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SHAKTI SUSTAINABLE ENERGY FOUNDATION

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Addressing HPMP stage II implementation challenges for the SME foam sector

STUDY REPORT

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About LNC Private Limited:
LNC Private Limited (LNC) provides consulting services in climate change, ozone layer protection, and clean energy development. It has deep expertise in implementation of the Montreal Protocol aspects.

About Shakti Sustainable Energy Foundation:
Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support renewable energy, energy efficiency and the adoption of sustainable transport solutions.

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List of Abbreviations

BA	Blowing Agent
CP	Cyclopentane
Ex-Com	Executive Committee of the Multilateral Fund for implementation of the Montreal Protocol
HC	Hydrocarbon
HCFO	HydroChloroFluoroOlefins
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HPMP	HCFC Phase-out Management Plan
ICC	Incremental Capital Cost
IE	Implementing Entity
IOC	Incremental Operating Cost
MF	Methyl Formate
MFS	Multilateral Fund Secretariat
ML	Methylal
MLF	The Multilateral Fund
MT	Metric Tonnes
NOO	National Ozone Officer
NOU	National Ozone Unit
ODP	Ozone Depletion Potential
NR	Natural Refrigerants
ODS	Ozone Depleting Substances
SME	Small and Medium Enterprise

Executive Summary

India is currently phasing out Hydrochlorofluorocarbons (HCFCs), an Ozone Depleting Substance (ODS), as part of its commitment under the Montreal Protocol for the protection of ozone layer. One of the major use of HCFC (HCFC-141b) is in foam manufacturing industry as a blowing agent. The larger enterprises have already shifted to cyclopentane, a non-ODS blowing agent. In current phase of transition, around 422 Small and Medium Enterprises (SMEs) must shift to a non-ODS blowing agent by the year 2020.

This study has looked at preparedness of various stakeholders in India for this transition phase, evaluation of possible options, trends in other countries, and possible solutions to smoothen the transition process. The key conclusions of this study are:

- There is no perfect drop-in replacement option for HCFC in foam sector for Indian SMEs which can provide similar performance levels compared to HCFC-141b with minimal cost impact for all sub-sectors. There are trade-offs in terms of ease of foam processing, final foam quality, increase in product costs, and Global Warming Potential (GWP) of such alternatives.
- SMEs generally lack know-how on chemicals they use for foam manufacturing including blowing agents. They also don't have technical resources for formulation optimization, and hence are majorly dependent on system houses.
- Unlike larger enterprises, many of the SME units might not shift to flammable alternative such as cyclopentane due to lack of required infrastructure, shortage of right technical capacity, and compliance requirements to handle flammable material.
- There are other alternatives such as Hydrofluorocarbons (HFCs), Hydrofluoroolefines (HFOs), Methylal (ML), Methyl Formate (MF), and water. HFO and HFC meet performance parameters but have high cost or GWP impact (HFC); MF and water could be cost effective options but might not have equivalent foam properties for all applications.
- Though some initial R&D work has been done by system houses in India to develop suitable formulations, however these have not been extensively tested by SMEs.
- Market creation for alternatives has not gained momentum due to general lack of awareness about phase-out schedule in the SME sector. Industry lacks a sense of urgency to evaluate and adopt non-HCFC alternatives.

Following recommendations are developed to support Indian SMEs choose appropriate replacement option as per their unique business situation:

- There is a need to develop a technology roadmap for the SME sector with significant efforts needed in R&D to develop India specific solutions;
- Technical assistance is required for SMEs to select appropriate replacement options;
- Market signalling is required for stakeholders to create business readiness;
- Enterprises unable to adopt viable solution will need business and financial support from the Government of India.

1. Project Background

The Montreal Protocol on substances that deplete the Ozone layer is an international treaty designed to protect the ozone layer by phasing out the consumption of numerous Ozone Depleting Substances (ODS) which are responsible for ozone depletion. HCFCs are currently being phased-out in a stage wise manner under the HCFC Phase-out Management Plan (HPMP).

The Multilateral Fund (MLF) under the Montreal Protocol assists developing countries meet their Montreal Protocol objectives. MLF receives financial contributions from developed countries, or non-Article 5 countries. As on December 2016 the contributions made to the MLF by some 45 countries totalled over US$ 3.6 billion.

MLF provides funds for implementation of HPMPs in developing countries. HPMP normally includes projects related to institutional strengthening, implementation of quota and licensing system, capacity building, technology conversion projects, and technology demonstration projects.

Technology conversion projects [1] receive Incremental Capital Costs (ICCs) and Incremental Operating Costs (IOCs) associated with the phase-out of HCFCs. Capital costs typically cover changes in equipment required to transition to a substitute. IOC typically cover: the added costs if the substitutes are more expensive; costs related to changes in the quantity of substitutes used in the product; and changes in other raw materials or energy consumption at the manufacturing facility

India has recently commenced HPMP stage-II. The objectives of India's HPMP stage-II are: Complete phase-out of HCFC-141b (primarily used in foam industry as a blowing agent) consumption by 2020 and phase-out of HCFC-22 (a refrigerant gas) in room air conditioner manufacturing and servicing of Refrigeration and Air-conditioning (RAC) sector. Sustainable reductions in consumption of HCFCs are expected to happen through implementation of a combination of interventions for technology transfer, training and capacity building, awareness building, monitoring and management, and policy and regulatory actions.

In accordance with the ODS (Regulation and Control) Amendment Rules 2014 in India and HPMP stage-II, the use of HCFC (HCFC-141b) in manufacturing of all foam products should be completely phased out by year 2020. This will result in reduction of 638.02 Ozone Depleting Potential (ODP) Tons by year 2020.

For phase-out of HCFC-141b as a blowing agent, various alternate options are available such as Methyl Formate (MF), Methylal (ML), Hydrocarbons (HC), super critical CO_2, Hydrofluorocarbons (HFC), water, and Hydrofluoroolefins (HFOs) etc. The selection is based on the maturity of the

[1] As per MLF guidelines, only enterprises set up before 21st September 2007 will be provided funding support.

technology, its availability in the local market at acceptable pricings, and the critical properties of the final product, including thermal conductivity, dimensional stability and density. Each alternate blowing agent to HCFC-141b has its own set of unique physical properties.

No blowing agent is a perfect drop-in for HCFC-141b which could provide similar performance levels along with minimal cost impact for all sub-sectors. There are trade-offs in terms of ease of foam processing, final foam quality, increase in product costs, and Global Warming Potential (GWP) of such alternatives. Thus, most of the phase-out activities require funding support for capital investments and operating costs.

Most of the large foam manufacturers (>50 tons HCFC-141b consumption per year) and system houses [2] were covered in the HPMP stage-I. These units have replaced HCFC-141b with cyclopentane (or its blends). Flammable alternatives like cyclopentane and its blends (i.e., iso- and n-pentane) are proven alternatives for foam formulations. ICC for conversion from HCFC-141b to pentanes are high due to their flammability. IOC are minimal for pentane-blown foam since the blowing agent tends to be cheaper than HCFC-141b and less blowing agent is needed relative to HCFC-141b. In fact, significant operating costs savings may also be realized.

The safety requirements associated with flammable alternatives such as hydrocarbons pose operational challenges for SMEs. Also, other available alternatives of blowing agent are not perfect drop-in options and hence SMEs may require support for transition.

2. About Foam Sector

Polyurethane foam

Foams have been used historically in diverse applications for cushioning, insulation, energy dissipation, buoyancy, weight reduction convenience and comfort. But among all the foams, polyurethane (PU) foam is most versatile, both in the properties of finished product and ease of application and production. PU foam technologies were developed as early as the 1930s in flexible, rigid and semi-rigid form.

Flexible PU foams are known for their excellent elastic and deformation characteristics. Their major applications are in furniture, cushioning (bedding, carpet backing), and packaging (electronics, equipment, crockery). Semi-rigid PU foams are mostly used in automotive industry (dash panels, liner, visors), arm rests, and footwear (shoe soles). However, the largest application of PU foam is in thermal application which uses rigid foam. The low thermal conductivity of foam offers excellent energy performance for insulation. Since the gas in the foam cell is the major contributor of thermal performance, role of blowing agent is very important. The other application of rigid foam is to provide structural integrity and buoyancy.

[2] System houses are chemical companies selling key raw materials called formulations for foam manufacturing including polyols, MDI and additives.

How foam is made?

Polyurethanes are formed by reacting a polyol (an alcohol with more than two reactive hydroxyl groups per molecule) with methane diisocyanate (MDI) in the presence of suitable catalysts, blowing agents and additives such as surfactants, flame retardants, and water etc. Foam can exhibit different types or properties depending on the selection of polyol and isocyanate. The blowing agent is used to blow the cell by increasing its volume and to form light weight PU foam. The catalysts are used to accelerate the reactions and surfactants are used to promote and stabilize the PU cells to retain the shape of the foam.

[Formulation]
Polyol + Isocyanate + Blowing Agents + Catalysts + Surfactants

Polyurethane foam

Role of Blowing Agents

In general terms, the role of blowing agent in a foam formulation is to ensure that the polymer matrix expands before solidifying. The expansion is created by increasing the temperature of the mixture which causes the blowing agent to volatilize. The density of the foam which is generated is dictated by the amount of blowing agent added and the processing conditions. The thermal conductivity (k-factor) of the blowing agent is also an important factor in the insulating foam. The gas which is trapped in the cells of the foam doesn't allow heat to pass through the foam. The lower the k-factor of the gas, the better it will be able to give insulating property to the foam.

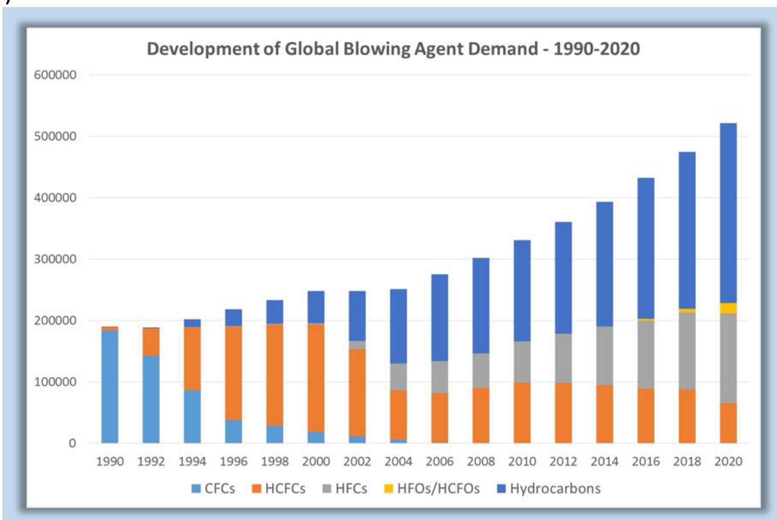
Blowing agent can be either chemical or physical. Chemical blowing agents are agents that take part in a reaction or decompose, giving off chemicals in the process. Water is a chemical blowing agent and releases CO_2 when it reacts with isocyanate. Physical blowing agents are gases that do not react chemically in the foaming process and are therefore inert to the polymer forming the matrix. HCFC-141b, which is now being phased out under HPMP of Montreal Protocol, is a physical blowing agent. The next generation blowing agents like HFC, HFO, and Methyl Formate etc. are all physical blowing agent.

Blowing agent impacts many of the important final foam qualities like foam insulation, foam density, compressive strength, aging properties, dimensional strength, and skin quality etc. Each alternative blowing agent to HCFC-141b has its own set of unique physical properties. Key selection criteria for a blowing agent include its gas k factor[3] (or lambda value), solubility in polyols, ease of processing, and vapour pressure.

[3] The *k* factor is the measure of heat that passes through a material (with units of W/mK). It represents the material's thermal conductivity or ability to conduct heat. Usually, insulation materials have a k factor of less than one. The lower the k factor, the better the insulation.

Globally, there is an increase in demand for PU foams in both insulation and non-insulation product categories. Blowing agent demand is also expected to keep up the growth pace with overall PU manufacturing. However, with HCFC phase-out in all major economies, other blowing agents are expected to increase their share in overall blowing agent market.

Figure 1: Growth in the use of Physical Blowing Agents by Type over the period from 1990 to 2020 (Source: FTOC 2014)



Source- 2014 Assessment Report: The Rigid and Flexible Foam Technical Options Committee (FTOC)

Overview of HCFC replacement options

Hydrocarbons (Pentane isomers: cylo-, iso-, and n-)
Methyl formate
Methylal
HFC-245fa and HFC-365/HFC-227 blend
HFOs
Water (CO_2)
Blends: pentanes/HFC, pentanes/HFO, HFC or HFO/water

Hydrocarbons (HCs), or specifically pentanes, are physical foam blowing agent which are commercially proven in all major countries. They have zero ODP and low GWP. The three isomers of pentane- Cyclopentane, n-pentane and Iso-pentane are generally used as foam blowing agent. Among the three, cyclopentane has the lowest k-factor due to its “bulkiness” and thus provides best insulation. n-pentane has the higher (worse) k-factor. Iso-pentane has similar k-factor as cyclopentane and its blends with cyclopentane improves the solubility in polyol. Cyclopentane, when used as a blowing agent in insulation foam, provides acceptable k-factors, good dimensional stability, and adhesion to liners or panels, which are critical foam properties. In integral skin foam, after expansion of foam cyclopentane condenses on the surface to form dense skin. Due to its flammable nature, it requires new technology modification (transportation, storage, and production stages) and safety requirements.

Water is a chemical blowing agent. It reacts with MDI and form CO_2 which then acts as blowing agent. Water blown foam has high k-factor (poor insulation) which further increases with time because the CO_2 which gets trapped in the foam cells eventually moves out and outside "air" enters the cells. The reduction in insulation value and cell stability can be addressed by adding more material which increases foam thickness and thus increase in costs. Water is used in relatively less critical insulation applications such as in-situ foams, surf boards, low density open-cell packaging foams, thermoware, and spray foam.

Methyl formate (MF) is a patented physical blowing agent with zero ODP and low GWP. It is marketed as Ecomate by Foam Supplies Inc. (FSI). MF is a flammable liquid, but its polyol blends has lower flammability and can be used safely. The k-factor of MF is acceptable for insulation foam. There is a need for its formulation optimization as it is more soluble in polyol than HCFC-141b. Without sufficient optimization, the MF blow foam can have excessive foam shrinkage and poor adhesion. Water can also be used with MF as a co-blowing agent.

Methylal is a physical liquid blowing agent and is flammable. It has good solubility and is miscible with all types of polyols used in manufacturing of PU foam. The methylal blown non-insulation foam shows same properties as HCFC-141b foam. Methylal-based insulation foams have 10% higher k-factors (worse) than HCFC-141b.

Hydrofluorocarbons (HFCs) are physical blowing agent with zero ODP and very high GWP. In comparison with other non-fluorinated foam, they have higher insulating value (i.e. lower k-factor). Currently there are three main HFCs used in foam application- HFC-245fa, HFC-365mfc (and its blend with HFC-227ea) and HFC-134a.

- HFC-245fa- It is primarily marketed as Enovate 3000 by Honeywell. It has good solubility in polyol and excellent flow properties but a high GWP of 1,020. HFC-245fa blown foam has reduced density and reduced panel waste due to easy processing. Its lower boiling point makes it difficult to store and transport. When used with water (0.2-2.5%) as co-blowing agent, there is about 50% reduction in HFC amount required and a gain in thermal performance.
- HFC-365mfc- It is marketed by Solvay as Solkane-365. HFC-365mfc based foam have a fine cell structure, good compressive and good insulation properties but it has a GWP value of 2,900. It has minor flammability issue but its blend with HFC-227ea (Solkane-365/227) overcomes this problem but also increase thermal conductivity.
- HFC-134a- Although widely used as a refrigerant, it is also used in foam manufacturing. But its use is minimal because of its processing difficulties.

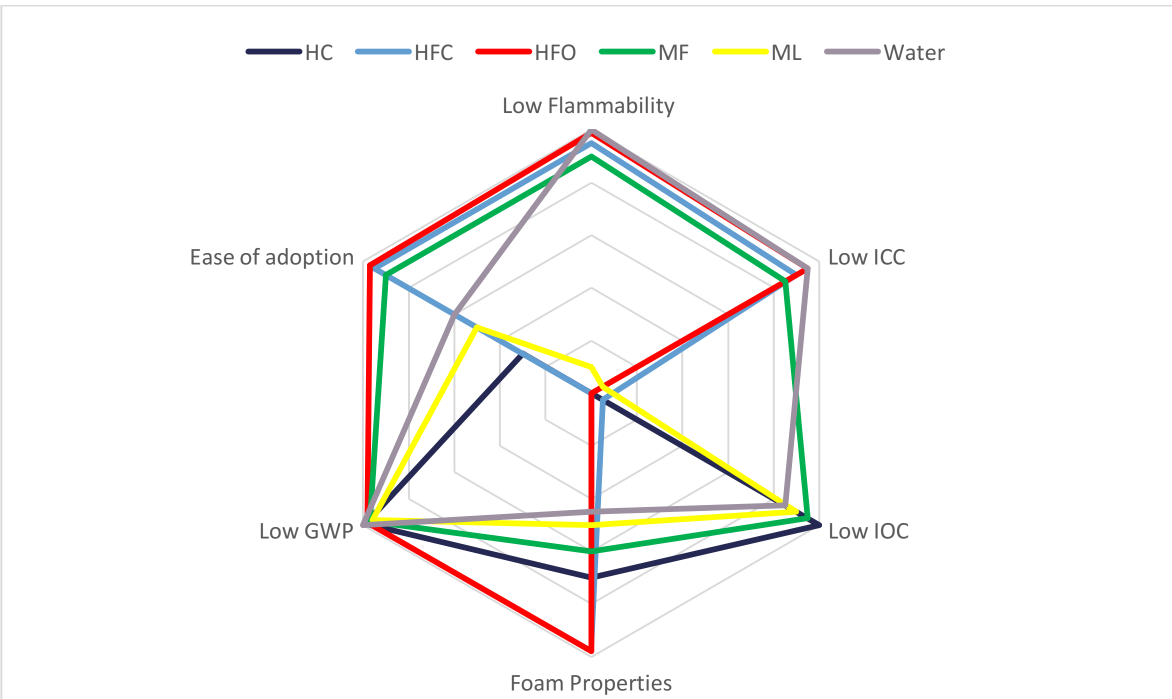
Hydrofluoroolefins (HFOs) and **HydroChloroFluoroOlefins (HCFOs)** are physical blowing agents with least impact on climate (zero ODP and very low GWP). They are currently marketed by Honeywell (HFO 1234ze, HCFO-1233zd) and Chemours (HFO-1336mzz). HFO 1336mzz and HCFO 1233zd are near drop-in for HCFC-141b in insulating foams and with excellent foam k-factors they can be used in appliances which require highest level of energy saving performance. However high costs and lack of regular availability in the market are two major deterrents for use of

HFOs/HCFOs. Recent international case studies suggest that water can be used as co- blowing agent to decrease the overall cost of polyol blends. Ultimate system costs remain uncertain, as does the geographic availability of those HFOs / HCFOs still to be fully commercialized.

Blends

- Improved energy efficiency standards are difficult if not impossible to achieve with cyclopentane alone, thus the drive for blends. HFC/HFO blends reduce k-factor, improve flow and density.
- MF could be co-blended with water to reduce operating costs and improve foam qualities.
- Water could be added to HFC/HFO to reduce operating costs. Water has low molecular weight and hence even smaller quantities (2-4%) could reduce use of another blowing agent by up-to 50%.

Table 1: Comparison of Replacement Options



Blowing Agent	Advantages	Disadvantages
HCFC-141b	Low cost High solubility, excellent processing Low k factor Non-flammable Standard processing equipment	High ODP High GWP To be phased-out
Hydrocarbons (pentanes)	No ODP or GWP concerns Low cost Acceptable solubility, processing Acceptable k factor Proven, mature technology	Flammable High capital conversion costs so only applicable to higher volume usage Not suitable for spray Safety concern for SME hand mix
HFC-245fa; HFC-365/ HFC-227	Zero ODP Good solubility, processing Equivalent k factors to HCFC-141b Proven technology Non-flammable	High GWP (>800) hence not a preferred option High cost
Water	Zero ODP Low GWP Non-flammable Low cost ((use of additional MDI adds cost) Excellent co-blowing option with HFCs, HFOs, and pentanes	Some processing challenges due to higher viscosity polyol blends High k factor (i.e., poor insulation) k factor decreases with time Poor adhesion without heated moulds, friability concerns Density penalty ~ 10%
HFOs	Zero ODP Low GWP (<15) Good solubility, excellent processing Equivalent or lower k factors than HCFC- 141b Proven in some applications Non-flammable	High cost (⩾ HFCs) Slightly higher catalyst amounts (cost) with HFO-1233zd
Hydrocarbon/ HFC or HFO Blends	Zero ODP Low GWP in hydrocarbon/HFO blends Reduced GWP in hydrocarbon/HFC blends Same equipment as hydrocarbon Lower k factors than hydrocarbon – helps meet stricter energy standards	High IOC ICCs high due to pentane
Methyl Formate	Not flammable in polyol blends Excellent solubility, good processing Acceptable k factors Acceptable foam properties Proven technology	Flammable as neat liquid Requires rigorous formula optimization
Methylal	Low cost Acceptable properties Medium k factors Some applications tested	Flammable as neat liquid High capital conversion costs

3. Foam sector in India

The foam industry structure in India has following key players-

- Foam manufacturing enterprises
- HCFC importers
- System Houses (supplier of foam formulations)
- Blowing agents suppliers

Foam manufacturing enterprises are categorized in large, medium, and small sizes based on their annual HCFC-141b consumption level. The large enterprises have yearly consumption of more than 50 Metric Tonne (MT), Medium enterprises have 20-50 MT HCFC-141b consumption pear year, and small enterprises have less than 20 MT HCFC-141b consumption in a year.

Table 2: Enterprises distribution as per sizes and annual consumption of HCFC 141b (MT).

Category	Number of enterprises	Total HCFC 141b consumption (MT)
Large >50 MT/year	25	2,190.50
Medium>20, <50 MT/year	41	1,332.20
Small <20 MT	381	1,710.60
Total	**447**	**5,233.30**

Source- IPUA survey 2014[4]

HCFC-141b is the main blowing agent used in the sector. It is used either as pure HCFC- 141b (added while mixing MDI and polyols) or pre-blended in polyols supplied by the polyurethane chemical suppliers known as System Houses. Most of the SMEs producing foam in India use blowing agent pre-blended in polyols.

SMEs generally lack know-how on chemicals they use for foam manufacturing including blowing agents. They also don't have technical resources for formulation optimization, and hence are majorly dependent on system houses.

There is no local production of HCFC-141b and therefore the entire requirement is met through imports by chemical suppliers, systems house, or directly by the foam manufacturers. HCFCs are covered by the import licensing system. Import is permitted only against an import license. The import license is issued by Directorate General of Foreign Trade (DGFT) based on recommendation from the Ozone Cell. While issuing import license it is ensured that total quantity imported in a year is below the consumption limit in the HPMP.

[4] Total import figures as reported in Article-7 data for year 2014= 4113 MT (a few enterprises are included both in small and medium categories hence some overlap and discrepancy in total import figures)

System houses provide the complex raw material mixtures including blowing agents, polyols and additives needed to make foam (termed as pre-blended polyols). These pre-blended polyols are supplied by system houses (either directly or through their distribution network).

There are about 20 identified System Houses who are producing or supplying customized HCFC-141b pre-blended polyol for various foam sectors. 15 system houses are indigenously owned and other five are multinational companies (Annexure 7).

As many of the alternate blowing agents such as MF, HFO and HFCs are under patent with international companies, these companies have also gained important role during HCFC phase-out. These companies have presence in Indian market (directly or through technology tie-ups).

Table 3: Patented alternate blowing agent suppliers

Blowing Agent (Brand name)	Chemical Supplier
HFO-1234ze (Solstice)	Honeywell
HFO-1234yf (Opteon YF)	Dupont
HCFO- 1233zd (Solstice)	Honeywell
HFC245fa (Enovate)	Honeywell
HFC 365mfc/HFC 277 (Solkane)	Solvay
Methyl Formate (Ecomate)	Foam Supplies

Sub-sectors of PU foam

Based on their end use, PU products are categorised into various sub-sectors. Following are sub-sectors serviced by SMEs in India.

Rigid PU foam: Commercial refrigeration, Discontinuous panels, General Insulation, Thermoware, Water Heaters and Spray Foam
Semi-rigid PU foam: Integral Skin
Flexible foam: Mattresses, carpets

Flexible PU foam sector converted from chlorofluorocarbons (CFCs) to methylene chloride as the blowing agent during the 1980s. Thus, current report is focussed on Rigid and Semi-rigid PU Foam as they are presently the main consumer of HCFC-141b in foam sector.

- Commercial Refrigeration: The types of products used in the commercial refrigeration include deep freezers, cold rooms, coolers, and display cabinets etc.
- Discontinuous panels: These panels are widely used in telecom shelters, partition doors, porta cabins, food processing, refrigerated vehicles etc. It is formed by injecting rigid foam mixture between two metal claddings.

- General Insulation: This sector includes pipe-in-pipe, block insulation and in-situ. Insulation considerably reduces the level of wasted energy and heat loss. The pipe-in-pipe technology involves the in-situ foaming of polyurethane insulation foam between a steel pipe and outer casing.
- Thermoware: These products primarily cater to household segments and include picnic boxes, flasks, casserole, etc. The Thermoware products are made by the injection process of PU foam.
- Water heaters: The benefits of using PU foam for water heaters are in energy efficiency and structural strength. Like Thermoware, water heaters are also made by the injection process of PU foam. This segment is also under energy labelling program and hence focus on insulation performance.
- Spray Foam: Spray foam is used in construction industry, on roofs and walls to create superior insulation that prevent air loss, thermal leaks and moisture penetration. Spray foam are closed-celled, air tight and resistant to mildew and fungal attack. Spray foam sector is gaining grounds in India.
- Integral Skin: Integral skin foam are used in steering wheel, back-foamed dashboards, arm rests, grab handles, etc. In furniture applications, it is used in arm rests, head rests, etc. Except for skin formation, the impact of blowing agent on final foam properties is limited. Insulation properties aren't very important for these products.

Table 4: Sub-sector wise distribution of Indian SMEs

Subsector	Medium enterprises <20MT, 50 MT>		Small enterprises >20 MT	
	Consumption (MT)	Number	Consumption (MT)	Number
Commercial Refrigeration	139.40	4	561.70	159
Discontinuous panels	478.80	15	452.50	69
General insulation	339.90	10	137.80	35
Integral skin	27.50	1	121.60	24
Spray foam	0.00	0	109.20	21
Thermoware	271.20	9	165.60	41
Water heaters	42.50	1	162.20	32
Total	1,299.30	40	1,710.60	381

Source- IPUA survey 2014[5]

[5] Total import figures as reported in Article-7 data for year 2014= 4113 MT (a few enterprises are included both in small and medium categories hence some overlap and discrepancy in total import figures)

4. HCFC phase-out in India

During HPMP stage- I (2011-2015), all 15 large foam manufacturing enterprises have moved from HCFC-141b to non-ODS, cyclopentane (CP) technologies. These large enterprises were the large consumers of HCFC-141b and can handle the alternate technology like CP, which has safety issues due to its flammability, and were thus targeted under HPMP stage-I. Technical Assistance has also been provided to 15 System Houses (Indian) for research and development of HCFC-free polyol formulations with blowing agents like MF, CP and HFOs for various sub-sectors with the expectation that these developed pre-blended polyol could be used by the SMEs.

The HPMP stage-II (2015-2020) focuses on converting SMEs to switch to non-ODS and low-GWP technologies. Out of total 40 Medium enterprises, 33 are eligible[6] to receive funding. These enterprises are expected to shift to CP, MF or HFOs. Out of total 365 eligible SMEs, approx. 150 are selected to receive ICC based on their size, adequate infrastructure and technical capability to undertake the conversion. These enterprises are expected to use CP or pre-blended polyols using CP and will receive ICC & IOC for the conversion.

Remaining enterprises are expected to choose other alternatives such as MF, water, and HFOs etc. ICC for the conversion to pre-blended polyols using HFO, HFC, and MF are minimal but IOC are significant for HFO and HFC blown foams due to high cost of blowing agents. CP as a blowing might not be a viable option for these enterprises due to lack of infrastructure and technical know-how to handle flammable blowing agents. Compliance requirements[7] to handle and use flammable materials such as CP are also major deterrent for use in small enterprises.

Survey findings

As part of this study various SMEs, system houses, and chemical suppliers were contacted to understand key challenges faced by Indian SMEs, availability of alternate blowing agents, and emerging trends etc.

SMEs: 104 enterprises have responded as part of survey conducted (combination of site visits and telephonic interviews) during July-Aug 2017. These enterprises cover all sub-sectors of SMEs. The key findings include:

- Though these 104 companies are covered as foam manufacturers in the IPUA survey 2014, it was observed that many of them are only into trading of goods with no facility for foam production.
- Enterprises have only basic awareness about the Montreal Protocol and HCFC phase-out. Most of them aren't well conversant with issues with emerging alternatives and their possible impact on business etc.

[6] Only enterprises setup before 21st September 2007 are eligible

[7] Indian Explosives Act, Hazardous Chemicals Rules

- Most of these enterprises purchase pre-blended polyols from system houses. They don't have strong technical understanding to do formulation optimisation as per end-product requirements and are dependent on system houses for such changes.
- These enterprises normally don't have good lab facilities or well-established testing protocols, and they normally follow visual or manual inspections.
- Over 90% of the respondents aren't aware of formulations based on alternate blowing agents or if their formulation suppliers (system houses) have alternatives to HCFCs.
- Most of them believe that HCFC 141b based formulations will be available in the market for next few years. Hence any action to switch to other alternatives is still far away.
- Some enterprises with higher usages have planned to switch to cyclopentane and have prepared project proposal to avail incremental capital costs available under HPMP. However, many of them haven't yet done any trials on cyclopentane and one reason commonly cited was lack of equipment to handle cyclopentane.
- Very few enterprises have done trials with alternative blowing agents based formulations (mostly with MF and cyclopentane). Even with these enterprises, detailed technical analysis isn't available to understand key technical issues faced by them.

System Houses:

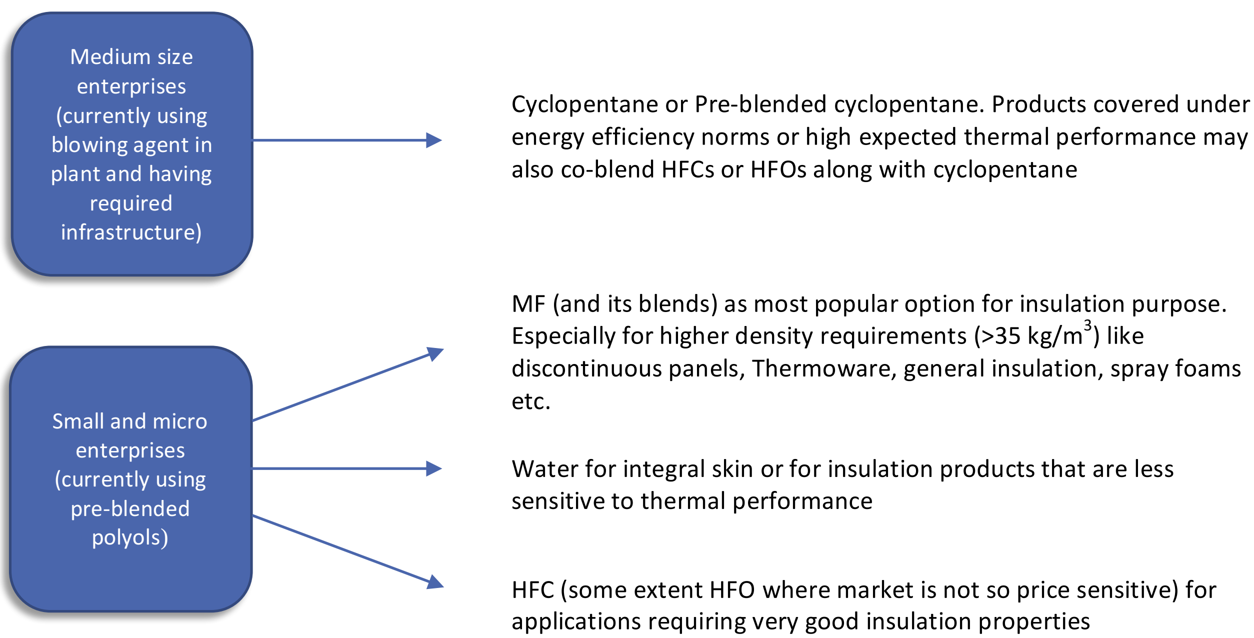
- Many of the system houses have claimed to have completed trials of formulation using alternate blowing agents. Most commonly tried blowing agents include cyclopentane and MF. Many of these trials seem to have been done to achieve HPMP stage-I milestones rather than to develop market ready formulations.
- Also, for most of these system houses trials were done only for a few sub-sectors or end-products. Not much efforts have also gone in optimising these formulations for each subsector or product.
- Easy availability of HCFC-141b in India and lack of urgency (deadline of 2020) were cited as main reasons for not doing more detailed R&D. They believe that optimised formulations could be developed only when there is enough demand in the market.
- Another reason cited was that many of the small & medium sized system houses lack strong R&D infrastructure (both equipment and manpower) and are dependent on larger system houses (especially on international system houses present in India) for development of formulations.
- A few large system houses (Indian and International) are also supplying water based formulations especially for applications with less focus on thermal properties.
- A few system houses have also confirmed availability of pre-blended CP based formulations for different applications. However, use of such formulations may still require investment in new equipment for manufacturing.
- MF was most widely tried blowing agent with no major performance issue identified during trials. But this was still not considered as a good drop-in, possibly due to lack of optimisations done for various applications.
- Not many instances of methylal as an alternate blowing agent for trials were mentioned. This is surprising as many other countries especially in Latin America have started or planned to use methylal for various applications including integral skin.

Emerging trends

Medium sized enterprises with good infrastructure would move to hydrocarbon (pre-blended and direct use). The prime reasons for shift to hydrocarbon are low cost of hydrocarbons and availability of ICC for conversion.

Micro and small enterprises will not shift to hydrocarbon due to lack of infrastructure and blowing agent flammability issues. MF will be chosen by enterprises with products having high importance of thermal performance. Many enterprises with insulation products may also shift to water if end-product has low thermal performance importance or is a low-priced product sold in low quality conscious market (products such as unbranded Thermoware, commercial refrigerators etc.). Water may also be used for integral skin applications such as shoe soles or furniture segments (skin quality could be obtained using high pressure moulds or separate spray chemical for external skin).

Applications which require high thermal performance such as water heaters, discontinuous panels etc. may find difficult to meet requirements with hydrocarbons, MF or water-based options. They may explore options of using HFOs or HFCs based formulations. Given high cost and availability issues of HFO, market may move towards HFC usage for such applications. A few systems houses are currently offering HFC based formulations in India.



5. Evaluation of HCFC replacement options

Blowing agent alternatives are typically evaluated against the criteria of properties of end-product, commercial availability, ease of processing, environmental soundness, and cost effectiveness. However, it should be noted that, the mix of performance properties (technical, economic and environmental) does not lead unambiguously to one single selection.

As part of this study, review of various international case studies of demonstration projects executed under the HPMP, the FTOC report, technical reports commissioned by MLF, case studies of chemical suppliers, and discussions with experts in India were conducted. Following section summarises this analysis related to evaluation of potential alternative blowing agents for various sub-sectors.

For evaluation, sub-sectors are divided in 3 categories: Insulation (commercial refrigeration, discontinuous panels, general insulation, Thermoware, and water heaters); Insulation (spray foam) and Non-Insulation (Integral Skins).

Insulation: commercial refrigeration, discontinuous panels, general insulation, Thermoware, and water heaters)

Commercial Refrigeration: number of SME 163, total consumption 701.1 MT, average consumption of HCFC 141b=4.30 MT

Discontinuous Panels: number of SME 84, total consumption 931.3 MT, average consumption of HCFC 141b= 11.09 MT

General Insulation: number of SME 45, total consumption 477.7 MT, average consumption of HCFC 141b=10.61 MT

Thermoware: number of SME 50, total consumption 436.8 MT, average consumption of HCFC 141b=8.73 MT

Water Heaters: number of SME 33, total consumption 204.7 MT, average consumption of HCFC 141b=6.20 MT

Low k-factor is the most critical property for this category. Other important properties include- dimensional stability, adhesion, and density. Higher foam density will result in lower k (better insulation) and higher costs. Processing parameters such as flow, viscosity etc. are also important for selection.

Options	Remarks
Hydrocarbons	Low costs, acceptable k-factor (worse insulation compared to HCFC 141b), good dimensional stability and adhesion. Suitable for enterprises which could comply with safety requirements. Small enterprises might not have required infrastructure to shift to hydrocarbon based systems. For products which need better thermal performance (or if they come under energy performance standards such as water heaters), co-blending with HFC/HFO could be tried.
Methyl Formate	Good option for SMEs. For equipment requiring high energy efficiency, co-blending with HFC/HFO could be explored. Good for pour-in-place applications such panels, appliances. Indian trials suggest good usage for densities above 35 kg/m^3 applications. Lower density applications may need optimisation. Possible foam shrinkage and poor adhesion, may need corrosion proof equipment Requires rigorous formulation optimisation to meet requirements for different products
Methylal	Limited use due to flammability issues and requirement for initial investments. Not may case studies available for successful trials for various products in India. May require higher foam density, adhesion issues.
HFCs	Good option where higher insulation value needed such as commercial refrigerators, water heaters, cold storage etc. Given that HFCs are not encouraged in HPMP stage-II, adoption might be limited Water co-blending could reduce operating costs
HFOs	Up-to 2% water co-blending could reduce HFOs consumption. However, requires strong technical know-how for such optimisations. Not many system houses may like to develop expensive pre-blended polyol for this small sub-sector, hence limiting its availability for use for SMEs
Water	It could be an option for applications which are not very sensitive to thermal performance, may require higher densities. Water could also be used for co-blending with HFCs/HFOs to reduce overall costs and GWP impact in case of HFCs usage. To compensate for

	low adhesion- additives may be required resulting in higher costs and optimisation requirements. Water based formulations have poor flow in moulds limiting its use for discontinuous panels, refrigerators etc. Large international system houses have done work to improve insulation properties while reducing foam densities and maintaining dimensional strength while using full water blown systems.

Insulation: Spray Foam

Spray Foam: number of SME 21, total consumption 109.2 MT, average consumption of HCFC 141b=5.2 MT

Spray foam is generally used in building insulation. It's a small sub-sector for SME in India, though its witnessing good growth in past few years. Low k-factor is a critical property as normally spray foams are used for insulation purposes. Other important properties include- dimensional stability, density, and adhesion. Higher foam density will result in lower k (better insulation) and higher costs.

Options	Remarks
Hydrocarbons	Due to flammability issues, hydrocarbons are not used in such application.
Methyl Formate	k factors are equivalent to cyclopentane, but not as low as HFCs or HFOs. Good options for SMEs however system houses need to develop optimised formulations.
Methylal	Not used commercially in this segment as end-product attributes are not achieved
HFCs	Given that HFCs are not encouraged in HPMP stage-II, availability might be limited, chiller may be required for storage. Water co-blending could reduce operating costs (up-to 50% reduction)
HFOs	Up-to 2% water co-blending could reduce HFOs consumption (up-to 50%). However, requires strong technical know-how for such optimisations.
Water	Bad insulation performance; lower dimensional strength and adhesion. Water could be used for co-blending with HFCs/HFOs to reduce overall costs and GWP impact in case of HFCs usage

Non-Insulation: Integral Skin

Integral Skin: **number of SME 25, total consumption 149.1 MT, average consumption of HCFC 141b=5.96 MT**

Integral skin has wide range of applications in automobile, footwear soles, and furniture. Many large automotive players are using fully water blown foams. In such cases, high skin quality is achieved using high pressure molds or additional chemical spray to achieve a layer of skin over water blown foams. Insulation performance is not critical for this sub-sector. The critical property for integral skin is the quality, hardness (look and feel), and thickness (durability) of the outer skin.

Options	Remarks
Hydrocarbons (n-Pentane)	Excellent skin quality (better than Methyl Formate and water), no shrinkage problem but due to flammability issues, hydrocarbon is not a suitable option for SME.
Methyl Formate	Good options for SMEs however system houses need to develop optimised formulations for various products Better properties for shoe soles compared to HCFC 141b, and within acceptable range for other applications. Shrinkage problem, may need further formulation optimisation. Equipment and components that encounter MF fully formulated systems should be preferably corrosion resistant
Methylal	Flammability and high initial costs could be a deterrent for adoption in SME. Considered as a good alternative for phase-out in many countries but limited know-how in India for this sub-sector.
HFCs	High costs might prohibit adoption by SMEs. This segment is very price sensitive and hence ability to pass on cost increase is limited. High GWP. Chiller may be required for the storage owing to low boiling point of HFCs.
HFOs	High costs might prohibit adoption by SMEs. This segment is very price sensitive and hence ability to pass on cost increase is limited
Water	Better high pressure molds and formulation optimisation may meet requirements of certain applications such as shoe-soles in this sub-sector. Water results in high viscosity of polyol blend, adhesion issues, and friability in final product. Literature survey suggests that use of better additives, catalysts and improved polyols could solve many of these problems.

Financial Evaluation

Systems based on CP and methylal require extensive technology upgradation. Such upgradations are covered by funding from the MLF in form of ICC. Other alternatives such as MF, water, HFOs, and HFCs may require minimal capital investments, especially since most of the SMEs use pre-blended polyols.

As capital cost is covered under the MLF funding or is minimal in case of other alternatives, the real impact comes from change in raw material costs. Following analysis shows impact of blowing agent on final foam costs. HCFC-141b based foam cost is assumed as 100 (baseline). For this analysis only change considered is blowing agent cost (annexure-4).

Insulation Foam

Blowing Agent	HCFC	CP	HFC	HFO	MF	Water
Foam Cost	100	93-96	125-160	150-190	95-97	105-115

Non-Insulation Foam

Blowing Agent	HCFC	CP	HFC	HFO	MF	Water
Foam Cost	100	95-97	130-150	140-155	95-98	95-105

Options like CP, MF, and water have least cost impact for SMEs. But CP might not be a viable option for many of the SMEs due to lack of required infrastructure, technical know-how, and stringent compliance requirements. MF and water could be adopted by SMEs if changes in foam properties due to use of these blowing agents are acceptable.

If foam properties such as insulation performance are critical then options like HFOs and HFCs can be adopted. However, these options may increase foam cost by 25-90%. HFCs have high GWP and its impact on climate must also be considered. Cost impact could be reduced by water co-blending. Literature survey suggests cost reduction by up-to 50% by using 0.5-2.5% water. However, such changes require extensive formulation optimisation. SMEs lack technical know-how for such optimisation and will rely on system houses for such measures.

In case significant cost reduction is not possible, SMEs may choose to use HFOs/HFCs only in cases where market is able to absorb cost increase. For applications like freezer on wheel, water heater where foam cost is not a major component of overall product cost (10-20%), increase in foam costs will have lesser impact on final product cost (up-to 2-10%). For such applications adoption of HFOs/HFCs will primarily depend on easy availability of formulations.

For sub-sectors like spray foam, thermoware, certain integral skin applications where foam plays a major role in overall cost structure (70-100% of end product costs), it might be difficult to pass-on additional costs to end customers. Such application might face challenges for adoption of HFOs/HFCs. MF or water may be good transition options till other alternatives become cost effective.

6. International case studies

Developed countries have shifted to non HCFC alternatives in foam sector many years back. Enterprises in Europe have primarily adopted hydrocarbons (except for spray foam) and enterprises in USA are using HFCs. Hydrocarbons are also blended with HFCs to improve thermal performance (this is also a trend in emerging economies especially for appliances covered under strict energy efficiency norms). There is limited use of oxygenated hydrocarbons such as Methyl Formate and Methylal. Water is also used especially for integral skin and spray foam applications (small quantities of HFCs also blended for some special applications). In Japan, super critical CO2 (patented technology) is also used for spray foams. SMEs in these countries are using HFCs and water as blowing agents. Pre-blended cyclopentane usage is also prevalent for some sectors in Europe.

Developing countries are also in transition phase for HCFC phase-out in foam sector. Large and medium sized enterprises have mostly adopted hydrocarbons in these countries. For SMEs, most prevalent replacement options are Methyl Formate and water blown foams. Water blown foams are also widely used for applications such as integral skins, products not very sensitive to thermal performance etc. In China, water based formulations are available for iceboxes, integral skin, spray foams, solar water heater, and shoe soles. Methylal though not a prevalent option in Asia has been adopted in Latin America including Brazil and Mexico. Super critical CO_2 and water are also tried for spray foam applications in countries like China and Indonesia.

One major difference between these developing countries and India is availability of local case studies on usage of alternatives in various applications. It is surprising that despite having a large foam industry, there are not many Indian case studies available especially in applications covered by SMEs.

Country	Key Strategy	Alternative BA
Mexico	Focus on System houses to ensure commercially viable BA options are available in the market	Local System Houses: Preblended CP, MF, and Methylal; HFO (future) International: HFC, water, HFO (future)
Brazil	Implementation through system houses only. Some individual projects done in SME (IS)	Methylal and Methyl Formate HFC
Malaysia	Focus on System houses to ensure commercially viable BA options are available for downstream users	MF, methylal HFC
China	Direct implementation and through downstream users of system houses	Preblended CP, water blown (solar water heaters, pipe insulation, spray, IS), HFO blends
Thailand	Direct implementation and through downstream users of system houses	CP, water (IS) and HFC blends(rigid foam, IS)

7. Recommendations

The key conclusion from this study is that there is no perfect drop-in replacement option for HCFC in SME foam sector that provides similar performance levels along with minimal cost impact for all sub-sectors. There are trade-offs in terms of ease of foam processing, final foam quality, increase in product costs, and Global Warming Potential (GWP) of such alternatives. There are other barriers as well for successful transition to non-ODS blowing agents in foam sector including lack of awareness about phase-out schedule, delay in market creation for replacement options, and lack of local case studies etc. Despite these barriers there are options with reasonable performance and cost impact and hence, business viability risk is not very high.

SMEs will need to evaluate possible options based on their unique business situation which will include:

- Selection of option that is easy to adopt without major changes in their current set-up
- Easy availability of such options in the market
- Impact on product quality and if such changes are acceptable to end users
- Financial viability of these options including if cost increase could be passed on to the end user or ability to absorb such increase in cost

Following are the recommendations to Government of India and other stakeholders to smoothen the transition process for Indian SMEs.

- Verification of SMEs to identify manufacturing enterprises
  - An extensive verification exercise should be conducted to identify enterprises involved in manufacturing as it was found during this study that many enterprises only trade goods and are not into manufacturing. These enterprises will not require assistance for HCFC-141b phase-out. This exercise will help Ozone Cell assess accurate investment requirement in SME foam sector.
- Market signalling is required for stakeholders to create business readiness
  - Direct communication to SMEs. Ozone cell could reach out to SMEs directly to inform them about phase-out schedule, need to take early actions for evaluation of appropriate replacement options, and available support infrastructure for SMEs. This could be best done through formal letters to SMEs, workshops, newsletter etc. It’s also important to maintain regularity in this communication.
  - Expedite technology conversion projects for enterprises covered under HPMP stage-II funding. Action of these projects will also provide signal to other SMEs to evaluate possible options for replacement.
  - Restricting HCFC 141b import quota. Ozone Cell may evaluate possibility of curtailing import quota and restricting supply in the market. Reduced availability of HCFCs will prompt creation of demand for replacement options. This will also be a signal to system houses to make formulations commercially available.

- Technical assistance to SMEs
    - Demonstration projects for various applications. Ozone Cell may like to form sub-sector/application specific technical taskforce comprising of SME representatives, system house and technical experts to conduct more trials in a planned manner and arrive at technical findings which could be shared with wider audience. Availability of these India specific case studies will promote adoption of appropriate solutions and reduce challenges for SMEs.
    - Study tours could be conducted for SMEs in Indian plants where trials have already been conducted (after taking proper care for confidentiality aspects). Application specific workshops should be conducted wherein international and local case studies could be shared for various replacement options. Ozone cell could also appoint a few technical experts whom SMEs could contact for technical queries.
    - An online tool could be created for SMEs to compute ICC & potential IOC for various options and to evaluate their plant's eligibility for conversion. This will help SMEs assess impact on their business and will help them choose appropriate option. This tool could be hosted on planned online MIS by the Ozone cell.
- Support in development of technology roadmap for the SME sector
    - For sub-sectors such as water heaters, freezer on wheels, and general insulation applications where insulation performance is critical and alternatives such as MF and water can't achieve desired k-levels and hence SMEs may need to adopt HFOs or HFCs. In such cases ideas to reduce costs of alternatives such as HFO or HFC should be promoted. Opportunities may exist to decrease consumption of blowing agent by water co-blending or to decrease the thickness of foam and still achieve desired insulation values. The resulting IOC reduction may be significant. Ozone Cell may like to commission such studies.
    - Some enterprises (typically with HCFC consumption of less than 1 MT per annum) use manual mixing of formulation in an open vessel. In such cases, alternative options are limited and its recommended that water could be considered as prime replacement option. The use of high GWP alternatives such as HFC-245fa would be highly emissive and the use of HCs would be unsafe.
- Support for enterprises unable to adopt viable solution
    - Though there is no perfect drop-in option, but there are options with reasonable performance and cost impact and hence, business viability risk is not very high. However, there could be some cases wherein enterprises would find it difficult to adopt replacement option and might face business closure risk. Government may provide support to these enterprises to change their product mix or shift to other business with financial support under other government schemes. Following financial support schemes under MSME could provide required support to these SMEs (www.msme.gov.in)
        - Credit Linked Capital Subsidy Scheme for Technology Upgradation
        - Marketing Assistance & Technology Up-gradation Scheme
        - Raw Material Assistance Scheme

Annexure-1

Blowing agent properties

	HCFC 141b	Cyclopentane	Methyl Formate	Methylal	HFO	CO_2 (water)	HFC245fa	HFC365mfc /HFC277
Molecular Formula	CH3CCl2F	C5H10	HCOOCH3	CH3OCH2OCH3	CHFCHCF3/ CF3CHCHCl / CF3CHCHCF3	H2O	CF3CH2CHF2	CF3CH2CF2CH3 CF3CHFCF3
Manufacturer			Foam Supplies		Honeywell/Arkema/Chemours		Honeywell	Solvay
Boiling Point °C	32	49.3	31.3	42	-19	-78.3	15.3	40.2
Molecular Weight	117	70.1	60	76	114	44	134	148
K Factor of blowing agent (@ 25°C)	9.8	12.0	10.7	11	10.6	16.3	12.2	10.6
LEL-UEL (Lower and upper explosive limit)	5.6-17.6%	1.4-8.0%	5-23%	1.6-17.6%	6.2-12.3%	None	None	3.8-13.3%
Flammability	(+++)	(---)	(--)	(--)	(+++)	(+++)	(++)	(++)
Solubility[8]	Good	Low	Excellent	Good	Good	Acceptable	Acceptable	Acceptable
GWP	730	11	Negligible	Negligible	6	1	1020	2900
ODP	0.11	0	0	0	0	0	0	0
ICC		High	Nominal	High		Low	Nominal	Nominal
IOC		Low	Moderate	Moderate	High	Nominal	High	High

[8] Solubility of blowing agent is an important property that affects foaming, cellular structure, and dimensional stability.

Annexure-2

Blowing agent Costs

Chemical	Prices INR/KG	
	Low	**High**
HCFC-141b	210	340
CP	120	200
HFC 245fa or HFC365/HFC277	800	1000
Methyl Format	180	250
HFO	1100	1500

*based on discussions with suppliers and recent international publications

Annexure-3

K factors based on demonstration projects

Appliance k-factor

Blowing Agent	k factor @ 24^{o}C (mW/mK)
HCFC-141b	18.50
CP	21.00
HFC 245fa	18.50
HFO 1233zd	17.10
Water (CO2)	24.00
Methylal	19.30

Discontinuous Panels k-factor

Blowing Agent	k factor @ 24^{o}C (mW/mK)
HCFC-141b	19.70
CP	22.30
HFC 245fa	20.90
HFO 1233zd	20.20
Methyl Formate	23.86
Blend of CP/HFO 1233zd (50-50)	20.80
Methylal	22.27

Spray Foam k-factor

Blowing Agent	k factor @ 24^{o}C (mW/mK)
HCFC-141b	19.50
HFC 245fa	19.90
HFO 1233zd	18.70
Methyl Formate	22.60
Water	24.00
Methylal	21.50

Annexure-4

Assumptions for financial evaluation of options

Chemical	Unit	Cost (INR)	Relative blowing agent molecular weight	% blowing agent in insulation foam	% blowing agent in integral skin
Polyol	kg	150			
MDI	kg	190			
HCFC-141b	kg	250	1	15-30	13-15
Cyclopentane	kg	175	0.6	9-18	7.5-9
Methyl formate	kg	225	0.51	8-15.5	7-8
HFO	kg	1100	1.4	21-42	18-21
HFC	kg	800	1.33	20-40	16-20

Annexure-5

Demonstration projects done in other countries

	CP/Preblended CP	Methylal	MF	HFO	HFC	Water	Supercritical CO_2
Discontinuous panels	Egypt	Brazil	USA				
Commercial Refrigeration	Egypt	Brazil				Ukraine, China	
General Insulation		Brazil	USA				
Water heater	Egypt	Brazil	USA	Norway	China, USA	USA	
Thermoware		Brazil	USA				
Integral Skin		Brazil, Mexico, Ukraine	Brazil			China	
Spray Foams		Brazil	Brazil, Mexico, Egypt, Jamaica	USA, Canada[2]		China	Colombia, China

Projects proposed under HPMP for SME sector

- Egypt- All SMEs (38) moving to MF
- Argentina- SMEs moving to HFO+ water blends
- Saudi Arabia- Will use HFO for spray foam
- Mexico- Focus on MF/Methylal and HFC; HFO to be considered in future
- China- Many enterprises have shifted to water as a blowing agent
- Thailand- HFO also considered as an option (water co-blending proposed to reduce costs)

Annexure-6

Sources of secondary research

UNEP JUNE 2016 Report of the Technology and Economic Assessment Panel (TEAP)
Low cost options for the use of hydrocarbon in the manufacture of PU foams (An assessment of MLF supported projects, March 2012)
Calculation of the Incremental Capital costs and Incremental Operating costs for Foam sector alternatives (Technical paper, MLF76)
Revised analysis of relevant cost considerations surrounding the financing of HCFC phase out (UNEP/OzL.Pro/ExCom/55/47).
Methyl formate as blowing agent in the manufacture of polyurethane foam systems: An assessment for the application in MLF projects, UNDP (UNEP/OzL.Pro/ExCom/62/9).
Methylal as blowing agent *in the manufacture of polyurethane foam systems: An assessment for the application in MLF projects, UNDP (UNEP/OzL.Pro/ExCom/66/17).*
Low-cost options for the use of hydrocarbons in the manufacture of polyurethane foam: An assessment for the application in MLF projects, UNDP (UNEP/OzL.Pro/ExCom/66/17).
Conversion demonstration from HCFC-141b-based to cyclopentane-based pre-blended polyol in the manufacture of rigid polyurethane foam at Guangdong Wanhua Rongwei Polyurethane Co. Ltd, World Bank (UNEP/OzL.Pro/ExCom/66/17).
Supercritical CO_2 technology for polyurethane spray foam, Japan/UNDP (UNEP/OzL.Pro/ExCom/71/6/Add.1).
2010 Report of the Rigid and Flexible Foams Technical Options Committee (FTOC)
HFO-1234ze as blowing agent *in the manufacture of extruded polystyrene foam boardstock: An assessment for application in MLF projects (UNEP/OzL.Pro/ExCom/67/6).*
The phase-out of HCFC-141b in rigid polyurethane insulating foams manufactured by small enterprises, World Bank (June 2014).

Annexure-7

Indian System Houses

- Jai Durga
- Organometallic
- Pine Resins
- Shiv Polymers
- Shivathene
- Amritchem
- Bestopuf
- Gomti Impex
- Manya International
- Royal Industries
- Shakun Industries
- Tandy Innovative Chemicals
- Expanded Polymer Systems
- Industrial Foams
- Manali Petrochemicals

International System Houses present in India

- BASF
- Covestro (erstwhile Bayer)
- Dow Chemicals
- Hunstman International

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