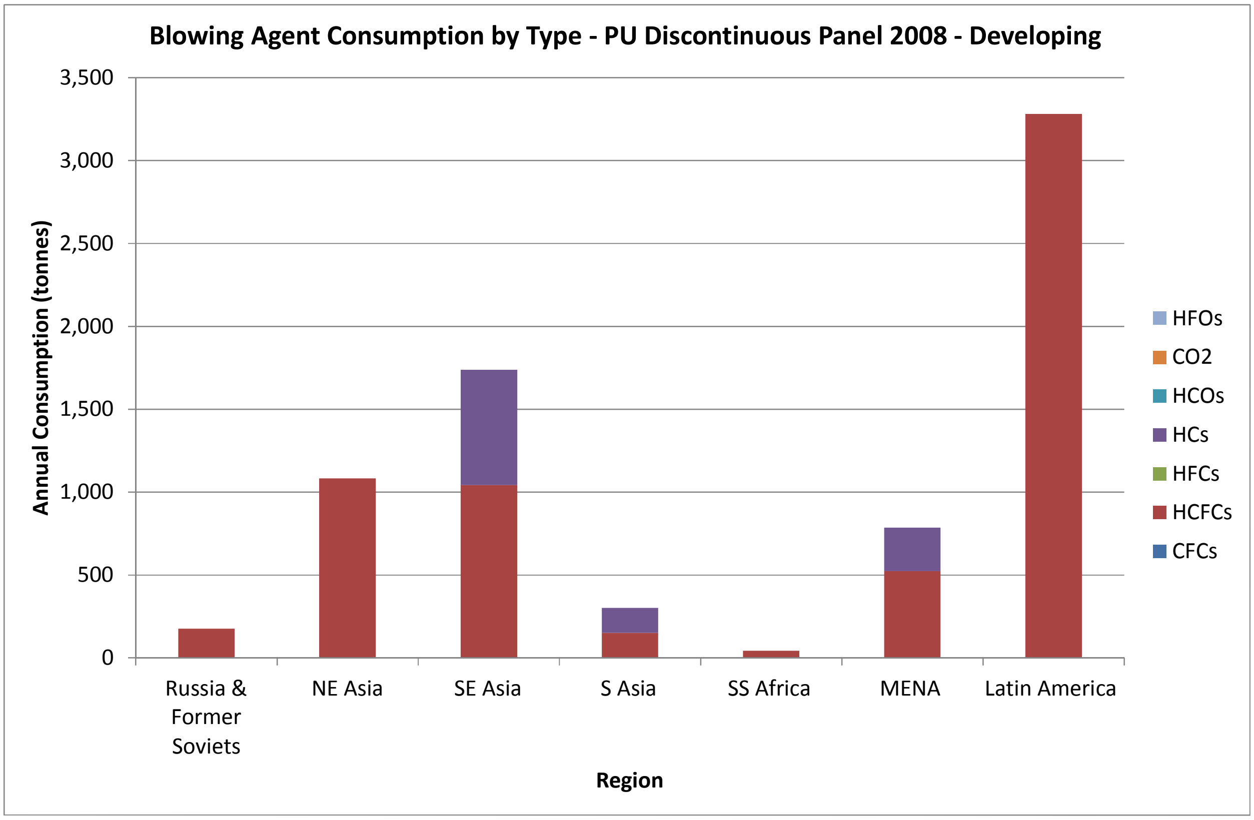
PU Discontinuous Panels

- *Current Market Trends*

A similar argument exists to that in developed countries about the proportion of the PU panel sector that will remain discontinuous as the market grows. However, an additional factor is in play in the developing country scenario. This is simply that the investment cost for continuous processing equipment is likely to be beyond many indigenous manufacturers. As is shown in the following graph, the manufacture of steel-faced discontinuous panels is quite widespread within the developing world and is likely to remain so for a significant period to come. Again, the value of prefabrication in a factory environment has additional value in a developing country scenario.

- *Current blowing agent selection*

As with continuous panels, the primary blowing agents were HCFCs in 2008. However, the proportion of the market based on this technology was higher, based on the lack of multi-national influence on the chosen investment strategies.



There have been reports from Latin America (notably Brazil) that this is an area where methyl formate may have a role based on its basic performance. Some commercialisation has taken place since 2008, although the longer-term prospects still need to be evaluated. Hydrocarbons and saturated HFCs will be the other choices likely to be considered in the short-term, with unsaturated HFCs (HFOs) unlikely to make inroads until commercialisation takes place and the cost implications have been fully assessed.

PU Spray Foam

- *Current Market Trends*

The requirement for the refurbishment of residential properties in China has led to the unprecedented growth of the PU Spray Foam market there. The centralised nature of parts of the economy in that region means that this trend might not be replicated to the same extent in other parts of the developing world. Nonetheless, the obvious value of PU Spray Foam in cost-effectively improving the thermal performance of existing buildings will certainly ensure that it has a major role in thermal insulation strategies around the world.

- *Current blowing agent selection*

The current estimate for the Chinese market alone is 70,000-80,000 tonnes per year currently. However, in 2008, this was considerably lower (probably around 25,000 tonnes) leading to a demand for blowing agent of between 2,500 tonnes and 3,000 tonnes for that year.

The sector is currently completely dependent on HCFCs (most typically HCFC-141b) and is seeking to resist the transition to saturated HFCs with their climate dis-benefits. However, the challenge for developing countries is to identify technologies that are largely unproven (at least on a large scale) within developed countries. Methyl formate, methylal and super-critical CO_2 have all been mentioned in this context and pilot projects have been targeted at evaluating each in the spray foam environment. In Mexico, for example, the PU spray foam market represents 30% of all HCFC consumption in that country and the HPMP is currently proposing methyl formate as the replacement of choice. However, the FTOC has concern that the evidence base is currently too low to demonstrate that methyl formate can be used safely and effectively in PU Spray applications[1].

PU One Component Foam

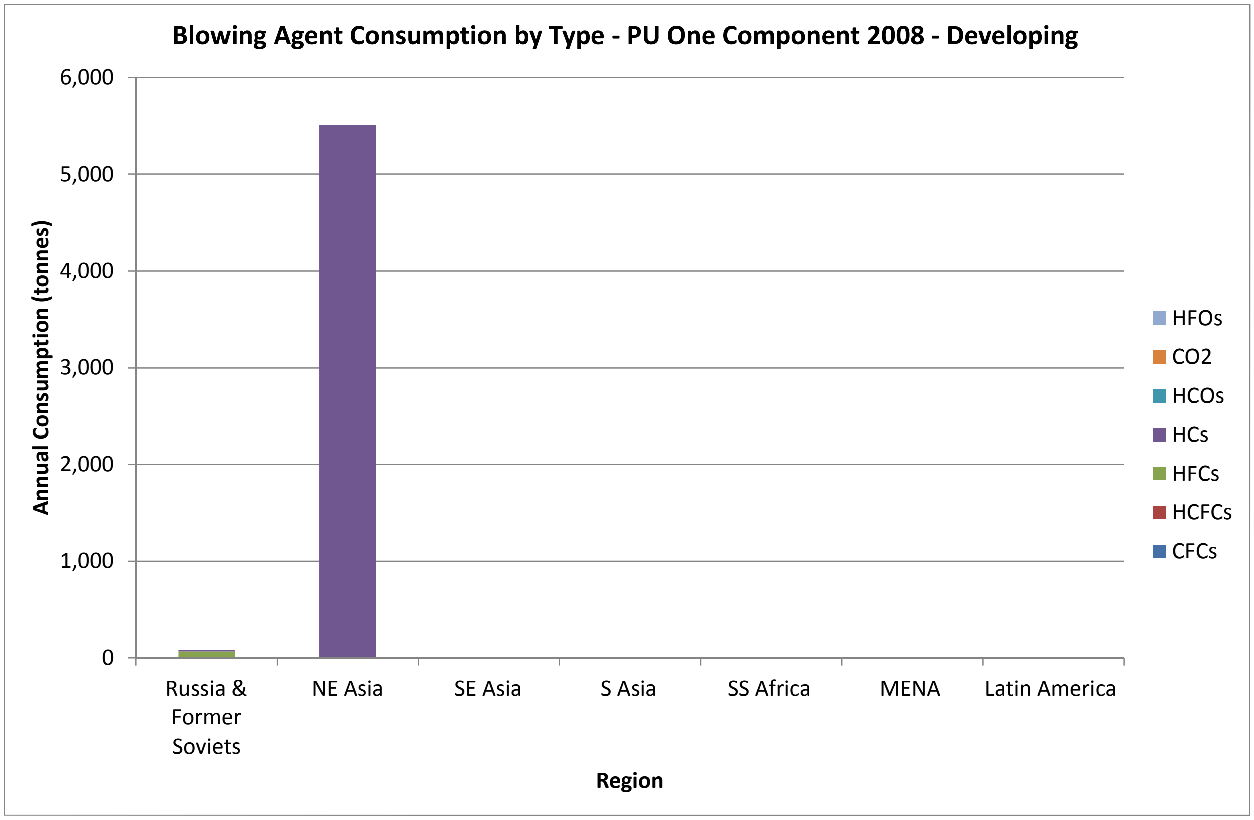
- *Current Market Trends*

The PU One Component Foam market is prevalent in two developing country regions. The first of these is 'Russia and the former Soviet States' primarily reflecting the extension of European building practices into these regions. The second, and most significant, market is China where approximately 150 million cans are produced annually. This accounts for approximately 100 ktonnes of PU chemical and up to 6,000 tonnes of blowing agent – making it a similar size to the European market.

- *Current blowing agent selection*

Although HFCs are understood to be the primary choice in the former Soviet States, the Chinese market has followed the European technology move into hydrocarbons. The following graph demonstrates this trend.

[1] The 'minority view' challenges this statement and cites the number of project submissions made to the MLF Secretariat in support of this position. However, the FTOC is conscious that the decision to submit or approve such products cannot be used as a 'proxy' for technology endorsement.



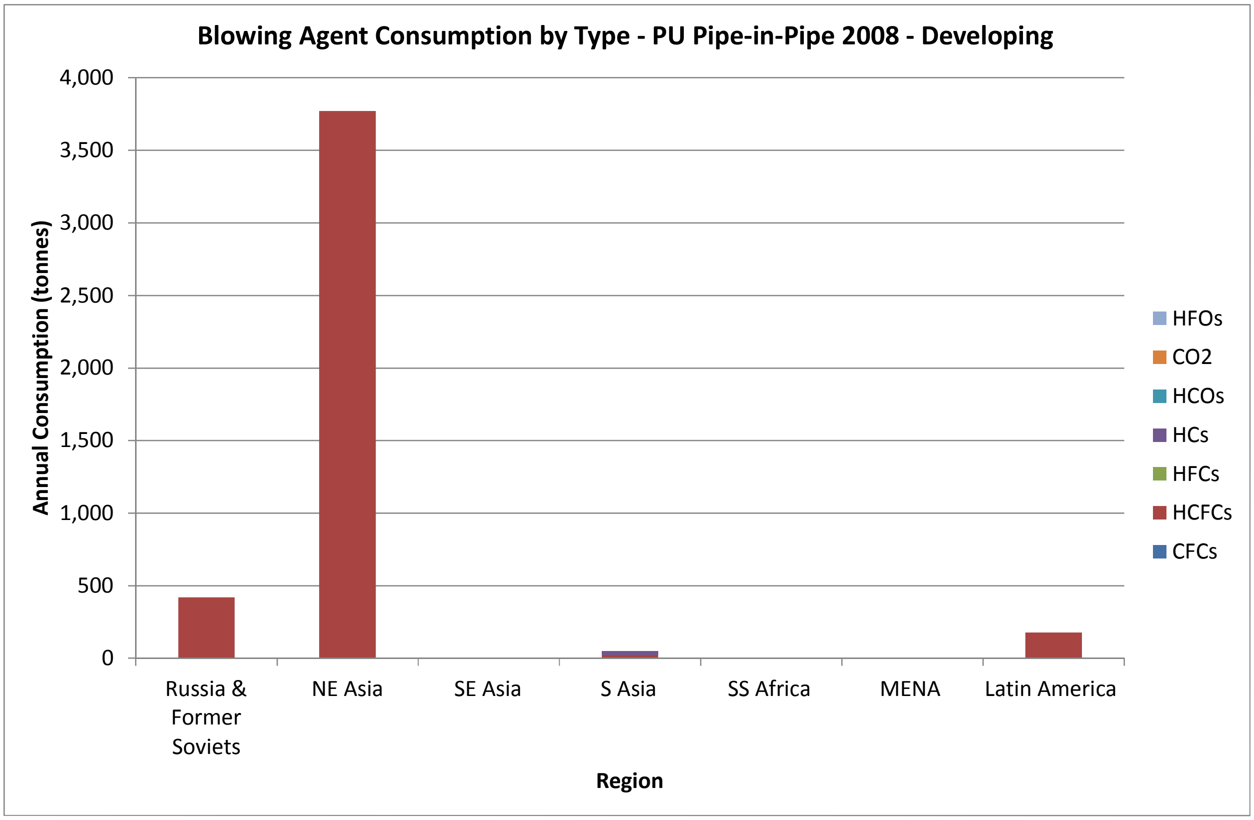
<u>PU Pipe-in-Pipe (including moulding of pipe sections)</u>

- *Current Market Trends*

As noted in the developed country section for this application, the more centralised economies have tended to adopted district heating systems as a means of distribution and, with it, have made good use of pre-insulated polyurethane pipes. As with PU One Component Foams, China is the dominant market for these, although there is considerable use in Russia and Former Soviet States as well.

- *Current blowing agent selection*

The current foam systems are based on HCFC technology, but there is a clear option to switch to hydrocarbon, based on the substantial experience gained in Europe using this technology. This will be particularly the case in China, where the economies of scale should make investment a rational proposition. The situation will be less clear in Russia and the former Soviet States, where some use of HFC-based technologies is also possible – particularly in smaller manufacturers.



<u>PU Block – Pipe Section</u>

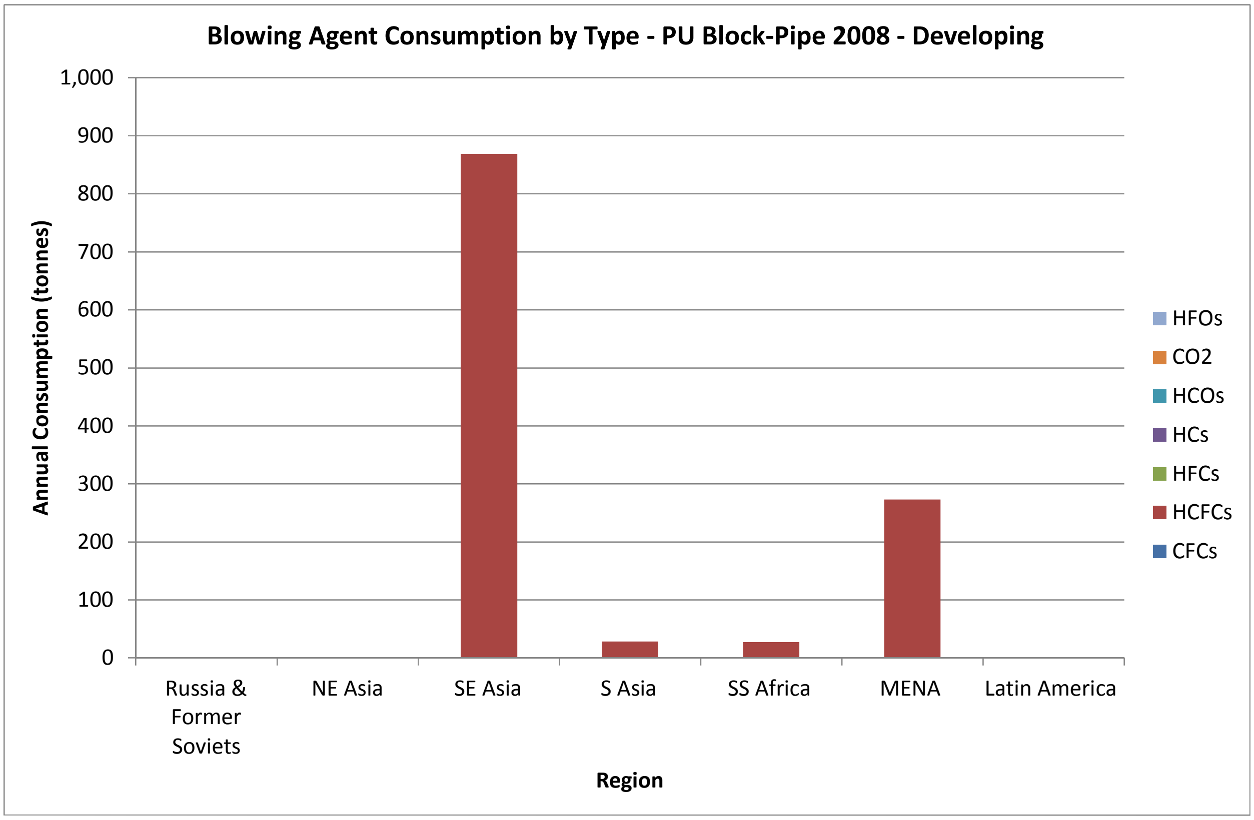
- *Current Market Trends*

These markets (both for pipe section and slabstock) are relatively mature in nature. In developing countries, the PU Block processes are almost exclusively discontinuous. This reflects the fact that investment costs are lower and small operations can be scattered across regions where larger scale investments would not be cost-effective. However, for the same reasons, it is particularly difficult to track the split between pipe section demand and slabstock demand, since the only distinction occurs at the block fabrication stage.

For the purposes of this report, it is assumed that the split between the two sectors is 50/50. This is largely an arbitrary split at this point and further bottom-up research would certainly help in validating this assumption. The main significance of the separation of the two product types is in the waste levels from each, with pipe section fabrication resulting in up to 50% waste in some instances.

- *Current blowing agent selection*

The dominant blowing agent choice at present is HCFCs. This sector therefore represents one of those requiring to be addressed under Decision XIX/6. It is also one that accounts for a large number of the really small consuming enterprises. The technology choices are therefore s-HFCs, or those potentially flammable blowing agents that can be shown to be managed at this scale. This may include pre-blended hydrocarbons, methyl formate and others, but pilot projects are yet to deliver conclusive messages for these technologies.



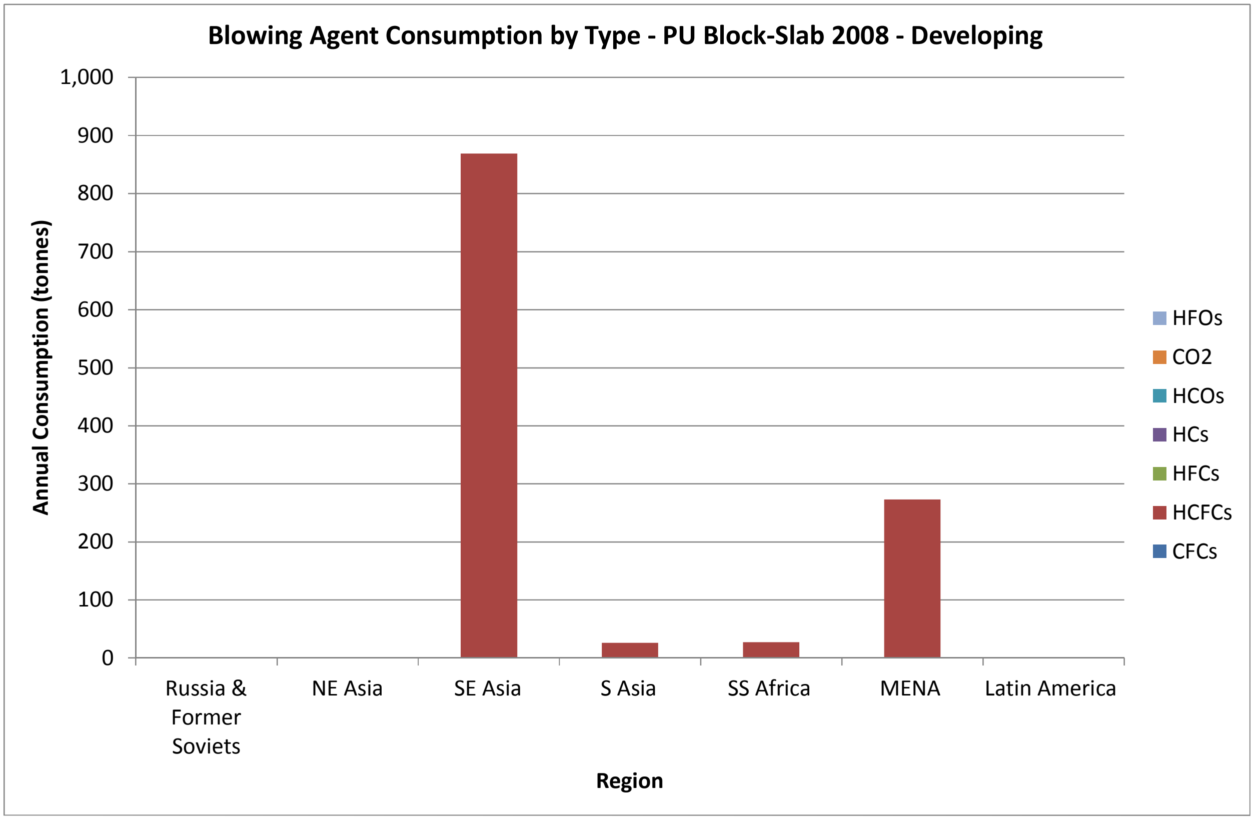
PU Block - Slabstock

- *Current Market Trends*

Comments for this sector are the same as those for PU Block – Pipe.

- *Current blowing agent selection*

Comments for this sector are the same as those for PU Block – Pipe.



FLEXIBLE POLYURETHANE FOAM

<u>PU - Flexible Slabstock</u>

The use of CFCs in flexible slabstock has been completely phased out over this Assessment period, if not before. There was little, if any, substitution with HCFCs as an auxiliary blowing agent and therefore the issues with respect to ozone depleting substances (ODS) are virtually fully resolved.

However, the Montreal Protocol through its Technical Options Committees has a duty of care to maintain an overview of the replacement technologies - particularly where there may be on-going health, safety or environmental concerns. These remaining paragraphs therefore briefly review the current status.

The main technologies now in use are methylene chloride and carbon dioxide (CO_2 (LCD)). Other, more minor technologies also exist and, between them all, they cover all applications. However, 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 some current replacement technologies.

Methylene chloride continues to be under scrutiny from a health and safety perspective. However, the pressure for replacement has not grown substantially since 2001.

Liquid carbon dioxide, while successful in developed countries, specifically when the use of methylene chloride is restricted or forbidden, proved to be a serious challenge in most Article 5(1) countries. The combination of a complicated technology with virtually unchallenged use of easy-to-process methylene chloride proved a major burden for an initially enthusiastic embrace of the environmentally preferable LDC option. In the USA there is also considerable use of acetone and in Europe some use of variable pressure technology. 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. The further uptake of Exotherm Management Technologies (EMT) continues to be monitored, although little has been published recently on the subject. There is also some recent, but unsubstantiated, information that methyl formate may be acting as a replacement for pentane, acetone and methylene chloride.

PU – Flexible Moulded

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. HCFC-141b is used in exceptional circumstances such as highly filled acoustical foams but is not essential as a replacement in this industry. The use of HCFCs in this industry is not allowed in most developed countries. Methyl formate has emerged as a legitimate replacement for HCFC-141b where it is still used and may also provide advantages over CO_2(water) where this technology has already been adopted.

PU – Integral Skin and Miscellaneous

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.

A variety of blowing agents has been identified as alternatives to HCFCs in this sector. These include CO_2 (water), various s-HFCs, n-pentane and methyl formate. With some drawbacks associated with skin formation using CO_2 (water) technologies, methyl formate may offer a particularly attractive alternative and there has already been considerable uptake in Latin America (most notably Brazil) already.

POLYOLEFIN FOAMS

There are three prime product types in the uncross-linked 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 this review.

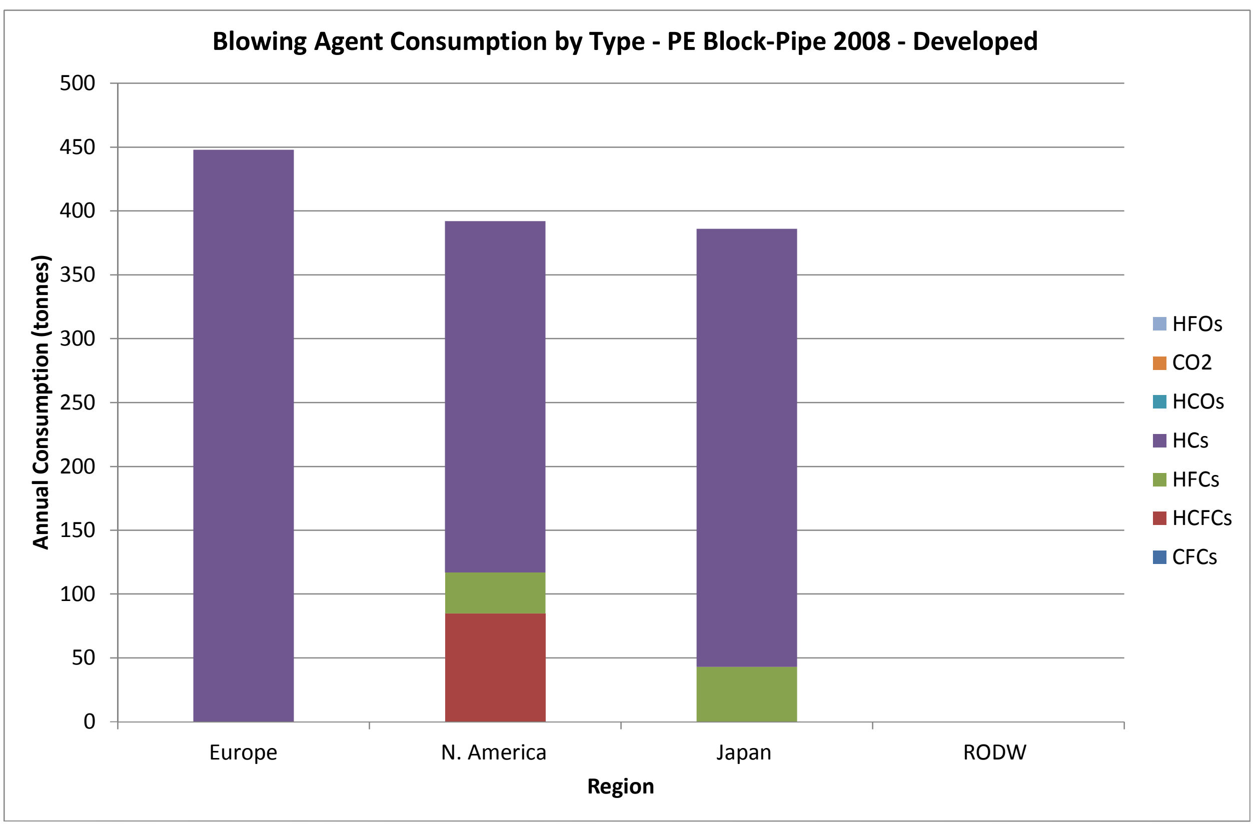
Developed Countries

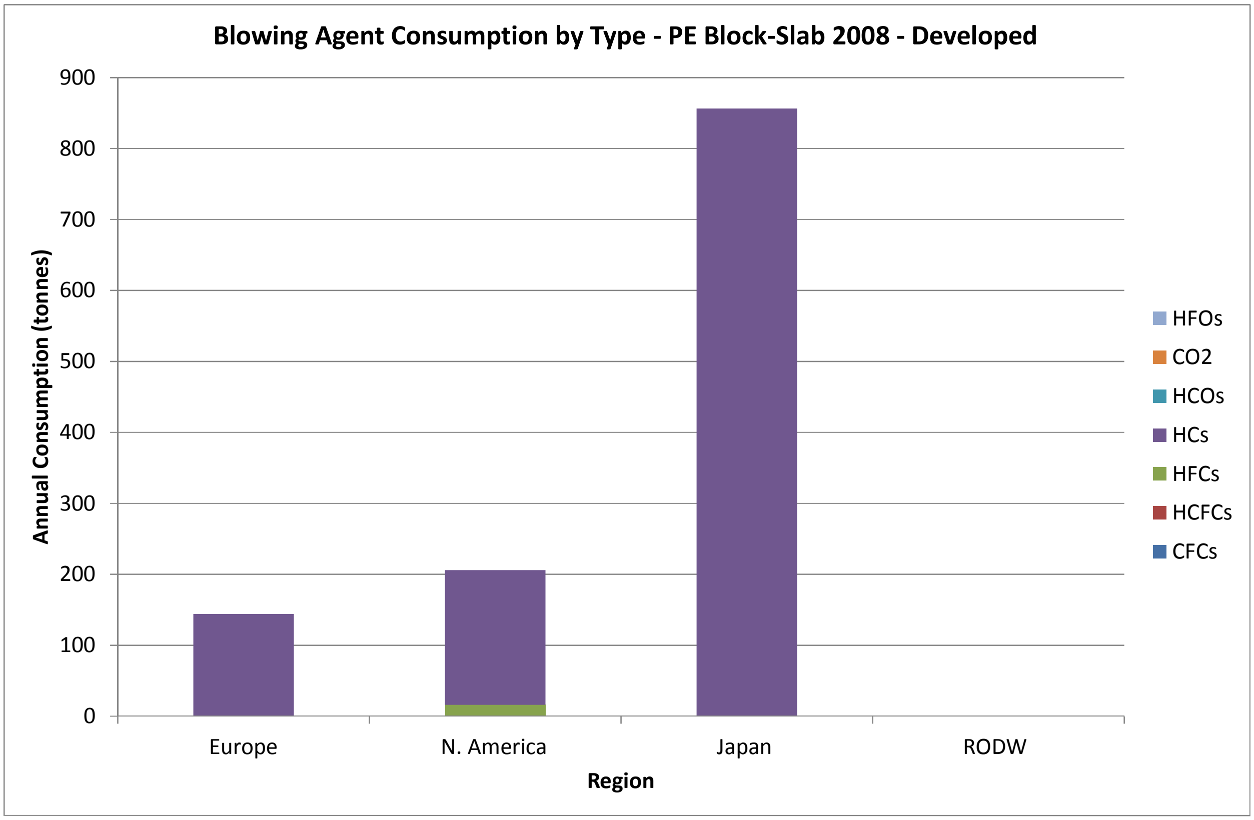
- *Current Market Trends*

The market for polyethylene pipe section continues to be buoyant based on the demand for low-cost, easy-to-install pipe insulation in the residential sector, where fire performance is less regulated in many regions. The product is particularly suited to do-it-yourself activities, since it is easy handled and manipulated. However, the actual thermal performance can be variable depending on the quality of installation.

- *Current blowing agent selection*

Hydrocarbons (typically iso-butane) are the dominant blowing agents in Europe and predominate in other regions too (see graph below)





For PE Block-Slab, the market is split between construction, leisure and packaging applications, with packaging dominating on some regions (e.g. Japan).

Developing Countries

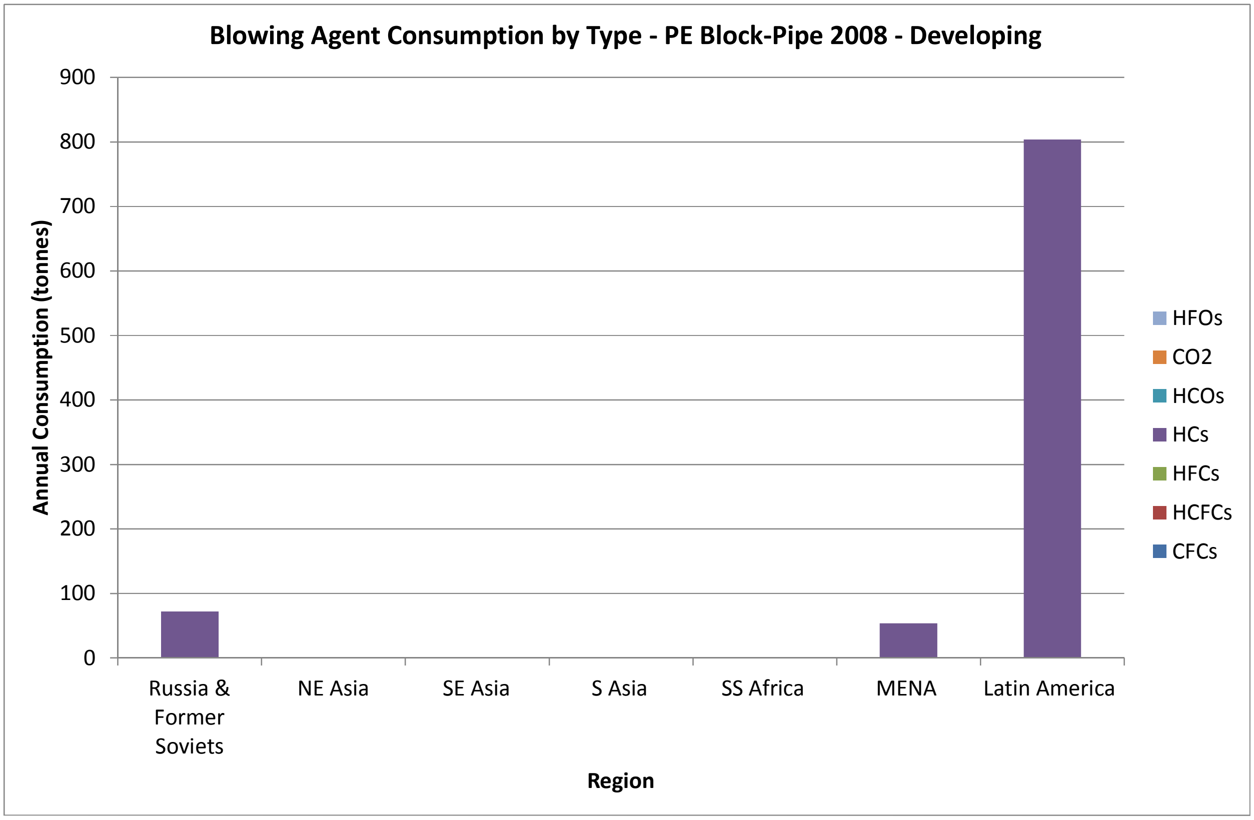
- *Current Market Trends*

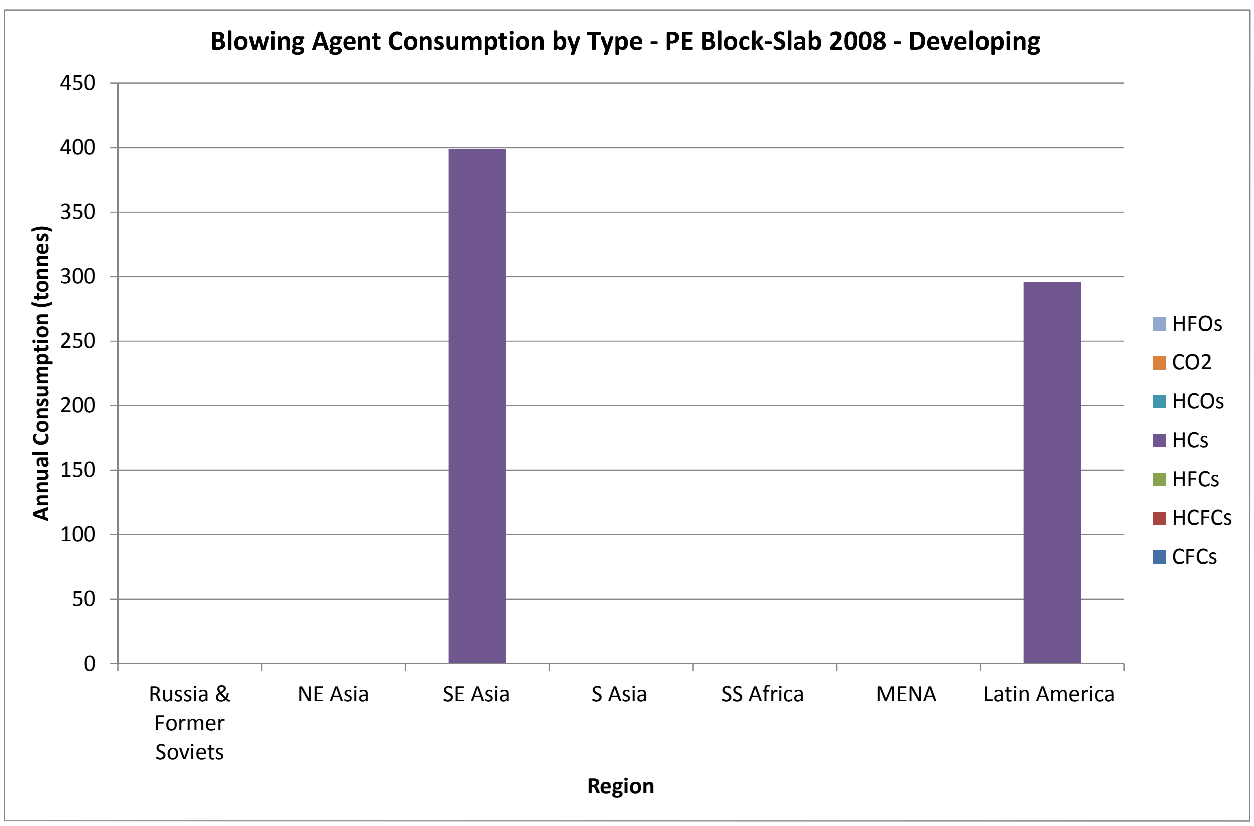
Although the markets are similarly characterised in developing countries as those in developed countries, the geographic distribution is limited rather more in this case by historic technology transfer, with Latin America embracing PE pipe section more significantly than other regions.

Latin America also has significant involvement with PE slab production, again with a similar application portfolio to that in developed countries. However, the larger market for slab in developing countries is found in South East Asia. As with Japan, this is understood to be underpinned by a larger use in the packaging sector.

- *Current blowing agent selection*

In all developing country regions, the dominant blowing agent is now hydrocarbon.


Blowing Agent Consumption by Type - PE Block-Pipe 2008 - Developing
Annual Consumption (tonnes)
900
800
700
600
500
400
300
200
100
0
Russia & Former Soviets
NE Asia
SE Asia
S Asia
SS Africa
MENA
Latin America
Region
HFOs
CO2
HCOs
HCs
HFCs
HCFCs
CFCs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Annual Consumption (tonnes)
450
400
350
300
250
200
150
100
50
0
Russia & Former Soviets
NE Asia
SE Asia
S Asia
SS Africa
MENA
Latin America
Region
HFOs
CO2
HCOs
HCs
HFCs
HCFCs
CFCs

EXTRUDED POLYSTYRENE FOAMS

Developed Countries

Sheet

- *Current Market Trends*

The XPS sheet market has a number of similarities with the PE Slab market in that a large proportion is used for leisure and packaging. In some instances, the packing requires some thermal performance (e.g. fast foods and hot drinks), but the thermal properties are no required to be persistent in the same way as thermal insulation applications in construction, transport or appliances. The market has been less studied quantitatively by the FTOC since the phase-out of CFCs and almost universal switch to hydrocarbons.

- *Current blowing agent selection*

As noted above, hydrocarbons (butane, isobutane, pentane, isopentane), HFCs (HFC-134a, HFC-152a); and hydrocarbon / CO_2 (LCD) blends, have found a range of commercial use with hydrocarbons being the dominant selection in most regions. HFC-152a also been used significantly in the United States to overcome local VOC emission regulations.

Few future developments are expected. However, capital investment required for the handling of flammability issues and on-going concerns over VOC emissions will be limiting factors in further expansion of hydrocarbon containing systems.

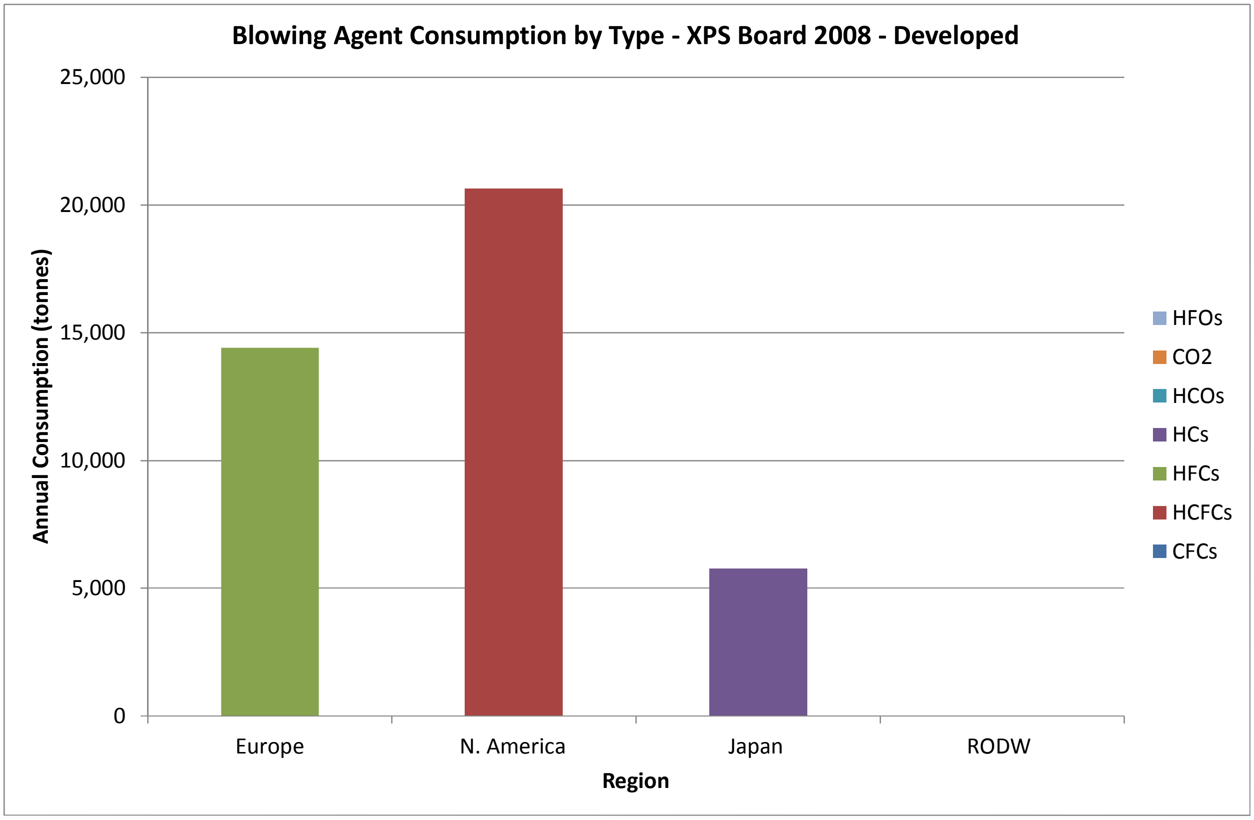
Board

- *Current Market Trends*

Extruded polystyrene board has effectively emulated the growth of PU/PIR products in the thermal insulation sector as markets have been stimulated by increased energy efficiency in buildings. The product's competitive position is underpinned by its particularly good moisture resistance, which has been responsible for widespread use as a floor insulation material in Europe. In North America, the product is typically competing with PIR ("polyiso") products in the residential sheathing market, as well as in a number of commercial and industrial building applications.

- *Current blowing agent selection*

The following graph illustrates the rather bizarre situation in terms of blowing agent selection by region as it was in 2008.



In Europe, the primary replacement technologies have been HFC-134a, HFC-152a and CO_2 (or CO_2/alcohol), while in Japan there has also been significant use of hydrocarbons (notably isobutene). In North America, the transition away from HCFCs has been more difficult because of particular product requirements, especially in the residential sector. HCFC-142b, therefore, remained the dominant blowing agent as at 2008. However, since then, transition to s-HFCs has occurred, as companies have mastered the adoption of HFC technology for sheathing products and also achieved the relevant building code requirements.

Investment criteria continue to be a barrier to further use of CO_2-based technologies in Europe, although pressures are likely to increase concerning the on-going use of HFCs. A review of the F-Gas regulation is on-going in the EU and will be completed before the end of 2011. There may be some future interest in the use of HFOs for this application, but cost considerations may necessitate the use of these substances as blends with HCs and possibly HCOs (e.g. di-methyl ether).

Developing Countries

<u>Sheet</u>

- *Current Market Trends*

The market drivers are very similar to those described for developed countries.

- *Current blowing agent selection*

Technologies have also shifted almost universally to hydrocarbon despite earlier concerns about the flammability of both the blowing agent and the substrates on high temperature extrusion lines. There is no immediate expectation for this sector to make any further blowing agent transitions.

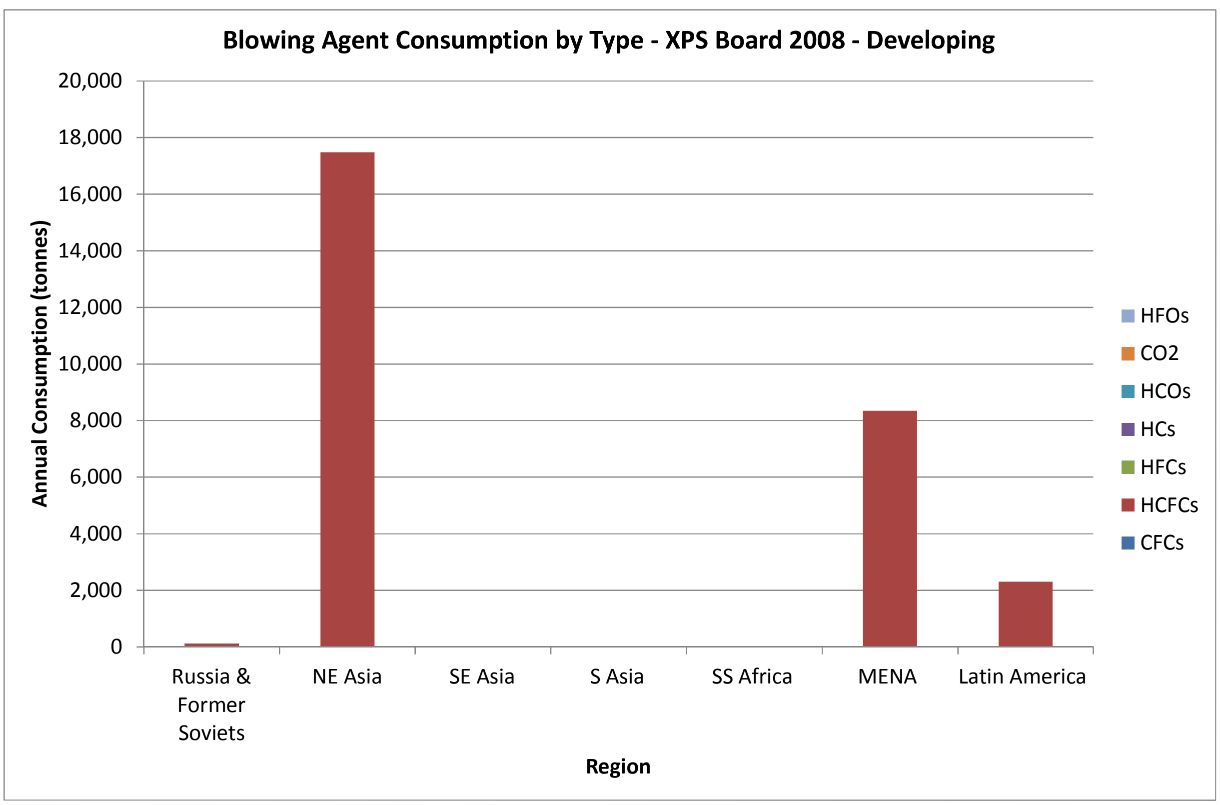
<u>Board</u>

- *Current Market Trends*

There has been substantial growth in markets for XPS board in a number of Article 5 countries, most notably in China and some middle-eastern countries. This has increased the demand for HCFCs by in excess of 15,000 tonnes per annum since 2001. However, latest information suggests that some recent fires in major Chinese cities may result in some retrenchment for both new and existing buildings, driven by new fire standards. Although EPS and some EPS might be the primary culprits, the impact could be seen across all organic foam products.

- *Current blowing agent selection*

The industry was totally based on HCFCs in 2008, although the split between HCFC-142b and HCFC-22 continues to remain unclear.



For other Article 5 countries, the relatively low cost of investment in locally produced manufacturing plant and the high demand for improved thermal performance in buildings is expected to drive further rapid growth of XPS board production. Prior to 2015, the predominant blowing agents are expected to continue to be HCFCs. Ultimately, hydrocarbons may prove the dominant blowing agents in these territories.

PHENOLIC FOAMS

Developed Countries

PF Boardstock

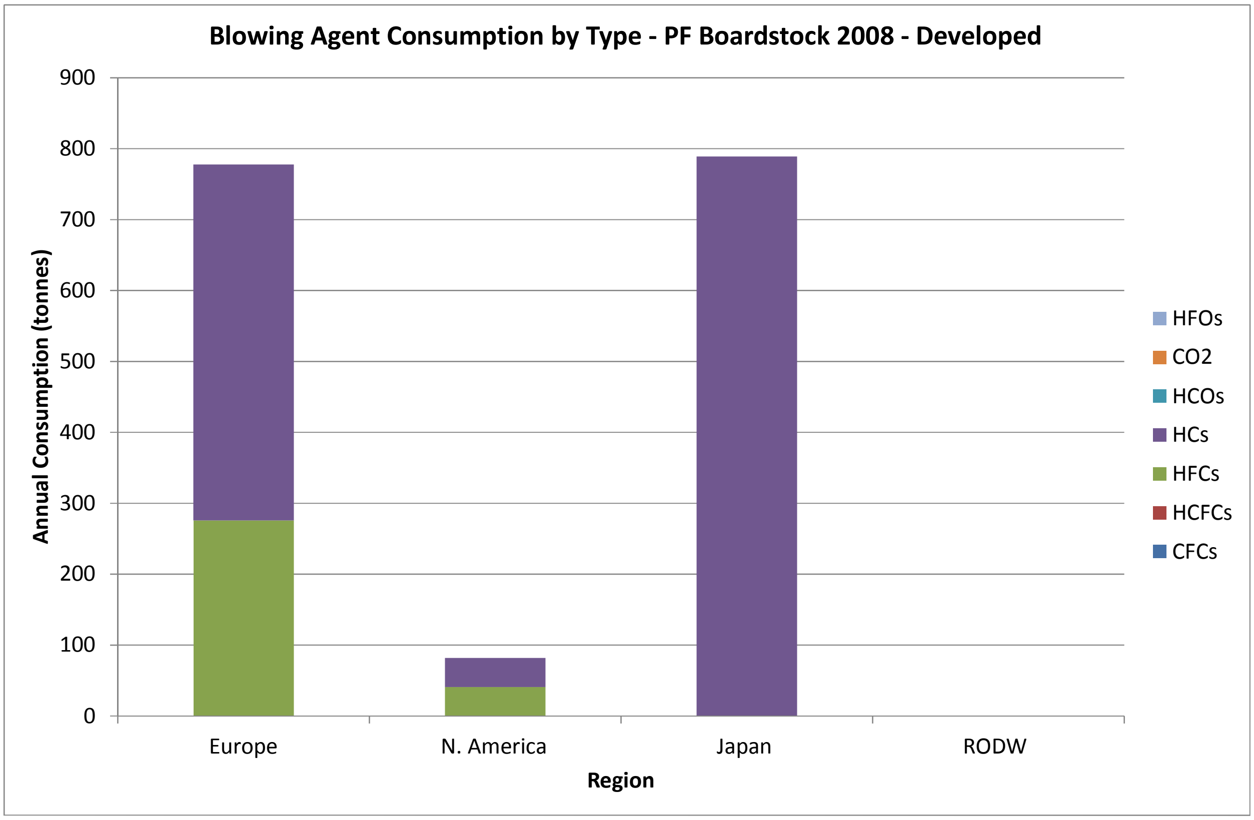
- *Current Market Trends*

Phenolic Foam boardstock has continued to make progress in the buoyant European market, with the key manufacturers being able to switch between PU boardstock and PF boardstock products, at will, against the same market specifications. This has meant that capacities can be better utilised and PU raw material shortages offset.

In Japan, the market has continued to be supportive of phenolic boardstock in view of its superior fire performance and highly competitive insulation values. However, the recent earthquake and tsunami have created interruptions in production which may have some short-term impact on supply.

- *Current blowing agent selection*

The bulk of the sector is now fully switched to hydrocarbon technologies, although this was slightly less the case in 2008 (see graph below):



There is still some use of 2-chloro-propane at one facility in Europe, but otherwise the industry is expected to normalise even further around the hydrocarbon option.

PF Pipes and Blocks

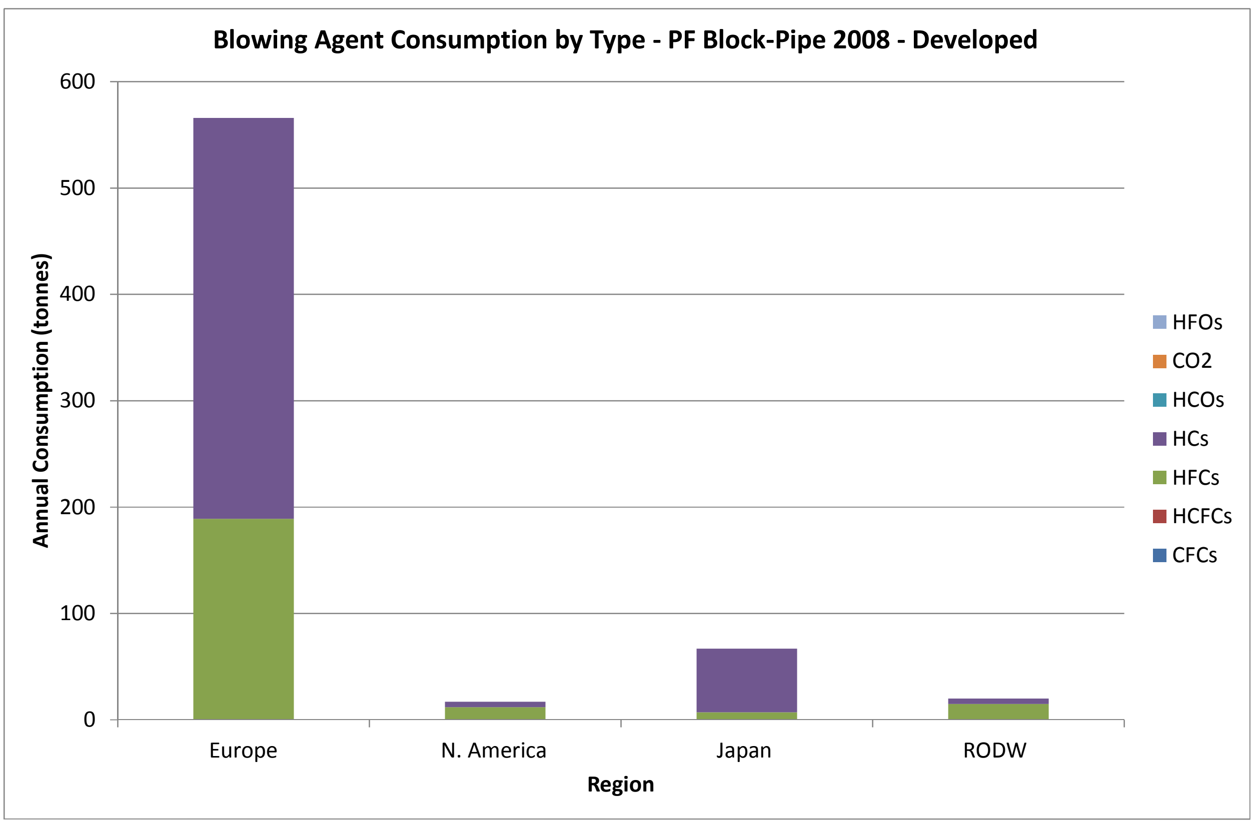
- *Current Market Trends*

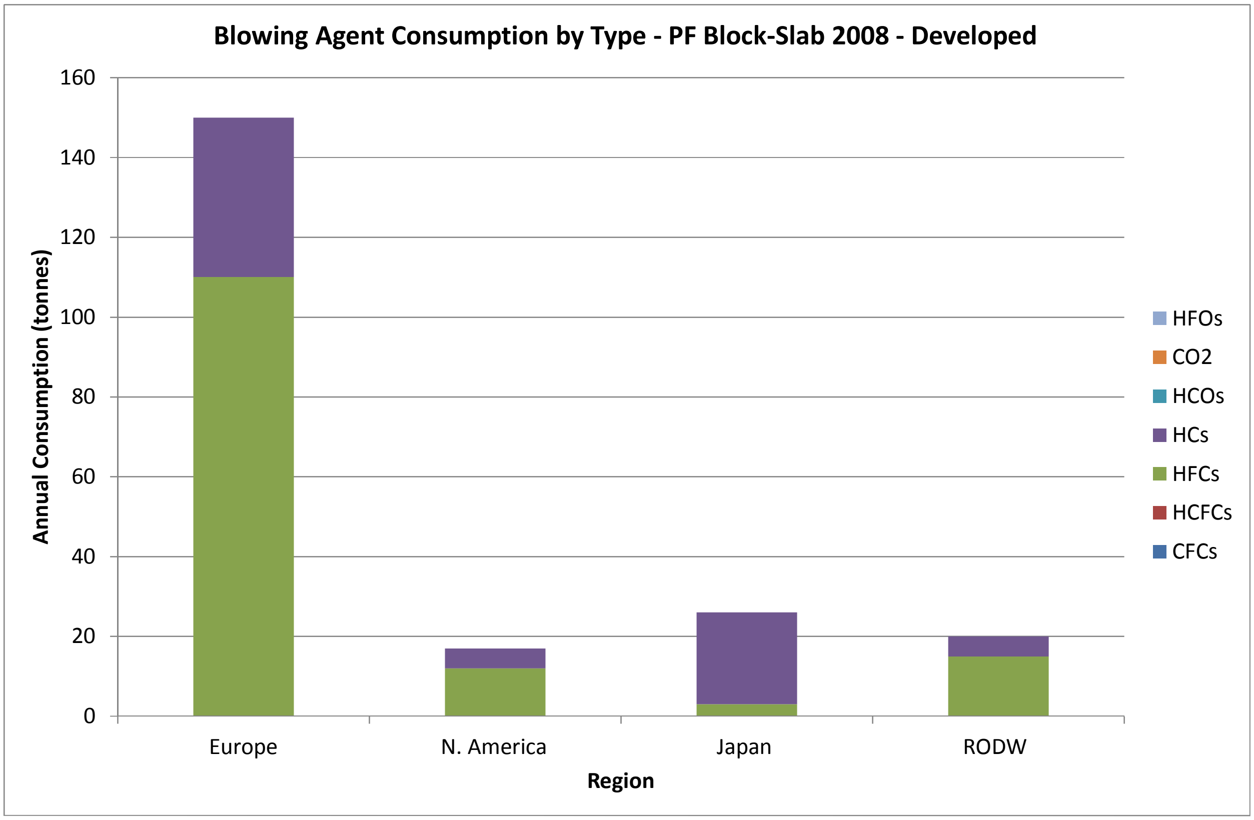
The market for phenolic pipe insulation continues to be highly regionalised with the United Kingdom representing the major market in Europe and, perhaps, the world. This results from a specific combination of 'reaction-to-fire' requirements which rules out competitive materials such as PU/PIR. The future direction of other markets in Europe will depend on the extent to which individual countries adopt maximum smoke requirements, which can now be specified through the European classification system.

The production economics have also been improved by the introduction of continuous process technologies for the more common sizes of pipe.

- *Current blowing agent selection*

The choice of blowing agent for the continuous process has been hydrocarbon. This has had little effect on the overall fire performance of the product or its market acceptance. For discontinuous block processes, the choice remains s-HFCs, particularly for the smaller manufacturers. This is reflected in the graph below:





Technology choices are the same for PF Block-Slab Foam, although hydrocarbon is less prevalent because no continuous process exists for this product group. Accordingly, s-HFCs are the most significant blowing agents in use, with the exception of Japan, where hydrocarbon solutions have been effectively engineered.

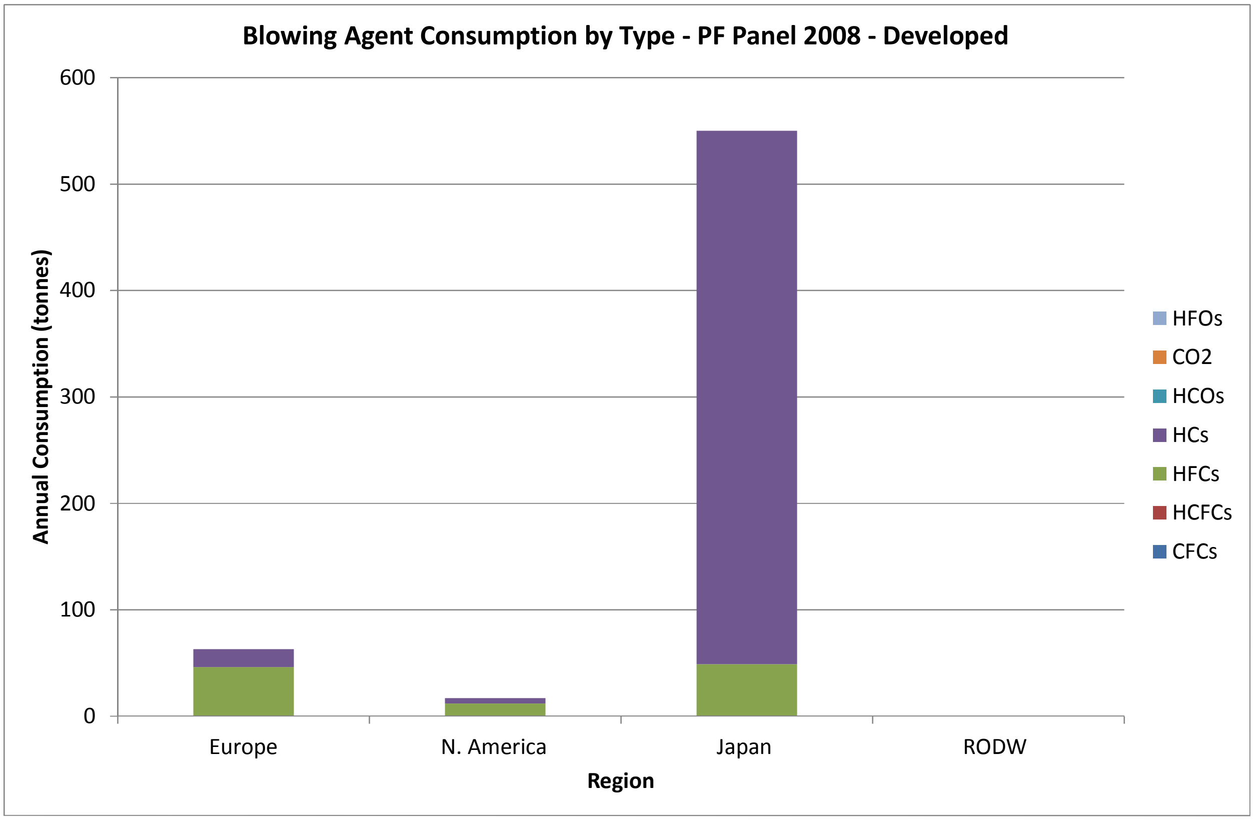
PF Panels

- *Current Market Trends*

The market for metal-faced phenolic foam panels is relatively mature in Japan. The primary products are for residential siding and office partitioning. These are usually discontinuously produced. The market in Europe is still in a fledgling state and is targeted at niche panel applications such as clean rooms, cold stores and computer safe rooms.

- *Current blowing agent selection*

Reflecting the size and maturity of the Japanese market, the technology has been able to be adapted for hydrocarbon blowing agents. In Europe, (most notably the UK), the size of production operations is insufficient to support hydrocarbon investments at present and s-HFCs are typically used.



Developing Countries

<u>PF Boardstock</u>

- *Current Market Trends*

At the present time, there are no known PF Boardstock manufacturers in developing countries.

- *Current blowing agent selection*

There is currently no blowing agent consumption.

<u>PF Pipes and Blocks</u>

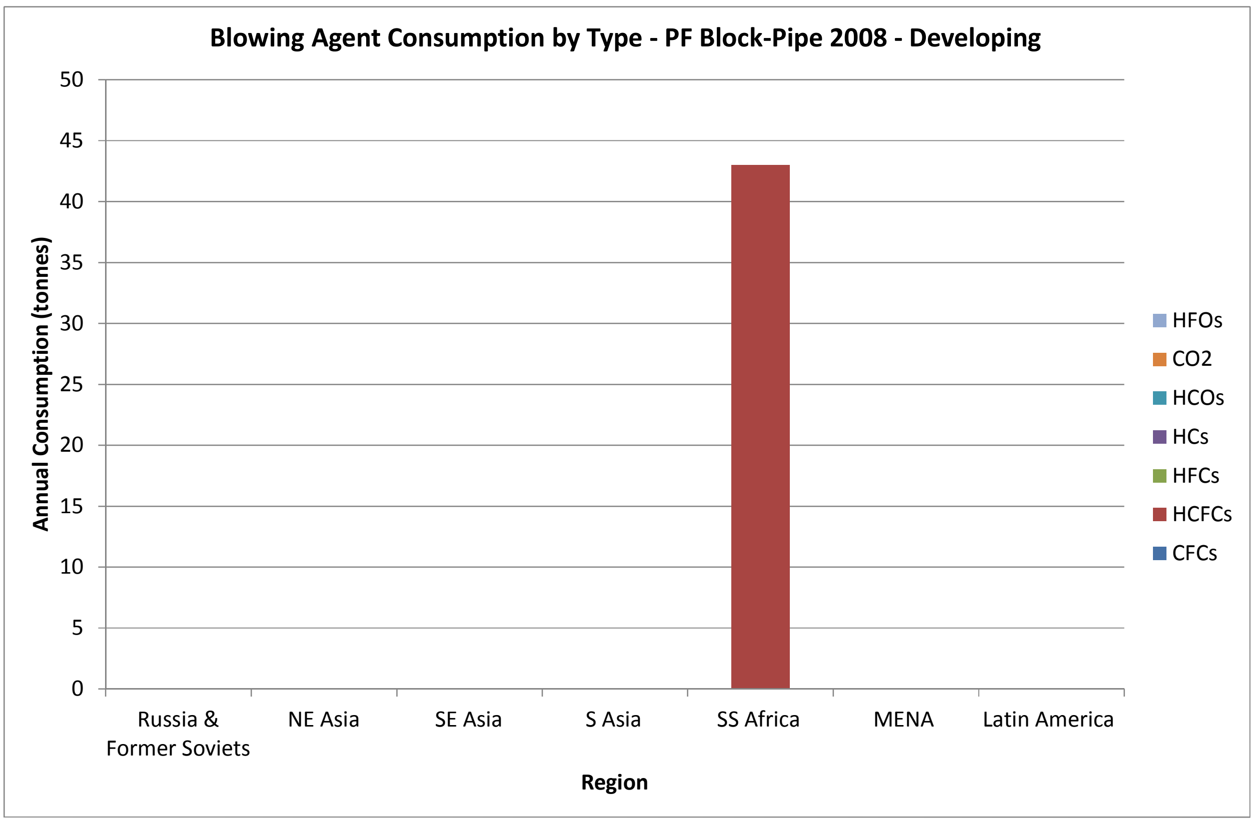
- *Current Market Trends*

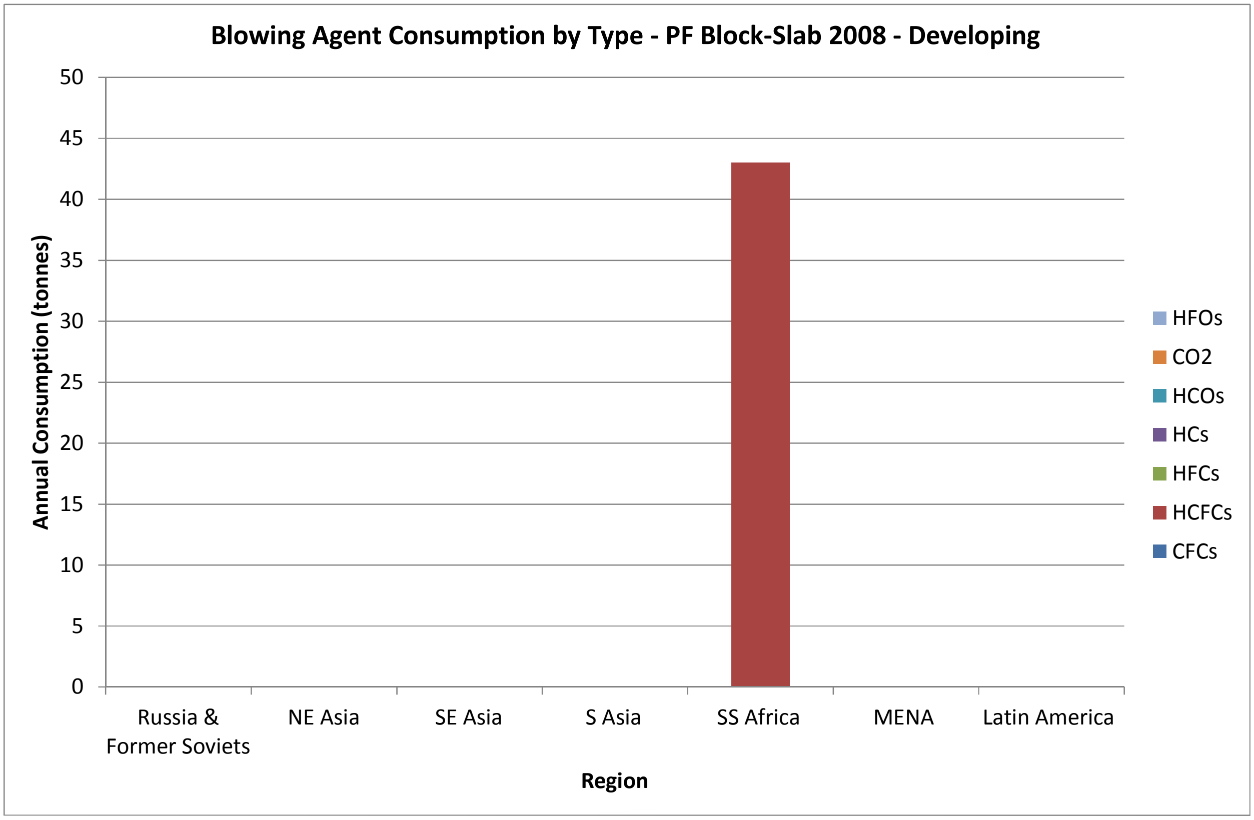
Historically, there was some PF Block Foam manufacture in India, but this is understood to have ceased as a consequence of limited market penetration and conversion costs out of ozone depleting substances. The only developing country consumption is now in South Africa, where

European block foam technology continues to be operated – partially supplying products for the mining sector.

- *Current blowing agent selection*

It is understood that HCFC-141b remains the blowing agent of choice in South Africa at present, although considerations are underway for a transition to non-ODS alternatives. Further investigations are on-going into potential choices, but the scale of the operation might leave s-HFCs as the only viable alternative in the short-term.





PF Panels

- *Current Market Trends*

At the present time, there are no known PF Discontinuous Panel manufacturers in developing countries.

- *Current blowing agent selection*

There is currently no blowing agent consumption.

CHAPTER 2: TECHNOLOGY OPTIONS

POLYURETHANE FOAMS

Developments on blowing agents in the PU foam sector

The primary challenge for the foam sector continues to be the phase-out of HCFCs in developing countries under Decision XIX/6. HPMPs are being developed to meet the 2013 freeze and the 10% use reduction in 2015. In developed countries HCFCs were completely eliminated by the middle of the last decade in the polyurethane (PU) foam sector and the substitute technologies and the usage patterns have reached a relatively mature status. The analysis of this experience along with the proper considerations associated with the markets differences and the scope of Decision XIX/6 focused on alternatives that minimize the climate change impact, provides a valuable insight for the HCFC phase-out in developing countries.

Developed Countries

The section describes the blowing agents currently used in developed countries:

Table 1. Blowing Agents currently used in developed countries	
PU RIGID FOAM	
Domestic refrigerators and freezers	c-pentane, cyclo/iso pentane blends, HFC- 245fa, HFC-134a
Other appliances	c-pentane, cyclo/iso pentane blends, HFC- 245fa, HFC-365mfc/227ea blends, HFC-134a, methyl formate, CO_2 (water)
Transport & reefers	c-pentane, cyclo/iso pentane blends, HFC- 245fa, HFC-365mfc/227ea blends, HFC-134a
Boardstock	c-pentane, n-pentane, iso pentane, cyclo/iso pentane blends, n-pentane/iso pentane blends, HFC- 245fa, HFC-365mfc/227ea blends
Panels – continuous	c-pentane, n-pentane, iso pentane, cyclo/iso pentane blends, cyclo/n-pentane blends, n-pentane/iso pentane blends, HFC-245fa, HFC-365mfc/227ea blends
Panels discontinuous	HFC- 245fa, HFC-365mfc/227ea blends, HFC-134a, c-pentane, n-pentane, iso pentane, cyclo/iso pentane blends, n-pentane/iso pentane blends, CO_2 (water), formic acid, methyl formate
Spray	HFC- 245fa, HFC-365mfc/227ea, Supercritical CO_2, CO_2 (water),
Blocks	c-pentane, n-pentane, iso pentane, cyclo/iso pentane blends, n-pentane/iso pentane blends, HFC- 245fa, HFC-365mfc/227ea blends, methyl formate
Pipe-in-pipe	c-pentane, n-pentane, HFC- 245fa, HFC-365mfc/227ea blends, CO_2 (water), methyl formate
One Component Foam	Mixtures of propane, butane and dimethyl ether, HFC-134a, HFO-1234ze
PU FLEXIBLE FOAM	
Integral Skin	CO_2 (water), HFC-134a, HFC- 245fa, HFC-365mfc/227ea blends, n-pentane, methyl formate
Shoe Soles	CO_2 (water), HFC-134a
Flex moulded	CO_2 (water), methyl formate

It is important to notice the different roles of the blowing agent in PU rigid and flexible foams. Although in both it has the primary function to physically expand the foaming mixture to produce the foam, in the case of rigid foam it should remain within the closed cells and contribute to the insulating performance. To fulfil this latter function, the blowing agent should have a low gaseous thermal conductivity plus a low rate of diffusion of the gas through the foam (matrix) so that the good insulating properties are retained for many years. A low solubility of the blowing agent in the PU matrix is also require to ensure that it is retained as a gas in the foam cell avoiding the solid plasticisation and the loss of thermal insulation. In the case of domestic refrigeration high solubility of the blowing agent in the thermoplastic material of the inner lining may result in a severe deterioration of the mechanical strength.

In the case of flexible foam, particularly in integral skin and shoe soles, the blowing agent has a critical role in forming a robust/aesthetic skin as a result of its condensation during the high-pressure injection process. For this application a relatively low boiling point of the blowing agent is desirable. During the CFC phase-out most of the shoe sole market migrated to all water blown formulations along with the use of polyester polyols to meet the abrasion resistance requirements From table 1, there is wide scale use of hydrocarbons in PU foams together with HFCs in some specific applications, such as HFC 245fa in most North American domestic refrigerators and freezers, and HFC-365mfc/227ea blends to meet the most stringent fire tests in panels. Formulations based on hydrocarbons have been refined over the years and their insulation performance, as expressed by foam thermal conductivity, is now similar to those for HCFC- 141b based foams. They can now also meet very stringent fire test requirements as panels or boards.

There is a clear exception to the trend to use hydrocarbons for PU foams; despite trials, HCs are not used in spray foams for safety reasons. Instead, HCFC 141b has been replaced by HFC 245fa or HFC365mfc/227ea blends, often in combination with significant amounts of CO_2 (water) – “reduced-HFC” technology. CO_2 (water) may be used when increasing foam thickness can compensate for the higher thermal conductivity of the foam. In Japan, supercritical CO_2 technology has been developed and is used. The strengths and weaknesses of the HC and HFC technologies are described in table 2.

Table 2. Strengths & Weaknesses of HC and HFC technologies			
SECTOR/OPTION	STRENGTHS	WEAKNESSES	COMMENTS
Rigid Foam			
Hydrocarbons (c-pentane & n-pentane & cyclo/iso blends)	Low GWP	Highly flammable	High conversion costs, uneconomic for SMEs. Not suitable for spray
	Low unit costs		Low operating costs
	Acceptable foam properties		Global industry standard
HFC-245fa, HFC-365mfc/HFC-227ea	Non-flammable	High GWP	Low conversion costs. Industry standard for spray
		High unit costs	High operating costs, could be improved by using "HFC reduced" HFC/ CO_2 (water) formulations
	Good foam properties		Improved insulation (versus HC)
Flexible Foam (Integral Skin & Shoe soles)			
n-pentane	Low GWP	Highly flammable	High conversion costs, uneconomic for SMEs
	Low unit costs		Low operating costs
	Good skin quality		
HFC-134a, HFC-245fa, HFC-365mfc/HFC-227ea	Non-flammable	High GWP	Low conversion costs
		High unit costs	High operating costs
	Good skin quality		

The major drawback of the hydrocarbon family is their flammability. This has a strong impact on both the capital costs for processing -to ensure that safety is properly engineered- and on product handling, which is particularly problematic for smaller enterprises. Efforts have been made to reduce costs at the foam manufacturers by pre-blending the hydrocarbons into polyols at systems houses. The challenge is to develop a long-term stable formulation with no phase separation. A successful industrial case has been reported in Northern Europe where a system house, for some years, has been delivering formulated polyols containing c-pentane in one-tonne containers and 200 l drums to different industries in Eastern and North-Eastern Europe (PROKLIMA, 2009). This approach allows reduced investments on the user's side without compromising the insulating efficiency and the long-term dimensional stability performance. This experience shows that investment in one blending facility may make it possible to reduce investments in manufacturing plants. While the cost of HC storage tanks, pumps and premixing stations can be avoided, the safety modifications for the polyol blend storage and foaming line and the installation of proper monitoring and ventilation systems will still be required. It is estimated that savings in increased capital cost (ICC) for the end user are in the order of 25 to 35%.

The technology based on CO_2, derived from the isocyanate-water reaction, has been used with limited success for commercial refrigeration (displays, vending machines) where insulation performance is not critical. Its major drawbacks are the relative poor insulating performance resulting from the relatively high lambda value of CO_2; the required increase in foam moulded density caused by the high permeability values of CO_2 through the polyurethane matrix; and the reduced "adhesion" to the substrates where it is applied (metal, thermoplastics), a consequence of the high amount of polyurea present in the polymer. In the Japanese spray market, the use of water blown foam along with patented super-critical CO_2 technology has been developed and commercialised; however, there may be limitations in some applications that require an improved insulating performance.

There is also a small use in developed countries of methyl formate (United States, Australia) particularly for commercial refrigeration, an application where the insulating performance is not critical and some global beverage players (i.e. Coca-Cola) are requesting foams based on non-HFCs, 0 ODP substances. Further discussion on this technology can be found below.

Although a large proportion of the industry in developed countries has settled on hydrocarbons or HFCs as their blowing agent of choice, there are increasing pressures -in the case of HCs- to improve the thermal performance of foams, particularly in the appliance sector, and to limit the future use of saturated hydrofluorocarbons (s-HFCs) and to phase these down where possible.

In this context, there is a growing interest in the potential role of the recently developed unsaturated HFCs (HFOs) in the domestic refrigeration sector and other rigid foam applications, particularly in North America, where saturated HFCs have a significant market, and in PU Spray foam both in Europe and North America. One of these (HFC-1234ze) has found some initial use in Europe as a replacement for HFC-134a in PU One Component Foams.

These compounds represent an emerging group of blowing agents that exhibit a number of the characteristics also displayed by saturated HFCs, but have considerably lower GWPs (< 15). The prime reason for these lower values relates to the shorter lifetime of the molecules in the atmosphere caused by the presence of a double bond between adjacent carbon atoms. Early work suggests that they deliver better thermal performance than their saturated counterparts, although toxicological work remains to be completed for those yet to be commercialised. Cost predictions are similar to saturated HFCs. Their main characteristics are presented in table 3.

Table 3. Saturated HFCs (HFOs)				
	HFO-1234ze	FEA-1100	HBA-2	AFA-L1
Chemical Formula	Trans- $CF_3CH=CHF$	Cis- CF_3-CH=CH-CF_3	Undisclosed	Undisclosed
Molecular Weight	114	164	Undisclosed	Undisclosed
Boiling Point (^{0}C)	-19	32	15.3<T<32.1	10.0<T<30.0
Gas Conductivity (mW/mK @ 10^{0}C)	13.0	10.7	Not Reported	15.9
Flammable Limits in Air (vol.%)	None to 28^{o}C^	None	None	None
TLV or OEL (ppm) (USA)	Unpublished	9.7	Undisclosed	Undisclosed
GWP (100 yr time horizon)	6	9.4	<15	<15

^ Flame limits of 7.0-9.5 at 30^{o}C are quoted

Developing Countries

One of the major challenges of the foam industry is the HCFC phase-out in developing countries under Decision XIX/6. This Decision calls for an accelerated phase-down of the use of HCFCs leading to their replacement, in the foam sector, by zero ODP blowing agents. At the same time, the Executive Committee (ExCom) of the Montreal Protocol is requested, when applying funding criteria, to give priority to cost effective projects with focus on substitutes that minimize other environmental impacts, including on the climate, taking into account global-warming potential, energy use and other relevant factors.

Today two types of polymeric foams use HCFCs as blowing agents: Polyurethane (PU) Foams (mainly HCFC-141b and some HCFC-22) and Extruded Polystyrene (XPS) Board Foams (HCFC-142b and HCFC-22). They compete with other materials, such as mineral fibres, EPS in thermal insulation and other applications. The PU foam sectors using HCFCs are insulating foams, integral skin foams and microcellular foams (shoe soles). In the last two sectors the usage is much less than in the insulating market because of the smaller overall market and the higher foam density. XPS board foams are mainly used for insulation purposes.

The main route for PU foams is to use hydrocarbons (HC), principally pentanes (n-pentane, c-pentane and cyclo/iso-pentane blends). This is particular true for the sectors where the large size of the companies (HCFC use > 50 tonnes/year) benefits the economics despite of the high conversion cost: domestic refrigeration, continuous panels and some commercial refrigeration and discontinuous panels manufacturers. In the case of medium size enterprises (50 tonnes/year >HCFC use >10 tonnes/year) the option of pre-blending hydrocarbons into polyols - described above- may represent a sustainable long-term approach. The Multilateral Fund and the Implementing Agencies have taken up the matter and two pilot projects have been sponsored and are under development (China and Egypt); one of them along with the introduction of a third HC stream at the mixing point. The results will be ready during 2011.

Although the use of HC technology provides lower operating costs than other alternatives such as HFCs, the significant capital costs for conversions make unviable its application for small size enterprises (HCFC use < 10 tonnes/yr). It is estimated that the minimal Incremental Capital Costs (ICC) for the conversion to HC are in the range of USD300,000 to USD500,000.

On the other side, in addition to their high GWP, the use of saturated HFC-based technologies (HFC 245fa, HFC-365mfc/HFC-227ea) may result in significant increases in operating costs owing to their higher unit prices and molecular weights. It is also clear that, despite of the promising results, their unsaturated counterparts (HFOs) are unlikely to be available in time to meet the early stages (pre-2015) of the HCFC phase-out as required under Decision XIX/6. In the interim, there is evidence that some enterprises manufacturing appliances in developing countries are already blending saturated HFCs with hydrocarbons to meet energy requirements.

From the above considerations, HCFC phase-out in sectors that include a large number of SMEs (a typical industry characteristic in the Article 5 countries) represents the most significant challenge. Many of the enterprises have little, if any, internal capacity to optimise formulations and their capacity to handle flammable compounds is limited. There continues to be a need to characterise the performance of foams made from low-GWP alternatives in the range of applications envisaged. This is an on-going exercise, but is particularly important for technologies that do not have a significant history of use in non-Article 5 countries. The role of the Pilot Projects sponsored under the Multilateral Fund are especially relevant here and the work of UNDP on methyl formate, for example, has already cleared the way for wider use in the flexible moulded and integral skin sectors with potential for others to follow.

In the case of rigid foam applications, perhaps the most critical case, a conventional testing programme for a new blowing agent includes[2]:

- Toxicology and ecotoxicology testing (ODP, GWP, toxicology)
- Processing characteristics:
  - ✓ Stability in polyol blends
  - ✓ Miscibility with polyols
  - ✓ Flow properties (flow index, minimum fill density)
  - ✓ Reaction times including jig dwell times
  - ✓ Atmospheric concentrations during processing and comparison with flammable limits in air
  - ✓ Effects on equipment – seals and metal parts
- Physical & Fire properties:
  - ✓ Closed cell content
  - ✓ Density/strength (compression strength) relationships
  - ✓ Dimensional stability versus temperature and ageing using accepted accelerated methods

[2] For a more fundamental approach tending to provide a performance explanation tests like cell gas analysis with time, water vapour transmission, glass transition temperature over time at different temperatures, etc., are desirable.

    - ✓ Thermal conductivity versus temperature and ageing using accepted accelerated methods
    - ✓ Foam friability
    - ✓ Adhesion to different substrates
    - ✓ Fire code testing for construction industry foam-based components
- Trials under commercial production conditions and long term testing of articles

For integral skin and shoe-soles, open celled applications where the blowing agent does not remain in the product, the testing programme on physical properties should include the skin appearance and related properties like abrasion resistance.

In addition to the option of pre-blended HCs into the polyols, new technology alternatives for the SMEs are emerging or have recently emerged: methylal, methyl formate and modified water blown formulations.

Methylal, also called dimethoxymethane, is a flammable liquid with a negligible GWP and a boiling point of 42 ºC. To date, it has been marketed primarily within the thermoplastic foam sector (extruded polystyrene and polyolefin) as a co-blowing agent with HFC-134a to date.

The use of methylal as a co-blowing agent in conjunction with hydrocarbons and HFCs for PU rigid foam applications (domestic refrigeration, panels, pipe insulation and spray) has been described in the literature. It is claimed (Lambiotte, 2006) that in continuous panels it promotes blending in the mixing head and improves the miscibility of pentane, the foam flow and uniformity, the adhesion to metal surfaces and the insulation properties by reducing the cell size. In discontinuous panels, the addition of a low percentage of methylal to HFCs (245fa, 365mfc or 134a) would make it possible to prepare pre-blends with polyols of low flammability with no detrimental effect on the fire performance of the foam. As in the case of hydrocarbons Methylal would reduce the cost and improve the miscibility, the foam flow and uniformity the adhesion to metal surfaces.

There is no known use of methylal as sole auxiliary blowing agent in PU foam. By decision 58/30 the ExCom approved a demonstration project to assess its use as a possible replacement of HCFCs in developing countries. The final report will be issued during 2011 but the partial results in integral skin/microcellular foams already released show an excellent skin formation compared to HCFC-141b.

However, the flammability of the methylal/polyols blends is a major point of concern. Data recently reported shows that the addition of more than 3 parts of methylal brings the flash point of the blend down to values lower than 35 ºC, similar to those obtained with hydrocarbons (InterTox, 2010). According to the Global Harmonised System such type of blends are classified as a flammable liquid of category 3. The impact of the increased capital cost needed to handle a blend of these characteristics at the end user can make the use of methylal prohibited for the SMEs.

Methyl Formate (MF), also called methyl-methanoate, is a flammable liquid with a negligible GWP and a boiling point of 31.5 ºC. Foam Supplies, Inc. (FSI) has promoted its use as a blowing agent in PU foams from 2000 onwards. The company filed on December 18th, 2001, for a US patent, which was issued on June 22nd, 2004. The use of this technology has grown significantly in the last four years, although continues to be very small in size. For all foam applications 365 tones were consumed worldwide in 2009 and around 1,000 in 2010, replacing over 2,000 tonnes of HCFC-141b[3].

It is reported that MF is finding increased use in the flexible moulded and integral skin foam applications. Consumption in Australia, South Africa and Brazil has been established. Table 4 describes the strengths and weaknesses of the low GWP alternatives for these applications.

The use of MF is also occurring in rigid foam applications, particularly in commercial refrigeration and discontinuous steel-faced panels. Additional work is progressing in the US, UK and elsewhere to broaden this range of use, but with mixed levels of success.

Table 4. Alternate technologies for Integral Skin Foam & Shoe-soles

SECTOR/OPTION	STRENGTHS	WEAKNESSES	COMMENTS
Methyl formate (MF)	Low GWP	Flammable	Conversion costs to be determined
	Moderate unit costs		Flammability of polyol/MF blends should be checked
	Good skin quality		Moderate operating costs
			Patented technology. Commercial restriction
CO_2 (water)	Low GWP	Poor skin quality	Suitable skin may require in-mould-coating – added expense
	Low conversion costs		Well proven in shoe-soles - used with polyester polyols
n-pentane	Low GWP	Highly flammable	High conversion, uneconomic for SMEs
	Low unit costs		Low operating costs
	Good skin quality		Well proven in application

There are some technical issues that would seem to act as barriers to the use in rigid polyurethane insulating foams of MF as a sole blowing agent and would also inhibit its use as a co-blowing agent in systems such as those primarily blown with CO_2 (water)-blown. These issues can be documented as follows:

[3] In its 2006 assessment report the FTOC estimated the global market of blowing agent for the incumbent foam applications in the year 2005 at around 360,000 tonnes.

- There is concern that measures to manage flammability for MF may require system houses to reformulate with more compatible polyols for rigid foam applications in order to reduce the risk. In some cases it may be more productive to blend methyl formate in the isocyanate component to obtain the required foam properties whilst avoiding flammable blends. The additional health risk associated with the isocyanate handling needs to be managed.

  According to the United Nations Global Harmonised Systems a liquid blend is classified as flammable in the number 3 category when exhibits a flash point between 23 and 60 ºC. Additionally, it is stated that "*liquids with a flash point of more than 35 °C may be regarded as non-flammable liquids for some regulatory purposes (e.g. transport) if negative results have been obtained in the sustained combustibility test* (which is the MF case)…" The current fully formulated polyols used in developing countries have HCFC-141b concentrations around 18 %, which -applying the ideal gas law- correspond to a MF concentration of 10.1 %[4]. At this concentration, according to the supplier´s data, virtually all type of polyols will result in MF/polyol blends with flash points lower than 35 ºC (Foam Supplies, Presentation given to the FTOC, Salt Lake City, 2006). To avoid the implied safety risk a significant reformulation work is required. This is particularly important for spray foam, an application where the foam injection process is not controlled.

- The gaseous thermal conductivity of MF is intermediate between HCFC-141b and c-pentane and would suggest the potential for foams with good thermal performance. However, MF is a potent solvent for the polyurethane matrix and the addition of MF either on its own or as a co-blowing agent with CO_2 (water) results -as recently reported- in a significant reduction in compressive strength (shrinkage). Such effects can be countered either by reducing the level of the MF component present, or by increasing the density of the foam. The former reduces, or even nullifies, any incremental benefit in thermal performance, while the latter increases weight and cost and, in doing so, may not be technically or economically viable. If co-blown with CO_2 (water) the rapid aging of thermal conductivity, characteristic of CO_2 (water) systems, is also likely to be evident. Where shrinkage occurs, insufficient adhesion to metal substrates is typically observed within discontinuous sandwich panel trials. Again, the plasticising effect may be countered by increasing density where this is a commercial option.

- There is a need for further aged data to assess the trends in thermal insulation performance and dimensional stability with time. As has already been noted, the current analysis suggests that there will be a very fine balance between these two characteristics even in the short-term. Therefore, long-term behaviour patterns are a particular area of focus at this time. There is a possibility that the operational window could be too narrow for commercial viability in some applications. The elucidation of the long-term performance is critically important in applications where the thermal performance is expected to be maintained for periods of up to 50 years.

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[4] The 'minority view' contends that applying the 'ideal gas law' is not correct in practice. However, it is acknowledged that the flash points associated with these polyol blends can be below 35^{o}C, creating the need to split the methyl formate component between the polyol and isocyanate streams.

- When MF is used as a co-blowing agent with other added blowing agents (e.g. hydrocarbons), it has the potential to improve thermal performance by favourably impacting the morphology of cells – usually by making the average cell size smaller and the cell size more uniform. This is an effect beyond the gaseous thermal conductivity itself and may result in the increasing use of MF as a component of blends, particularly in place of c-pentane if this continues to remain in short supply.

- There does not yet appear to be evidence available related to the levels of MF in the atmosphere for several production processes. In particular, there is little experience of using MF-based systems for spray foam.

- There is a further concern about the stability of MF owing to the observed (by cell gas analysis) hydrolysis to formic acid, CO_2 and CO. This would serve to reduce the concentration of MF in the foam cells and potentially contribute to further deterioration in thermal performance.

- The presence of formic acid, either from breakdown of methyl formate, or through deliberate addition, can lead to corrosion of dispensing machine components (Cannon, Brazil, 2010)[5]. Machinery suppliers have investigated this effect and identified a number of components that would need to be monitored and replaced at regular intervals.

Water Blown Formulations. As mentioned before, historically the development of water blown foams has been a real challenge due to its intrinsic physical hurdles such as higher thermal conductivity, lower foam dimensional stability -which requires and increased moulded density-, and higher surface brittleness, resulting in a potentially weaker adhesion to metal facings. As result, the use of all water blown foam in the industry is today still limited.

However, global system houses have recently reported the development of new water blown technology characterized by an improved performance that can now be considered in line with HCFC low-level technologies -characterized by relative high foam lambda values- (3rd Polyurethane Exhibition & Conference in India - PU TECH 2011). This solution, focused on addressing the discontinuous panels and commercial refrigeration applications, leaves the opening to be converted later on into co-blowing with physical blowing agents by the time when new proven low ODP low GWP non-flammable solutions will be available.

It is claimed that, as a result of improved flow and optimized density distribution, applied densities are now in the same range of HCFC low-level technology with minimum impact on foam dimensional stability and mechanical properties. The systems would allow easy filling of the cavities and could be processed with a mould temperature of 40°C. Typical initial thermal conductivity is in the range of 22-23 mW/mK (measured at 10°C), relatively higher compared to

[5] The ‘minority view’ continues to challenge this assertion, although, as the text explains, the machinery suppliers are already taking action.

pentane and/or some HFCs blown systems but still acceptable for commercial refrigeration and discontinuous panels.

It is also reported that the addition of formic acid as chemical blowing agent to these systems can result in quantified improvements in foam aesthetic, flow, density distribution and adhesion even at low mould temperatures. Nevertheless, some drawbacks have been identified and need to be taken into consideration. They are linked to potential corrosion, which requires the involvement of equipment suppliers to check the equipment suitability, and the eventual release of carbon monoxide that makes it necessary the checking of the atmospheric concentrations and proper ventilation. Despite these drawbacks, this technology is being used in developed countries where enhanced flow, lower density and improved aesthetics are key requirements, i.e. the production of sandwich panels for cold store applications.

PHENOLIC FOAMS

Historically significant phenolic foam markets were developed in Europe and Japan based on a combination of Boardstock and Block/Pipe products. The development of similar markets in North America was thwarted by poor experience with a specific roofing board technology (Koppers) that created corrosion problems on steel-decks.

A further traditional application of phenolic foam has been as floral foam. The primary brand globally is known as 'Oasis'. However, this material has never significantly been blown with ozone depleting substances, except in the case of small 'me too' producers. It is therefore not the prime focus of attention in this report.

PF Boardstock

The traditional blowing agent for phenolic boardstock was CFC-11, although this was rapidly superseded by HCFC-141b. The use of HCFC-141b presented a particular challenge for the phenolic emulsion chemistry because of its solubility and the major technology holders found it necessary to modify the blowing agent with additives to make it less soluble in the foam mix.

In the transition that took place from HCFC-141b in Europe, it became self-evident that the phenolic product itself was sufficiently robust in its fire performance to accommodate hydrocarbon blowing agents for the bulk of end-uses. Therefore, the bulk of continuous processes are now based on n-pentane, either on its own or in blends with other hydrocarbons. One technology in Europe had moved directly from CFC-11 to 2-chloro-propane and continues to use this blowing agent as the basis for its product range.

There is limited use for saturated HFCs in these continuous processes, since thermal performance based on optimised hydrocarbon formulations is seen as sufficient for most end-uses. Although it is not yet clear how the emergence of unsaturated HFCs might affect the blowing agent choices for future phenolic boardstock formulations, the overall performance of the various hydrocarbon-based technologies make it unlikely that there will be further technology transitions in the short term.

There has been little, if any, implementation of phenolic foam boardstock facilities in developing countries to date, so any future investment is likely to be based completely on technology transfer from Europe or elsewhere.

PF Blocks & Pipe Sections

As with other phenolic foam product/process types, except for the floral foam industry, CFC-11 was the basic blowing agent of choice. In some cases, the boiling point of the blowing agent was modified by using CFC-11/CFC-113 blends in order to ensure the appropriate rise/cure profile. This was particularly important for phenolic chemistry where the sensitivity between temperature and cure rate is high. The reduction in the latent heat of evaporation in the early stages of the reaction helped to ensure appropriate processing times.

In similar fashion to the phenolic boardstock sector, the first transition was to HCFC-141b, with the same use of additives to reduce solubility of the blowing agent. In moving from HCFC-141b under the regulatory pressures in both Europe and North America, the industry initially moved to saturated HFCs. The choice was typically HFC-365mfc/227ea for boiling point reasons (as for CFC-11/CFC-113 blends). There is still a lack of widespread use of hydrocarbons in phenolic block processes for insulation purposes, although its use continues for floral foams. The introduction of a continuous pipe section process has enabled reduction in foam losses, but has also enabled a switch in blowing agent to hydrocarbons, based on the more controllable environment. The bulk of phenolic pipe section supply in the UK is now based on this technology.

It should be noticed that phenolic foam continues to be something of a niche product in most global markets and has seen little success to date in developing countries. However, its innate potential continues to be recognised in a number of important and growing markets. In general terms, it is believed that any further development of a manufacturing base in developing countries will be supported by comprehensive technology transfer from one of the current technology holders.

As a consequence, there seems to be little requirement for support for the transition of existing phenolic foam facilities in developing countries.

THERMOPLASTIC FOAMS (POLYOLEFIN & XPS)

Extruded thermoplastic foams are the only ones that have historically used ozone depleting substances. In the case of extruded polystyrene, products fall into two categories: ‘board’ and ‘sheet’, with ‘board’ being used for a variety of insulation, buoyancy and recreational activities, while ‘sheet’ has been focused on food and other packaging. Polyolefin (both polyethylene and polypropylene) foams have also found uses in these sectors, but the use of polyolefin foams in insulating applications has been more limited.

Equipment for the manufacture of extruded thermoplastic products varies substantially by region and application. In North America, the manufacturing lines tend to be long, for optimum speed and also capable of producing wide boards (typically 1.2 metres) at thicknesses down to 25mm. This requirement necessitates a substantial engineering solution and makes the transfer from one blowing agent to another very challenging. In Europe, the requirements are more modest, with many lines generating product at a maximum of 0.6 metres in width and at greater thicknesses. In South East Asia (most notably China), where the demand for extruded polystyrene foam is growing at its fastest, the technical and processing requirements are still more limited. In many cases, the polystyrene being used for extrusion has a high recycled content, making it less easy to process. Products generated in this scenario tend to be lower grade than in North America and Europe and are typically processed on 0.6 metre lines.

Most thermoplastic foams still depending on HCFCs have used a combination of HCFC-142b and HCFC-22. The proportions of each have varied considerably depending on the application and, in some instances, each blowing agent has been used in isolation. Alternatives to HCFC-142b/22 include, saturated and unsaturated HFCs, hydrocarbons, CO_2 and CO_2/ethanol. CO_2, in isolation, has been found to be particularly difficult to process, which is one of the reasons why combinations with oxygenated hydrocarbons have been explored. Even then, there have been some shortcomings in the technology that have limited processing speeds and product ranges.

The unsaturated HFCs have the potential to provide the best solution from a purely technical and environmental perspective. Hydrocarbons also offer a significant solution provided that the flammability issues can be managed at both product and process level. The extruded foam industry has had significant experience of managing hydrocarbons in the ‘sheet’ sector, which tended to bypass HCFCs and move straight to hydrocarbons when phasing out of CFCs. However, the experience of fires was commonplace and led some to conclude that this was not really a sustainable solution. Nevertheless, few ‘sheet’ manufacturers have stepped back from their choice and have presumably found coping strategies.

There is an additional challenge for ‘board’ products, however. “Board” products are relatively thick for both construction and packaging applications. In developed countries where hydrocarbons have been adopted (particularly in polyolefin foams), this led to a particular problem with boards in storage and transport. In essence, the rate of diffusion of hydrocarbon out of the products was not sufficiently fast after production to avoid the build-up of flammable gases in the post-production areas. This led to some incidents. The matter was finally addressed by most manufacturers through the use of perforating equipment to release the hydrocarbon blowing agent physically.

Another major challenge for the thermoplastic foams sector lies in dealing with investment costs and/or blowing agent availability. The following table illustrates the fact that penalties are likely to be faced either in the context of investment cost (e.g. hydrocarbons or CO_2) or in operating costs and availability (saturated and unsaturated HFCs). However, it should be noted that HFC-134a is relatively widespread because of its existing use as a refrigerant.

Blowing Agent Criterion	**HCFC-142b/22**	**Hydrocarbons**	**Saturated HFCs**	**Unsaturated HFCs (HFOs)**	**CO_2**	**CO_2 /ethanol**
Investment Costs	+	++/+++	+	+	+++	++/+++
Operating Costs	++	+	++/+++	+++	+/++	+/++
Widespread Availability	++	++	+/++	+	+/++	+/++
Potential to blend	++	++/+++	+++	++	++/+++	++/+++

+++ High; ++ Medium; + Low;

An additional factor to consider is the lead time that would be required for further conversion, especially for non-Article 5 countries, bearing in mind the testing necessary to meet strict building codes.

Extruded Polystyrene (XPS) Board

The use of extruded polystyrene is primarily in the construction sector where it is used for a variety of insulation purposes, both in walls and roofs, but most notably in floors, where the product has specific competitive advantages. The product has competed successfully against both rigid polyurethane foams and mineral fibre in all the major regions of the world, although its mode of success has varied depending on the regional demand patterns. This point speaks to the versatility of extruded polystyrene in its application.

The whole extruded thermoplastic foam sector was established on the ease of use of CFC-12 as a blowing agent. It was only when the phase-out of CFCs was required that the split between choices for ‘board’ and ‘sheet’ materials occurred. Sheet products moved predominantly to hydrocarbons, while board products chose to use HCFC-142b/22 blends for the most part, in order to retain the requisite thermal performance.

When the blend was chosen, it was known that the cell wall permeability of HCFC-142b was significantly lower than that of HCFC-22. Therefore, the long-term thermal performance of products would largely be determined by the proportion of HCFC-142b in the blend and its subsequent retention. Since HCFC-22 is a major refrigerant, its availability has been greater, and its price lower, throughout its period of use. This has been particularly important in some developing country regions where access to HCFC-142b has been more difficult and the cost significantly higher. Since some product and building codes will have been written around the sole use of HCFC-22, it may make the transitional hurdle a little easier when phase-out of HCFCs is finally embraced.

The extruded polystyrene sector is continuing to grow rapidly in China and elsewhere in Asia and practical transitional solutions will be essential. It seems unlikely that either saturated or unsaturated HFCs will make major in-roads in the markets for reasons of cost and availability. Therefore, the most likely solution will be based on hydrocarbons, on their own or in blends. The level of investment needed to support this is unclear, but, since the plants are relatively small, and there is parallel experience with extruded polystyrene sheet, it may be that the transition will be less challenging than currently envisaged. CO_2 seems unlikely as a solution in isolation.

The extrusion process remains highly emissive, and this puts a particular burden on the avoidance of high GWP solutions, such as saturated HFCs. The only time when such an approach might be justified is in applications and jurisdictions where thermal performance is absolutely paramount. In these cases, it may be possible to make further transitions from saturated to unsaturated HFCs in due course.

Polyolefin Foams

Polyolefin foams have made less penetration into the construction markets that have been the bedrock of the extruded polystyrene industry. The one exception to this has been in the pipe insulation sector, where the added resilience offered by the product has proved of substantial value. The primary use for polyolefin foams has been as a high performance packaging material – particularly when used for the packaging of delicate, high value equipment.

The choice of blowing in the polyolefin foam sector has followed a very similar pattern to that of extruded polystyrene foam. However, because of the lack of a large demand for insulating properties, the industry switched more fully to hydrocarbons when transitioning from CFCs. The remaining use of HCFCs in this product sector is much more limited than in the extruded polystyrene sector. Nevertheless, where use does exist -possibly in goods related to recreational applications- technical assistance may be necessary to ensure that appropriate precautions are taken in any final switch to hydrocarbons.

The polyolefin foam sector is only seen to present a limited challenge in the efforts to phase of HCFCs under Decision XIX/6. It would appear that relevant climate-positive solutions are available and that widespread experience exists concerning their use. There may be some, as yet, unidentified niche applications that could present more of a challenge, but no evident has yet emerged to this effect.

CHAPTER 3: BANKS AND RECOVERY OPTIONS

RECENT TEAP WORK ON THIS ISSUE

The Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol has been actively quantifying and locating banks of ODS in a series of studies responding to decisions of the Parties. The latest of these was Decision XX/7 which initiated the most comprehensive review of banks and potential mitigation options yet.

The Task Force convened by the TEAP to complete this work reported in two separate reports: Phase 1 in June 2009 and Phase 2 in October 2009. The second of these reports focused particularly on the quantification of savings that could be achieved, the timing at which recovery and destruction would be required and the cost of so doing. As had been the case in earlier studies, the TEAP Task Force divided the ODS Banks into three major categories of ‘effort’: low, medium and high. Although ‘effort’ is partially a synonym for ‘cost’, this is not completely the case, since there is some adjustment for the fact that the relative costs of some sectors, such as foams, will always be higher than other sectors, such as refrigeration. Rather than having all refrigerant recovery in the ‘low’ category and all foam in the ‘high’ category, there is some offsetting to allow a level of differentiation within each sector. Note that although the emphasis of the research was on reducing ODS emissions, most of the conclusions could also apply to reducing HFC emissions as well.

The TEAP analysis also recognized that recovery from densely populated (urban) areas would be easier than from sparsely populated (rural) areas. Its full analysis is summarized in the following table:

Sector	***Low Effort***	***Medium Effort***	***High Effort***
Domestic Refrigeration – Refrigerant	DP	SP	
Domestic Refrigeration – Blowing Agent	DP	SP	
Commercial Refrigeration – Refrigerant	DP	SP	
Commercial Refrigeration – Blowing Agent	DP	SP	
Transport Refrigeration – Refrigerant	DP/SP		
Transport Refrigeration – Blowing Agent	DP/SP		
Industrial Refrigeration – Refrigerant	DP/SP		
Stationary Air Conditioning – Refrigerant	DP	SP	
Other Stationary Air Conditioning – Refrigerant	DP	SP	
Mobile Air Conditioning – Refrigerant	DP	SP	
Steel-faced Panels – Blowing Agent		DP	SP
XPS Foams – Blowing Agent			DP/SP*
PU Boardstock – Blowing Agent			DP/SP*
PU Spray – Blowing Agent			DP*/SP*
PU Block – Pipe		DP	SP
PU Block – Slab		DP	SP
Other PU Foams – Blowing Agent			DP/SP*
Halon – Fire Suppression	DP	SP	

DP = Densely Populated Areas; SP = Sparsely Populated Areas
* Still technically unproven

This table underlined the fact that, even before cost elements were explicitly addressed, the management of existing ODS banks, in foams, was seen as representing the most significant challenge (largely high effort). Indeed, in some instances (e.g., PU Spray Foams) it was acknowledged that recovery and destruction of blowing agents from those sources was still globally unproven technically. This reflects the fact that flows of ODS into building demolition waste streams are still in their infancy and there is little global experience as yet in managing such materials. Even in Japan, where the regulation of demolition processes attracts high levels of compliance, a study on ODS Bank Management in the built environment conducted by the Japan Technical Committee on Construction Materials (JTCCM) in the period 2002-2005 concluded that it was not possible to mandate the recovery and destruction of ODS in buildings because of continuing uncertainties about technical feasibility and economic impacts. Of course, this is not to rule out the likelihood that experience will spawn innovation and technological development in this area. However, the Japanese view was that this is best achieved by voluntary action, often supported by incentives, rather than unenforceable legislation.

The main conclusions from this work were that the refrigerant banks represented the most cost-effective ODS bank management options (as measured in $ per tonne of CO_2 saved), partially because of their easier accessibility and partially because the baseline emissions for refrigerants are higher than for foams, which tend to display relatively low emissions during the majority of their lifecycles.

For appliances, it was clear that measures to manage ODS banks would need to be implemented within the next five years, even in developing countries, if the main ozone and climate benefits arising from CFC recovery and destruction were to be realised. This fact is highlighted in the next section where the location of ODS banks on foams is analysed for 2008.

For foams, the main areas where recovery at end-of-life could be legitimately expected at low/medium effort, were identified as:

- Domestic Appliances
- Commercial Refrigeration
- Steel-faced panels
- Block Pipe Section & Slab

Progress on recovery and destruction from these product areas are reviewed further in the later sections of this chapter.

BANK ESTIMATES IN 2008

In the period leading up to the preparation of this report, it had been anticipated that the Committee would provide baseline bank estimates for 2020. However, in view of the large uncertainties still associated with the selection of alternatives and the sensitivities involved in making quantitative predictions about future consumption, it was decided to limit this chapter to the assessment of banks as at 2008.

The following tables provide a summary of the banks of blowing agents contained within foams in developed and developing countries for 2008.

Foam Banks - Developed Countries - 2008								
	CFCs	HCFCs	HFCs	HCs	Other	Total	% CFC* Available	% HCFC* Available
PU - Dom. Appliances	283528	144834	55607	224807	0	708776	21.59%	99.80%
PU - Other Appliances	27324	68954	22953	17789	255	137275	46.30%	99.88%
PU - Reefers	12342	18639	6816	6970	0	44767	28.33%	98.83%
Total Appliances	*323194*	*232427*	*85376*	*249566*	*255*	*890818*	*23.94%*	*99.75%*
	36.28%	*26.09%*	*9.58%*	*28.02%*	*0.03%*			
PU - Boardstock	616683	297973	7560	383219	0	1305435	100.00%	100.00%
PU - Continuous Panel	147619	56633	21552	116124	0	341928	100.00%	100.00%
PU - Disc. Panel	123785	85377	38707	20801	0	268670	100.00%	100.00%
PU - Spray	97608	102470	40733	0	523	241334	100.00%	100.00%
PU - Block-Pipe	10220	4660	1631	3379	0	19890	18.74%	98.15%
PU - Block-Slab	26168	12192	4110	8573	0	51043	27.11%	98.64%
PU - Pipe-in-Pipe	38950	15506	3531	10767	0	68754	100.00%	100.00%
XPS - Board	250016	369145	26339	28113	0	673613	100.00%	100.00%
PE - Block-Pipe	8033	5183	516	8055	0	21787	18.74%	98.15%
PE - Block-Slab	8057	3317	643	9234	0	21251	27.11%	98.64%
PF - Boardstock	10699	6724	1772	13741	0	32936	100.00%	100.00%
PF - Disc. Panel	4364	3640	559	3399	0	11962	100.00%	100.00%
PF - Block-Pipe	3865	3153	1038	2849	0	10905	18.74%	98.15%
PF - Block-Slab	1185	987	626	606	0	3404	27.11%	98.64%
Total Constr./Other	*1347252*	*966960*	*149317*	*608860*	*523*	*3072912*	*96.75%*	*99.95%*
	43.84%	*31.47%*	*4.86%*	*19.81%*	*0.02%*			
Grand Total	**1670446**	**1199387**	**234693**	**858426**	**778**	**3963730**	82.66%	99.91%
	42.14%	*30.26%*	*5.92%*	*21.66%*	*0.02%*			
	* Availability based on correction for banks already in waste stream							

The table shows that only around 24% of CFC blowing agent banks remains available in Domestic Appliance Foams with the remainder already in landfill. By contrast, most the HCFC remains available. For the ‘construction and other’ foams, only the products produced from block foams have significantly reached their end-of-life and entered into the waste stream. The opportunity for recovery from products is, therefore, still substantial if appropriate techniques can be developed to recovery and destroy blowing agents economically.

Foam Banks - Developing Countries - 2008								
	CFCs	HCFCs	HFCs	HCs	Other	Total	% CFC* Available	% HCFC* Available
PU - Dom. Appliances	241750	108607	1217	181904	0	533478	72.98%	100.00%
PU - Other Appliances	7977	16902	0	0	0	24879	85.93%	100.00%
PU - Reefers	14850	23767	531	0	0	39148	81.91%	100.00%
Total Appliances	*264577*	*149276*	*1748*	*181904*	*0*	*597505*	*73.87%*	*100.00%*
	44.28%	*24.98%*	*0.29%*	*30.44%*	*0.00%*			
PU - Boardstock	1709	0	0	784	0	2493	100.00%	N/A
PU - Continuous Panel	22306	9092	0	2621	0	34019	100.00%	100.00%
PU - Disc. Panel	55536	34961	0	4205	0	94702	100.00%	100.00%
PU - Spray	60232	37146	0	0	0	97378	100.00%	100.00%
PU - Block-Pipe	8011	2953	0	0	0	10964	67.58%	100.00%
PU - Block-Slab	12509	4562	0	0	0	17071	75.55%	100.00%
PU - Pipe-in-Pipe	42387	21122	0	227	0	63736	100.00%	100.00%
XPS - Board	70311	184277	0	44	0	254632	100.00%	100.00%
PE - Block-Pipe	8815	0	0	4898	0	13713	67.58%	N/A
PE - Block-Slab	10975	0	0	5324	0	16299	75.55%	N/A
PF - Block-Pipe	782	198	0	0	0	980	67.58%	100.00%
PF - Block-Slab	782	198	0	0	0	980	75.55%	100.00%
Total Constr./Other	*294355*	*294509*	*0*	*18103*	*0*	*606967*	*96.04%*	*100.00%*
	48.50%	*48.52%*	*0.00%*	*2.98%*	*0.00%*			
Grand Total	**558932**	**443785**	**1748**	**200007**	**0**	**1204472**	85.55%	100.00%
	46.40%	*36.84%*	*0.15%*	*16.61%*	*0.00%*			
	* Availability based on correction for banks already in waste stream							

By way of contrast to the developed country scenario, approximately 73% of banked CFCs in domestic appliance foams were still available for recovery and destruction in 2008. There are no significant HCFCs already in the waste stream and these remain available for recovery and destruction where economically viable.

RECOVERY ACTIVITIES IN THE APPLIANCE SECTOR

Experiences to date – Developed Countries

In contrast to the challenges of the building sector, there is considerably more experience in managing foams from appliances and commercial refrigeration equipment. In several regions of the world, including Europe and Japan the recovery of blowing agents from domestic refrigerators and freezers has been required. This has been extended over time to cover other types of appliance. In the case of Europe this has been driven by product lifecycle legislation such as the WEEE[6] Regulation rather than the ozone regulations per se, although efforts have been made to ensure that both regulatory strands are complementary to one another.

This said, there have been on-going concerns in Europe about the percentage of end-of-life appliances being de-manufactured in line with the legislative requirements as well as the maintenance of adequate standards for recovery and destruction within those operations designated to manage the process. Even in Germany, a recent study uncovered a number of failures to uphold the existing standards. Further investigation revealed that the most likely cause of these malpractices has been the over-capacity in the sector, with prices for the de-manufacture of domestic refrigerators dropping from their initial levels in excess of $25/unit to values as low as $8/unit.

Another factor to consider here is that voluntary carbon finance cannot be leveraged in the region, even though the relevant methodologies (Voluntary Carbon Standard (VCS) and Climate Action Reserve (CAR)) apply to these recovery and destruction operations. This is because the market sees no 'additionality' from ODS recovery and destruction in regions where the measure is already mandated. Even if such funding were to be available, its contribution would be less substantial for HCFC recovery and destruction than for CFC recovery and destruction. This observation arises from the lower GWP of HCFCs in comparison with CFCs. This issue is dealt with further within the following developing country discussion, where a further analysis by TEAP is presented.

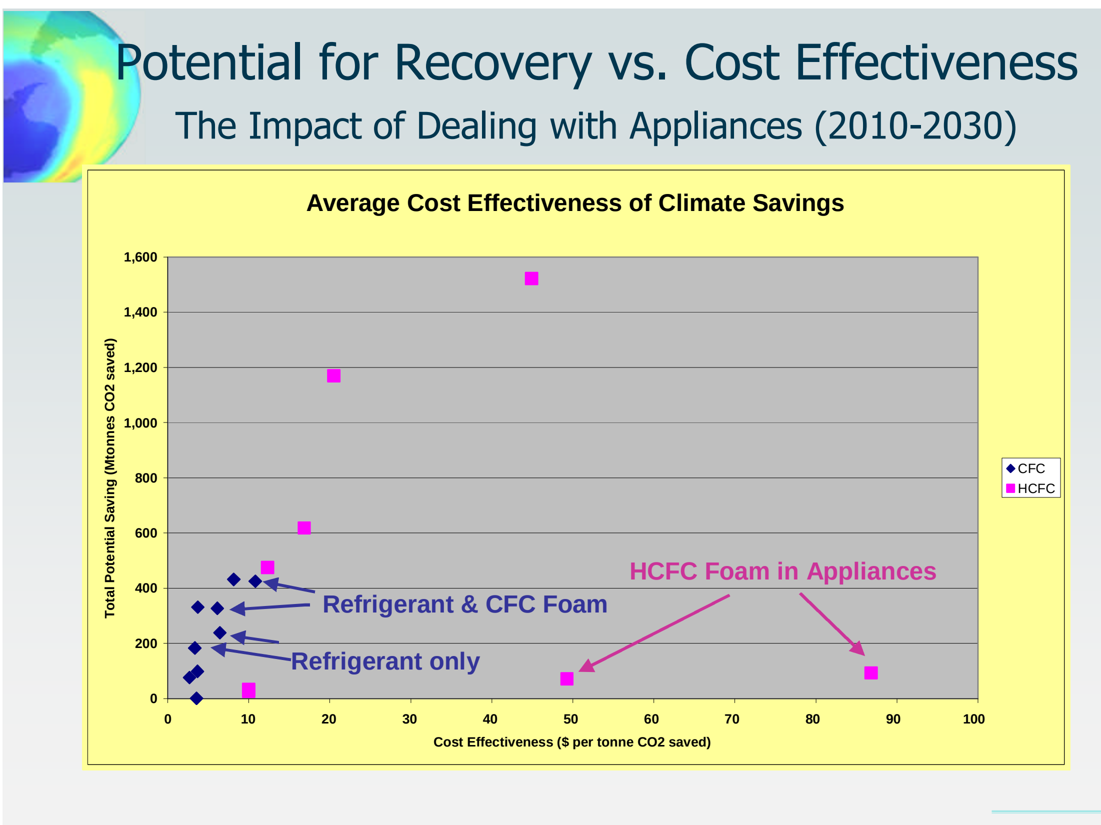
In North America, there is still no federal requirement for the recovery of blowing agent from foams in appliances. However, there are a number of state level initiatives which encourage recovery and destruction. California is looking at the option of using their wider cap-and-trade mechanisms for the inclusion of ODS recovery, using the Climate Action Reserve methodology as a basis. However, this methodology necessarily needs to take a conservative view on savings and the uncertainties around anaerobic degradation of ODS in landfills has led to lower baseline emission estimates and a reduction in the realisable savings from end-of-life measures. With the low current valuation of carbon, even on exchanges with high reputations such as CAR, the financial incentives may be insufficient to encourage widespread recovery and destruction of foam blowing agents, despite the adoption of semi-automated processes with lower investment costs.

[6] WEEE – 'Waste Electrical and Electronic Equipment'

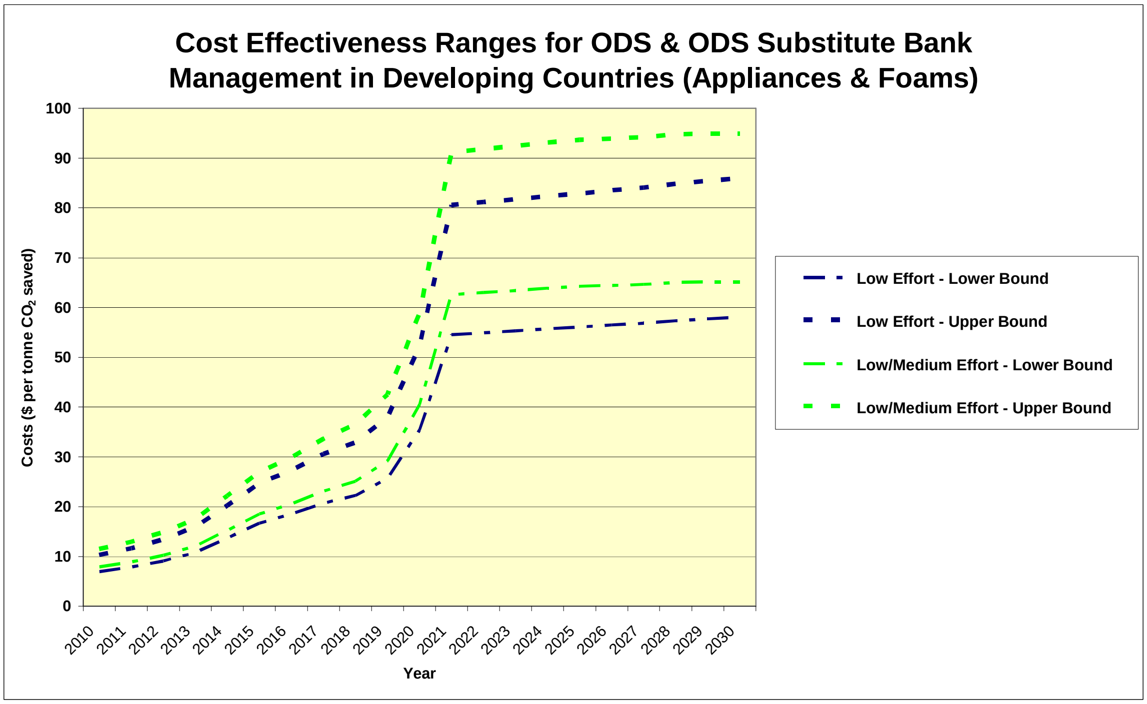
The other driver for recovery of ODS in appliances in North America has been the introduction of energy efficiency schemes, promoted by the energy supply companies to reduce demand in vulnerable regions of the territory. However, these schemes are not obliged to recover ODS and it is often left to the environmental consciousness of the individual companies to influence decisions to include recovery from units. This is even more the case for blowing agents than it is for refrigerants, since blowing agents are further along the cost-abatement curve.

<u>Experiences to date – Developing Countries</u>

An additional piece of analysis of the TEAP data for developing countries, as presented at the July 2010 Geneva Workshop on ODS Bank Management, illustrated the significant difference between CFC and HCFC recovery in terms of cost-effectiveness. Depending on location (urban or rural) the cost of recovery and destruction of HCFCs in appliance foam can range from \$60-\$90 per tCO_2-eq. saved or even more in developed countries where transport and labour costs are higher. This compares to a figure of \$10 per tCO_2-eq. saved for CFCs where the opportunity exists for both the refrigerant and foam blowing agent to be recovered at the same time. The analysis doesn't take into account the recovery of HFC-134a refrigerant in the appliance, which can, of course, provide additional climate benefit for a given investment under appropriate circumstances.



One of the other factors to consider is that waste streams are unlikely to be segregated by blowing agent type and the cost-effectiveness will vary according to the product mix arriving at end-of-life on an annual basis. The following graph illustrates how this might change with time for appliances in developing countries. It can be seen that the period of greatest cost-effectiveness is between now and 2020. After that time, higher carbon prices would be needed to support the cost-effectiveness of recovery of predominantly HCFCs.



RECOVERY ACTIVITIES IN THE BUILT ENVIRONMENT

Experiences to date by Region (incl. logistics)

As noted in the earlier sections of this Chapter, the only low/medium effort recovery options for foams in the buildings sector are found in the building services (e.g. pipe and duct insulation) and in certain forms of prefabricated construction (e.g. steel-faced panels).

In practice, the quantity of block manufactured and used globally for pipe insulation and other building services products (e.g. duct insulation) is relatively small as a proportion of the total. Where pipe section is produced from block (or, indeed, extruded from thermoplastic foams), there is a potential for recovery during decommissioning. This may also be the case for block foam prefabricated for use in composite panels.

For steel-faced panels there is also some relevant experience, since these products tend to be used on buildings in Europe with shorter average life-times than traditional constructions (typically 30 years). Although these are only now reaching the waste stream in any number, the potential to use existing refrigerator de-manufacturing equipment or even direct incineration exists. In most cases, the presence of the steel facings also adds to the economic case since these can be recovered and recycled. Nevertheless, across the European Union's 27 member states (EU-27) there is a large range of demolition waste practice. Only where waste segregation is already highly advanced (e.g., Austria) does the economics of recovery and destruction stack-up. This is demonstrated in the following table, although it should be noted that the final relative cost-effectiveness (in cost per tonne of CO_2 saved) between appliances and panels will depend on the blowing agent mix reaching the waste stream:

Cost effectiveness – Panels vs. Appliances

Tonnage Band	Domestic Appliance	JTCCM (Japan)	Kingspan Panels (trial projects)	Austria Study
Dismantling	-------	€ 55-65	€65-90	Discounted!
Sorting	-------	€ 3-4	€ 4-6	Discounted!
Transport	€ 25-35	€ 20-25	€ 5-10	€ 20-30 (based on steel-faced panels @ €200/te)
Destruction	€ 40-50	€ 20-25	€ 25-35	
Total	€ 65-85	€ 98-119	€ 99-141	€ 20-30

Per kg of blowing agent

There is therefore some reticence within some Member States to see any move towards a mandated recovery and destruction requirement for ODS in steel-faced panels. However, the potential of an incentive-led approach, perhaps based on carbon valuation, may prove a more mutually acceptable way forward.

Moving onto more general ODS banks in building foam, the most recent study completed by the Building Research Establishment (BRE) in the United Kingdom, the assessment of cost associated with the management of ODS in buildings was in the order of £200 ($300) per tCO_2-eq. saved (BRE, 2010). It should be stressed that the prime purpose of this study was not to review costs in detail, but it is interesting to note that this assessment supports the view that average recovery costs from the wider building sector would be proportionately higher than those associated with steel-faced panels.

FUTURE TRENDS AND DRIVERS

Financing

The future trends in carbon financing are far from settled at this time following the failure of the Copenhagen Conference of the Parties to meet a binding agreement on the way forward. Although the Cancun meeting endorsed alternative bilateral and multilateral funding options via the Nationally Appropriate Mitigation Actions (NAMAs), it is still not clear whether these will sit alongside existing mechanisms or actually replace them. Either way, there is expected to be wholesale reform of the current Clean Development Mechanism (CDM). In turn, this is leading to considerable uncertainty about the valuation of carbon savings in the short to medium terms. With this in mind, the valuation of carbon in the short-term depends on intrinsic valuations placed on carbon mitigation at national level rather than a market-based carbon price per se. The only region where this is not strictly true is in Europe, where the EU Emissions Trading Scheme (EU ETS) continues to provide a direct monetary basis (around €17 per tonne of CO_2 as at May 2011). However, as noted earlier in this chapter, there is no specific leverage for ODS recovery from appliances, because the measure would not be additional to the regulatory base (WEEE and the recast Ozone Regulation).

Other Regulatory Drivers

With continuing uncertainties about the cost-effectiveness of blowing agent recovery from foams in a number of key sectors, it is unlikely that regulation will extend significantly in the next five years, particularly because access to public or private finance is likely to be limited under the current economic constraints. The link between proposed regulation and the cost has been heightened considerably in recent years because of the need for Regulatory Impact Assessments in a number of jurisdictions. There is concern amongst some industry sectors that penalising the low/medium effort product base by the stigma of regulatory control, when other high effort products are likely to remain unregulated would drive counter-productive market behaviour.

APPENDIX 1: REVIEW OF ALTERNATIVE BLOWING AGENTS

The major blowing agents being commercially used as substitutes for HCFCs in the foam sector, or being considered for commercial introduction in the short-term, are shown in the sub-sections that follow – each of which contains a table with basic properties and supply information. These tables are supplemented by descriptive paragraphs which 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 Section. 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 other environmental factors, such as classification as volatile organic compounds (VOCs) may have a bearing on local acceptance. The reader is therefore encouraged to make a full evaluation of the national and local circumstances when choosing blowing agent options.

The tables 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.

The blowing agents options have been divided in seven different families:

1.1 HCFCs
1.2 Hydrocarbons
1.3 Carbon Dioxide
1.4 Oxygenated Hydrocarbons (Methyl Formate, Methylal and Dimethyl Ether)
1.5 Chlorinated Hydrocarbons (Methylene Chloride, Trans-1,2 di-chloroethylene and 2-chloropropane)
1.6 Saturated HFCs
1.7 Unsaturated HFCs (HFOs)

1.1 HCFCs

	HCFC-141b	HCFC-142b	HCFC-22
Chemical Formula	CH_3CFCl_2	CH_3CF_2Cl	$CHCIF_2$
Molecular Weight	116.95	100.50	86.47
Boiling Point (^{0}C)	31.9	-9.2	-40.8
Gas Conductivity (mW/mK @ 10^0C)	8.8	8.4	9.9
Flammable Limits in Air (vol.%)	7.6-17.7	6.2-17.9	-
TLV or OEL (ppm) (USA)	500	1000	1000
GWP (100 yr time horizon)	725	2310	1810
Key Producers	Arkema, Cgangsu 3f, Daikin, Hangzhou Fist, Kangtai Fluorine Chemical, Quzhou Rongqiang, Shandong Dongda, Solvay, Zhejiang Lantian, Zhejiang Sanmei	Arkema, Cgangsu 3f, Daikin, Hangzhou Fist, Kangtai Fluorine Chemical, Shandong Dongda, Solvay, Zhejiang Sanmei	Arkema, Cgangsu 3f, Daikin, DuPont, Honeywell, Produven, Quimobasicos, Quzhou Rongqiang, Shandong Dongyue, Solvay, Zhejiang Sammei, Zhejiang Quhua.

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[7]

Chemical name:	1,1-dichloro-1-fluoroethane
Formula:	CH_3CFCl_2
Molecular Weight:	116.95
EC Number (EINECS):	605-613-2
CAS Number:	1717-00-6
Density (g/cm^3)	1.25 (10 °C)
Boiling Point (°C)	31.9
Vapour pressure (mm_{Hg})	525 (25 ºC)
Gas Conductivity (mW/m. K)	8.8 (10 °C), 9.7 (25 °C)
Vapour density (air=1)	4.1
Solubility in water	1.7 g/L

HSE properties

Toxicological data:	
WEEL, 8 hr. TWA, ppm	500
Autoignition temperature	550 °C
Flammable limits in air (vol. %)	7.6-17.7
VOC	No
GWP[8] (100-yr Time Horizon)	725
ODP	0.11

Commercial status

Producers: Arkema, Changshu 3f, Daikin, Hangzhou Fist, Kangtai Fluorine Chemical, Quzhou Rongqiang, Shandong Dongda, Solvay, Zhejiang Lantian, Zhejiang Sanmei.

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7 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/247.html. Consulted April 2011.

8 IPCC Fourth Assessment Report: Climate Change 2007.

HCFC – 142b

Description & Usage

HFC-142b is a gas at room temperature, highly flammable. It is used as a foam blowing agent for 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[9]

Chemical name:	1-chloro-1,1-difluoroethane
Formula:	CH_3CF_2Cl
Molecular Weight:	100.50
EC Number (EINECS):	200-891-8
CAS Number:	75-68-3
Density/Specific gravity	1.107 (25 ºC)
Boiling Point (°C)	-9.2
Vapour pressure (mm_{Hg})	7786 (25 ºC)
Gas Conductivity (mW/m. K)	8.4 (10 °C), 11.5 (25 °C)
Vapour density (air=1)	3.49
Solubility in water	Slightly soluble

HSE properties

Toxicological data:	
TLV or OEL (USA, ppm)	1000
WEEL, 8 hr. TWA, ppm	1000
Autoignition temperature	632 °C
Flammable limits in air (vol. %)	6.2-17.9
Flash Point	-65 ºC
VOC	No
GWP[10] (100-yr Time Horizon)	2310
ODP	0.066

Commercial status

Producers:	Arkema, Changshu 3f, Daikin, Hangzhou Fist, Kangtai Fluorine Chemical, Shandong Dongda, Zhejiang Lantian, Zhejiang Sanmei.

9 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/131.html. Consulted April 2011.

10 IPCC Fourth Assessment Report: Climate Change 2007.

HCFC-22

Description & Usage

HCFC-22 is a non-flammable colourless 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[11]

Chemical name:	Chlorodifluoromethane
Formula:	$CHClF_2$
Molecular Weight:	86.47
EC Number (EINECS):	200-871-9
CAS Number:	75-45-6
Density (g/cm^3)	1.41 (20 °C)
Boiling Point (°C)	-40.8
Vapour pressure (mm_{Hg})	6290 (25 ºC)
Gas Conductivity (mW/m. K)	9.9 (10 °C), 11.0 (30 °C)
Vapour density (air=1)	2.98
Solubility in water	3 g/L
	Soluble in most organic solvents

HSE properties

Toxicological data[12]	
TLV (as TWA) 1992-1993)	1000 ppm, 3540 mg/m^3 (ACGIH
TWA (NIOSH REL)	1000 ppm (3500 mg/m^3)
Decomposition temperature	480 °C
VOC	No
GWP[13] (100-yr Time Horizon)	1810
ODP	0.055

Commercial Status

Producers:	Arkema, Changshu 3f, Daikin, DuPont, Honeywell, Produven, Quimobasicos, Quzhou Rongqiang, Shandong Dongyue, Solvay, Zhejiang Sammei, Zhejiang Quhua.

11 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/83.html. Consulted April 2011.

12 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/83.html. Consulted April 2011.

13 IPCC Fourth Assessment Report: Climate Change 2007.

1.2 Hydrocarbons

	Cyclo-Pentane	n-Pentane	Iso-Pentane	Iso-Butane	n-Butane
Chemical Formula	$(CH_2)_5$	$CH_3(CH_2)_3CH_3$	$CH_3CH(CH_3)CHCH_3$	$CH_3CH(CH_3)CH$	$CH_3CH_2CH_2CH_3$
Molecular Weight	70.1	72.1	72.1	58.1	58.1
Boiling Point (^{0}C)	49	36.1	28	-11.7	-0.45
Gas Conductivity (mW/mK @ 10^{0}C)	11.0	14.0	13.0	15.9	13.6
Flammable Limits in Air (vol.%)	1.5-8.7	1.4-8.0	1.4-8.3	1.8-8.4	1.8-8.5
TLV or OEL (ppm) (USA)	600	610	1000	800	800
GWP (100 yr time horizon)	<25	<25	<25	<25	<25
Key Producers	Chevron Phillips, Haltermann Products, ExxonMobil, Haldia Petrochemical Ltd., Maruzen Petrochemical, Puyang Zhongwei Fine Chemical	Beijing Yanshan Petrochemical Co. Ltd., Chevron Phillips, Haltermann Products, ExxonMobil, Maruzen Petrochemical, Shell	Chevron Phillips, Haltermann Products, ExxonMobil, Jilin Jinlong Industrial Co	Bayer, Chevron Phillips, ExxonMobil, Refinery of Jinling Petrochemical	Chevron Phillips, ExxonMobil, Shanghai Petrochemical Co. Ltd.

^ Measured at 0 $^{\circ}$C

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[14]

Chemical name:	Cyclopentane
Formula	C_5H_{10}
Molecular Weight	70.13
EC Number (EINECS)	206-016-6
CAS Number	287-92-3
Density (g/cm^3)	0.746 (20 °C)
Boiling Point (^{o}C)	49
Melting point (^{o}C)	-93.3
Vapour pressure (mmHg)	318 (20 °C)
Gas Conductivity (mW/m.K)	11.0 (10 °C)
Vapour density (air=1)	2.42 (20 °C)
Solubility in Water	Insoluble

HSE properties[15]

Toxicological data	
TLV (as TWA) (ACGIH 1993-1994)	600 ppm, 1720 mg/m^3
TWA (NIOSH REL)	600 ppm, 1720 mg/m^3
Flammable limits in air (%)	1.5 - 8.7
Autoignition Temperature	380 °C
Flash Point (°C)	-42
VOC	Yes[16]
GWP (100-yr Time Horizon)	<25[17]
ODP	0

Commercial Status

Producers	Chevron Phillips, Haltermann Products, ExxonMobil, Haldia Petrochemicals Ltd., Maruzen Petrochemical, Puyang Zhongwei Fine Chemical Co., Ltd.

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14 **http://ull.chemistry.uakron.edu/erd/Chemicals/8000/6348.html. Consulted April 2011.**

15 **http://ull.chemistry.uakron.edu/erd/Chemicals/8000/6348.html. Consulted April 2011.**

16 Subject to regulations that can vary from country to country and within a country even from region to region.

17 **Precise figure varies according to local atmospheric conditions.**

ISOPENTANE

Description and Usage

Isopentane 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[18]

Chemical name:	2-Methylbutane
Formula	C_5H_{12}
Molecular Weight	72.15
EC Number (EINECS)	201-142-8
CAS Number	78-78-4
Density (g/cm^3)	0.620 (20°C)
Boiling Point (^oC)	28
Melting point (^oC)	-160
Vapour pressure (mmHg)	727 (25 °C)
Gas Conductivity (mW/m.K)	13.0 (10 °C)
Vapour density (air=1)	2.48 (20 °C)
Solubility in Water	< 0.1 g /100ml (23°C)

HSE Properties[19]

Toxicological data	
TWA (ACGIH)	600 ppm
Odor threshold (ppm)	10
Flammable limits in air (%)	1.4 – 8.3
Autoignition Temperature (°C)	420
Flash Point (°C)	-57
VOC	Yes[20]
ODP	0
GWP (100-yr Time Horizon)	<25[21]

Commercial Status

Producers	Chevron Phillips, Haltermann Products, ExxonMobil, Jilin Jinlong Industrial Co.

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18 **http://ull.chemistry.uakron.edu/erd/Chemicals/2000/45.html. Consulted April 2011.**

19 **http://ull.chemistry.uakron.edu/erd/Chemicals/2000/45.html. Consulted April 2011.**

20 **Subject to regulations that can vary from country to country and within a country even from region to region**

21 **Precise figure varies according to local atmospheric conditions.**

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[22]

Chemical name:	n-Pentane
Formula	C_5H_{12}
Molecular Weight	72.1498
EC Number (EINECS)	203-693-4
CAS Number	109-66-0
Density (g/cm^3)	0.62 6 (20 °C)
Boiling Point (^oC)	36.1
Melting point (^oC)	-129.7
Vapour pressure (mmHg)	512 (25 °C)
Gas Conductivity (mW/m.K)	14.0 (10 °C)
Vapour density (air=1)	2.48 (20 ^oC)
Solubility in Water	0.04 g /100ml (23 °C)

HSE Properties[23]

Toxicological data	
TWA (OSHA PEL)	1000 ppm, 2950 mg/m^3
TWA (NIOSH REL)	120 ppm, 350 mg/m^3
C (NIOSH REL)	610 ppm, 1800 mg/m^3 (15-minute)
LEL (NIOSH IDLH)	1500 ppm
Flammable limits in air (%)	1.4 – 8.0
Autoignition Temperature (°C)	285
Flash Point (°C)	- 49
VOC	Yes[24]
ODP	0
GWP (100-yr Time Horizon)	<25[25]

Commercial Status

Producers	Beijing Yanshan Petrochemical Co. Ltd., Chevron Phillips, Haltermann Products, ExxonMobil, Maruzen Petrochemical, Shell.

22 **http://ull.chemistry.uakron.edu/erd/Chemicals/8000/7301.html. Consulted April 2011.**

23 **http://ull.chemistry.uakron.edu/erd/Chemicals/8000/7301.html. Consulted April 2011.**

24 **Subject to regulations that can vary from country to and from region to region**

25 **Precise figure varies according to local atmospheric conditions.**

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[26]

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 (^oC)	-11.7
Melting point (^oC)	-255.3
Vapour pressure (mmHg)	2580 (25 ^oC)
Gas Conductivity (mW/m.K)	15.9 (20 ^oC)
Vapour density (air=1)	2.01 (20 ^oC)
Solubility in Water	Slightly soluble

HSE properties[27]

Toxicological data	
TWA (NIOSH REL)	800 ppm, 1900 mg/m^3
Flammable limits in air (%)	1.8 – 8.4
Flash Point (°C)	-107
Autoignition Temperature (°C)	460
GWP (100-yr Time Horizon)	<25[28]
VOC	Yes[29]
ODP	0

Commercial Status

Producers	Bayer, Chevron Phillips, ExxonMobil, Refinery of Jinling Petrochemical

26 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/24.html. Consulted April 2011.

27 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/24.html. Consulted April 2011.

28 Precise figure varies according to local atmospheric conditions.

29 Subject to regulations that can vary from country to country and within a country even from region to region

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[30]

Chemical name:	n-butane
Formula	C_4H_{10}
Molecular Weight	58.12
EC Number (EINECS)	203-448-7
CAS Number	106-97-8
Density (g/cm^3)	0.579 (20 °C)
Boiling Point (^{o}C)	-0.45
Melting point (^{o}C)	-138.35
Vapour pressure (mmHg)	1556 (20 °C)
Gas Conductivity (mW/m.K)	13.6 (0°C)
Vapour density (air=1)	2.046
Solubility in Water	61mg/L (20 °C)

HSE properties[31]

Toxicological data	
TWA (ACGIH TLV)	800 ppm
TWA (OSHA PEL)	800 ppm
Odor threshold (ppm)	50000
Flammable limits in air (%)	1.8 - 8.5
Flash Point (°C)	-60
Autoignition Temperature (°C)	405
GWP (100-yr Time Horizon)	<25[32]
VOC	Yes[33]
ODP	0

Commercial Status

Producers	Chevron Phillips, ExxonMobil, Shanghai Petrochemical Co. Ltd.

30 http://ull.chemistry.uakron.edu/erd/Chemicals/22000/20510.html. Consulted April 2011.

31 http://ull.chemistry.uakron.edu/erd/Chemicals/22000/20510.html. Consulted April 2011.

32 Precise figure varies according to local atmospheric conditions.

33 Subject to regulations that can vary from country to country and within a country even from region to region

1.3 Carbon Dioxide

CARBON DIOXIDE

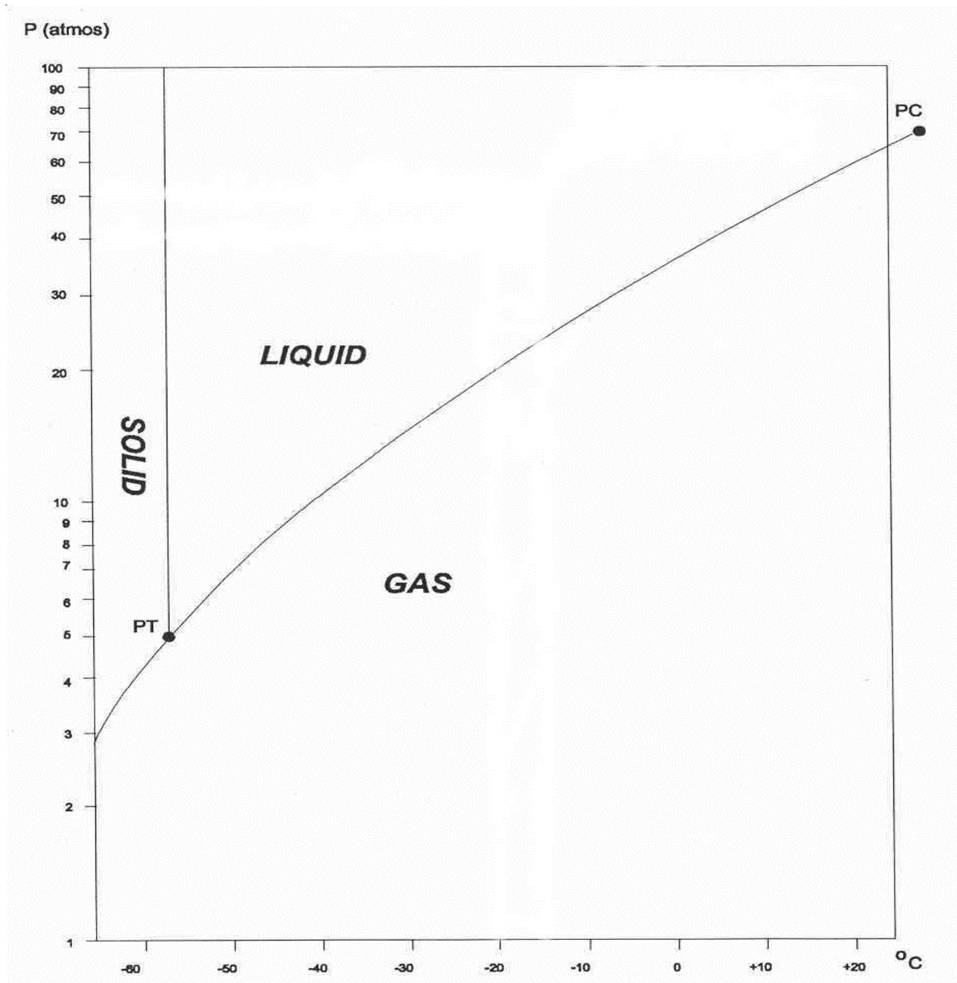
Description & Usage

Carbon Dioxide (chemical formula CO_2) is a gas in normal conditions and exists 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[34]

Formula	CO_2
Molecular weight	44.0
EC Number (EINECS):	204-696-9
CAS Number:	124-38-9
Triple point	
Pressure (bar)	5.11
Temperature (°C)	-56.6
Critical point	
Pressure (bar)	75.2
Temperature (°C)	31
Specific volume (L/kg)	2.156
Density	1.56 g/cm^3 (20 °C)
Vaporisation Heat (Kcal/kg)	83.20 (triple point)
Sublimation Heat (Kcal/kg)	136.40 (1 atm)
Heat of formation of gas (Kcal/kg)	2.137 (25 °C)

[34] http://ull.chemistry.uakron.edu/erd/Chemicals/8000/6241.html. Consulted April 2011.



Phase diagram for carbon dioxide

HSE Properties

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

Commercial Data

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

- From mining sources (natural CO_2). Carbon Dioxide exists 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 foam (flexible slab-stock, flexible moulded, integral skin, rigid) the carbon dioxide is generated chemically by the reaction between water and isocyanate.

1.4 Oxygenated Hydrocarbons

	Methylal	**Methyl Formate**	**Di-methyl Ether**
Chemical Formula	$CH_3\,OCH_2OCH_3$	$CH_3(HCOO)$	CH_3OCH_3
Molecular Weight	76.1	60.0	46.07
Boiling Point (^{0}C)	42	31.5	-24.8
Gas Conductivity (mW/mK @ 15^{0}C)	Not available	10.7 (@ 25^{0}C)	15.5
Flammable Limits in Air (vol.%)	2.2-19.9	5.0-23.0	3.0-18.6
TLV or OEL (ppm) (USA)	1000	100	1000
GWP (100 yr time horizon)	<25	<25*	1
Key Producers	Spectrum Chemicals, Alcan International, Kimbester (China) Caldic Lambiotte & Cie	BOC Foam Supplies	Multiple Chinese producers Air Liquide

METHYL FORMATE (ECOMATE®)

Description & Usage

Ecomate® is a colourless, flammable liquid with an ethereal odour. It is a registered trademark of Foam Supplies, Inc. protected by Patent No. 6753357. It is being promoted as blowing agent for PU rigid foams mainly but also for flexible foams and microcellular elastomers with zero ODP and GWP. Use has been reported in commercial refrigeration.

Physical and Chemical properties[35]

Chemical composition:	Methyl Formate 97.5 %, Methanol 2.5 %
Molecular Weight	60
EC Number (EINECS):	203-481-7
CAS Number:	107-31-3
Density (g/cm^3)	0.98 (20 °C)
Boiling Point (°C)	32.1
Melting Point (°C)	-100
Vapour pressure (mm Hg)	476.4 (20 °C)
Gas conductivity (mW/m. K)	10.7 (25 °C)
Water solubility (%)	33 (20 ºC)

HSE Properties[36]

Toxicological data:	
Methyl Formate	
ACGIH, TWA (ppm)	100
ACGIH, TWA (ppm)	100
TWA, OSHA (ppm)	100
Flammable limits (vol. %)	5.0 - 23.0
Flash point (°C)	approx. -28
Autoignition Temperature (°C)	approx. 440 ºC
VOC	No
GWP (100 years)	Negligible
ODP	0

Commercial Status

Current Supplier:	BOC, Foam Supplies

[35] http://www.ecomatesystems.com. Consulted April 2011.

[36] MSDS, Foam Supplies, reviewed on 12.03.2010.

1.5 Chlorinated Hydrocarbons

	Methylene Chloride	Trans-1,2-dichloroethylene	2-chloropropane
Chemical Formula	CH_2Cl_2	ClHC=CHCl	$CH_3CHClCH_3$
Molecular Weight	84.9	97	78.5
Boiling Point (^{0}C)	40	48	35.7
Gas Conductivity (mW/mK @ 10^{0}C)	Not available	Not available	Not available
Flammable Limits in Air (vol.%)	None	6.7-18	2.8-10.7
TLV or OEL (ppm) (USA)	35-100	200	50
GWP (100 yr time horizon)	Not available	<25	Not available
Key Producers	Multiple Sources	Arkema	Alfa Aesar

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.
The low photochemical ozone creation potential (PCOP) and lack of ozone depletion potential (ODP) made it a significant CFC-replacement in the manufacture of polyurethane flexible foam.

Physical and Chemical properties[37]

Chemical name:	Dichloromethane
Formula:	CH_2Cl_2
Molecular Weight:	84.93
EC Number (EINECS):	200-838-9
CAS Number:	75-09-2
Density (g/cm^3)	1.322 (20 °C)
Boiling Point (°C)	39.8
Melting Point (°C)	-95
Viscosity (cp)	0.41 (25 °C)
Refractive index	1.4244 (20 °C)
Vapour pressure (mmHg)	349 (20 °C)
Vapour density (air=1)	2.9
Water Solubility	10-50 mg/ml

HSE properties

Toxicological data:	
TLV (ppm)	50
OSHA PEL (ppm)	25
Flash point	-4 ºC
Autoignition temperature	605 ºC
LFL (%)	13
UFL (%)	223
GWP[38] (100-yr Time Horizon)	8.7

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

[37] **http://ull.chemistry.uakron.edu/erd/Chemicals/8000/6380.html. Consulted April 2011.**

[38] **IPCC Fourth Assessment Report: Climate Change 2007.**

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 and Solvay offer product versions that have been specifically stabilized for the use in PU foam.

TRANS-1,2-DICHLOROETHYLENE

Description & Usage

Trans-1,2-dichloroethylene is a liquid at room temperature and is recommended for use in a variety of polyurethane foam blowing applications primarily in combination with HFC-134a and HFC-245fa. Studies have shown that trans-1,2-dichloroethylene moderates the frothing effect particularly with HFC-134a and significantly improves its blowing efficiency.

Physical and Chemical Properties[39]

Chemical name:	trans-1,2-dichloroethylene
Formula:	$C_2H_2Cl_2$
Molecular weight:	96.94
EC Number (EINECS):	205-860-2
CAS Number:	156-60-5
Specific gravity:	1.26
Boiling point (°C)	48
Vapor pressure @ 25°C (mm Hg)	333
Heat of vaporization (kJ/mol)	30.3
Vapor density (air = 1) @ 20°C	1.8
Solubility @ 25°C (g trans / 100 g water)	0.63

HSE properties[40]

Toxicological data:	
TLV	200 ppm (ACGIH TLV® 8-hr TWA)
Flammable limits in air (volume %)	6.7 - 18
Flash point (°C)	-12
Minimum ignition energy @ 25°C (mJ)	40.5
Autoignition temperature (°C)	460°C
Volatile Organic Compound	**Yes**
GWP (100-yr Time Horizon)	Negligible
ODP	0

Commercial Status

Current Producers:	Arkema

[39] **http://ull.chemistry.uakron.edu/erd/Chemicals/2000/108.html. Consulted April 2011. MSDS, Arkema, Revised 03.04.2006.**

[40] **MSDS, Arkema, Revised 03.04.2006.**

1.6 Saturated HFCs

	HFC-134a	HFC-152a	HFC-245fa	HFC-365mfc	HFC-227ea
Chemical Formula	CH_2FCF_3	CHF_2CH_3	$CF_3CH_2\ CHF_2$	$CF_3CH_2\ CF_2\ CH_3$	$CF_3CHF\ CF_3$
Molecular Weight	102	66	134	148	170
Boiling Point (^{0}C)	-26.2	-25	15.3	40.2	-16.5
Gas Conductivity (mW/mK @ 10^{0}C)	12.4	14.3*	12.5*	10.6*	11.6
Flammable Limits in Air (vol.%)	None	3.9-16.9	None	3.8-13.3	None
TLV or OEL (ppm) (USA)	1000	1000	N/A	N/A	1000
GWP (100 yr time horizon)^	1430	124	1030	794	3220
Key Producers	Arkema, Daikin, DuPont, Honeywell, Kangtai Fluorine Chemical, Produven, Quzhou Rongqiang, Shandong Dongyue, Solvay, Zhejiang Guomao, Zhejiang Lantian, Zhejiang Sammei, Zhejiang Quhua	Changshu 3f, Daikin, DuPont, Hangzhou Fist, Solvay, Shandong Dongyue, Zhejiang Lantian, Zhejiang Sammei.	Honeywell, Central Glass, Zhejiang Lantian	Solvay	Solvay

* Measured at 24-25^{0}C

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 and North America.

Physical and Chemical properties[41]

Chemical name:	1,1,1,2-Tetrafluoroethane
Formula:	CF_3CH_2F
Molecular Weight:	102.03
EC Number (EINECS):	212-377-0
CAS Number:	811-97-2
Density (g/cm^3)	1.2076 (25 °C)
Boiling Point (°C)	- 26.2
Vapour pressure (mm_{Hg})	4730
Gas conductivity (mW/m. K)	12.4 (10 °C), 13.7 (25 °C)
Vapour density (air=1)	3.18
Solubility in water	1.5 g/L

HSE properties

Toxicological data[42]:	
TLV or OEL (USA) (ppm)	1000
WEEL, 8 hr. TWA, ppm	1000
Flash Point	-79 ºC
Flammable limits in air (vol. %)	None
VOC	No
GWP[43] (100-yr Time Horizon)	1430
ODP	0

Commercial status

Producers:	Arkema, Daikin, DuPont, Honeywell, Kangtai Fluorine Chemical, Produven, Quzhou Rongqiang, Shandong Dongyue, Solvay, Zhejiang Guomao, Zhejiang Lantian, Zhejiang Sammei, Zhejiang Quhua.

41 http://ull.chemistry.uakron.edu/erd/Chemicals/6000/5730.html. Consulted April 2011.

42 MSDS, DuPont, Revised 18.04.2007.

43 IPCC Fourth Assessment Report: Climate Change 2007.

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[44]

Chemical name:	1,1-Difluoroethane
Formula:	CH_3CHF_2
Molecular Weight:	66.05
EC Number (EINECS):	200-866-1
CAS Number:	75-37-6
Density (g/cm^3)	0.886 (30 °C)
Boiling Point (°C)	- 25
Vapour pressure (mmHg)	4100 (25 °C)
Gas conductivity (mW/m. K)	14.3 (25 °C)

HSE properties

Toxicological data:	
AIHA recommended TWA (ppm)	1000
Flammable limits in air (vol. %)	3.7 - 10
Flash Point	-81 ºC
VOC	No
GWP[45] (100-yr Time Horizon)	124
ODP	0

Commercial status

Current Producers:	Changshu 3f, Daikin, DuPont, Hangzhou Fist, Solvay, Shandong Dongyue, Zhejiang Lantian, Zhejiang Sammei.

44 http://ull.chemistry.uakron.edu/erd/Chemicals/2000/32.html. Consulted April 2011.

45 IPCC Fourth Assessment Report: Climate Change 2007.

HFC-245fa

Description & Usage

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

Physical and Chemical properties[46]

Chemical name:	1,1,1,3,3-Pentafluoropropane
Formula:	$CF_3CH_2CHF_2$
Molecular Weight:	134.05
EC Number (EINECS):	610-280-1
CAS Number:	460-73-1
Density (g/cm^3)	1.106 (97 °C)
Boiling Point[47] (°C)	15.3
Freezing Point (°C)	-103
Vapour Pressure (KPa)	123 (20 °C)
Gas Conductivity (mW/m. K)	12.05 (20 °C)
Water Solubility	0.13 g/L

HSE properties

Toxicological data:	
WEEL, 8 hr. TWA (ppm)	300
Flammable limits in air[48] (vol. %)	*None*
Flash Point[49] (°C)	*None*
VOC	No
GWP[50] (100-yr Time Horizon)	1030
ODP	0

Commercial status

Current Producers: Honeywell, Central Glass, Zhejiang Lantian.

46 http://ull.chemistry.uakron.edu/erd/Chemicals/24000/22949.html. Consulted April 2011.

47 MSDS, Honeywell, Revised 28.08.2007.

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

49 ASTM D 3828-87; ASTM D1310-86.

50 IPCC Fourth Assessment Report: Climate Change 2007.

HFC - 365mfc

Description & Usage

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

Physical and Chemical properties[51]

Chemical name:	1,1,1,3,3-Pentafluorobutane
Formula:	$CF_3CH_2CF_2CH_3$
Molecular Weight:	148.09
EC Number (EINECS):	430-250-1
CAS Number:	406-58-6
Density/Specific gravity	1.26 (25 ºC)
Boiling Point (°C)	40.2
Vapour pressure (kPa)	53 (25 °C)
Heat of vaporization (kJ/kg.K)	177
Gas conductivity (mW/m. K)	10.6 (25 °C)
Vapour density (air = 1)	5.11
Solubility in Water[52] (mg/L)	26.1 (25 °C)

HSE Properties

Toxicological data:	
SAEL (Solvay Acceptable Exposure Limit) 2007[53] (ppm)	1000
Flammable limits in air (vol. %)	3.6-13.3
Minimum Ignition Energy (mJ)	10.8 (25 °C)
Flash point (°C)	< –27
Autoignition Temperature (°C)	594
GWP[54] (100-yr Time Horizon)	794
ODP	0

Commercial Status

Current Producers:	Solvay

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.

51 http://www.solvaychemicals.co.uk/product/datasheet/0,0,-_EN-1000798,00.html. Consulted April 2011.

52 http://esc.syrres.com/interkow/webprop.exe?CAS=406-58-6. Consulted April 2011.

53 MSDS, Solvay, Issued 16.09.2008.

54 IPCC Fourth Assessment Report: Climate Change 2007.

HFC 227ea

Description & Usage

HFC-227ea is used as a component in non-flammable HFC-365mfc blowing agent blends. Its prime purpose is to suppress flammability (flash-point) of the blowing agent and/or of the polyol system. Commercially available are blends with HFC-227ea ratios of 7% and 13% by wt.

Physical and Chemical properties[55]

Chemical name:	1,1,1,2,3,3,3 Heptafluoropropane
Formula:	CF_3CHFCF_3
Molecular Weight:	170
EC Number (EINECS):	207-079-2
CAS Number:	431-89-0
Density/Specific gravity	1.54
Boiling Point (°C)	-16.5
Vapour pressure @ 25 °C (bar)	4.6
Gas Conductivity (mW/m.K at 10 °C)	11.6
Gas Conductivity (mW/m.K at 25 °C)	12.7
Vapour density (air=1)	30.2 (25°C)
Solubility in Water	≈ 0.4 g/l (20°C)
Decomposition temperature	425 °C
Flammable limits in air (vol. %)	none

HSE properties

Toxicological data:	
AEL TWA	1000 ppm[56]
VOC	No
GWP[57] (100-yr Time Horizon)	3220
ODP	0

Commercial Status

Current Producers:	Solvay

55 **Manufacturer´s information, Solvay Fluor GmbH, Germany. http://www.solvaychemicals.com/EN/products/Fluor/Hydrofluorocarbons_HFC/Solkane227technicalgrade.a spx. Consulted April 2011.**

56 **Manufacturer´s Information, Solvay Fluor GmbH, Germany. MSDS, Rem Tec International, Revised 30.11.2009.**

57 **IPCC Fourth Assessment Report: Climate Change 2007.**

1.7 Unsaturated HFCs (HFOs)

	HFO-1234ze	FEA-1100	HBA-2	AFA-L1
Chemical Formula	Trans- $CF_3CH=CHF$	Cis- CF_3-CH=CH-CF_3	Undisclosed	Undisclosed
Molecular Weight	114	164	Undisclosed	Undisclosed
Boiling Point (^{0}C)	-19	32	15.3<T<32.1	10.0<T<30.0
Gas Conductivity (mW/mK @ 10^{0}C)	13.0	10.7	Not Reported	15.9
Flammable Limits in Air (vol.%)	None to 28^{o}C^	None	None	None
TLV or OEL (ppm) (USA)	Unpublished	9.7	Undisclosed	Undisclosed
GWP (100 yr time horizon)	6	5	<15	<15
Key Producers	Honeywell	DuPont	Honeywell	Arkema

^ Flame limits of 7.0-9.5 at 30^{o}C are quoted

APPENDIX 2: 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
New Zealand
Niue
Palau
Papua New Guinea
Samoa
Solomon Islands
Tonga
Tuvalu
Vanuatu

Russia & Former Soviet Countries

Armenia
Azerbaijan
Belarus
Georgia
Kazakhstan
Kyrgyzstan

Russian Federation
Tajikistan
Turkmenistan
Ukraine
Uzbekistan

APPENDIX 3: UNEP FOAMS TECHNICAL OPTIONS COMMITTEE

Committee Member	Affiliation	Country
Mr. Terry Armitt	Hennecke	United Kingdom
Mr. Paul Ashford, Co-chair	Caleb Management Services Limited	United Kingdom
Mr. Chris Bloom	Dow	United States
Mr. Roy Chowdhury	Australian Urethane Systems	Australia
Mr. Kiyoshi Hara	Japanese Urethane Manufacturers Assoc	Japan
Mr. Mike Hayslett	Maytag/AHAM	United States
Dr. Mike Jeffs	Consultant	Belgium
Mr. Candido Lomba	ABRIPUR	Brazil
Mr. Yehia Lotfi	Technocom	Egypt
Mr. Christoph Meurer	Solvay	Germany
Ms. Francesca Pignagnoli	Dow	Italy
Mr. Miguel Quintero, Co-chair	Consultant	Colombia
Mr. Ulrich Schmidt	Haltermann Products	Germany
Mr. Enshang Sheng	Huntsman Polyurethanes	China
Ms. Helen Walter-Terrinoni	Du Pont	United States
Mr. Tom Werkema	Arkema	United States
Mr. Dave Williams	Honeywell	United States
Mr. Allen Zhang	Owens Corning	China