JABATAN ALAM SEKITAR

# GREENING
## THE FOAM INDUSTRY : ACHIEVING SUCCESS IN HCFC CONVERSION

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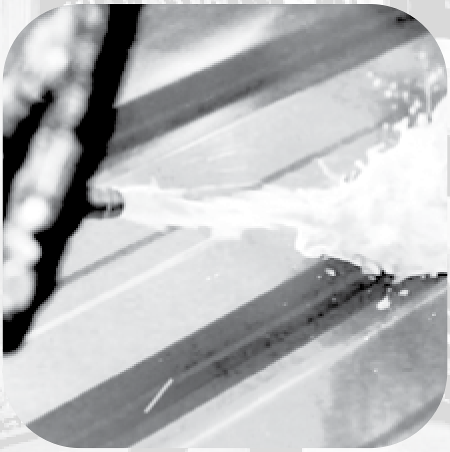

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# EXECUTIVE SUMMARY

Since 2012, Malaysia has been at the forefront of global environmental efforts with the launch of its Hydrochlorofluorocarbon Phase-Out Management Plan (HPMP). This initiative reflects the country's commitment under the Montreal Protocol, aimed at phasing out substances that harm the ozone layer and contribute to climate change. Through the HPMP, Malaysia's Department of Environment (DOE) has actively implemented programs across multiple sectors, including refrigeration and air-conditioning, polyurethane foam production, firefighting and solvents.

One of the most significant contributors to HCFC consumption in Malaysia is the polyurethane industry, which relies heavily on HCFCs as blowing agents in foam production. Polyurethane foam has become a staple in modern life, serving critical roles in thermal insulation, sound absorption, and even integral skin applications for industrial and consumer products.

Many foam makers are small and medium-sized enterprises (SMEs) who may not have the financial and human resources to keep abreast of technological and policy developments, nor even aware of the Government's HCFC phase-out policy or, of alternative technologies. Some SMEs may not even realize that they are using ozone depleting substances. To address these hurdles, the government has developed a strategic framework under the HPMP, which includes financial assistance, technology transfer and capacity-building initiatives to guide these industries towards environmentally sustainable practices.

This book highlights the transformative journey of Malaysia in safeguarding Earth's ozone layer and promoting sustainable practices in the polyurethane foam sector. Exploring the complexities in shifting industrial practices and highlighting the government's collaboration with international bodies like United Nations Development Programme (UNDP), United Nations Industrial Development Organisation (UNIDO) and the World Bank. Through this collaboration, Malaysia continues to make progress in reducing its environmental impact, particularly in the polyurethane foam sector, while maintaining economic growth and industrial development.

In safeguarding the Earth's ozone layer, Malaysia's proactive measures and commitment underscore the global imperative to address environmental challenges. The transformative journey outlined in this chapter illuminates the nation's pivotal role in phasing out ozone-depleting substances and promoting sustainable practices, particularly in the polyurethane foam sector. As we delve into subsequent chapters, the intricate details of Malaysia's initiatives and achievements will further underscore the significance of its efforts in contributing to a healthier and more sustainable planet.

# FOREWORD

For decades, the protection of the ozone layer has been a global priority due to its critical role in safeguarding life on Earth. However, industrial activities over the decades have significantly impacted this vital layer, primarily through the use of ozone-depleting substances (ODS), such as Chlorofluorocarbons (CFCs), Carbon Tetrachloride (CTC), Methyl Bromide, Hydrochlorofluorocarbons (HCFCs) and etc. In response to this threat, countries worldwide have united to take action. Malaysia's commitment to this cause began with ratifying the Montreal Protocol in 1989, leading to significant efforts to phase out harmful substances while simultaneously promoting industrial advancement and sustainability.

The Hydrochlorofluorocarbon Phase-Out Management Plan (HPMP) is one of Malaysia's strategies for addressing this issue. Various sectors, including the polyurethane (PU) foam industry, have worked towards eliminating HCFCs, particularly HCFC-141b, which has been used extensively as a blowing agent. Through programmes such as the HPMP, Malaysia has supported its industries in adopting more sustainable alternatives, demonstrating that environmental responsibility and economic growth can go hand in hand.

This book, "Greening the Foam Industry: Achieving Success in HCFC Conversion," provides an overview of Malaysia's progress in the foam sector under the HPMP. It highlights the steps taken, the milestones achieved, and the key role played by the industries particularly the system houses and foam manufacturers in transitioning to non-ODS alternatives. These efforts have contributed to mitigating ozone depletion and supported broader environmental goals, including reducing greenhouse gas emissions.

The book also serves as a valuable resource for stakeholders, capturing the challenges faced, solutions implemented, and lessons learned during this transition. It underscores the importance of collaboration between the government, industry, and partners in achieving shared environmental goals.

As we look ahead to the next phase of the HPMP and the continued phase-out of HCFC, this publication reminds us of the importance of working together toward sustainable development. I hope this book will serve as both a reflection on our achievements and an inspiration for ongoing efforts to protect the environment for future generations.

"Environment, Our Shared Responsibility"

**DATO' WAN ABDUL LATIFF BIN WAN JAFFAR**
Director General,
Department of Environment
Malaysia

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# ACRONYMS AND ABBREVIATION

AP – Approved permit

C5 - Cyclopentane

CFCs – Chlorofluorocarbons

$CO_2$ – Carbon Dioxide

CSR – Corporate Social Responsibility

CTC – Carbon Tetrachloride

DOE – Department of Environment

EESC – Effective Equivalent Stratospheric Chlorine

EQA – Environmental Quality Act

GWP – Global Warming Potential

$H_2O$ - Water

HC – Hydrocarbons

HCFCs – Hydrochlorofluorocarbons

HCFOs – Hydrochlorofluoro olefins

HDI – Hexamethylene Diisocyanate

HFCs - Hydrofluorocarbons

HFOs – Hydrofluoroolefins

HPMP – Hydrochlorofluorocarbon Phase-Out Management Plan

IPDI – Isophorone Diisocyanate

MDI – Methylene Diphenyl Diisocyanate

MIDA – Malaysian Industrial Development Authority

MITI – Ministry of International Trade and Industry

MLF – Multilateral Fund

MT - Matric Tonnes

NCFCP – National Chlorofluorocarbons Phase-Out Plan

NGO - Non-governmental organization

$O_3$ – ozone

ODP – Ozone Depleting Potential

ODS – Ozone Depleting Substances

OH - Hydroxyl Groups

PPE - Personal Protective Equipment

PU – Polyurethane

R&D - Research and Development

SMEs - Medium-sized Enterprises

TDI - Toluene Diisocyanate

UNDP - United Nations Development Programme

UNEP - United Nations Environment Programme

UNIDO - United Nations Industrial Development Organisation

UV – Ultraviolet Radiation

# Chapter 1
# UNVEILING THE TRUTH

## Protecting Earth's Ozone Layer: A Global Endeavor

The stratosphere, a layer of the Earth's atmosphere located 10 to 50 kilometres above the surface, hosts approximately 90% of the ozone, commonly known as the ozone layer. This ozone shield is crucial for safeguarding life on Earth by absorbing harmful ultraviolet (UV) radiation from the sun, including a significant portion of UVB and all of UVC. This protection is important in preventing an array of adverse effects, such as skin cancers, cataracts, and ecological harm to both flora and fauna (UNEP 2022).

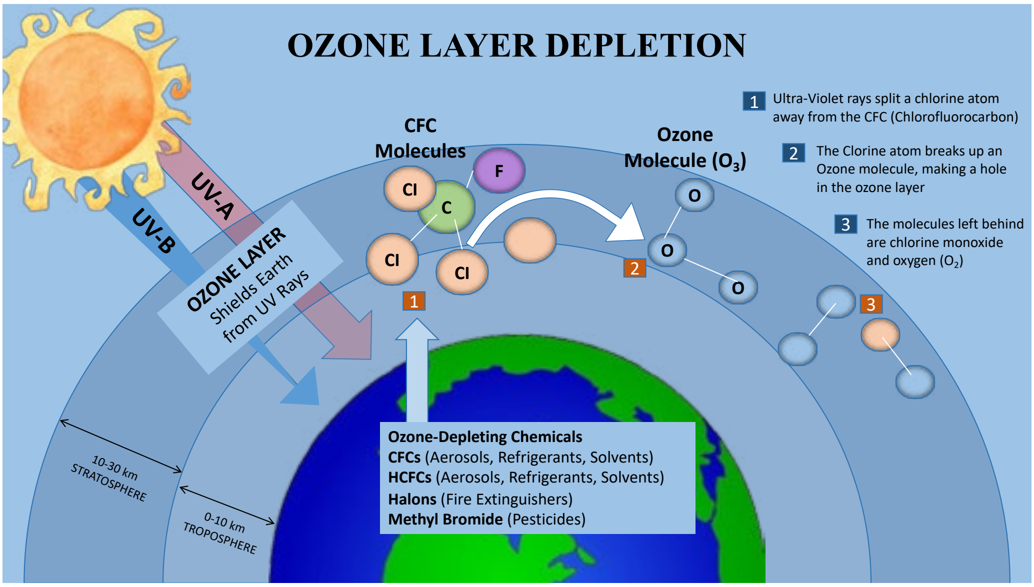


*Figure 1.1: The depletion of ozone layer.*

In the 1970s, scientists unveiled a concerning reality that man-made chemicals, particularly chlorofluorocarbons (CFCs) found in everyday products like refrigerators and aerosol sprays, could deplete the protective ozone layer ***(Fig. 1.1)***. Observation stations worldwide soon confirmed this alarming discovery, where a significant hole in the ozone layer was emerging over Antarctica during the spring season, leading to increased harmful UV rays.

## The Ozone Layer

The ozone layer, a fragile shield of gas located in the Earth's stratosphere, plays a crucial role in protecting life on our planet. It absorbs and scatters the majority of the sun's harmful ultraviolet (UV) radiation, preventing it from reaching the Earth's surface. However, human activities have significantly damaged this protective layer, leading to serious environmental and health consequences. Protecting and restoring the ozone layer is imperative for ensuring a safe and healthy future.

The primary function of ozone layer is to block most of the high-frequency ultraviolet radiation from the sun, which can cause skin cancer, cataracts, and immune system suppression in humans, as well as detrimental effects on marine ecosystems and terrestrial plant life. Without this protective layer, life on Earth would be exposed to extreme UV radiation levels, making the planet a much less hospitable place.

## Causes of Ozone Depletion

Ozone depletion is primarily caused by human-made chemicals known as ozone-depleting substances (ODS). The most notorious of these are chlorofluorocarbons (CFCs), once widely used in refrigeration, air conditioning, applications that involve foam-blowing, and aerosol propellants. When these chemicals are released into the atmosphere, they eventually reach the stratosphere, where UV radiation breaks them down, releasing chlorine and bromine atoms. These atoms then react with ozone molecules, causing their destruction as shown in ***Fig. 1.2***.

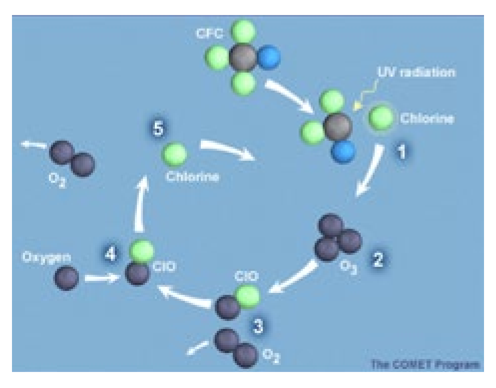


***Figure 1.2: The mechanism of destruction by the ozone depleting substance (ODS)***
*Source: UCAR*

## The Montreal Protocol: An International Response

In response to this environmental issue, the world leaders sat together to address the degradation of the ozone layer, with the initial thrust coming from the developed nations. The Vienna Convention for the Protection of the Ozone Layer of 1985 provided the platform that helped promote cooperation among nations by exchanging information on the effects of human activities on the ozone layer. Building on the Vienna Convention, a more comprehensive plan for the global phase-out of ozone-depleting substances (ODS) was deemed necessary and this was called the Montreal Protocol on Substances that Deplete the Ozone Layer. This agreement was signed in 1987 and, following ratification, entered into force in 1989. To date, the protocol has been ratified by 198 countries, and Malaysia became part of this global endeavour in 1989.

The Protocol is an agreement among nations that establishes schedules for gradual reductions in the consumption of ozone-depleting substances based on use within each participating country. The Protocol also places restrictions on trade in ODS with non-parties to the Protocol.

As the scientific basis of ozone depletion became more certain after 1987 and substitutes and alternatives became available to replace ODS, the Montreal Protocol was strengthened with amendments and adjustments, with the recent Kigali Amendment being one of the more significant ones in combating global warming. Globally, the Montreal Protocol is seen as one of the most successful International Conventions and Malaysia has made substantial progress in implementing the Protocol. Malaysia's prompt ratification of the Montreal Protocol underscores its commitment to responsibly phase out ODS consumption. As a party operating under Paragraph-1, Article-5 (developing countries) of the Montreal Protocol, Malaysia became eligible to receive technical and financial assistance, including the transfer of technology under the Protocol.

The ban on the production of most CFCs began in 1996 for developed countries and in 2010 for developing countries, with some exceptions for essential uses. By now, almost all CFCs are banned globally, with a few exemptions for critical applications. The complete phase-out of these substances continues to be enforced and monitored under the terms of the Montreal Protocol, with adjustments and updates as necessary to ensure the protection of the ozone layer. The ODS phase-out activities have provided considerable co-benefits to the climate change mitigation. **The Montreal Protocol's success in phasing out ODS has also significantly reduced greenhouse gas emissions.** By 2010, the total avoided net annual emissions of ODS were estimated to be equivalent to around 10 gigatonnes of $CO_2$ per year. This figure highlights the dual benefit of the Protocol: protecting the ozone layer and mitigating climate change by preventing the release of potent greenhouse gases.

**The Montreal Protocol** on Substances that Deplete the Ozone Layer is an international treaty designed to protect the ozone layer by phasing out the production and consumption of numerous substances responsible for ozone depletion. Some key points about the protocol are:

**Adoption and Entry into Force:**
The Montreal Protocol was adopted on September 16, 1987, and entered into force on January 1, 1989.

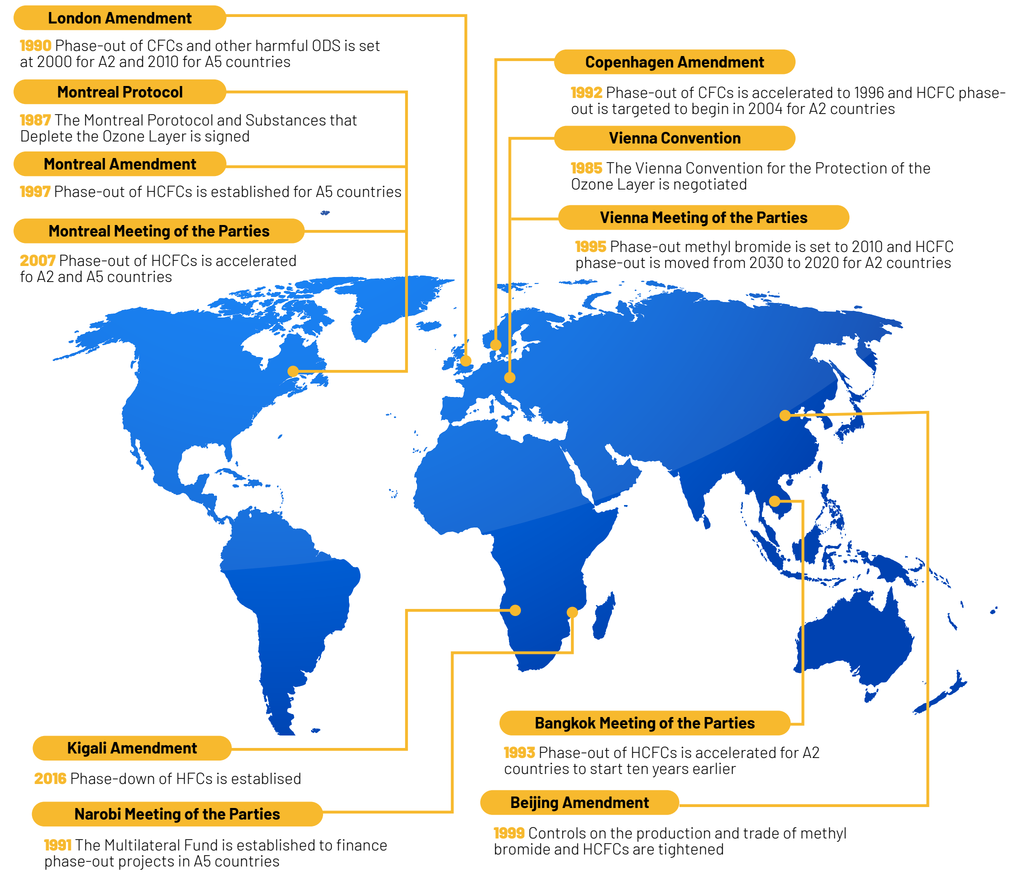
**Ozone-Depleting Substances (ODS):**
The treaty targets a wide range of chemicals, including chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform, methyl bromide and hydrochlorofluorocabons. These substances have been shown to cause significant damage to the stratospheric ozone layer.

**Amendments and Adjustments:**
The protocol has been amended multiple times to include additional substances and to accelerate the phase-out schedules. Key amendments include the London (1990), Copenhagen (1992), Montreal (1997), and Beijing (1999) Amendments. The Kigali Amendment in 2016 targeted the phase-down of hydrofluorocarbons (HFCs), which are potent greenhouse gases.

**Implementation and Compliance:**
The protocol includes provisions for financial assistance, technology transfer, and capacity-building to help developing countries meet their obligations. The Multilateral Fund was established to provide financial support to these countries.

**Success and Impact:**
The Montreal Protocol is considered one of the most successful environmental agreements. It has significantly reduced the global production and consumption of ODS, leading to the gradual recovery of the ozone layer. The protocol has also contributed to mitigating climate change, as many ODS are also potent greenhouse gases.

**Scientific and Regulatory Framework:**
The protocol is supported by a robust scientific assessment process. Panels of experts regularly review the state of the ozone layer and the effectiveness of the treaty, providing guidance for future actions.



**London Amendment**
1990 Phase-out of CFCs and other harmful ODS is set at 2000 for A2 and 2010 for A5 countries

**Montreal Protocol**
1987 The Montreal Porotocol and Substances that Deplete the Ozone Layer is signed

**Montreal Amendment**
1997 Phase-out of HCFCs is established for A5 countries

**Montreal Meeting of the Parties**
2007 Phase-out of HCFCs is accelerated fo A2 and A5 countries

**Copenhagen Amendment**
1992 Phase-out of CFCs is accelerated to 1996 and HCFC phase-out is targeted to begin in 2004 for A2 countries

**Vienna Convention**
1985 The Vienna Convention for the Protection of the Ozone Layer is negotiated

**Vienna Meeting of the Parties**
1995 Phase-out methyl bromide is set to 2010 and HCFC phase-out is moved from 2030 to 2020 for A2 countries

**Kigali Amendment**
2016 Phase-down of HFCs is establised

**Narobi Meeting of the Parties**
1991 The Multilateral Fund is established to finance phase-out projects in A5 countries

**Bangkok Meeting of the Parties**
1993 Phase-out of HCFCs is accelerated for A2 countries to start ten years earlier

**Beijing Amendment**
1999 Controls on the production and trade of methyl bromide and HCFCs are tightened

*The Montreal Protocol and its amendments.*
Source: www.epa.gov

## Global Efforts to Protect the Ozone Layer

The protection of the ozone layer, which shields Earth from harmful ultraviolet (UV) radiation, has long been a global environmental priority. Apart from the Government, industries play a significant role in both contributing to ozone depletion and aiding in ozone recovery. Several decisive actions should be considered by the industries to address the issue.

These include:

1. Phasing out Ozone-Depleting Substances (ODS) namely the CFCs, HCFCs, and halons. These chemicals, one widely used in refrigeration, air conditioning, aerosols, and fire suppression, were key contributors to ozone depletion. Industries were required to transition away from ODS to more environmentally friendly alternatives. Many sectors, particularly the chemical and manufacturing industries, have developed substitutes like HFCs, which do not harm the ozone layer.
2. Developing and implementing alternatives to existing ODS such as green and natural refrigerants as well as foams. Innovations in alternative chemicals that do not harm the ozone layer have been essential. This includes the development of hydrofluorocarbons (HFCs), hydrocarbons, and other eco-friendly compounds. Many industries have moved towards natural refrigerants such as ammonia, carbon dioxide, and hydrocarbons, which have no ozone-depleting potential and low impact to the climate.
3. Using cleaner production techniques. Many industries have embraced cleaner production technologies and techniques that reduce reliance on ODS or avoid their use entirely. This includes advancements in alternative

technologies in air conditioning, refrigeration, and manufacturing that use non-ozone-depleting substances. Some companies have integrated environmental responsibility into their core strategies, focusing on ozone-friendly production processes and technologies as part of their corporate social responsibility (CSR) initiatives.

4. Practising recycling and safe disposal in daily production routine. Industries involved in refrigeration and air conditioning are encouraged to recover and recycle refrigerant during the maintenance and disposal of old equipment. This prevents the release of harmful chemicals into the atmosphere. Proper disposal and retrofitting of products containing ODS are essential for preventing further ozone depletion. Specialized processes for capturing and destroying these substances have been developed.
5. Ensuring compliance with international regulations. The Montreal Protocol has set clear benchmarks for phasing out ODS. Industries have an essential role in ensuring compliance with these international regulations and contribute to global efforts in reversing ozone depletion. Industries are often required to report on their ODS usage, monitor emissions and adopt best practices to reduce ozone-depleting emissions.
6. Many industries have positioned themselves as leaders in environmental innovation by developing new products and systems that are both efficient and ozone friendly. Some industry leaders have advocated for stricter environmental regulations and supported global agreements like the Kigali Amendment to the Montreal Protocol, which aims to phase down HFCs, although they are greenhouse gases rather than ODS.
7. Public awareness and collaboration are also essential. Industries can educate consumers on the importance of choosing ozone-friendly products and services. Companies often collaborate with governments, NGOs, and international bodies to ensure the development and implementation of policies that protect the ozone layer, ensuring a collective effort in addressing this global issue. Several campaigns have been launched to support the Montreal Protocol.

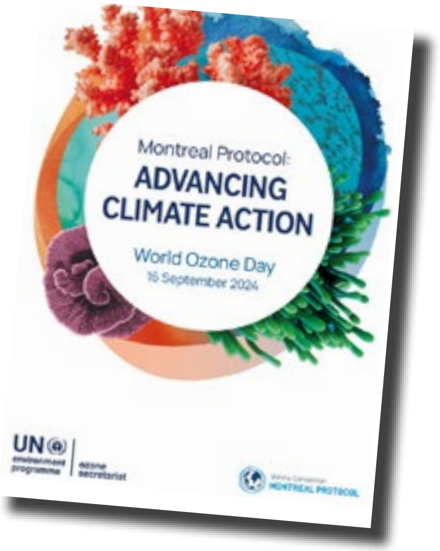


*Figure 1.3: The theme for 2024 World Ozone Day as part of the campaign to support Montreal Protocol*

## Road to Ozone Recovery

The international community has taken significant steps to address ozone depletion. The most notable effort is the Montreal Protocol, adopted in 1987. This landmark agreement has successfully phased out the production and consumption of many ODS. As a result, the ozone layer is gradually recovering, with projections suggesting it could return to pre-1980 levels by the middle of this century if current policies remain in place. Certain campaigns are highly effective at conveying and spreading messages. ***Fig. 1.3*** shows one of the posters created to promote and support the mission of the Montreal Protocol.

The Montreal Protocol and its amendments successfully regulated the production and consumption of ozone-depleting substances (ODS), halting their growth. As a result, the total chlorine levels from ODS are expected to return to 1980 levels by around 2070 (WMO 2014). ***Fig. 1.4*** illustrates the trend of EESC based on observations up to 2100. EESC is a measure of the cumulative potential of ODS to harm the ozone layer over time. EESC rose sharply from

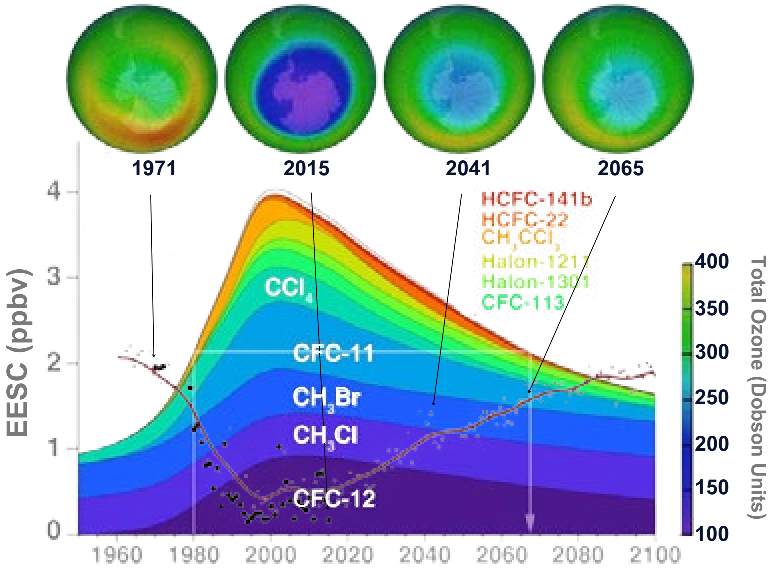


***Figure 1.4: Trends in Effective Equivalent Stratospheric Chlorine (EESC) (left) and impact on Antarctic ozone depletion, showing satellite data and model simulations of October total ozone levels (right) from 1950 to 2100.***

*Source: Newman P.A. 2018.*

1950s, peaking in 2000, before beginning a steady decline due to global mitigation effort. The chart identifies key contributors to ozone depletion, such as CFCs, halons, HCFCs, and other substances like methyl bromide ($CH_3Br$) and carbon tetrachloride ($CCl_4$), with CFCs dominating the peak period. This decline is directly tied to international agreements like the Montreal Protocol, which phased out the production and use of many ODS, replacing them with less harmful alternatives. Although the decline in EESC is promising, the slow atmospheric breakdown of these substances means full ozone recovery will take decades, underscoring the need for continued global cooperation and vigilance. ***Figure 1.4*** also shows the scientific prediction that ozone would start increasing as a result of ODS decline. A full return to the 1960s total ozone levels will be achieved by 2100.

## The Polyurethane (PU) Foam Sector: A Key Focus

The polyurethane foam industry, in particular, has had a significant historical impact due to its past reliance on chemicals like chlorofluorocarbons (CFCs), which are ozone-depleting substances (ODS). Polyurethane foam is used in various applications, such as insulation, furniture, mattresses, and automotive parts. During the production of polyurethane foam, blowing agents are used to create its cellular structure. Historically, the industry relied on CFCs and, later, hydrochlorofluorocarbons (HCFCs) as blowing agents. These chemicals, when released into the atmosphere, contributed to the destruction of the ozone layer by breaking down ozone ($O_3$) molecules in the stratosphere. This led to the formation of the ozone hole, especially over the Antarctic region. Since the global recognition of the ozone depletion problem, industries, including the polyurethane foam sector, have been central to the efforts to protect the ozone layer.

## Phase-out of Ozone-Depleting Substances (ODS)

Under international agreements like the Montreal Protocol (1987), the polyurethane foam industry began phasing out the use of CFCs and HCFCs. This agreement is regarded as one of the most successful environmental treaties, leading to a reduction in the use of ODS globally. The industry has shifted to using alternative blowing agents such as hydrofluorocarbons (HFCs), hydrocarbons, and more recently, hydrofluoroolefins (HFOs), which have zero ozone-depleting potential (ODP). However, some of these alternatives still have high global warming potential (GWP), so the focus is also on low-GWP solutions.

## Malaysia's Ozone Depleting Substances Phase-Out Programs

### Country Program – First Phase

The polyurethane foam sector emerged as a significant user of chlorofluorocarbons, becoming a key battleground in Malaysia's environmental initiatives. In 1992, the Department of Environment, serving as the focal point of the National Ozone Unit, initiated the First Phase of the Country Program to phase out ozone-depleting substances and achieved the reduction obligations. The polyurethane foam sector emerged as a significant user of chlorofluorocarbons, becoming a key battle ground in Malaysia's environmental initiatives. The following table ***(Table 1.1)*** shows the most common types of ODS involved in the foam sector, together with their ozone-depletion and global-warming potential.

With support from the Multilateral Fund (MLF) and key implementing agencies such as the United Nations Development Program (UNDP), United Nations Industrial Development Organization (UNIDO), and the World Bank, Malaysia successfully phased out 5,200 ODP tonnes between 1993 and 2003, with the foam sector alone accounting for 2,000 ODP tonnes ***(Fig.1.5)***. The initial projects focused on

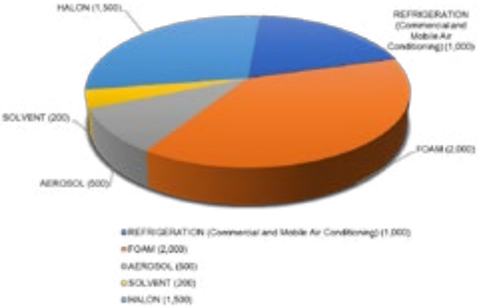


*Figure 1.5: Total ODS phase out (in ODPT) achieved (1993-2003)*

*Table 1.1 Common types of ODS used in foam sector*

| Substances | | ODP* | GWP** | Remarks |
|---|---|---|---|---|
| $CFCl_3$ | CFC-11 | 1.0 | 4,000 | Controlled substances in Annex A, Group I to the Montreal Protocol |
| $CF_2Cl_2$ | CFC-12 | 1.0 | 8,500 | |
| $CHF_2C_l$ | HCFC-22 | 0.055 | 1,700 | Controlled substances in Annex C, Group I to the Montreal Protocol |
| $CH_3CFCl_2$ | HCFC-141 b | 0.11 | 725 | |
| $CH_3CF_2Cl$ | HCFC-1426 | 0.065 | 2,000 | |

- ODP = ozone depletion potential. CFC-11 is taken as a reference object here and its ODP is set as 1.

Therefore the ODP of other ODSs can be described by numbers according to their ozone-depleting potential compared to CFC-11 .

** GWP = global warming potential. $CO_2$ is taken as the reference object here and the GWP of other substances can be described by numbers according to their global warming potential compared with $CO_2$. The data in this table are from the 1996 IPCC report. 100 years.

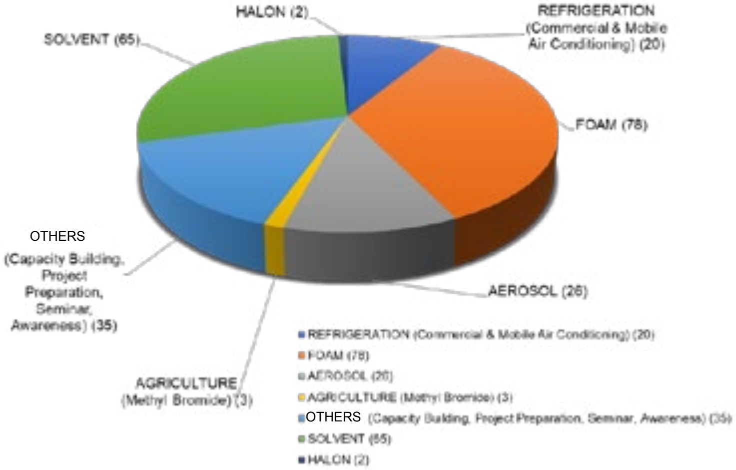


*Figure 1.6: Total ODS Phase out activities by sectors in Malaysia (1993-2003)*

transitioning to ODS-free technologies or non-CFC alternatives, and 78 PU foam projects were carried out ***(Fig.1.6)*** during this period. ***Figure 1.7*** exhibits the consumption percentage of all types of HCFCs in Malaysia

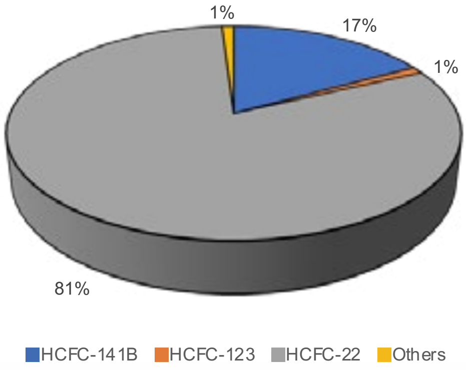


*Figure 1.7: HCFC Consumption in Malaysia (2009)*

## National Chlorofluorocarbons Phase-Out Plan (NCFCP)

To address the remaining CFCs, Malaysia implemented the NCFCP. In 2001, the country secured USD 11.517 million from the MLF to support the plan's implementation. A significant milestone was achieved as Malaysia ban the importation of CFCs, halons, and carbon tetrachloride (CTC) by 1 January 2010. This accomplishment was reinforced by the revision of the Environment Quality Act 1974 through the gazettement of the Environmental Quality (Prohibition on the Use of Chlorofluorocarbons, and Other Gases as Propellants and Blowing Agents) Order of 1993, which called on companies to comply with prohibitions on the production of all CFC-based foam by 1 January 1999. However, recognizing the transitional challenges within the foam industry under the NCFCP, the government introduced a brief grace period that allowed existing foam manufacturers to complete their technology conversion projects following this order.

For the PU foam transition project under the NCFCP, financial assistance was extended to 32 foam enterprises, with 21 of them securing funding for the acquisition of PU foam machinery. This funding covered associated transition expenses, including testing and trials, and retrofitting existing high-pressure foam injection machines. Concurrently, 14 enterprises with low CFC consumption (1.5 MT per year) received vouchers valued at USD 7,500. These vouchers were designated for the purchase of machines including technical assistance from the World Bank approved suppliers.

## Transition from CFCs to HCFCs

Like many other countries, Malaysia adopted hydrochlorofluorocarbons (HCFCs) as an intermediate alternative during the transition away from CFCs, especially in rigid and closed-cell PU foam manufacturing industries. HCFC-

141b emerged as the preferred blowing agent among rigid PU foam manufacturers due to its exceptional insulation properties, although alternatives such as HFC-134a and cyclopentane were also considered. Other alternative technologies such as methylene chloride, liquid carbon dioxide, and low index additives for slab and water-blown formulation were also employed, especially by flexible and integral skin foam manufacturers.

Following the successful phase-out of chlorofluorocarbons (CFCs) in accordance with the Montreal Protocol, Malaysia shifted its attention toward hydrochlorofluorocarbons (HCFCs). While initially regarded as intermediate alternatives with a lower ozone-depleting potential than CFCs, HCFCs still have the capacity to contribute to ozone layer depletion. The hydrogen atoms in HCFCs enable them to break down more rapidly in the atmosphere plus a reduction of a chlorine atom has reduced their Ozone Depleting Potential (ODP). However, this breakdown still releases the chlorine atoms, which, under certain conditions, can participate in ozone-depleting reactions (Smith, Johnson & Brown 2018).

## HCFC Phase Out Management Plan (HPMP)

Malaysia, recognizing the environmental concerns associated with HCFCs, continued the initiative to protect the ozone layer through the HCFC Phase Out Management Plan (HPMP) framework. The HPMP is structured in multiple stages, each targeting specific reduction milestones based on the reduction schedule committed under Montreal Protocol ***(Fig. 1.8)***. The key planned regulatory actions under the HPMP are as listed in ***Table 1.2***.

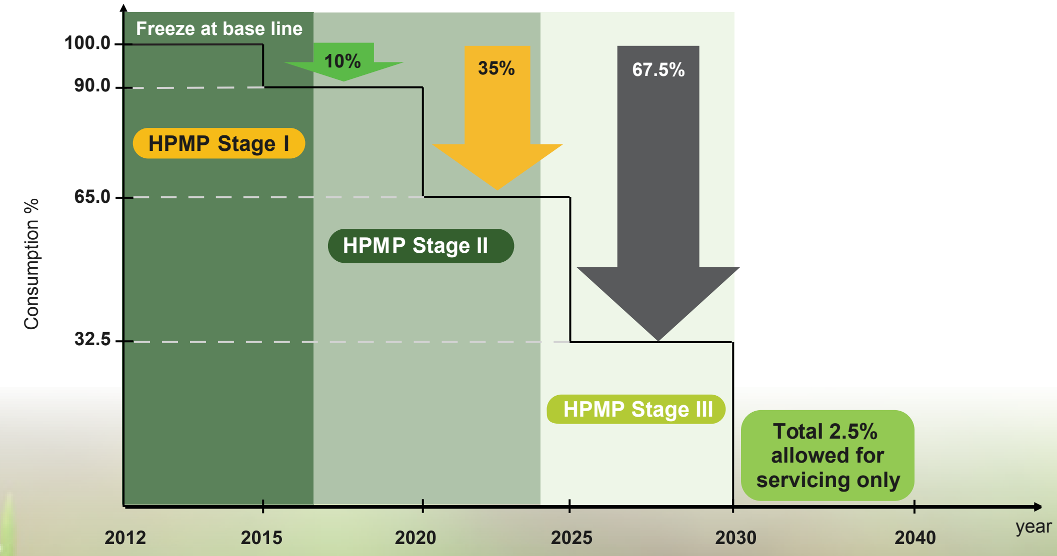


*Figure 1.8: Phase-out schedule for Malaysia in controlling HCFC consumption*

*Table 1.2 Planned Regulatory Action for HCFC Phase Out*

| YEAR | PLANNED REGULATORY ACTION |
|---|---|
| 2012 | • Establishment of Approved Permit (AP) import quota system based on HCFC Baseline (515.8 ODPT).<br>• Amend existing regulations for controlling use, imports, manufacturing, assembly and installation of products consisting of HCFCs.<br>• Licensing re-export of HCFCs.<br>• Enforcement Approve Permit (AP) quota system. |
| 2013 | • Prohibition of establishment and expansion of new HCFC based manufacturing capacities.<br>• Establish incentive system for promoting use of alternatives to HCFC.<br>• Certification of technicians handling HCFCs. |
| 2015 | • Prohibition of manufacturing, assembly and import of HCFC-based air conditioners (2.5 HP and lower) for use in Malaysia.<br>• Prohibit imports of polyols preblended with HCFCs.<br>• Include HCFCs in the list of restricted gases. |
| 2020 | • Prohibit the manufacture, assembly and import of all products and equipment using HCFC (except for essential use).<br>• Prohibit HCFC 141b as blowing agent.<br>• Prohibit the use of HCFC in the manufacturing and installation of new fire extinguishing systems. |
| 2023 | • Prohibition on the use of HCFC-141b and preblended polyol containing HCFC-141b substances. |
| 2025 | • No more installation of new products and equipment using HCFCs. |
| 2030 | • AP limited to 2.5% of baseline for servicing use only. |
| 2040 | • Total ban on the import and use of HCFCs. |

The **Stage I (2012–2016)** is the initial phase aimed to achieve compliance with the 2013 and 2015 control targets for HCFC consumption. It involved a combination of interventions, including technology transfer investments, policy and regulatory measures, technical assistance, training, awareness campaigns, and management coordination. The goal was to facilitate Malaysia's compliance with minimal impact on the national economy, environment, and occupational health. With support from the Multilateral Fund (MLF) and the United Nations Development Program (UNDP), Malaysia achieved a significant milestone by facilitating the transition of 13 medium and large foam enterprises from HCFC-141b to ozone-friendly alternatives. Simultaneously, technical assistance was extended to four system houses to customize low-global warming potential (GWP) formulations and cost-effective alternatives.

The **Stage II (2017–2023)** on the other hand, building on the progress of Stage I. This phase focused on further reducing HCFC consumption particularly in the foam sector. The regulatory actions involved ban on the use and import of new HCFC-based refrigeration and air conditioning equipment effective on 1 June 2020 and ban on the use of HCFC-141b in foam sector by 1 January 2023. Additionally, import of HCFC-141b for the use of foam sector to the country is prohibited. Capacity building activities in RAC servicing sectors continued to be implemented where more than 12,000 technicians trained under the Certified Service Technicians Program (CSTP).

The **Stage III (2024–2030)** was launched on 11 October 2024 where this stage aims for the complete elimination of HCFCs by 2030 mainly in the refrigeration and air-conditioning sector. Several activities have already implemented. Other than strengthening policies and regulations, various industries are encouraged to adopt environmentally friendly and energy-efficient alternatives to HCFCs. In order to achieve these, effective capacity building and awareness efforts are undertaken by providing training and resources to stakeholders to support the transition away from HCFCs.

As of November 2024, Malaysia has successfully reduced HCFC usage by 70%, surpassing the original target of 43%. This achievement highlights the country's commitment to environmental sustainability and compliance with international protocols. Through these strategic phases, Malaysia is on track to meet its goal of completely phasing out HCFCs by 2030, aligning with global efforts to protect the ozone layer and mitigate climate change.

# Chapter 2

# INSIDE POLYURETHANE

## What is Polyurethane?

This chapter delves into the world of polyurethane foam, understanding its composition, characteristics, and the pivotal role it plays in various industries.

Polyurethane foam, commonly known as PU foam, is a versatile material with widespread applications across the automotive industry, furnishings, manufacturing, building, construction, appliances, and daily consumer products. Polyurethane can be categorized into several main types including flexible, integral skin, and rigid PU foams. Each type possesses unique properties, influencing their suitability for specific applications.

## The Science and Technology of Polyurethane

Polyurethane is used in a wide range of applications. It is formed by reacting a polyol (an alcohol with more than two reactive hydroxyl groups per molecule) with a diisocyanate or a polymeric isocyanate ***(Fig. 2.1)*** in the presence of suitable catalysts and additives.

**In 1937, Otto Von Bayer and his team made history by creating the first polyurethane. This groundbreaking discovery has revolutionized polymerization reactions, establishing the foundation for diverse industrial applications. Otto Von Bayer's work marked a pivotal moment in polymer chemistry, paving the way for polyurethane's widespread use in everyday products.**

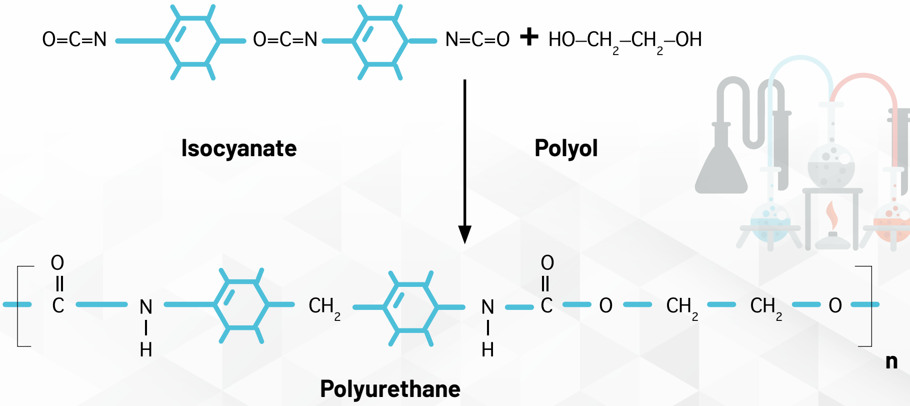


*Figure 2.1: The reaction between the polyol and the isocyanate produces polyurethane.*

## Polymeric Foams

Polymeric foams are a diverse group of materials made from large molecules called polymers, and they have a unique structure filled with tiny air bubbles. They can be divided into two main categories, the non-insulating foams and (thermal) insulating foams and are summarized in ***Figure 2.2***.

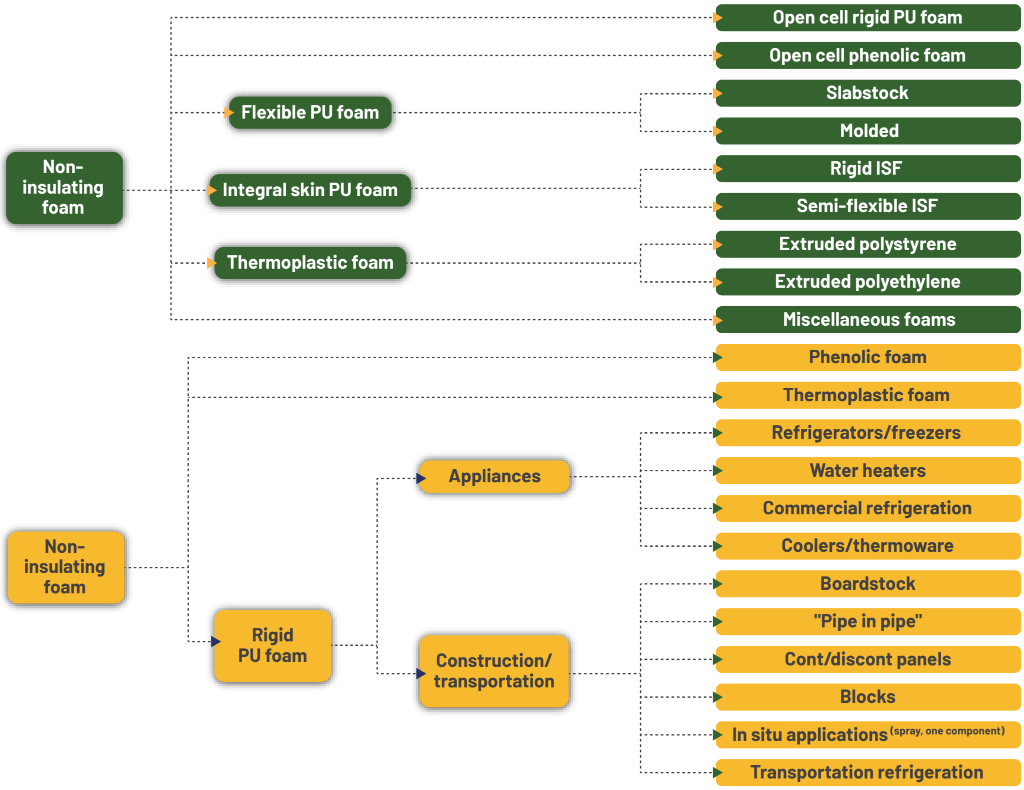
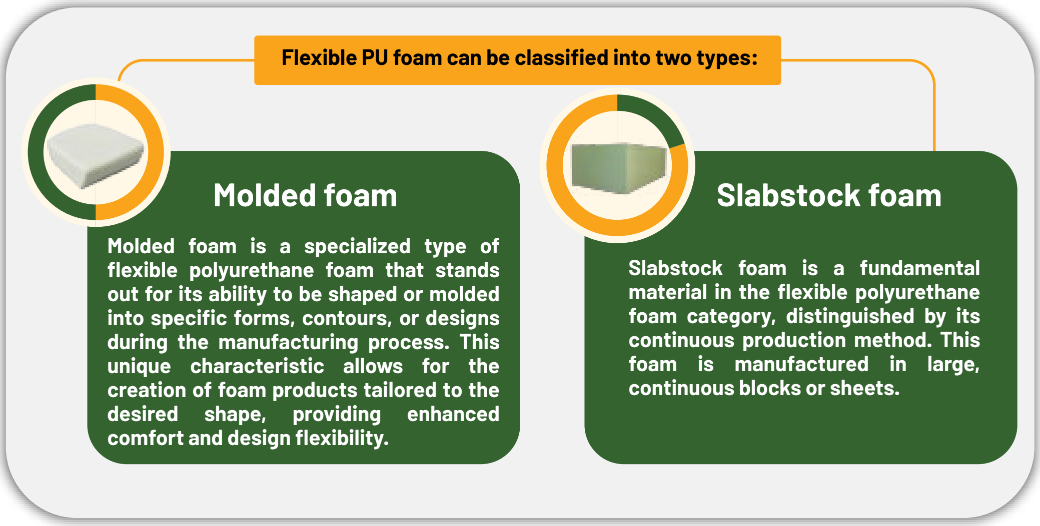


*Figure 2.2: The non-insulating foams and (thermal) insulating foams and their applications.*

## Polyurethane Flexible Foam

Polyurethane flexible foam, a type of foam known for its soft and elastic properties, excels in flexibility, comfort, and widespread application across various industries. This foam effortlessly molds to different shapes, providing a luxurious and comfortable feel. While HCFC-141b may have been used as an interim transition to the CFC-11 blowing agent, the flexible foam industry has increasingly shifted toward more environmentally friendly alternatives, such as water-blown formulations and methylene chloride. It can further be divided into molded and slab stock flexible foams as shown in ***Fig. 2.3***.



**Flexible PU foam can be classified into two types:**

### Molded foam

Molded foam is a specialized type of flexible polyurethane foam that stands out for its ability to be shaped or molded into specific forms, contours, or designs during the manufacturing process. This unique characteristic allows for the creation of foam products tailored to the desired shape, providing enhanced comfort and design flexibility.

### Slabstock foam

Slabstock foam is a fundamental material in the flexible polyurethane foam category, distinguished by its continuous production method. This foam is manufactured in large, continuous blocks or sheets.

*Figure 2.3: The flexible foam occurs either in moulded foam or in slab stock foam.*

## Integral Skin Foam

Integral skin foam features a relatively rigid outer layer, providing durability, while the inner foam exhibits elasticity and a comfortable texture. This type of foam is commonly used in automotive ***(Fig. 2.4)*** and furniture applications, including steering wheels, vehicle dashboards, car seats, handrails, furniture handrails, and motorcycle cushions. While HCFC-141b might have been employed in the past as a transitional substitute for CFCs in the production of integral skin foam, many products in this category just like ones in the flexible foam have shifted toward more environmentally friendly alternatives, particularly water-blown formulations.

*Figure 2.4: Integral skin foam for office chairs and automotive parts such as steering and dashboard.*

## Polyurethane Rigid Foam

Rigid PU foams serve as important materials in various industries, offering a wide range of applications due to their exceptional insulation and structural properties. Rigid PU foam contributes to energy efficiency and performance across different sectors.

Widely utilized in appliances, sandwich panels, and pipes, rigid PU foams are renowned for their high insulating efficiency, playing a crucial role in energy conservation and reducing electricity consumption. Their strength and lightweight characteristics make them a preferred choice for constructing durable yet lightweight components, thereby contributing to the overall efficiency and performance of various applications. ***Fig. 2.5*** exhibited the versatility of rigid polyurethane foam applications.

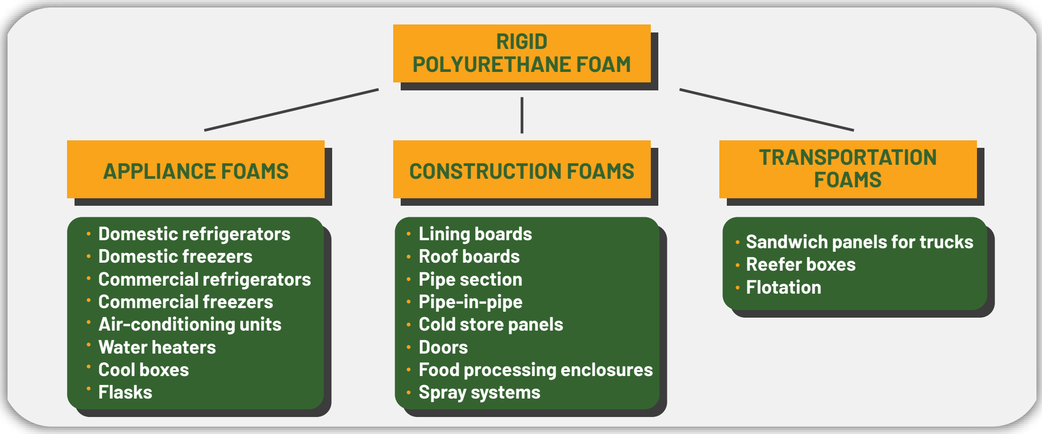
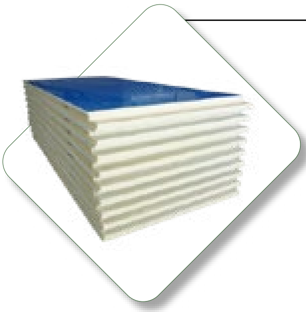


*Figure 2.5: Rigid polyurethane foam and its various applications in industry.*



## Sandwich Panels for Construction

In the construction and cold chain industries, rigid PU foam is extensively used in the fabrication of sandwich panels. These panels, consisting of two outer layers typically made of metal and a rigid PU foam core, serve crucial functions such as thermal insulation, structural support, and lightweight construction. By effectively minimizing heat transfer, they help maintain stable temperatures within cold rooms, thereby preserving the quality of perishable goods.

## Pipe Insulation

Rigid PU foam is employed to insulate pipes in various industrial settings. The foam's ability to resist heat transfer ensures that pipelines maintain optimal temperatures, preventing energy losses and enhancing the efficiency of heating or cooling systems.

## Insulated Boxes

Rigid PU foam plays a pivotal role in the insulation of ice boxes. Its excellent insulation properties maintain low temperatures, preserving the freshness of perishable items and extending the longevity of stored ice. The lightweight and durable nature of PU foam further enhance the portability and overall efficiency of these storage solutions.

## Refrigerated Truck Containers

In the transportation of temperature-sensitive goods, refrigerated truck containers leverage rigid PU foam insulation. This application ensures that products, such as perishable foods or pharmaceuticals, remain at the desired temperature during transit, maintaining their quality and integrity.

## Refrigerators and Freezers

In refrigeration applications, rigid PU foam serves as a crucial insulator in appliances like refrigerators and freezers. Its efficiency in maintaining low temperatures not only preserves the freshness of food but also aids in energy conservation, lowering electricity consumption.

Can be tailored to be either flexible or rigid, suitable for various applications.

Excellent wear resistance and durability.

Resistance to many chemicals, including oils, solvent and grease.

Good adhesion properties, making them useful in coatings and adhesives.

Good thermal and sound insulation properties.

*Properties of Polyurethane*

## Key Components in Polyurethane Production

The production of polyurethane involves the reaction of isocyanates and polyols, and it often includes various additives to achieve specific properties.

### Raw Materials

**Isocyanates:**

The main types of isocyanates used in polyurethane production are:

- **Aromatic Isocyanates:** Common examples include toluene diisocyanate (TDI) and methylene diphenyl diisocyanate (MDI). These are often used in the production of flexible and rigid foams.
- **Aliphatic Isocyanates:** Examples include hexamethylene diisocyanate (HDI) and isophorone diisocyanate (IPDI). These are used in coatings, elastomers, and adhesives, particularly where UV stability and color retention are important.

**Polyols:**

Polyols are alcohol compounds with multiple hydroxyl groups (-OH). The main types are:

- **Polyether Polyols:** Produced by the polymerization of epoxides, such as propylene oxide or ethylene oxide, with an initiator. They are commonly used in flexible foams and coatings.
- **Polyester Polyols:** Produced by the polycondensation of diacids and diols. They are typically used in elastomers and coatings due to their higher mechanical strength and resistance to chemicals.

### Polyurethane Additives

***Catalysts:*** Catalysts are used to control the reaction rate between isocyanates and polyols. They can be either amine catalysts which are often used in flexible foam production or metal catalysts such as tin-based compounds used in various applications, including rigid foams and coatings.

***Surfactants:*** Surfactants help to stabilize the foam structure by reducing surface tension during foaming. Silicone-based surfactants are commonly used.

***Blowing Agents:*** These are used to create the cellular structure in foam products. They can be physical blowing agents, like hydrocarbons and hydrochlorofluorocarbons, or chemical blowing agents, such as water, which reacts with isocyanates to release $CO_2$ gas.

***Flame Retardants:*** These are added to improve the fire resistance of polyurethane products. Common flame retardants include halogenated compounds, phosphorus-containing compounds, and inorganic additives.

***Fillers and Reinforcements:*** These materials, such as calcium carbonate, glass fibres, or carbon black, are added to enhance mechanical properties, reduce cost, or impart specific characteristics.

***Colorants and Pigments:*** These are added to give colour to the polyurethane products.

***Antioxidants and UV Stabilizers:*** These additives protect polyurethane products from degradation caused by exposure to heat, oxygen, and ultraviolet light.

Each of these components plays a crucial role in determining the final properties of polyurethane products, making it possible to tailor them for specific applications.

# Chapter 3
# TECHNOLOGY AND INNOVATION

> **Polyurethane foam is a type of polymeric material formed through the reaction of polyols and diisocyanates. It is known for its versatility, as it can be manufactured with varying degrees of rigidity and flexibility to suit different applications.**

## The Production Process

The production of polyurethane foam typically involves the following steps ***(Fig. 3.1)***:

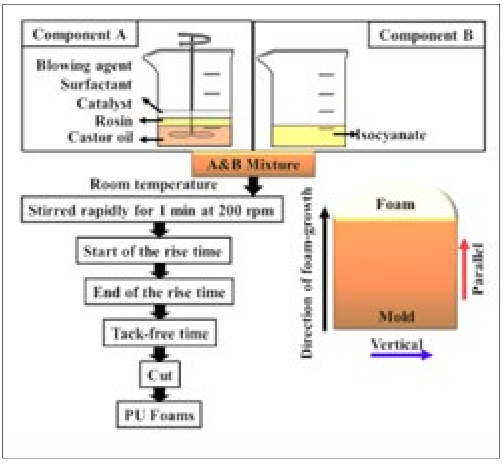


*Figure 3.1: The formation of polyurethane foam*

***Mixing:*** Polyols and diisocyanates are mixed with additives like catalysts, blowing agents, and surfactants.

## Composition

- **Polyols:** These are alcohols with multiple hydroxyl groups that react with diisocyanates to form polyurethane.
- **Diisocyanates:** Organic compounds with two isocyanate groups that react with polyols in the presence of catalysts, blowing agents, and other additives to create foam.

***Reaction:*** The mixture undergoes a chemical reaction, generating gas bubbles that expand the mixture into a foam. During the polymerization, a crosslinking process occurs upon nucleation with the aid of blowing agent ***(Fig. 3.2)***.

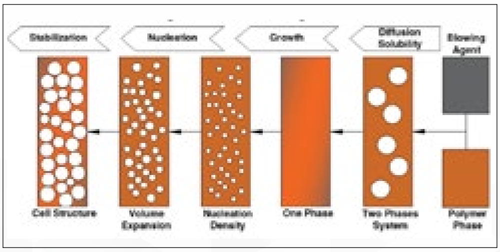


*Figure 3.2: Stages of foaming process*

***Curing:*** The foam is allowed to set and harden into its final form, which can then be cut or shaped as needed.

## Transition to Alternative Non-ODS Blowing Agents

Blowing agents are crucial in the production of polyurethane foam, as they create the foam's cellular structure by generating gas bubbles during the chemical reaction ***(Fig. 3.3)***. The nature of these bubbles determines whether the foam will have an open-cell or closed-cell structure ***(Fig. 3.4)***.

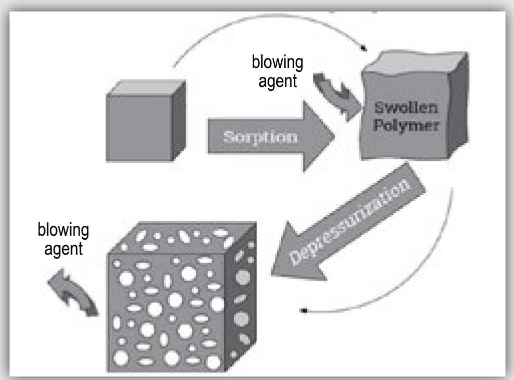


*Figure 3.3: The role of blowing agent in the making of polyurethane foam*

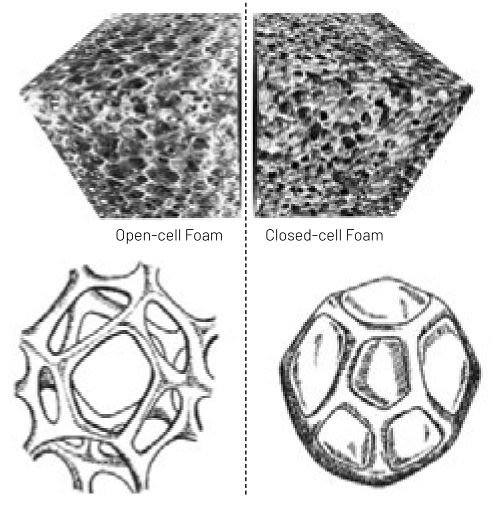


*Figure 3.4: Open and closed cells*

**Open-cell foam** features interconnected cells that form a spongy structure with many air pockets.

**Properties:**

- Soft and flexible.
- Lower density and less rigid.
- Good for sound absorption and cushioning.

**Closed-cell foam** has discrete, enclosed cells filled with gas, making it more rigid and impermeable.

**Properties:**

- Harder and more rigid.
- Higher density and greater strength.
- Excellent thermal insulation and water resistance.

By adjusting these variables, manufacturers can control the properties of the foam to suit specific applications, from soft cushions to rigid insulation panels.

Transitioning from ODS (CFC and HCFC) to alternative blowing agents such as hydrocarbons (HCs), hydrofluoro olefins (HFOs), carbon dioxide ($CO_2$), water, and natural/bio-based options needs intensive attention. Each alternative has varying environmental impacts, so choosing the most suitable alternative depends on factors like foam type, application, and regulatory requirements. Many industries have difficulties to replace the CFC with HCFC-141b at the earlier stage. However, after some years of adjusting, HCFC-141b has proven its better performance than CFC in rigid foam industries. Upon transition to zero ODS substances with the initiative of HPMP, several studies have been conducted by universities and industries through collaborative works.

At global stage, some researches have come out with new blowing agents such as Ecomate®, Opteon™ 1150, HCFO-1233zd-E, Solstice® and many others that are still in progress. Environmental concerns and safety factors that are being considered aside from being zero ODP, are low global warming potential, low carbon dioxide emission, non-flammable, non-toxic and chemical accessibility.

Reformulating foam recipes to optimize performance with alternative blowing agents is necessary. This involves adjusting ratios of raw materials (polyols, isocyanates) and additives to achieve desired foam properties (density, thermal conductivity) while minimizing environmental impact. Collaborating with chemical suppliers and conducting thorough testing are crucial in this process and some of the selections are shown in ***Fig. 3.5***.

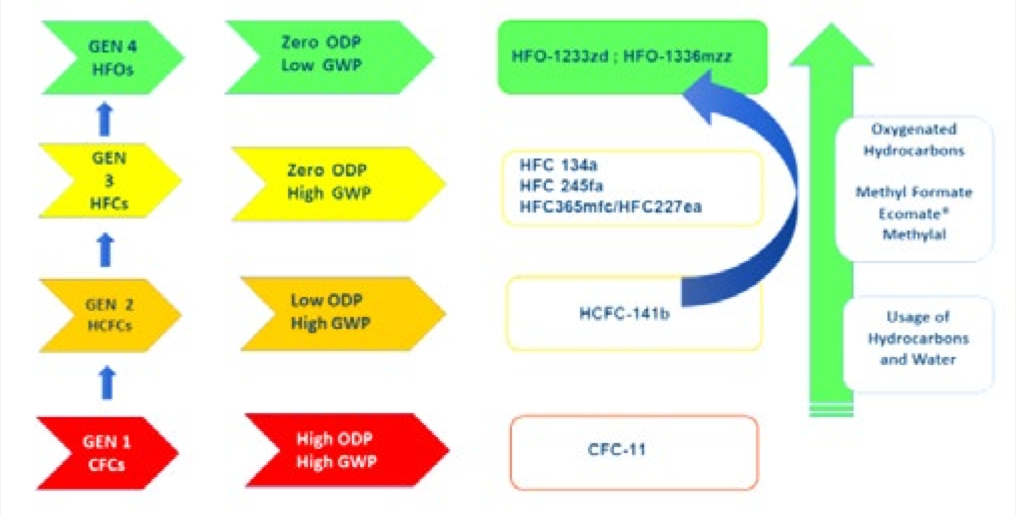


*Figure 3.5: Evolution of blowing agents used in the PU foam industry.*

Several of the proposed blowing agents are not accessible in Malaysia either due to limitation of transporting for safety hazard precaution or because of custom clearance that prohibits the entrance of the goods. During formulation development, properties of blowing agents ***(Table 3.1)*** are considered with safety as priority aside from compatibility.

*Table 3.1: Blowing Agents and Their Properties*

| Substance | GWP | Molecular Weight (MW), g/mol | Incremental GWP | BP (°C) | K, mW/mK @10°C | ODP | Polyol Solubility | Relative Cost | Flammability | Flammability of Formulation | Solvent Effect | Chemical Stability in Formulation | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **HCFC-141b** | 725 | 117 | Baseline | 32 | 8.8 | 0.11 | ++ | 1 | N | N | + | + | Used Direct / Indirect (from water) |
| **$CO_2$** | 1 | 44 | -725 | 100 | 14.5 | 0 | ++ | 0.1 | N | N | - | - | Explosive |
| **Pentane (Iso-)** | <15 | 72 | -718 | 28 | 13.0 | 0 | — | 0.5 | Y | Y | - | - | - |
| **Pentane (n-)** | <15 | 72 | -718 | 36 | 14.0 | 0 | — | 0.5 | Y | Y | - | - | - |
| **Pentane (Cyclo-)** | <15 | 72 | -718 | 49.3 | 11.0 | 0 | - | 0.5 | Y | Y | - | - | - |
| **HFC-245fa** | 1,030 | 134 | 443 | 15.3 | 12.5 | 0 | + | 4 | N | N | - | - | - |
| **HFC-365mfc** | 794 | 148 | 279 | ~33 | ~10.8 | 0 | + | 4 | N | Y/N | - | (-) | - |
| **HFC-134a** | 1,430 | 102 | 522 | - | - | 0 | - | - | Y | - | - | - | Flammable |
| **Methyl Formate (MF)** | Negligible | 60 | -725 | 31.5 | 10.7 | 0 | ++ | 1.5 | N | Y/N | ++ | - | Reported For Co-blowing Only |
| **Methylal (Dimethoxymethane)** | Negligible | 76 | -725 | 42.3 | 14.53 | 0 | ++ | 0.5 | Y | N | - | — | Used In Flexible Slabstock |
| **Acetone** | Negligible | 58 | -725 | 56.08 | 16.1 | 0 | ++ | 0.5 | N | N | — | - | Emerging |

Note:

+ increasing effect
- Decreasing effect

## Evolution from CFCs to Environmentally Friendly Alternatives

The historical use of CFCs as blowing agents raised environmental concerns due to their ozone-depleting nature. Innovations emerged to address these challenges, leading to the adoption of more sustainable alternatives. Before the ODS phase-out began, CFC-11 served as the primary blowing agent, evolving from open-celled to closed-cell polyurethane foams. The peak usage was reported in the late 1980s. The transition from CFCs to more environmentally friendly blowing agents in the production of polyurethane foams has been a key focus area. A stage-by-stage evolution in the polyurethane industry occurs. Initially, CFCs (CFC-11 and CFC-12) were widely used as blowing agents in the production of polyurethane foams due to their excellent performance characteristics, such as low thermal conductivity, chemical stability, and compatibility with polyurethane formulations. HCFCs, such as HCFC-141b, were introduced as transitional alternatives to CFCs.

### *Transition to HCFCs*

HCFC-141b and HCFC-142b replaced CFCs as transitional blowing agents. They had a lower ozone depletion potential (ODP) compared to CFCs but were not completely free of environmental concerns, as they still contributed to global warming. The industry adopted HCFCs as a stopgap measure while searching for more sustainable options. They have lower ODP but are still potent greenhouse gases. HCFC-141b, in particular, was widely used in the production of rigid polyurethane foams for insulation.

### *Shift to HFCs*

HFC-134a, HFC-245fa, and HFC-365mfc are in a class of synthetic compounds commonly used as refrigerants, blowing agents, and solvents. These compounds have no ozone depletion potential (ODP), making them less harmful to the ozone layer compared to hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs). They are also non-flammable substances. However, they have global warming potential (GWP) and are therefore regulated under environmental frameworks like ***Table 3.2*** the Kigali Amendment to the Montreal Protocol.

Additionally, the HFCs are difficult to use as they need special equipment (nozzle) to flow in the HFCs in gaseous state to the polyol systems. Some modifications have to be made to the mixing tanks and resulted in higher investment. A few companies would import the pre-blended polyols from a very limited number of producers abroad.

*Table 3.2: Properties of hydrofluorocarbons*

| **Hydrofluorocarbons (HFCs)** | |
|---|---|
| **Overview:**<br>HFCs are physical blowing agents with zero ODP and high GWP, offering high insulation value indicated by a lower k-factor. Two mz jain types commonly used: | |
| **Types of HFCs in Foam Applications** | |
| **HFC-245fa (Enovate 3000 by Honeywell)** | • Exhibits good solubility in polyol and excellent flow properties.<br>• Challenges in storage and transportation due to lower boiling point.<br>• Blending with water as a co-blowing agent reduces the required HFC amount and improves thermal performance.<br>• Environmental Impact: ODP: 0, GWP: 1,030 |
| **HFC-365mfc (Solkane-365 by Solvay)** | • Boasts fine cell structure with good compressive and insulation properties.<br>• Environmental Impact: ODP: 0, GWP: 794 (HFC-365mfc), 3,220 (HFC-227ea)<br>• Flammability: Presents minor concerns, addressed by blending with HFC-227ea (Solkane-365/227). |
| **Challenges** | • Governed by the Kigali Amendment of the Montreal Protocol, HFCs are subject to regulatory measures due to their high GWP, making them a less preferred option within the industry.<br>• High costs prompt exploration of alternatives with lower environmental impact. |

### *Current Environmentally Friendly Alternatives*

The polyurethane industry has been exploring and adopting several environmentally friendly blowing agents to align with global environmental goals. They include hydrocarbons; hydrofluoroolefins (HFOs); carbon dioxide ($CO_2$); water and methylal as well as methyl formate.

### *Hydrocarbons (HCs)*

Cyclopentane, ***n***-pentane and isopentane are widely used for their low GWP and zero ODP ***(Table 3.3)***. However, they are flammable, requiring strict safety measures. Cyclopentane has been the most preferred blowing agent due to its possible compatibility in the polyol blend. Other than being the lowest cost and most available compared to the pentane series and other type of exclusive blowing agents, its usage is almost similar to HFC-141b. Modification of formulations is very minimal that involve a slightly higher dosage of the cyclopentane in replacing the HFC-141b.

Cyclopentane is highly flammable (flash point: -37°C) and can form explosive mixtures with air. Proper risk assessment is critical. The mixing area needs to be well-ventilated to prevent vapor accumulation. The polyol blend is homogenized before adding cyclopentane. The cyclopentane is introduced slowly into the polyol blend under controlled conditions to prevent excessive vapor release. The mixing vessel is purged with nitrogen gas to reduce oxygen levels and prevent explosive conditions. It is best to employ system that can capture cyclopentane vapors and recycle them safely. In addition, installation of gas detectors around the mixing area to identify cyclopentane leaks; operating the mixing vessel within safe pressure and temperature limits and equip the system with automatic shutdown mechanisms in case of anomalies are those measures suggested for better handling of cyclopentane.

*Table 3.3: Properties of hydrocarbons*

| **Hydrocarbons** | | |
|---|---|---|
| **Overview:**<br>Hydrocarbons, particularly pentanes, are established and environmentally friendly choices as foam blowing agents. Cyclopentane is recognized for excellent insulation, while n-pentane and Iso-pentane offer alternative attributes. | | |
| **Environmental Impact:** | ODP: 0 | |
| | GWP: 3 – 10 | |
| **Types of Pentanes:** | Cyclopentane | Valued for excellent insulation properties due to its "bulkiness." |
| | n-pentane and Iso-pentane | Suitable for specific applications despite not being as "bulky" as cyclopentane. |
| **Safety Considerations** | Despite their environmental benefits, it is crucial to acknowledge the flammable nature of hydrocarbons, including pentanes. | |
| | Equipment and Safety | • Specialized equipment may be required for handling and incorporating these blowing agents.<br>• Proper safety measures, including handling, storage, and equipment modifications, ensure a secure working environment. |

### *Hydrofluoroolefins (HFOs)*

HFO-1233zd(E) and HFO-1336mzz(Z) are emerging as preferred alternatives ***(Table 3.4)*** due to their very low GWPs and non-flammable nature. They are used in both spray foam and rigid foam applications, providing good insulation and safety profiles. These HFOs are expensive and seldom used in applications that have low demanding requirements.

*Table 3.4: Properties of hydrofluoroolefins (HFOs) and hydrochlorofluoroolefins (HCFOs)*

| **Hydrofluoroolefins (HFOs) and Hydrochlorofluoroolefins (HCFOs)** | | |
|---|---|---|
| **Overview:**<br>HFOs and HCFOs represent advanced classes of physical blowing agents known for their minimal climate impact. Marketed by industry leaders such as Honeywell (HFO 1234ze, HCFO-1233zd) and Chemours (HFO-1336mzz), these agents have gained attention for their environmentally friendly attributes. | | |
| **Environmental Impact** | HFO 1234ze | ODP: 0; GWP: 6 |
| | HCFO-1233zd | ODP: 0; GWP: 3.7 |
| | HFO-1336mzz | ODP: 0; GWP: 2 |
| **Foaming Characteristics** | • HFO 1336mzz and HCFO 1233zd are considered near drop-in replacements for HCFC-141b in insulating foams, implying minimal modifications to existing processes.<br>• Foams produced with HFO 1336mzz and HCFO 1233zd exhibit excellent k-factors, indicating superior insulation performance.<br>• These agents find application in energy-saving appliances, highlighting their contribution to energy-efficient technologies. | |
| **Challenges and Considerations:** | • HFOs may be more expensive, potentially raising the overall cost of PU foam products for consumers.<br>• Limited availability of HFOs may pose supply chain challenges, affecting the stability of PU foam production. | |
| **Mitigation Strategy** | Water as Co-Blowing Agent: To address cost concerns, recent international case studies propose the use of water as a co-blowing agent. This strategy aims to reduce the overall cost of polyol blends, enhancing the economic feasibility of HFOs and HCFOs. | |

### *Carbon Dioxide ($CO_2$)*

Carbon dioxide, $CO_2$ as a blowing agent ***(Table 3.5)*** has been utilized in some polyurethane foam formulations. Its use results in foams with different properties and requires specialized equipment due to the unique physical characteristics of $CO_2$. It requires precise equipment to handle and maintain appropriate pressures during processing. $CO_2$ is sometimes used in the production of foam trays and other packaging materials, as it is considered safe for food contact. In niche applications, $CO_2$ is used to produce edible foams for culinary purposes. $CO_2$ is used as a physical blowing agent (as opposed to chemical blowing agents) in processes like injection moulding and extrusion. The $CO_2$ is injected under high pressure into a molten polymer and expands when the pressure is released, creating a foam structure. It can also be generated as a byproduct of the chemical reaction between water and isocyanates.

### *Water ($H_2O$)*

Water can be used as a chemical blowing agent, producing $CO_2$ during the reaction with isocyanates. This method is environmentally friendly but may affect foam properties such as thermal insulation. The flammability of some hydrocarbon-based blowing agents poses safety concerns, necessitating the use of flame retardants and specific handling protocols. The thermal insulation properties of alternative blowing agents can vary, impacting energy efficiency in applications like building insulation. Switching to new blowing agents often requires changes in production processes and equipment.

Compatibility with existing systems and the impact on foam properties are key considerations. Newer, environmentally friendly blowing agents can be more expensive, influencing market adoption and overall product cost ***(Table 3.5)***.

*Table 3.5: Properties of water/ evolved $CO_2$ by product*

| **Water / $CO_2$** | | |
|---|---|---|
| **Overview:**<br>Water serves as a chemical blowing agent in foam production, participating in a reaction that generates carbon dioxide for foaming. | | |
| **Environmental Impact** | | ODP: 0 and ODP: 1 |
| **Foaming Process:** | | Water reacts with Methylene Diphenyl Diisocyanate (MDI), leading to $CO_2$ formation for foam cell expansion. |
| **Characteristics of Water-Blown Foam:** | High k-factor (Thermal Conductivity): | • High Thermal Conductivity (k-factor): Indicates relatively poor insulation.<br>• Over time, $CO_2$ escaping from foam cells increases the k-factor. |
| | Mitigation Strategy | To compensate for decreased insulation, manufacturers may increase foam thickness, which can impact material usage and production costs |
| **Applications** | | Water-blown foam finds application in less critical insulation scenarios, including in-situ foams, surfboards, low-density open-cell packaging foams, thermoware, and spray foam. |

***Methylal and methyl formate***

Methylal and methyl formate are valued for their performance-enhancing properties, environmental friendliness, and cost-effectiveness, making them indispensable in the production of polyurethane foams and other applications.

Methylal, or dimethoxymethane ($CH_2(OCH_3)_2$), is a low-boiling-point, volatile compound with high solubility in organic solvents and low toxicity ***(Table 3.6)***. In the PU industry, it serves as a physical blowing agent for creating fine, uniform cellular structures in foams, enhancing their insulation properties and structural integrity. Its low global warming potential (GWP) and biodegradability make it an eco-friendly alternative to traditional chlorofluorocarbon and hydrofluorocarbon blowing agents. Additionally, methylal is used as a solvent in polyurethane coatings, adhesives, and sealants, further broadening its utility.

*Table 3.6: Properties of methylal*

| **Methylal** | |
|---|---|
| **Overview:**<br>Methylal serves as a physical liquid blowing agent in PU foam manufacturing, offering advantages in solubility and compatibility. | |
| **Environmental Impact:** | ODP: 0<br>GWP: less than 1 |
| **Flammability and Safety** | • Methylal is a flammable liquid, requiring safety measures.<br>• Preblending at the system house level may reduce flammability risks for downstream users. |
| **Foaming Characteristics:** | • Good solubility and miscibility with various polyols.<br>• Non-insulation foam blown with methylal mirrors the properties of HCFC-141b foam. However, methylal-based insulation foams exhibit a 10% higher k-factor compared to HCFC-141b.<br>(Note: A higher k-factor implies a lower insulation efficiency, which may impact the material's ability to resist heat transfer.) |

Methyl formate ($HCOOCH_3$) is another critical chemical in the PU industry. With its high vapor pressure and excellent blowing efficiency ***(Table 3.7)***, it is widely used as a chemical blowing agent in the production of rigid and flexible polyurethane foams. During the reaction process, methyl formate decomposes into carbon dioxide and other gases, efficiently generating foam structures. Its low environmental impact and cost-effectiveness make it a popular choice for manufacturers aiming to meet sustainability goals while maintaining economic feasibility.

*Table 3.7: Properties of methyl formate*

| Methyl formate (MF) or Ecomate by Foam Supplies Inc. | |
|---|---|
| **Overview:**<br>Methyl Formate (MF), marketed as Ecomate by Foam Supplies Inc. (FSI), is a patented physical blowing agent for foam production, offering environmentally friendly attributes. | |
| **Environmental Impact** | ODP: 0<br>GWP: 5 or less |
| **Flammability and Safety** | • MF is a flammable liquid, requiring safety measures. However, blending with polyols may reduce flammability and enhance safety. |
| **Foaming Characteristics** | • Acceptable k-factor for insulation foam.<br>• Higher solubility in polyol compared to HCFC-141b. |
| **Optimization** | Formulation adjustments are crucial for optimal MF performance, addressing potential challenges like shrinkage and poor adhesion. |

Both methylal and methyl formate contribute significantly to the industry's push for sustainability, aligning with global regulations such as the Montreal Protocol and Kigali Amendment. These chemicals offer enhanced performance, including improved foam insulation and structural consistency, while also being compatible with diverse applications. However, their flammability and the need for optimized formulations to ensure compatibility pose challenges that manufacturers must address.

The polyurethane industry is at the forefront of the transition towards more sustainable and environmentally friendly practices, driven by regulatory frameworks and market demand for green products. The shift from CFCs to current alternatives reflects a broader commitment to environmental stewardship and the pursuit of innovative solutions. The industry continues to innovate, focusing on developing and commercializing blowing agents with even lower GWPs and improved performance characteristics. There is a growing emphasis on the entire lifecycle of polyurethane products, including the use of bio-based raw materials and recycling of polyurethane foams.

# Chapter 4

# HCFC PHASE-OUT MANAGEMENT PLAN: PU FOAM SECTOR

## Understanding the HCFC Phase-Out

The HCFC Phase-Out Management Plan (HPMP) stands as a pivotal component of Malaysia's commitment to the Montreal Protocol. Recognizing the harmful impact HCFCs could cause to ozone layer depletion, Malaysia has undertaken a comprehensive strategy to gradually eliminate these controlled substances. This chapter delves into the specific strategies and initiatives implemented within the polyurethane (PU) foam sector to facilitate this transition.

Malaysia's journey toward phasing out hydrochlorofluorocarbons (HCFCs) began with the establishment of a baseline, calculated as the average HCFC consumption during 2009 and 2010, which amounted to 515.8 ODP tonnes. This baseline became the cornerstone for developing a systematic and sustainable approach to gradually reduce HCFC consumption. The polyurethane (PU) foam and refrigeration and air-conditioning (RAC) sectors were identified as the largest consumers of HCFCs, with HCFC-141b serving as a key blowing agent in foam production and HCFC-22 and HCFC-123 widely used in RAC systems.

HPMP Stage I (2012–2016) laid the foundation for Malaysia's HCFC phase-out efforts, targeting a 10% reduction in consumption by 2015. This initial phase focused on transitioning larger PU foam enterprises to alternatives like cyclopentane and providing technical support to system houses to develop low-global-warming-potential (GWP) formulations. Key regulatory measures, such as the licensing system for HCFC imports, were introduced to support compliance. By the end of Stage I, Malaysia successfully phased out 94.6 ODP tonnes of HCFC-141b, marking a critical step forward.

In HPMP Stage II (2017–2023), Malaysia expanded its efforts to include small and medium enterprises (SMEs) and targeted a 35% reduction in HCFC consumption by 2023. This phase emphasized stricter regulatory measures, such as banning HCFC-141b in foam production by January 2023, as well as capacity-building programs to support SMEs in adopting sustainable alternatives. With the foam sector conversion fully completed, this phase represented a pivotal achievement in Malaysia's phase-out journey.

Having completed foam sector conversions, HPMP Stage III (2024–2030) shifts its focus to the RAC servicing sector and chiller sector. This phase prioritizes the adoption of low-GWP alternatives, enhanced enforcement mechanisms, and recovery and reuse practices. Through this phased approach, Malaysia has demonstrated its ability to align environmental protection with industrial growth.

## HCFC Consumption in PU Foam Sector

The polyurethane foam (PU foam) sector in Malaysia encompasses various applications across several segments, including flexible foam (used in mattresses and sofas), integral skin foam (found in car steering and dashboards), and rigid foam (applied in insulated products). While many enterprises engage in PU foam production, our focus in this chapter lies on those involved in the HCFC Phase-out Management Plan (HPMP), particularly those producing rigid and closed-cell foam products.

Historically, HCFCs, particularly HCFC-141b, have been favored as blowing agents in rigid PU foam due to their exceptional insulation properties and dimensional stability (low risk of shrinkage and expansion problem). Consequently, enterprises within this segment have heavily relied on HCFCs as an intermediate transition before shifting to ozone-friendly alternatives. Meanwhile, manufacturers of flexible and integral skin foam have largely transitioned to non-HCFC alternatives, such as water-blown and methylene chloride formulations.

Products manufactured by local enterprises in the rigid PU foam segment, as stated in Chapter 2, include insulated panels for construction, cold storage rooms, insulated roofing panels, refrigerators, truck containers, ice boxes, and insulated pipes. ***Table 4.1*** shows the HCFC used in foam sector by application in the survey conducted in 2009. HCFC is mainly used as the blowing agent in the production of discontinuous sandwich panels. Other applications include refrigeration equipment, insulated boxes, pipe insulation, spray insulation, furniture and automotive upholstery.

HCFCs are not locally produced in Malaysia; thus, the entire domestic demand is met through imports from international sources such as China, South Korea, and Europe. This reliance on imports extends beyond chemicals to essential equipment, as PU foam machinery is manufactured overseas and imported into Malaysia.

In this context, the presence of local suppliers with blending facilities (known as System House) plays a crucial role in supporting the local PU foam manufacturing industry. Companies such as BASF, Cosmo, Colorex, Dow Chemicals, Maskimi Polyol, PPTM, Mitsui Chemicals PU, RLA Polymers, and Oriken provide essential raw materials and services needed for polyurethane production, with the added advantage of blending capabilities within the country. These blending facilities allow local manufacturers to obtain customized foam formulations that meet specific performance requirements and environmental standards without needing to rely on entirely imported finished products. This not only ensures a more flexible and responsive supply chain but also reduces lead times,

*Table 4.1: HCFC Consumption in Foam Sector (2009)*

| Sub-Sector | Application (Number of Enterprise) | 2009 HCFC Consumption (metric tonnes) |
|---|---|---|
| Rigid Foam | Discontinuous sandwich panels (30) | 1,045 |
| | Refrigeration equipment (10) | 90 |
| | Insulated boxes (1) | 40 |
| | Pipe insulation (10) | 40 |
| | Spray insulation (10) | 50 |
| | Others (40) | 60 |
| | **Total (Rigid Foam)** | **1,325** |
| Integral Skin Foam | Furniture and automotive (3) | 10 |
| | **Total (Integral skin)** | **10** |
| | **TOTAL** | **1,335** |

minimizes logistics costs, and allows for quicker adaptation to market changes or regulatory shifts.

In addition to system houses, the importation of high-quality PU foam machinery from companies like Cannon, OMS, RIM Polymers, SAIP, Maron and Rujian ensures that Malaysian manufacturers have access to state-of-the-art technology. These machines are essential for efficient and precise foam production, but the ability to source critical chemical inputs locally through blending facilities further enhances the sustainability and resilience of the industry.

The HCFC and chemical supply structure for the polyurethane foam industry is shown in ***Fig. 4.1***. Detailed supply chain for the polyurethane foam industry, focusing on the flow of materials and components from raw material suppliers to end-users. This involves raw material and chemical suppliers; system houses (custom formulations, packaging and distribution); equipment manufacturers; polyurethane foam manufacturers; quality control and testing; distribution (logistics and warehousing); end-users include the construction industry (for insulation and structural panels), automotive industry (for seating and interior components), furniture and bedding industry, and appliance manufacturers as well as retail and commercial sales: in some cases, products may also be sold directly to consumers or contractors through retail outlets and last but not least recycling and disposal which should be assisted by the end-of-life management.

Key considerations in the supply chain include efforts to develop more sustainable materials and processes, including the use of bio-based polyols and more environmentally friendly blowing agents; innovation and R&D: continuous research and development to improve product performance, reduce costs, and address environmental concerns.

## Interventions under HPMP

Unlike other HCFC-using sectors such as refrigeration and air-conditioning, which benefit from the support of active associations such as MACRA and ASHRAE, where their members can keep abreast of the latest technological development, the polyurethane foam sector in Malaysia lacks similar organizational support. Despite this, the PU foam industry plays a vital role in the country's economy, with approximately 100 local manufacturers producing rigid polyurethane foam. These manufacturers comprise about 13 large-scale organized manufacturers, 20 medium-sized manufacturers, and numerous smaller enterprises.

In an effort to phase out the use of HCFC-141b, a commonly used blowing agent in rigid PU foam production, Malaysia has adopted several initiatives under the HCFC Phase-Out Management Plan (HPMP). These interventions focus on reducing HCFC-141b usage through a combination of financial support for technology conversions to environmentally friendly alternatives, capacity

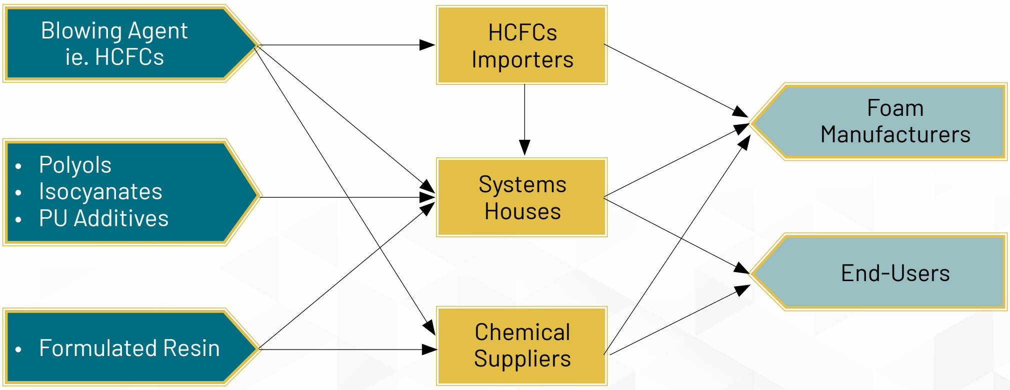


*Figure 4.1: Supply chain for the PU foam industry.*

> **“During the HPMP Stage I, financial assistance for technology conversions was provided, focusing on 13 selected large and medium-sized enterprises. In parallel, technical assistance was extended to four (4) local system houses to develop low-GWP alternatives.”**

building, and regulatory framework. The HPMP aims to assist the PU foam industry by providing access to modern, ozone-friendly technologies and supporting manufacturers in adopting cleaner, more sustainable production processes. Through these efforts, the HPMP will not only facilitate compliance with international environmental standards but also enhance the competitiveness and sustainability of Malaysia’s PU foam industry in the long run.

### *Financial Initiatives and Support*

Financial initiatives and support play a critical role in facilitating the transition of foam industries away from HCFCs towards more sustainable alternatives within the polyurethane foam sector. Recognizing the importance of financial assistance in overcoming barriers to adoption, Malaysia leverages the Multilateral Fund channeled through the UNDP and Department of Environment (DOE) to provide funds and alleviate the initial costs associated with technology conversion. This financial initiative helps offset the higher upfront costs associated with transitioning away from HCFCs and encourages investment in environmentally friendly solutions such as hydrocarbons (HCs), methylal, and natural substances like carbon dioxide ($CO_2$) or water. By reducing financial barriers, enterprises are empowered to make sustainable choices that align with both environmental and economic goals. Upgrading their equipment not only contributes to improved energy efficiency and productivity but also fosters a more sustainable business model.

During the HPMP Stage I, financial assistance for technology conversions was provided, focusing on 13 selected large and medium-sized enterprises. These companies were chosen for their capacities to transition to ozone-friendly alternatives efficiently. In parallel, technical assistance was extended to four (4) local system houses to develop low-GWP alternatives The strategy was designed to target larger companies first, as they had greater resources and capacity to implement the necessary conversions. At the same time, system houses prepared downstream users, mainly smaller enterprises, to adopt these alternatives in the upcoming Stage II.

In HPMP Stage II, the conversion strategy followed a phased approach, beginning with enterprises that had capacities greater than 20 metric tonnes (MT). Once these larger companies had completed their transitions, attention shifted to medium-sized enterprises, and eventually to smaller companies with capacities below 5 MT. This gradual progression was based on the expectation that, over time, cost-effective alternative technologies would become more widely available and mature as ongoing research and development efforts advanced. This structured approach allowed for a smooth transition across businesses of varying sizes while promoting the adoption of environmentally friendly alternatives.

### ***Technology Transfer and Capacity Building***

Technology transfer and capacity building initiatives are crucially important in facilitating a smooth transition for Malaysia's PU foam sector. These initiatives empower PU foam manufacturers, system houses and other stakeholders with the tools and expertise needed to adopt new technologies and implement best practices.

This initiative enables industries to adopt updated manufacturing processes and equipment that are compatible with alternative blowing agents, which offer environmental benefits by minimizing impact to ozone depletion. Some of these alternatives, such as cyclopentane, require stricter safety protocols due to their flammable nature, requiring careful attention during handling, transportation, operation, and storage. Capacity building programs address these safety concerns comprehensively, ensuring health and safety of workers while safeguarding the environment.

Recognizing the importance of knowledge exchange, Malaysia actively fosters collaborative partnerships. These partnerships involve international and local experts, equipment manufacturers and polyol system providers. Through these collaborations, Malaysia facilitates the transfer of best practices, cutting-edge technologies like closed-loop recycling systems, and innovative solutions to local enterprises. The stakeholders that are able to enhance their understanding of alternative blowing agents, advance production techniques, safety protocols for handling flammable blowing agents and quality control measures. As a result, these initiatives facilitate knowledge exchange between domestic enterprises and international experts, accelerating the adoption of innovative solutions.

Capacity-building programs encompass a wide range of activities, such as specialized workshops, seminars, study tours, and technology showcases, all tailored to the unique needs and priorities of the polyurethane foam sector. Industry stakeholders gain access to practical guidance, technical support, and real-world case studies that demonstrate successful technology implementations, empowering them to navigate challenges more effectively and maximize the benefits of transitioning to new and sustainable technology.

### ***Regulatory Framework***

Malaysia has adopted a proactive approach in phasing out controlled substances under the Montreal Protocol, specifically targeting sectors such as PU foam manufacturing. To facilitate this transition, the country has formulated policies and legislations to restrict and limit the use of these controlled substances like HCFC-141b, which has been widely used as a blowing agent on the PU foam industry. These strategies include monitoring the importation and consumption of such substances and promoting the use of non-ODS substitutes within the PU foam sector.

A key component of this regulatory framework is the Application Import Permit System (AP System), which was initially administered by the Ministry of International Trade and Industry (MITI). In 2012, the DOE assumed responsibility for the AP System to oversee the importation and consumption of HCFCs. The system was further strengthened in 2014 with the introduction of licensing for re-export of HCFC, providing a more comprehensive mechanism for regulating ODS use in the foam industry.

Specific to the PU foam sector, Malaysia has implemented policies and legislation to regulate and reduce the use of controlled substances, including HCFC-141b, within the foam sector. The foundation of Malaysia's environmental policy dates back to 1974 with the introduction of the Environmental Quality Act (EQA). Amendments to this Act included provisions prohibiting the use of CFCs in various sectors. The following initiatives have been central to reducing the PU foam sector's reliance on ODS:

- **Environmental Quality (Prohibition on the Use of CFCs and Other Gases as Propellants and Blowing Agents) Order, 1993**
- **Environmental Quality (Refrigerant Management) Regulations, 2020**
- **Occupational Safety and Health Act (1974)**
- **Factories and Machinery Act (1967)**
- **Customs Act (1967)**

These regulations authorize the Government to control the importation, installation and disposal of ODS in the foam sector, ensuring a systematic reduction of substances like HCFC-141b. The overarching strategy for HCFC phase-out under HPMP, specifically for PU foam sector, includes:

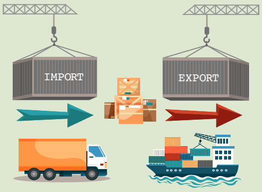
a) Ban on export of HCFC-141b contained in pre-blended polyols starting from 31 December 2018;
b) Ban on imports of pre-blended polyols containing HCFC-141b from 1 January 2022; and
c) Prohibition on the all use of HCFC-141b, except in solvent sector, starting from 1 January 2022.

However, the COVID-19 pandemic significantly disrupted the PU Foam sector, leading to temporary closures of manufacturers and trade disruptions throughout the year 2020 and 2021. Consequently, support for the sector was limited, affecting the implementation of technology conversion activities. Consequently, Malaysia was unable to enforce the HCFC-141b ban from 1 January 2022. Nonetheless, Malaysia successfully implemented the ban on HCFC-141b imports as of 1 January 2023, and plans are underway to revise current regulations to officially classify HCFC as a controlled substance within the PU foam sector.

These efforts reflect the Government's commitment to ensuring the PU foam industry transitions to more sustainable, ozone-friendly alternatives, while balancing industry needs with environmental priorities.

## *HCFC Phase-out Strategy*

### Import/Export Control Mechanism



- All importers of HCFC substances required to obtain an import / export permit.
- Import quota allocated to each importers every year.
- Import quota allocation is determined based on the country's obligation under MP.

### Education & Public Awareness Programme

- The Government also organise various educational and public awareness programmes like World Ozone Day Celebration, seminar, workshops, webinars on the need to protect the ozone layer and study tours.

### Technical Assistance

- Technology Conversion in Foam Sector.
- Assistance to system houses.
- Certified Service Technician Programme in RAC Sector.
- Technical Assistance to the Solvent Sector.

### Regulatory & Policies

- Environmental Quality (Prohibition on the Use of CFCs and Other Gases as Propellants and Blowing Agents) Order, 1993 (currently being review to include HCFC).
- Environmental Quality (Refrigerant Management) Regulations, 2020.

## HCFC Reduction in Foam Sector

Intervention efforts under the HPMP have proven successful, as evidenced by the significant reduction in HCFC consumption over the years. In the foam sector specifically, each successful conversion of a foam enterprise has directly contributed to decreasing HCFC usage. ***Figure 4.2*** highlights the significant reduction of HCFC-141b consumption during the implementation of the HPMP from 2012 to 2023. HCFC-141b consumption declined sharply from 315.61 ODPT tonnes in 2012 to 0.49 ODP tonnes in 2023, with the steepest drops occurring in the initial years up to 2018. This suggests that early regulatory measures or large-scale industry shifts were instrumental in driving the initial reductions.

The number of foam companies converted to alternative technologies steadily increased throughout the period. Initial progress was slow, with only 1 company converted in 2013, but momentum grew, especially after 2019. By 2023, 55 enterprises had been converted, resulting in almost zero consumption in HCFC-141b, reflecting a concerted effort to transition businesses away from reliance on HCFC-141b. This shows the effectiveness of the HPMP in leveraging enterprise-level transitions to achieve sustainable phase out of HCFC consumption.

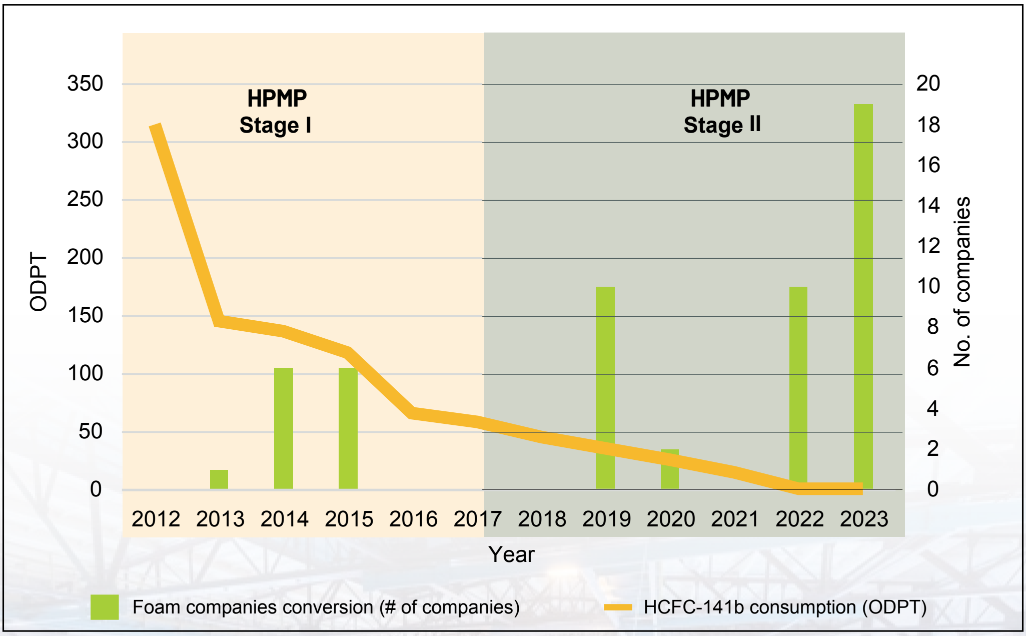


*Figure 4.2: The progressive reduction trend of HCFC-141b by number of companies.*

# Chapter 5
# THE BENEFICIARIES

This chapter unfolds the success stories of foam enterprises and system houses that have been instrumental in driving shift towards more sustainable foam production. It provides valuable insights into the blowing agent alternatives adopted, the strategies employed, and the achievements that have marked their eco-conscious journey. The chapter delves into the proactive steps taken by these enterprises, such as acquiring new machinery or adapting existing equipment, shedding light on the dynamic processes involved in their transition. Additionally, it emphasized the critical role of system houses as innovative hubs, actively formulating and implementing low-GWP and cost-effective alternatives. These success stories not only showcase individual enterprise accomplishments but also contribute to the broader narrative of how the foam industry is aligning with global initiatives for ozone layer protection, with a specific focus on Malaysia's commitment to environmental stewardship.

## Technical Assistance to Local System Houses

The system houses were vital in bridging the gap for SMEs by offering pre-formulated, HCFC-free solutions, reducing the need for these smaller manufacturers to independently undertake expensive research or machinery upgrades. By providing ready-to-use formulations and ongoing technical support, system houses ensured that SMEs could transition smoothly to ozone-friendly technologies, without significant in-house R&D investment. This collaboration helps SMEs to stay competitive while aligning with global environmental standards.

Recognizing the critical role that system houses play in the transition to sustainable foam production, the Government placed significant emphasis on supporting these entities from

*Figure 5.1: Production of HCFC-Free Polyol Products*

the very beginning of HPMP Stage I. This assistance was crucial for system houses to focus on the research and development of alternative polyol systems that were both environmentally friendly and commercially viable. It also ensured that system houses could upgrade their infrastructure, ranging from laboratory improvements to modifications of manufacturing facilities—allowing them to produce, test and distribute HCFC-free formulations at scale ***(Fig. 5.1)***.

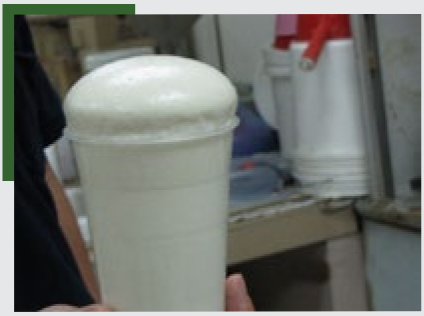
Under the HPMP, four polyol system houses received both financial and technical assistance to bolster their research and development efforts in formulating non-HCFC polyol systems. Most of the funding was allocated to upgrading existing facilities and laboratories, which was essential in fostering innovation in sustainable foam production. These companies explored the use of cyclopentane as an alternative to HCFC-141b. At the program's initial stage, these system houses received assistance in developing customized formulations using new and emerging low-GWP alternative technologies. They focused on aliphatic compounds such as methyl formate and Methylal, as well as emerging technologies like FEA-1100, HBA-2, and AFA-L1, all of which were suited for pre-blending in polyols.

***Fig. 5.2*** provides an overview of the new alternative blowing agents formulated by the four polyol system houses as part of their efforts to transition from HCFC-141b to environmentally friendly alternatives. Each system house has developed unique product formulations that utilize low-GWP blowing agents, supporting the foam manufacturing industry's shift toward more sustainable and ozone-friendly solutions. These system houses formulated the polyol blend and supplied to local polyurethane manufacturers. The addition of these blowing agents has been implemented in replacement to HCFC 141 b with the support of the blowing agent producers. Several trial runs have been conducted prior

*Figure 5.2: New alternative blowing agents formulated by system houses under HPMP*

**Company Name:** COLOREX SDN BHD
**Blowing Agent:** METHYL FORMATE
**Product Name:** COLOREX RG101-1E

**Company Name:** MASKIMI POLYOL SDN BHD
**Blowing Agent:** 1233ZD (E)
**Product Name:** MASKIMIFOAM 778B/2HW



**Company Name:** ORIKEN POLYURETHANE SD
**Blowing Agent:** METHYLAL
**Product Name:** ORITHANE RG4340M

**Company Name:** PPT (M) SDN BHD
**Blowing Agent:** METHYL FORMATE
**Product Name:** RG1504H6

to actual usage in the processing plants. Each blowing agents has different implication to the final properties of the polyurethane foams.

Notably, Maskimi Polyol Sdn Bhd innovated by using bio-polyol derived from palm oil to address compatibility issues encountered when using cyclopentane as a blowing agent. Meanwhile, Colorex Sdn Bhd shifted its focus to water-blown flexible foam rather than continuing with the production of rigid foam. Oriken Polyurethane Sdn Bhd has made several attempts to various blowing agents and finalized methylal as replacement to HCFC-141b. PPT (M) Sdn Bhd on the other hand, used methyl formate in its polyol blend.

Upon the completion of HPMP Stage II, all four system houses concluded that cyclopentane, along with a hybrid system combining cyclopentane and water, represented the best options for alternative blowing agents in the PU foam industry. This conclusion highlights the companies' efforts to meet global environmental standards, with new formulations reducing reliance on ozone-depleting substances while fulfilling the technical needs of the polyurethane foam sector.

There are five key milestones ***(Fig. 5.3)*** for the polyol system houses, which highlight their journey in developing and commercializing HCFC-free polyol systems, with the Department of Environment (DOE) and industrial experts providing essential technical guidance throughout the process.

The first milestone involved the specifications of reformulated rigid foam polyol systems including declaring the composition and any related drawings involved in the processing machines. The plant layout was redesigned to accommodate the new production processes, and an implementation plan was outlined. The second milestone deals with the operational documentation. The standard operating documents are prepared and several visual inspections have been directed. The third milestone identify barriers and challenges in practice by steering several visual inspections. The initial test results are collected and compared with previous practice. The limitations are highlighted. This continued in the fourth milestone whereby several visual inspections have been carried out at sites of trial production. Other activity includes the safety audit which covers the storage, handling and training. The batch-to-batch test results are compared and reproducibility as well as stability are counterchecked. The final milestone (the fifth) required the industry to propose the

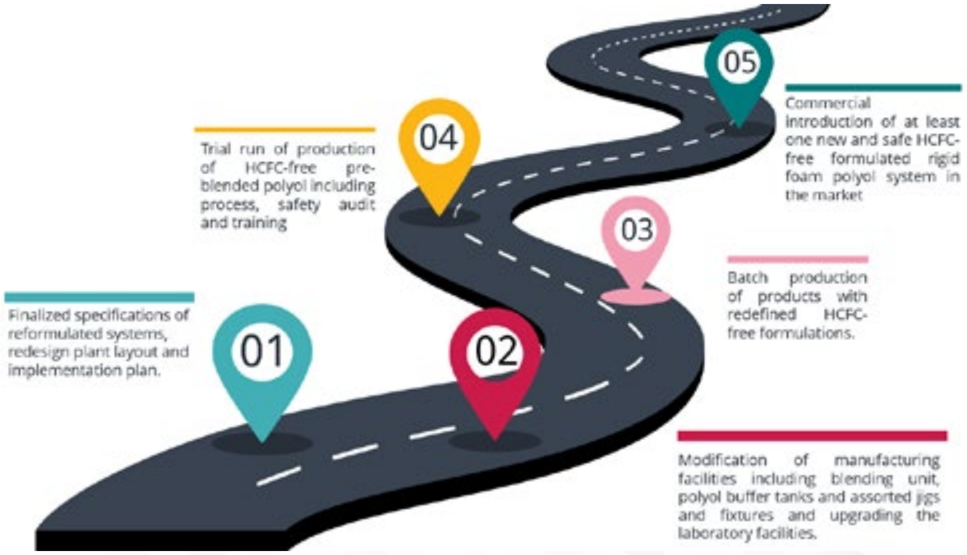


*Figure 5.3: Five key milestones for the polyol system houses to develop and commercialize HCFC-free polyol systems.*

reformulated version of system and supplying evidence of results consistency.

Throughout these milestones, the technical guidance provided by the DOE and industrial experts was pivotal in ensuring that the polyol system houses could navigate the complex process of transitioning to HCFC-free systems. Their involvement helped to streamline compliance with safety and environmental standards, while also ensuring that the new systems were technically sound, efficient, and commercially viable.

The involvement of system houses in the initial stage allowed for the development of a robust supply chain for HCFC-free alternatives. This created a ripple effect, as the system houses not only provided the necessary formulations but also served as technical support centers for manufacturers, helping them navigate the complexities of machinery upgrades, safety audits, and process optimizations required for the new technologies. HPMP's strategic decision to focus on system houses as key drivers of change ensuring that even companies with limited resources could adopt low-GWP blowing agents like cyclopentane, methylal, and water-blown systems.

## Technology Conversion for PU Foam Manufacturer

HPMP strategy for the PU foam industry focuses on ensuring a targeted and efficient transition away from HCFC-141b. The strategy prioritizes larger manufacturing enterprises that consume substantial amounts of HCFC-141b and have the technical and managerial capacity to implement alternative technologies. These enterprises are viewed as capable of leading the transition due to their ability to adopt mature, low-GWP alternatives, ensuring both compliance with environmental and safety standards.

During the preparation of HPMP Stage I in 2010, it was estimated that Malaysia had around 100 polyurethane (PU) foam manufacturers. This group included 13 large, well-organized manufacturers, approximately 20 medium-sized companies, and the remainder were small-scale manufacturers. In terms of consumption, the large PU foam manufacturers are the major contributor with 91.7% from overall PU foam consumption.

In HPMP Stage I, the 13 large polyurethane foam manufacturing companies ***(Table 5.1)*** were selected to undergo the technology conversion first. The selection process considered their annual consumption of HCFC 141b and their readiness to transition from the baseline systems (HCFC-141b) to alternative technologies. These manufacturing companies purchased polyol blend without blowing agent and the blowing agent separately for several reasons. Blowing agents are very common to diffuse out due to their low boiling point (volatile) especially during transportation and in storage. This issue can be crucial when the properties of the foam are not achieved due to amount reduction of the blowing agents in the polyol blend. In addition, the reduction in the blowing agents affect the production costs. Thus, polyurethane foam manufacturer preferred to do their own blending of blowing agent prior to daily processing. Some companies used excessive amount of blowing agents and some others lack awareness of its storage safety. By focusing on these companies, the strategy ensures that the phase-out of HCFCs is both implementable and sustainable, helping meet the 2015 compliance targets.

**HPMP's strategic decision to focus on system houses as key drivers of change ensuring that even companies with limited resources could adopt low-GWP blowing agents like cyclopentane, methylal, and water-blown systems.**

*Table 5.1: Foam Sector Technology Conversion in HPMP Stage I*

| Enterprise size (MT) | Quantity of Enterprises | Final Alternative Technology |
|---|---|---|
| Group 1 (> 100 MT) | 2 | Cyclopentane, n-pentane system |
| Group 2 (50 - 100 MT) | 2 | Cyclopentane |
| Group 3 (20 - 50 MT) | 9 | Cyclopentane |

HPMP Stage II, initiated in 2017, followed the successful conversion of 13 large PU foam manufacturers during Stage I. In this phase, the remaining 77 enterprises has began their technology conversion process. Over the 3-5 years since the introduction of new alternatives by system houses, these technologies had matured, enabling some enterprises to be ready for immediate conversion. However, others required more time to evaluate and determine the most suitable alternatives for their specific products and production processes.

All large enterprises consuming more than 20MT HCFC in Stage I and Stage II, successfully transitioned to using cyclopentane and pre-blended cyclopentane as alternative. However, the flammable nature of cyclopentane presents unique safety challenges, particularly when used in large quantities. As a result, these companies may need to adhere to stricter safety regulations compared to those using non-flammable alternatives. This distinction is critical for ensuring the safety of operations and personnel, necessitating careful planning and implementation of additional safety measures.

To mitigate the high costs associated with implementing these new safety protocols and production setups, each enterprise has made strategic counter investments in their facilities. This includes upgrading equipment, enhancing safety systems, and providing comprehensive training for employees on handling cyclopentane safely. Ultimately, while the transition to cyclopentane may involve higher initial expenditures, the benefits of aligning with environmental goals and ensuring safe operations can lead to significant long-term advantages. In addition to the transition to cyclopentane, several small and medium-sized polyurethane (PU) foam enterprises have opted for alternatives such as Methylal, HFOs, or HFCs. These alternatives were chosen based on several factors, including availability, cost-effectiveness, compatibility with existing systems, and their impact on foam properties. The cost of conversion has emerged as a significant concern, as many enterprises lack the necessary funds to support the transition.

Among these enterprises, 18 micro and small-sized companies have faced particularly severe financial challenges during the conversion. On one hand, converting to flammable blowing agents proved unfeasible due to the substantial capital investments required for safety measures. Furthermore, adopting HFOs was not a sustainable solution, given their high operational costs and an unstable supply chain. Water-blown systems were also evaluated as part of the technology selection process. However, tests conducted with available water-blown systems in

> **“All large enterprises consuming more than 20MT HCFC in Stage I and Stage II, successfully transitioned to using cyclopentane and pre-blended cyclopentane as alternative.”**

Malaysia revealed underperformance in several technical requirements. Additionally, these systems would require costly mould replacements and adaptations, as well as significant improvements in operational practices and environmental standards, which would further escalate project capital costs. As a result, some companies (***Table 5.2***) have opted to adopt high-GWP HFCs and have requested to be removed from the HPMP-II program. Furthermore, eight additional micro and small-sized enterprises closed down during this period, primarily due to the impacts of the COVID-19 pandemic. Nine (9) companies were ineligible for HPMP funding assistance but also transitioned to HFCs independently.

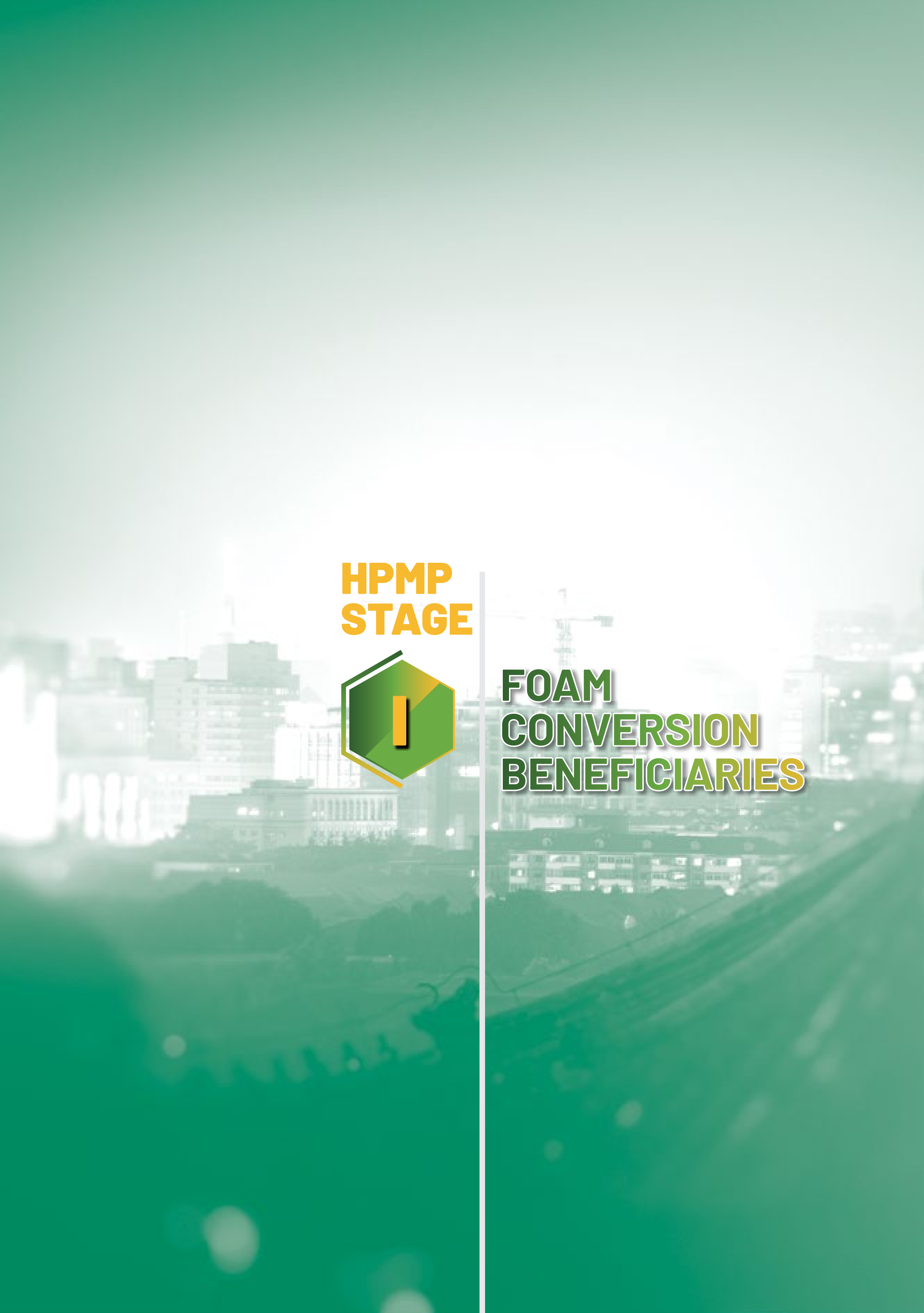
*Table 5.2: Foam Sector Technology Conversion in HPMP Stage II*

| Enterprise size ( MT) | Quantity of Enterprises | Final Alternative Technology |
|---|---|---|
| Group 1 (> 20 MT) | 11 | Cyclopentane, pre-blended cyclopentane |
| Group 2 (5-20 MT) | 20 | Cyclopentane, pre-blended cyclopentane, Methylal, HFO |
| Group 3 (1-5 MT) | 10 | Pre-blended cyclopentane, Methylal, HFO |
| Group 4 (below 1 MT) | 1 | Methylal and Pre-blended cyclopentane |

A Memorandum of Agreement (MOA) was prepared between the Department of Environment Malaysia (DOE) and all project beneficiaries, establishing mutual understanding and commitment to the project. The progress was verified and compensated based on the achievement of five planned milestones during conversion to use non-HCFC technology in foam manufacturing ***Figure 5.4***.

*Figure 5.4 : Milestone for foam project benefiaries*

| **Milestone 1** | **Milestone 2** | **Milestone 3** | **Milestone 4** | **Milestone 5** |
|---|---|---|---|---|
| **Implementation of work plan and works drawings for plant re-layout** | **Procurement of equipment and service providers** | **Plant Modifications** | **Installation and commissioning of procured equipment** | **Completion and phase-out of HCFCs** |
| The planning for procurement of new material sources and phase out strategy as well as indicative production process were conducted.<br>These include civil, structural, electrical and mechanical where applicable. | The issuance of purchase order for auxiliary equipment or tools to tailor to usage of cyclopentane or any non-ODS blowing agent that require safety for storage and handling. | All civil, structural, electrical and/ or mechanical works are completed.<br>A new factory system policies (not limited to safety, operation and handling) are developed.<br>A programmed employee training (not limited to safety, operation and handling) is conducted based on the selected type of blowing agent. | The prototype/ sample from the production trial run has been evaluated to comply to several industrial standards by evaluating the foams.<br>A series of plant visits and inspection by all relevant parties has been conducted.<br>Testing and approval by relevant parties have also been obtained. | Relevant parties have carried out the inspection of plant and machinery in order to determine the suitability and compliance to DOE approved standards. |
| 01 | 02 | 03 | 04 | 05 |



# HPMP STAGE I

# FOAM CONVERSION BENEFICIARIES

# HPMP STAGE › FOAM CONVERSION BENEFICIARIES

## › BERJAYA STEEL PRODUCT SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Commercial refrigeration** | **Machine type:** High Pressure<br>**Model:** Cannon & OMS | **43** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** February 2013<br>**Completion Date:** November 2014 |


**BEFORE**


**AFTER**

## › CYCLEWORLD CORPORATION SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panels (PUR and PIR) & coldroom** | **Machine type:** High Pressure & Low Pressure<br>**Model:** OMS & Cannon | **160** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** January 2013<br>**Completion Date:** April 2015 |

BEFORE

AFTER

## › INSAFOAM INSULATION (MALAYSIA) SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated piping** | **Machine type:** High Pressure<br>**Model:** Cannon | **41** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** September 2013<br>**Completion Date:** July 2015 |

BEFORE

AFTER

## › KWANG TAI REFRIGERATIONS & ELECTRICAL SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Commercial Refrigeration** | **Machine type:** Low Pressure<br>**Model:** Cannon | **31** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** March 2014<br>**Completion Date:** July 2015 |

**BEFORE**

**AFTER**

## › LINEAR PANEL MARKETING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panel** | **Machine type:** High Pressure<br>**Model:** OMS | **38** | **Cannon** | **Procuring new machinery** | **Start Date:** February 2013<br>**Completion Date:** May 2015 |

**BEFORE**

**AFTER**

## › OCEAN ROTO MOULDING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated box** | **Machine type:**<br>Low pressure & High pressure<br>**Model:**<br>RIM | 49 | **Cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>May 2013<br>**Completion Date:**<br>December 2014 |

BEFORE

AFTER

## › PANGKAT INDUSTRIAL SDN. BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panel** | **Machine type:**<br>High Pressure & Low Pressure<br>**Model:**<br>KM & Cannon | 38 | **Cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>May 2013<br>**Completion Date:**<br>November 2014 |

BEFORE

AFTER

## › RICWIL (MALAYSIA) SDN. BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated piping** | **Machine type:** High Pressure<br>**Model:** Cannon | **63** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** February 2013<br>**Completion Date:** December 2014 |

**BEFORE**

**AFTER**

## › RIGID FOAM INDUSTRIES (M) SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panel** | **Machine type:** High pressure & Low Pressure<br>**Model:** KM & Hongwei | **55** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** November 2012<br>**Completion Date:** December 2014 |

**BEFORE**

**AFTER**

## › SAI COND SALES & ENGINEERING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panel** | **Machine type:** Low pressure<br>**Model:** Cannon | **35** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** December 2013<br>**Completion Date:** April 2015 |


**BEFORE**


**AFTER**

## › SUPIERA ENTERPRISE SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panel** | **Machine type:** High pressure<br>**Model:** Cannon | **36** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** December 2013<br>**Completion Date:** November 2014 |


**BEFORE**


**AFTER**

## › UNITED PANEL SYSTEM (M) SDN. BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panel** | **Machine type:** High pressure<br>**Model:** Elastogran | **207** | **n-pentane system** | **Procuring new machinery** | **Start Date:** March 2013<br>**Completion Date:** March 2014 |

**BEFORE**

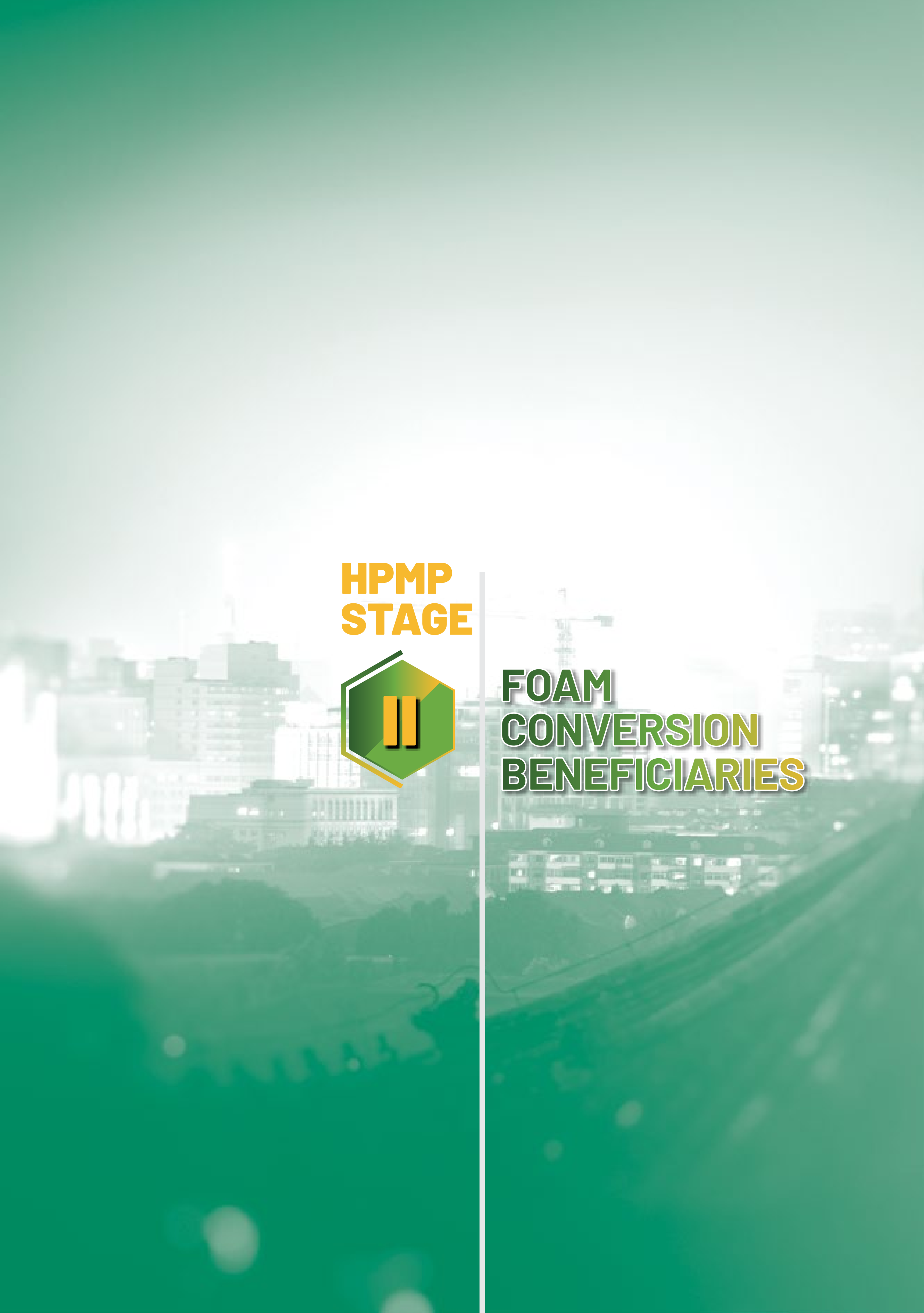
**AFTER**

## › ZUN UTARA INDUSTRY SDN. BHD

| Foam products | Baseline equipment | HCFC consumption (2009, MT) | System installed | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Commercial Refrigeration** | **Machine type:** High pressure<br>**Model:** OMS | **33** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** September 2013<br>**Completion Date:** May 2015 |

**BEFORE**

**AFTER**



# HPMP STAGE II

# FOAM CONVERSION BENEFICIARIES

# HPMP STAGE II › FOAM CONVERSION BENEFICIARIES

## › WONG BROTHERS REFRIGERATION SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Coldroom & panel** | **Machine type:** High pressure<br>**Model:** Cannon A200 | **20** | **Cyclopentane system** | **Procuring new machinery (A Compact 200FC Penta Basic)** | **Start Date:** March 2018<br>**Completion Date:** December 2019 |

## › TECK CHUAN INDUSTRIAL SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel & coldroom** | **Machine type:** Low pressure<br>**Model:** Cannon C100 | **23.09** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** December 2017<br>**Completion Date:** December 2019 |

## › ASTINO SOUTHERN SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated roofing** | **Machine type:** Low pressure<br>**Model:** Taiwan Q2459 | **23.4** | **Cyclopentane & pre-blended cyclopentane systems** | **Procuring new machinery** | **Start Date:** December 2017<br>**Completion Date:** December 2019 |

## › RC&A REFRIGERATION PARTS SUPPLIES SDN BHD

(WELMETRA INDUSTRI S/B)

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Coldroom & panel** | **Machine type:**<br>High pressure<br>**Model:**<br>GMA H200 | **27.5** | **Cyclopentane & pre-blended cyclopentane systems** | **Procuring new machinery** | **Start Date:**<br>April 2018<br>**Completion Date:**<br>December 2019 |

## › THUNG HING METAL INDUSTRY SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated roofing** | **Machine type:**<br>Low pressure<br>**Model:**<br>Taiwan | **29** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>April 2018<br>**Completion Date:**<br>December 2019 |

## › LE NAM MEGASHEET (M) SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **PU insulated roofing** | **Machine type:**<br>Low pressure<br>**Model:**<br>Taiwan | **40.48** | **Pre-blended cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>March 2018<br>**Completion Date:**<br>November 2019 |

## › KOSSAN FRP INDUSTRIES SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Thermal & ice box** | **Machine type:**<br>High pressure<br>**Model:**<br>GMA H40& 100 | **40.48** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>March 2018<br>**Completion Date:**<br>November 2019 |

## › POWER METAL TECHNOLOGIES (M) SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **AHU panels** | **Machine type:**<br>High pressure<br>**Model:**<br>Cannon A40 & OMS Eco 100 | **35.12** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>March 2018<br>**Completion Date:**<br>December 2019 |

> **“We are extremely grateful to the DOE for their extraordinary grant, which has empowered our transition to non-HCFCs. This important change not only protects the ozone layer but also proudly reflects our unwavering commitment to protecting the environment.”**

## › OOI JOO KEE & BROTHERS SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated roofing** | **Machine type:** Low pressure<br>**Model:** Taiwan HJ | **62.92** | **Cyclopentane & pre-blended cyclopentane systems** | **Procuring new machinery** | **Start Date:** March 2018<br>**Completion Date:** December 2019 |

## › ASIA ROOFING INDUSTRIES SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **PU insulated roofing** | **Machine type:** Low pressure<br>**Model:** Jason Machine/LZ22 | **76** | **Cyclopentane system** | **Procuring new machinery** | **Start Date:** December 2017<br>**Completion Date:** May 2019 |

## › THERMOFOAM MARKETING SDN BHD

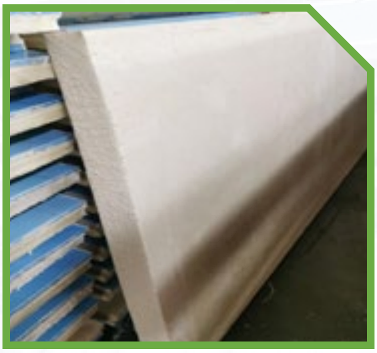
| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:** High Pressure<br>**Model:** OMS C100 | **22.3** | **Cyclopentane** | **Procuring new machinery** | **Start Date:** July 2022<br>**Completion Date:** December 2023 |

## › ALPS POLYMERS

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated box** | **Machine type:** High pressure<br>**Model:** Canon HC 40 | **5** | **Pre-blended methylal system** | **Retrofitting** | **Start Date:** August 2023<br>**Completion Date:** December 2023 |

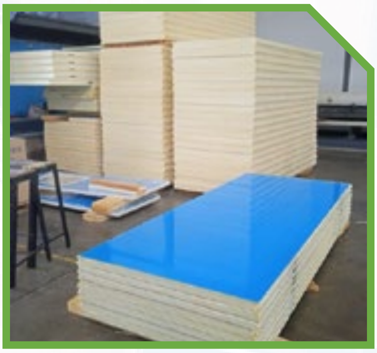
## › TOP AMITY SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panels** | **Machine type:**<br>High Pressure and Low Pressure<br>**Model:**<br>GMA LV100 | **5.01** | **Pre-blended cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>June 2020<br>**Completion Date:**<br>December 2022 |



## › CHONG BROTHERS COLDROOM ENGINEERING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Sandwich panels** | **Machine type:**<br>High pressure<br>**Model:**<br>OMS/ Ecomaster | **5** | **Pre-blended cyclopentane system** | **Procuring new machinery** | **Start Date:**<br>June 2020<br>**Completion Date:**<br>October 2022 |



## › NYC PRODUCTS SDN BHD

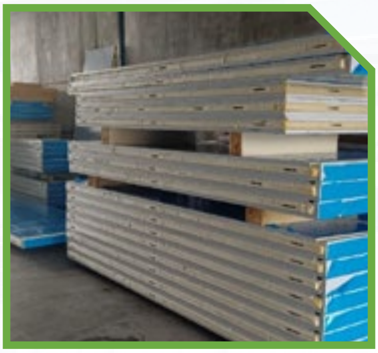
| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Floral Hard Foam** | **Machine type:**<br>High pressure<br>**Model:**<br>Cannon A200 | **5.75** | **Water blown** | **Retrofitting** | **Start Date:**<br>January 2022<br>**Completion Date:**<br>December 2022 |

## › SNOWFALL REFRIGERATED TRUCK & COLDROOM SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel & commercial Truck** | **Machine type:**<br>Low pressure<br>**Model:**<br>Saip Se100 | **6** | **Pre-blended methylal** | **Procuring new machinery** | **Start Date:**<br>January 2021<br>**Completion Date:**<br>December 2021 |

## › P.K.L INSULATION TRADING

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:**<br>High pressure<br>**Model:**<br>Elastogran Pu80 | **6** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:**<br>January 2021<br>**Completion Date:**<br>February 2024 |

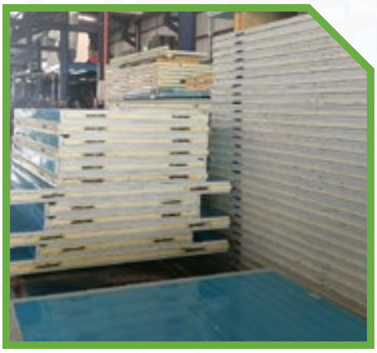


## › HI-TECH PRE-INSULATED PIPES S/B

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Pre-insulated pipes** | **Machine type:**<br>Low pressure<br>**Model:**<br>Cannon A100 | **6.11** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:**<br>February 2021<br>**Completion Date:**<br>August 2022 |

## › COOLMAX REFRIGERATION INDUSTRIES

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:** Manual | **7** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:** June 2020<br>**Completion Date:** February 2023 |



## › P.S. COLDROOM ENGINEERING SDN BHD

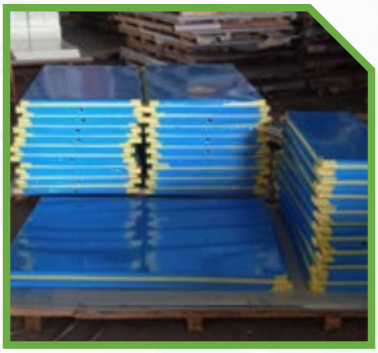
| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:** High pressure<br>**Model:** OMS Eco 200 | **6.8** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:** June 2020<br>**Completion Date:** April 2022 |

## › WATER-CARE INDUSTRIES SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Solar Heat Water** | **Machine type:**<br>High pressure<br>**Model:**<br>OMS Eco 100 | **7.48** | **Water blown** | **Retrofitting** | **Start Date:**<br>July 2022<br>**Completion Date:**<br>December 2022 |

## › COOLAXIS SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel & AHU** | **Machine type:**<br>High pressure<br>**Model:**<br>Cannon/ B60 | **7.8** | **Pre-blended cyclopentane** | **Procuring new machine** | **Start Date:**<br>June 2020<br>**Completion Date:**<br>April 2022 |



## › POWER COOL ENGINEERING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Commercial Chiller & Freezer** | **Machine type:**<br>Low pressure<br>**Model:**<br>Taiwan 307-500 | **8.4** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:**<br>June 2020<br>**Completion Date:**<br>August 2023 |

## › SMC COMPOSITE SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel water tank** | **Machine type:**<br>High pressure<br>**Model:**<br>Ecoplus 35R<br>MT 12-E | **8.75** | **Pre-blended methylal** | **Procuring new machinery** | **Start Date:**<br>July 2022<br>**Completion Date:**<br>May 2023 |

## ASTINO (M) COLOUR STEEL SHEET SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated roofing** | **Machine type:**<br>Low pressure<br>**Model:**<br>1) Taiwan/ HJ10307053-1<br>2) Jaan Sherng FA | **10.12** | **Pre-blended cyclopentane** | **Retrofitting** | **Start Date:**<br>July 2017<br>**Completion Date:**<br>November 2019 |

## › ROTO SPEED MOULDING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Thermal ice box & Insulated box** | **Machine type:**<br>Low pressure<br>**Model:**<br>GMA LV 30 & 100 | **11.132** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:**<br>December 2020<br>**Completion Date:**<br>February 2023 |

## › INSULATED BOX MANUFACTURER SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated box** | **Machine type:** High pressure<br>**Model:** Cannon A100 | **12** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:** June 2020<br>**Completion Date:** May 2023 |

## › HEWGANT SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Insulated box** | **Machine type:** High pressure<br>**Model:** OMS/ H40 | **13.01** | **Pre-blended cyclopentane** | **Retrofitting** | **Start Date:** June 2019<br>**Completion Date:** September 2020 |

## › CENTURY MANUFACTURING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:**<br>High pressure<br>**Model:**<br>GMA/ H100 | **14.35** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:**<br>June 2020<br>**Completion Date:**<br>October 2022 |

## › ALLIED FOAM INSULATION SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Pre-insulated pipe** | **Machine type:**<br>Low pressure<br>**Model:**<br>C100/LV100 | **16** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:**<br>Mac 2020<br>**Completion Date:**<br>December 2022 |

## › PERNIAGAAN NAM SING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Commercial Chiller & Refrigerator** | **Machine type:** High pressure<br>**Model:** Cannon A100 | **3** | **Pre-blended methylal** | **Retrofitting** | **Start Date:** June 2023<br>**Completion Date:** December 2023 |

## › MSM EQUIPMENT MANUFACTURER SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Commercial Chiller & Refrigerator** | **Machine type:** High pressure<br>**Model:** Cannon Hp | **3.3** | **Pre-blended cyclopentane** | **Retrofitting** | **Start Date:** December 2020<br>**Completion Date:** December 2023 |

## › SPEED COLDROOM ENGINEERING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Model:** OMS Eco 200 | **3.67** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:** December 2020<br>**Completion Date:** October 2022 |

## › NATURE PANNEL SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:** Manual | **3.8** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:** December 2020<br>**Completion Date:** October 2022 |

## › FRIGOTEC ENGINEERING & REFRIGERATION SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Cold Truck & Panel** | **Machine type:** Manual | **4** | **Pre-blended cyclopentane** | **Procuring new machinery** | **Start Date:** January 2021<br>**Completion Date:** March 2023 |

## › POLY UNIFOAM VISION SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Pre insulated Pipe** | **Machine type:** Low pressure<br>**Model:** GMA LV100 | **4.025** | **Pre-blended methylal** | **Retrofitting** | **Start Date:** September 2022<br>**Completion Date:** August 2023 |

## › KIM REFRIGERATION INDUSTRIES SDN BHD

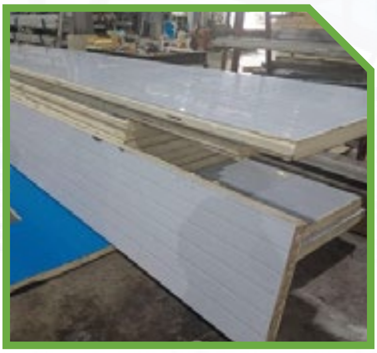
| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel & commercial refrigerator** | **Machine type:**<br>Low Pressure<br>**Model:**<br>SAIP SE30 | **4.2** | **Pre-blended methylal** | **Retrofitting** | **Start Date:**<br>August 2023<br>**Completion Date:**<br>December 2023 |

## › TECK GUAN STEEL SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Roofing** | **Machine type:**<br>HP & LP<br>**Model:**<br>Taiwan | **0.57** | **$H_2O/CO_2$** | **Procuring new machinery** | **Start Date:**<br>December 2022<br>**Completion Date:**<br>February 2023 |

## › THERMO COOLING ENGINEERING SDN BHD

| Foam products | Baseline equipment | HCFC consumption (2015, MT) | Ozone-friendly alternatives | Conversion method | Transition process |
|---|---|---|---|---|---|
| **Panel** | **Machine type:**<br>HP & LP<br>**Model:**<br>China & Cannon B100 | **4.15** | **Cyclopentane** | **Procuring new machinery** | **Start Date:**<br>December 2020<br>**Completion Date:**<br>November 2023 |



> **“Through the implementation of this technology, we have learned that it is an ozone-friendly and sustainable solution.”**

## Sustainable Manufacturing Practices

The polyurethane foam industry has evolved significantly from its early days of using harmful chemicals to adopting more eco-friendly alternatives. Through adherence to international agreements, technological innovation, and commitment to sustainability, the industry plays a significant role in protecting the ozone layer.

Although the industry has made significant strides in reducing its ozone-depleting footprint, there are several on-going challenges in line to the mission. Some alternatives to CFCs, like HFCs, while ozone-friendly, have high GWP, contributing to climate change. There is a global effort to transition to substances that are both ozone-friendly and have low GWP. Apart from this, continuous efforts are needed to meet global regulatory requirements (e.g. Kigali Amendment to the Montreal Protocol, which addresses HFCs) and to invest in greener, more sustainable alternatives. Therefore, on-going advancements are necessary to ensure that both ozone layer protection and climate change mitigation are addressed simultaneously.

The role of ODS related industries, in general, in protecting the ozone layer has shifted from being part of the problem to being a key part of the solution. By phasing out harmful chemicals, developing alternatives, adhering to international regulations, and adopting sustainable practices, industries play a vital role in healing the ozone layer and preventing further damage. The continued collaboration between industries, governments, and environmental organizations will be crucial in maintaining the success of these efforts.

# Chapter 6
# BARRIERS AND CHALLENGES

The transition to zero ozone-depleting substances (ODS) in the polyurethane foam industry presents a complex array of challenges, shaped by the diverse roles and interests of multiple stakeholders ***(Fig. 6.1)***. Manufacturers face the dual challenge of innovating to develop environmentally friendly alternatives while ensuring that product performance and cost efficiency remain uncompromised. Government agencies and international organizations serve as enforcers of regulations and providers of incentives, driving the adoption of sustainable practices across the industry.

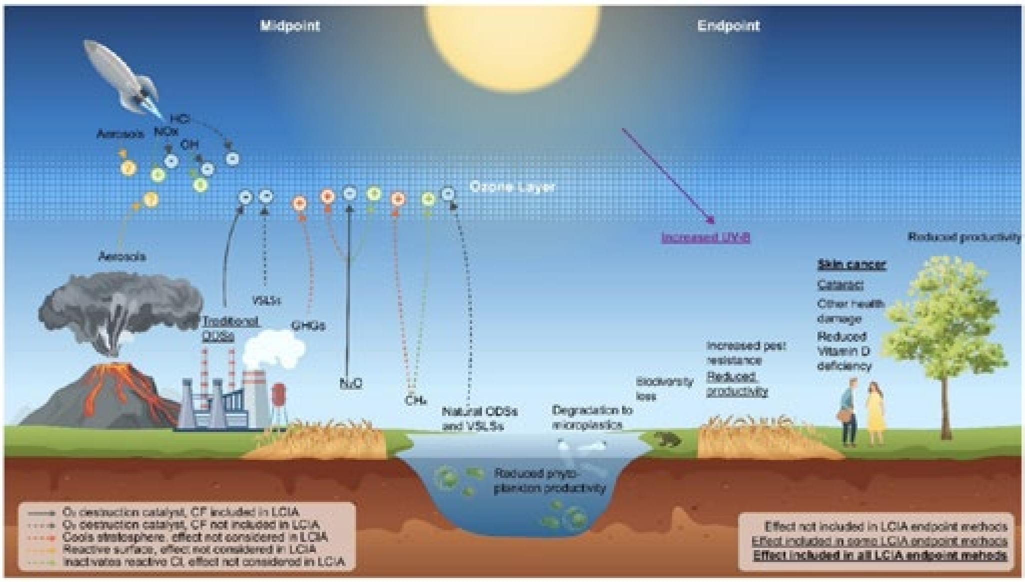


*Figure 6.1: Summary of the limitations and challenges related to midpoint and endpoint characterization. Plus (+) signs refer to positive effects on the ozone layer, minus signs to negative effects, and question marks to undecided effects. Illustration by: Francesco Gavardi.*

Furthermore, industry and trade associations help to facilitate collaboration, ensuring effective knowledge-sharing and standard-setting to support the transition. Complementing this effort, research and development entities drive innovation by exploring new materials and technologies. The influence of customers and end-users also plays a significant role, as their growing preference for eco-friendly products continues to shape market demand. Similarly, builders and contractors contribute to advancing this agenda by integrating and promoting zero-ODS solutions in the construction sector, thereby reinforcing the industry's overall progress toward sustainability. Environmental groups, NGOs, and advocacy organizations provide crucial oversight, advocating for policies and practices that prioritize ecological health. Investors and financial institutions contribute by funding sustainable projects and enterprises, while supply chain partners ensure the availability and integration of alternative materials. Successfully navigating these interconnected dynamics is essential for a smooth and impactful transition to zero ODS in the polyurethane foam industry.

Polyurethane foam manufacturing industry must adapt their processes and materials to eliminate ODS. The transition from ozone-depleting substances to more environmentally friendly alternatives presents several significant challenges that must be addressed. One of the primary issues is finding suitable alternative chemicals to replace substances like chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), as these new blowing agents and chemical formulations must offer similar or better performance while ensuring they do not contribute to ozone depletion. Suppliers of alternative blowing agents and other chemicals play a crucial role in providing the necessary support to the PU foam industry.

Another major challenge is the cost implications, as developing, testing, and implementing new technologies and materials can be expensive. This includes the costs of research and development, pilot production, and scaling up to full production, which can place a financial burden on manufacturers. Additionally, ensuring that new materials meet the required performance and quality standards for various applications is crucial. New blowing agents must provide comparable or improved insulation properties, fire resistance, and durability, which can be difficult to achieve.

Government agencies such as Department of Environment (DOE), MITI and Royal Malaysian Customs Department (RMCD) are entities responsible for setting and enforcing environmental regulations and standards as well as control imports of ODS. The Montreal Protocol, in particular, focuses on phasing out substances that deplete ozone layer. While organisations such as UNDP, UNIDO, UNEP and the World Bank serve as the Implementing Agencies that provide technical assistance, financial resources and capacity building support for projects aimed at phasing out ODS and promoting sustainable alternatives as symbolised.

Navigating the complex landscape of regulatory compliance also presents a hurdle, as different regions may have varying standards and timelines for phasing out ODS. Staying compliant with these regulations can be challenging especially for global manufacturer. The transition often requires significant changes in industry readiness, including adjustments in manufacturing processes, equipment, and worker training, all of which require careful planning and coordination.

Market acceptance can also be a barrier, as customers and end-users may be resistant to adopting new products, particularly if they perceive the alternatives as being more expensive or less effective.

**Furthermore, while the goal is to eliminate substances that deplete the ozone layer, it is essential to ensure that the new alternatives do not have other negative environmental impacts, such as contributing to global warming or pollution.**

Supply chain issues may further complicate the transition, as the availability of new materials and chemicals may be limited, making it crucial to establish a reliable supply chain to support the transition to these new technologies. Addressing these challenges requires coordinated efforts from governments, industries, and stakeholders to ensure a smooth and sustainable transition.

Academic Institutions such as universities and research institutes have been intensively conducting studies on new alternatives and technologies. Companies and laboratories focused on developing and testing new chemical formulations and processes. Those who use polyurethane foam in construction and insulation are well informed about and adapt to new materials. End-users of products containing polyurethane foam have slowly understand the benefits and changes associated with new materials.

Financial providers and investors invest in new technologies and have greater influence the pace and scale of the transition. Companies involved in the distribution of raw materials and finished products, ensure that new materials are available and delivered efficiently.

The barriers to transitioning to zero ODS in the polyurethane foam industry can be categorized into several main areas. They are as listed below:

### Technical

**Performance Issues:** New blowing agents and formulations may not yet match the performance of ODS-containing products in terms of insulation, durability, and other critical properties.

**Compatibility:** New chemicals may not be compatible with existing production processes or formulations, requiring significant modifications.

### Economic

**High Costs:** Developing and implementing new technologies can be costly. This includes research and development expenses, equipment upgrades, and potential increased costs for new raw materials.

**Market Prices:** New alternatives may have higher costs, which could affect the price competitiveness of the end products.

### Regulatory

**Compliance:** Adhering to evolving regulations and standards can be complex and burdensome. Different regions might have varying requirements and timelines.

**Certifications:** Gaining the necessary certifications for new products or processes can be time-consuming and costly.

### Operational

**Process Adaptation:** Manufacturing processes may need to be redesigned or upgraded to accommodate new materials, which can disrupt production and require investment.

**Training:** Engineers, technicians and workers may need specialized training to handle new technologies and processes.

### Market

**Customer Acceptance:** There may be resistance from customers who are accustomed to traditional products and may be sceptical about the benefits or reliability of new alternatives.

**Demand Fluctuations:** Changes in market demand for products using new technologies could affect the economic feasibility of transitioning.

### Supply Chain

**Material Availability:** New blowing agents and chemicals might have limited availability or supply chain issues, making it difficult for manufacturers to obtain the necessary materials.

### Environmental and Health

**Unintended Consequences:** New alternatives must be evaluated to ensure they do not have other environmental or health impacts, such as contributing to global warming or toxicity.

*The economic perspectives of the polyurethane foam market*

## Challenges in Selecting Alternative Blowing Agents

The polyurethane foam industry faces significant challenges as it transitions from traditional blowing agents to more environmentally sustainable alternatives. These challenges are driven by increasing pressure from environmental regulations aimed at reducing the use of high-global-warming-potential (GWP) substances, as well as the need to address technological limitations and economic constraints.

This segment delves into the key issues associated with various alternative blowing agents, including hydrofluorocarbons (HFCs), hydrofluoroolefins (HFOs), methylal, Ecomate® (Methyl Formate), water-based systems, hydrocarbons, pre-blended hydrocarbons and third-stream injection in the mixing head. Each of these alternatives comes with its own set of advantages and drawbacks, from their environmental impact and cost to safety concerns and technical feasibility.

**Hydrofluorocarbons (HFCs)**, such as 245fa, 365mfc, and 227ea, have been widely used as blowing agents in polyurethane foam production. However, they are limited by their high Global Warming Potential (GWP) and cost. When Malaysia ratified the Kigali Amendment to the Montreal Protocol in 2020, which aims to phase down the use of HFCs, this necessitates the industry to seek alternatives with lower GWP. While HFCs have been effective, their environmental impact and impending regulations present a significant challenge for future implementation.

**Hydrofluoroolefins (HFOs)** are emerging as a promising alternative due to their low GWP. However, they still face limitations in large commercial-scale supply and high costs, ranging between USD 15-20 per kilogram. The production infrastructure for HFOs is not yet fully established, leading to supply chain constraints and elevated prices. This makes large-scale commercial use of HFOs difficult for many Malaysian manufacturers, particularly smaller companies that may not have the resources to absorb these higher operational costs.

**Methylal,** a potential alternative, is flammable both as a pure substance and when blended in polyols. This flammability necessitates safety precautions similar to those required for hydrocarbons. While Methylal presents an affordable and technically feasible option, its flammability poses a challenge, especially for enterprises operating with limited capital to invest in extensive safety upgrade.

**Ecomate® (MethylFormate)** is another alternative blowing agent that is flammable in its pure form. However, it can be formulated into non-flammable system (below 6 ppm). While this characteristic provides an advantage in terms of safety, but the challenge remains in ensuring proper formulation and handling to maintain safety. Careful management is essential to avoid accidents, which may require additional training and investment in safe production practices.

**Water-based system** present a feasible alternative in some applications in Malaysia, particularly due to their low environmental impact. However, these systems have certain limitations, such as slower reaction rates and lower foam insulation properties compared to other blowing agents. Despite these drawbacks, water-based systems are a viable option for specific applications where environmental concerns outweigh performance considerations.

**Hydrocarbons,** such as cyclopentane, are a well-established and widely used blowing agent in PU foam production. They are cost-effective and have a long history of use in the industry. However, hydrocarbons are highly flammable and explosive, which significantly increases capital costs due to the need for specialized equipment and safety measures. These safety concerns limit their application in certain contexts where flammability and explosion risks (***Fig. 6.2***) are critical factors. These safety concerns are particularly challenging for small and medium-sized enterprises (SMEs) in Malaysia, which may struggle to afford the significant investments needed to safely use hydrocarbons in their production processes ***(Fig. 6.3)***.

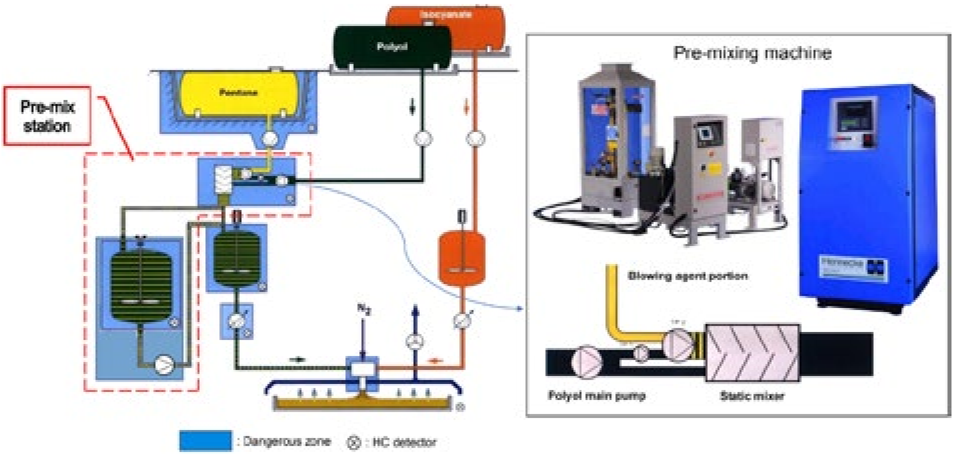


*Figure 6.2: Normal process for cyclopentane (C5) adoption.*

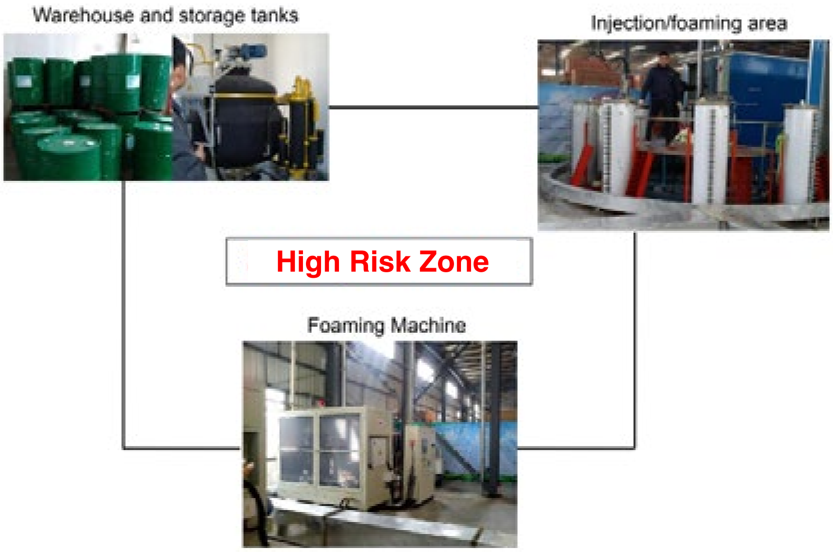


*Figure 6.3: High Risk zones for pre blended cyclopentane system*

Pre-blended hydrocarbons offer a solution to some of the challenges associated with using hydrocarbons as blowing agents. By pre-blending, the handling and storage of pure hydrocarbons can be minimized, reducing safety risks. However, the flammability and explosion hazards associated with hydrocarbons still persist, requiring careful management and safety protocols. Capital investment for machineries and their accessories ***(Fig. 6.4)*** is significant for the long-run safe operations.

Malaysia's PU foam industry faces a complex landscape of challenges as it seeks to transition to non-ODS blowing agents. While alternatives such as HFOs, methylal, Ecomate®, water-based systems, and hydrocarbons offer potential solutions, each comes with its own set of limitations and risks. Industries that have shifted away from high-GWP substances like HFCs is driven by regulatory pressures and environmental concerns. However, the successful adoption of alternative blowing agents will require a careful balance of performance, safety, cost, and environmental impact (***Fig. 6.5***). As the industry

*Figure 6.4: The mixing head and the fully automated injection machine for cyclopentane (C5) adoption.*

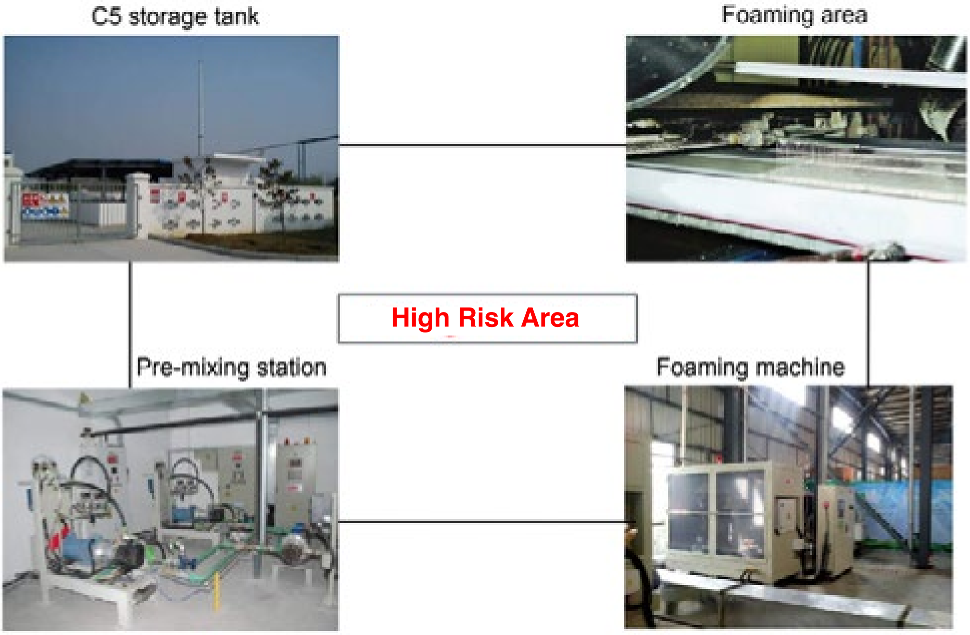


*Figure 6.5: The risks with hydrocarbon such as cyclopentane (C5) should focus on four identified high risk areas.*

continues to evolve, innovation and technological advancements will be crucial in overcoming these challenges and ensuring a sustainable future for polyurethane foam production.

## Machines and Equipment Adjustments

Machine adaptation and optimization are critical components in the transition to using alternative blowing agents in foam production. As the industry moves away from traditional ozone-depleting substances (ODS) and high-global warming potential (GWP) chemicals, the need for equipment that can safely and efficiently handle new materials has become increasingly important. In Malaysia, machines and equipment for the production of polyurethane foam are entirely imported. Technical services can be obtained through sales distribution houses which sometimes offer training and demonstration of machines and equipment. However, blowing agents that are easily form into gaseous state and / or flammable, require either modification of the existing machine or a total replacement to a new machine.

Specialists from countries such as Germany, Italy, the United States, and China are frequently consulted for technical issues, resulting in prolonged downtimes due to the time needed for their expertise. This reliance underscores the need for Malaysia to develop local expertise and enhance its capacity for machine production and maintenance to ensure a more efficient and self-reliant transition to new technologies.

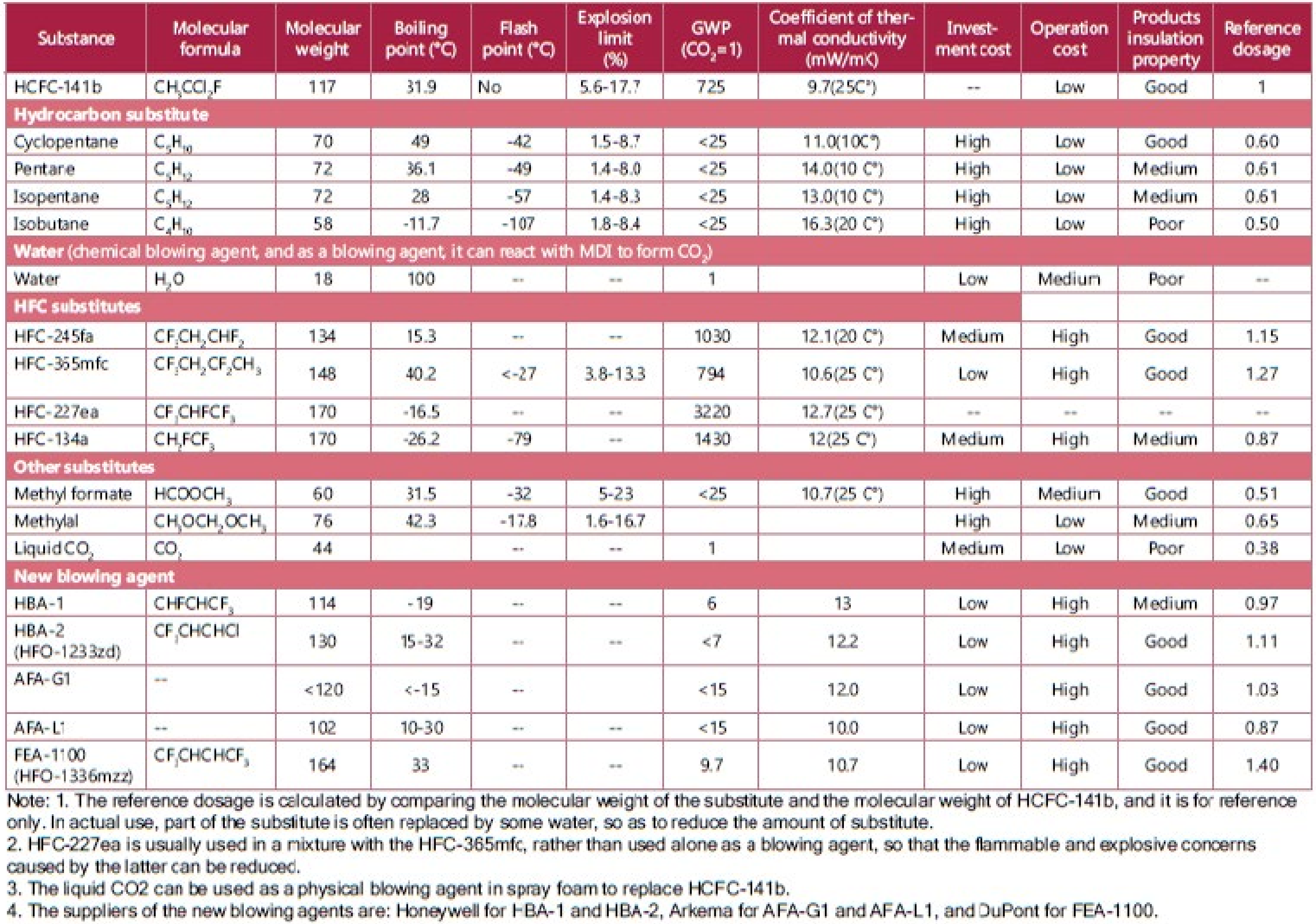
One of the foremost challenges in transitioning to alternative blowing agents is ensuring compatibility and adaptation with existing foam production machines. Different blowing agents have unique chemical and physical properties (***Table 6.1***), which may necessitate specific equipment adaptations or upgrades. For instance, certain blowing agents such as formic acid, methyl formate, hydrofluoroolefin and etc. might require corrosion-resistant materials in equipment due to their reactivity to standard steel drum. Moreover, machines designed for traditional blowing agents may not be compatible with the physical properties of alternatives, such as their boiling points, densities, or viscosities. Evaluating and ensuring compatibility is crucial to maintain optimal performance and safety.

Blending and dispensing systems are essential in the accurate metering and mixing of alternative blowing agents with polyols and isocyanates. The precise formulation is essential to achieving the desired foam properties while minimizing material waste. Upgrading these systems may involve installing more sophisticated pumps and mixers capable of handling varying viscosities and densities of new agents. Advanced controls and sensors are also necessary to ensure consistent and accurate dosing, which is vital for maintaining product quality and process efficiency.

Mixing equipment ensures the efficient blending of cyclopentane with polyol for foam production, with different types of mixers utilized to meet the specific needs of the process. High-shear mixers, such as rotor-stator mixers and inline high-shear mixers, are ideal for ensuring rapid and uniform blending of cyclopentane into the polyol. These mixers generate turbulence to quickly disperse the cyclopentane, ensuring a consistent blend. Static mixers, on designed for continuous blending, are installed directly in the pipelines. The polyol blend and cyclopentane are mixed as they flow through a series of elements designed to induce mixing, making them efficient for continuous processes.

Agitated mixing tanks utilize properly designed agitators, such as marine impellers, turbine mixers, or pitched-blade impellers, to create sufficient turbulence for cyclopentane dispersion. These tanks must be sealed effectively to prevent cyclopentane evaporation and minimize the risk of ignition. Vacuum mixers are particularly useful in degassing the blend and reducing the risk of vapor accumulation, especially when high

**One of the foremost challenges in transitioning to alternative blowing agents is ensuring compatibility and adaptation with existing foam production machines.**



| Substance | Molecular formula | Molecular weight | Boiling point (°C) | Flash point (°C) | Explosion limit (%) | GWP ($CO_2$=1) | Coefficient of thermal conductivity (mW/mK) | Invest-ment cost | Operation cost | Products insulation property | Reference dosage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HCFC-141b | $CH_3CCl_2F$ | 117 | 31.9 | No | 5.6-17.7 | 725 | 9.7(25C°) | -- | Low | Good | 1 |
| **Hydrocarbon substitute** | | | | | | | | | | | |
| Cyclopentane | $C_5H_{10}$ | 70 | 49 | -42 | 1.5-8.7 | <25 | 11.0(10C°) | High | Low | Good | 0.60 |
| Pentane | $C_5H_{12}$ | 72 | 36.1 | -49 | 1.4-8.0 | <25 | 14.0(10 C°) | High | Low | Medium | 0.61 |
| Isopentane | $C_5H_{12}$ | 72 | 28 | -57 | 1.4-8.3 | <25 | 13.0(10 C°) | High | Low | Medium | 0.61 |
| Isobutane | $C_4H_{10}$ | 58 | -11.7 | -107 | 1.8-8.4 | <25 | 16.3(20 C°) | High | Low | Poor | 0.50 |
| **Water** (chemical blowing agent, and as a blowing agent, it can react with MDI to form $CO_2$) | | | | | | | | | | | |
| Water | $H_2O$ | 18 | 100 | -- | -- | 1 | | Low | Medium | Poor | -- |
| **HFC substitutes** | | | | | | | | | | | |
| HFC-245fa | $CF_3CH_2CHF_2$ | 134 | 15.3 | -- | -- | 1030 | 12.1(20 C°) | Medium | High | Good | 1.15 |
| HFC-365mfc | $CF_3CH_2CF_2CH_3$ | 148 | 40.2 | <-27 | 3.8-13.3 | 794 | 10.6(25 C°) | Low | High | Good | 1.27 |
| HFC-227ea | $CF_3CHFCF_3$ | 170 | -16.5 | -- | -- | 3220 | 12.7(25 C°) | -- | -- | -- | -- |
| HFC-134a | $CH_2FCF_3$ | 170 | -26.2 | -79 | -- | 1430 | 12(25 C°) | Medium | High | Medium | 0.87 |
| **Other substitutes** | | | | | | | | | | | |
| Methyl formate | $HCOOCH_3$ | 60 | 31.5 | -32 | 5-23 | <25 | 10.7(25 C°) | High | Medium | Good | 0.51 |
| Methylal | $CH_3OCH_2OCH_3$ | 76 | 42.3 | -17.8 | 1.6-16.7 | | | High | Low | Medium | 0.65 |
| Liquid $CO_2$ | $CO_2$ | 44 | | -- | -- | 1 | | Medium | Low | Poor | 0.38 |
| **New blowing agent** | | | | | | | | | | | |
| HBA-1 | $CHFCHCF_3$ | 114 | -19 | -- | -- | 6 | 13 | Low | High | Medium | 0.97 |
| HBA-2 (HFO-1233zd) | $CF_3CHCHCl$ | 130 | 15-32 | -- | -- | <7 | 12.2 | Low | High | Good | 1.11 |
| AFA-G1 | -- | <120 | <-15 | -- | | <15 | 12.0 | Low | High | Good | 1.03 |
| AFA-L1 | -- | 102 | 10-30 | -- | -- | <15 | 10.0 | Low | High | Good | 0.87 |
| FEA-1100 (HFO-1336mzz) | $CF_3CHCHCF_3$ | 164 | 33 | -- | -- | 9.7 | 10.7 | Low | High | Good | 1.40 |

Note: 1. The reference dosage is calculated by comparing the molecular weight of the substitute and the molecular weight of HCFC-141b, and it is for reference only. In actual use, part of the substitute is often replaced by some water, so as to reduce the amount of substitute.

2. HFC-227ea is usually used in a mixture with the HFC-365mfc, rather than used alone as a blowing agent, so that the flammable and explosive concerns caused by the latter can be reduced.

3. The liquid CO2 can be used as a physical blowing agent in spray foam to replace HCFC-141b.

4. The suppliers of the new blowing agents are: Honeywell for HBA-1 and HBA-2, Arkema for AFA-G1 and AFA-L1, and DuPont for FEA-1100.

*Table 6.1: The physical parameters and technical evaluation of the commonly used substitutes for HCFC-141b in PU foam*

Source: Journal of Applied Polymer Science 81(2):486 - 493 concentrations of cyclopentane are involved. Additionally, continuous metering and mixing systems incorporate metering pumps to precisely dose cyclopentane into the polyol stream, ensuring a controlled ratio and consistent blending throughout the process. These various mixing systems are integral to achieving the desired foam properties while managing safety and efficiency.

The third-stream injection in the mixing head is a technique used to introduce blowing agents into the polyurethane foam formulation. This method allows for greater flexibility in the use of different blowing agents and formulations. However, it requires precise control and advanced equipment, which can increase production complexity and costs). The successful implementation of this technique depends on the specific formulation and application requirements.

The pressure and temperature control systems of production machines must be carefully managed when dealing with alternative blowing agents. For instance, hydrocarbons or carbon dioxide ($CO_2$) may require different processing conditions compared to traditional ODS. Machines must be capable of operating under the specific pressure and temperature ranges suitable for these agents. This often involves upgrading components such as compressors, heaters, and coolers, and integrating precise control systems to maintain stable processing conditions. Failure to do so could result in suboptimal foam properties or even safety hazards.

Safety systems and compliance are paramount, especially when handling flammable or pressurized substances like certain alternative blowing agents. Equipment must be outfitted with appropriate safety controls, including gas detection systems, explosion-proof components, and emergency shutdown mechanisms. Additionally, compliance with relevant safety standards and regulations is non-negotiable. This includes adherence to industry-specific guidelines and governmental regulations regarding the safe handling and storage of potentially hazardous materials. Personal protective equipment (PPE) such as flame-resistant clothing, chemical-resistant gloves, safety goggles, and respiratory gear must be provided based on the specific hazards. Regular training ensures workers are well-versed in safe handling practices, hazard identification, and emergency response. Regular training ensures workers are well-versed in safe handling practices, hazard identification, and emergency response ***(Fig. 6.6)***.

*Figure 6.6: Workers wearing proper safety gear with visible safety signage*

Spill and leak management protocols, supported by containment systems and routine inspections, help prevent accidents. Fire prevention measures, such as automatic suppression systems, Class B fire extinguishers, and restrictions on open flames, are critical ***(Fig. 6.7).*** Routine equipment maintenance ensures all safety features function effectively, while emergency response plans prepare personnel for incidents like spills or fires. Compliance audits and real-time monitoring systems for detecting flammable gases or toxic emissions further enhance safety. Additionally, proper waste management of materials, including contaminated containers and expired blowing agents, is vital for environmental safety. By adopting these measures, the industry can create a safer work environment while ensuring compliance with regulations and standards.

Energy efficiency is another critical consideration in machine adaptation and optimization. As companies strive for sustainability, upgrading machinery to improve energy efficiency can significantly reduce overall energy consumption and operational costs. This may involve installing energy-efficient pumps, motors, and heating systems, as well as optimizing process flows to minimize energy losses. Enhanced energy efficiency not only lowers operational costs but also supports broader sustainability goals by reducing the carbon footprint of the production process.

Material handling and storage systems must be optimized to accommodate alternative blowing agents safely and efficiently. This could involve the installation of dedicated storage tanks, specialized piping, and handling procedures designed to prevent leaks or emissions. The physical and chemical properties of alternative agents may require unique storage conditions, such as specific temperature or pressure controls, to ensure safety and maintain material integrity.

Proper handling and disposal of discarded drums containing raw materials, particularly those that

*Figure 6.7: Preblended C5 tank is securely installed inside a safety cabinet and equipped with a flammable gas detector*

**Proper training ensures that personnel understand the unique properties and handling requirements of alternative blowing agents.**

are flammable or toxic, is critical to ensure safety and environmental protection. Drums should first be thoroughly emptied and cleaned to remove residual materials, using approved methods to prevent chemical reactions or emissions. Cleaning should be performed in well-ventilated areas, and workers must wear appropriate personal protective equipment (PPE), such as chemical-resistant gloves, safety goggles, and respirators. Drums should then be labelled as "empty" and stored in a designated, secure area away from ignition sources and incompatible substances. For flammable materials, grounding and bonding measures should be used to prevent static electricity buildup. Toxic material drums may require additional precautions, such as sealed containment or segregation from general waste.

Disposal must comply with local regulations and guidelines, involving certified hazardous waste disposal services for final treatment or recycling. Documentation of the disposal process is essential to ensure traceability and compliance with environmental laws. Regular training of personnel involved in drum handling and disposal is vital to minimize risks, and facilities should conduct periodic audits to assess and improve disposal practices. These measures collectively ensure the safe handling and disposal of discarded drums, protecting both workers and the environment.

A proactive maintenance and lifecycle management approach is essential to ensure machines operate at peak efficiency and reliability. Regular inspections and servicing help prevent downtime and optimize performance, extending the lifespan of the equipment. A well-implemented maintenance schedule can identify potential issues before they lead to significant problems, thus minimizing unplanned outages and maintaining consistent production quality.

Training and skill development are vital for operators and maintenance staff, especially when new materials and processes are introduced. Proper training ensures that personnel understand the unique properties and handling requirements of alternative blowing agents. It also helps them become familiar with updated machine processes and safety protocols, enhancing both efficiency and safety. Skilled operators are better equipped to troubleshoot issues and maintain optimal production conditions, reducing the risk of accidents or product defects.

Fostering a culture of continuous improvement within the organization is crucial for exploring new technologies and best practices. Regularly assessing and benchmarking performance metrics can identify opportunities for optimization, whether in terms of efficiency, safety, or environmental impact. By encouraging innovation and staying abreast of technological advancements, companies can continually enhance their processes and maintain a competitive edge.

Finally, monitoring and reporting systems should be established to track machine performance, material usage, and emissions. Transparent reporting on environmental impacts and compliance with regulatory requirements demonstrates a commitment to sustainability and stakeholder accountability. Advanced monitoring tools can provide real-time data on various aspects of the production process, enabling quick response to any deviations and ensuring adherence to best practices.

The adaptation and optimization of machines for alternative blowing agents in foam production involve a comprehensive approach encompassing compatibility assessments, system upgrades, safety considerations, energy efficiency, and continuous improvement. By addressing these aspects, companies can not only comply with environmental regulations but also achieve optimal performance and sustainability in their production processes. As the industry evolves, on-going innovation and a proactive stance toward adaptation will be crucial in navigating the challenges and opportunities presented by new materials and technologies.

## Overcoming The Challenges

The transition to ozone-depleting substances, ODS-free production in the polyurethane (PU) foam industry is a complex and multi-faceted endeavour. It requires a comprehensive support program encompassing various phases, from initial assessment to continuous improvement, with concerted effort to address technical, financial, regulatory and operational hurdle. One of the most significant obstacles has been matching the performance of traditional ozone-depleting substances (ODS) like CFCs and HCFCs, known for their superior insulation and stability. Alternative agents such as hydrofluoroolefins (HFOs), hydrocarbons, and $CO_2$ often require process modifications to achieve comparable thermal efficiency, fire safety, and dimensional stability. Additionally, adapting manufacturing processes to accommodate these new agents involves costly equipment upgrades, formulation changes, and research investments, posing a substantial burden on small and medium-sized enterprises (SMEs).

Safety and regulatory challenges further complicate the transition. For instance, the flammability of hydrocarbons necessitates enhanced safety measures, while manufacturers must navigate evolving global standards and certifications. Resistance from businesses accustomed to established processes, coupled with limited awareness of the environmental and technical benefits of alternatives, has slowed adoption. Supply chain issues, such as the limited availability of zero-ODP blowing agents in certain regions, add another layer of complexity. These challenges highlight the need for a structured and supportive framework to guide the industry toward sustainability.

Recognizing the magnitude of these challenges, the Malaysian government has played a crucial role in assisting the PU industry through the HPMP. The HPMP provides a comprehensive framework that includes technical, financial, and regulatory assistance to ease the industry's transition.

One of the key components of the HPMP is the provision of financial support, particularly for SMEs. Subsidies and funding opportunities help companies invest in new equipment and adopt alternative technologies without bearing the full financial burden. Additionally, the program facilitates technology transfer, ensuring access to advanced and safer machinery designed for zero-ODP production. Through training programs and capacity-building initiatives, the HPMP equips industry personnel with the skills and knowledge needed to handle new processes, improve safety, and comply with environmental regulations.

Beyond addressing immediate technical and financial challenges, the HPMP emphasizes sustainability and long-term improvement. Regular monitoring and evaluation of the program ensure compliance with ODS-free standards and identify areas for enhancement. Public awareness campaigns and industry workshops foster collaboration among stakeholders, driving innovation and knowledge-sharing across the sector. By creating a reliable supply chain for environmentally friendly blowing agents and promoting best practices in recycling and waste management, the HPMP supports the industry in achieving both environmental and operational sustainability.

# Chapter 7

# SUSTAINING GREEN PRACTICES IN PU FOAM INDUSTRY

The PU foam industry in Malaysia has had to balance economic growth and environmental responsibility. As one of the largest consumers of blowing agents in Southeast Asia, Malaysia's role in this global transition is critical. The government, industry stakeholders, and international organizations have all recognized that achieving sustainability in this sector is not just about adhering to regulations but also about embracing green innovation and practices that ensure long-term environmental protection while maintaining the industry's competitive edge.

Sustainable green practices in the PU foam industry involves transitioning towards eco-friendly production methods that minimize environmental harm while maintaining product quality and economic viability. The primary goal of sustainable greening is to reduce the industry's reliance on harmful substances like ODS and high-GWP chemicals and to adopt technologies and practices that are in line with global sustainability goals.

## Role of Government in Driving Sustainability

The Government, through the DOE, is committed to phasing out ozone depleting substances. This is demonstrated by its strong policy framework, highlighted by the comprehensive and collaborative approach to eliminate ODS through the HPMP. DOE uses the Approved Permit (AP) system and strict import quotas for HCFC, to ensure Malaysia aligns with the reduction schedule agreed under the Montreal Protocol.

Collaboration with different government agencies, such as Ministry of International Trade and Industry (MITI), Malaysian Industrial Development Authority (MIDA) and Royal Malaysian Customs Department, further strengthen these efforts. The Royal Malaysian Customs Department conducts random checks to prevent quota misuse at import or export checkpoints. While, MITI and MIDA work closely with DOE to facilitate smoother transitions for industries, ensuring they have access to necessary resources and guidance.

As part of their buy-in strategy, the DOE adopted a carrot-and-stick approach to help Malaysian industries transition away from using ODS. This was particularly important because many ODS users were SMEs that had invested heavily in equipment and facilities reliant on these substances. The switch to alternatives, such as cyclopentane, could have been financially burdensome and potentially detrimental to their businesses. Therefore, it was crucial to incentivize the transition while simultaneously raising awareness about the consequences of non-compliance.

### Role of Industry Towards Sustainable Greening Practices

Polyurethane (PU) industry in Malaysia is actively contributing to sustainable practices through various certifications and adherence to international standards. Companies like BASF have achieved significant sustainability milestones. BASF under Engineering Plastics Compounding plant in Pasir Gudang, Malaysia, has obtained both the International Sustainability and Carbon Certification (ISCC+) and REDcert$^2$ certifications (source: BASF). These certifications verify the sustainable sourcing and production processes of their PU materials, supporting customers in meeting their sustainability objectives. The PU industry adheres to several ISO standards to ensure quality and environmental responsibility:

- ISO 9001:2015: Specifies requirements for a quality management system, ensuring consistent product quality and customer satisfaction.
- ISO 14001:2015: Specifies requirements for an environmental management system, helping organizations enhance environmental performance.
- ISO 45001:2018: Specifies requirements for an occupational health and safety management system, ensuring safe and healthy workplaces.

These certifications demonstrate a commitment to quality, environmental stewardship, and workplace safety. The CertiPUR certification (source: ORSA Foam) is a voluntary program that assesses the environmental, health, and safety properties of flexible polyurethane foams used in bedding and upholstered furniture. It prohibits the use of harmful substances and sets stringent limits for certain components, ensuring that certified foams are free from heavy metals, carcinogenic dyes, and phthalate plasticizers.

The Montreal Protocol mandates the elimination of ODS in manufacturing processes. Malaysia's PU industry complies with this by avoiding the use of ODS, such as CFCs and HCFC, in foam production. This compliance is crucial for accessing international markets that enforce strict environmental regulations.

Many companies in the PU industry collaborate with vocational institutions and training centers to provide specialized courses on polyurethane chemistry, manufacturing processes, and sustainability practices. The focus areas include optimizing energy efficiency, implementing green manufacturing, and adopting non-ODS materials in production. Leading PU companies collaborate with local universities to drive innovation in eco-friendly materials, including bio-based polyurethane and recyclable PU foam. These partnerships often provide internships and research opportunities for students, fostering the next generation of industry experts.

Malaysia's Collaboration between the industry and educational institutions ensures that curricula are aligned with international sustainability and eco-certification standards. Human Resource Development Fund (HRDF) supports upskilling programs in advanced manufacturing techniques relevant to the PU industry. Training programs in automation, circular economy principles, and compliance with ISO standards are prioritized. Employees are encouraged to obtain certifications such as CertiPUR and ISO-related qualifications to ensure they are equipped with knowledge of global standards. Talent development focuses on training workers in data analytics, Internet of thing (IoT), and automation technologies to improve efficiency and sustainability. Regular industry events, such as the Asia Polyurethane Association conferences, allow professionals to exchange knowledge on sustainable practices and new technologies.

Some foam companies and system houses establish in-house R&D facilities to focus on developing low-emission PU foams and other green products, offering employees opportunities to specialize in cutting-edge technologies.

In summary, Malaysia's polyurethane industry is advancing sustainable greening through adherence to international certifications, eco-product labelling, and compliance with global environmental standards, thereby enhancing its competitiveness in the global market.

### Public Awareness and Engagement Programs

The Government recognized the importance in ensuring stakeholders, including manufacturers, suppliers and consumers, are well-informed about the environmental impact of ODS and adopting ozone-friendly alternatives. Over the course of HPMP Stage I and Stage II implementation, the DOE, in collaboration with other stakeholders, organized national ODS seminars to share the latest developments in non-ODS technologies and policies surrounding the PU foam industry. Based on visits by experts to enterprises during expert meeting in 2017 and further discussion with NOU, a Technical Guidance Document for foam sector was developed. The technical guidance was prepared to provide detail understanding of various HCFC alternatives that foam enterprise can adopt.

Technical training workshops and study tours were also organized for the industry, to provide valuable insights into sustainable practices and sharing of real-world case studies, to encourage industries to transition to greener technologies. Two technical visits were conducted during the implementation of HPMP. These tours provided Malaysian stakeholders with a deeper understanding of alternative technologies and best practices for adopting low-GWP and zero-ODP blowing agents like methylal and cyclopentane. By observing successful implementations abroad, Malaysian companies gained valuable insights into overcoming challenges such as supply chain issues, equipment modifications, and safety protocols.

### Study Tour to China

(12-16 March 2018)

The study tour brought together 12 Malaysian foam enterprises, three system houses and officers from DOE and UNDP. The objective was to enhance the capacity of Malaysian stakeholders through practical industrial exposure. The program included workshops with China's Foreign Cooperation Office (FECO), industry experts, and policy makers, focusing on alternative technologies to HCFCs. Participants visited foam manufacturers, equipment suppliers, and system houses that showcased advanced, non-HCFC technologies. Through these visits, participants gained first-hand insights into technology options, including chemical and equipment innovations, and expanded their professional networks within Malaysia and abroad.

## Study Tour to India

(28 April – 3 May 2024)

The India study tour, conducted in collaboration with the DOE and India's Ministry of Environment, Forests & Climate Change (MOEFCC), aimed to understand India's strategies for adopting low-global-warming-potential (GWP) alternatives post-HCFC phase-out. Malaysian delegates included officials from DOE, academic representatives, and technical personnel from PU system houses.

Key site visits included Manali Petrochemicals (MP), a PU system house manufacturing polyols and preblended polyol systems using blowing agents such as cyclopentane, Ecomate, and methylal. Delegates observed India's approach to addressing supply chain issues and technical challenges, such as corrosion from methylal. Another highlight was the visit to Central Institute of Petrochemicals Engineering & Technology (CIPET), a research and academic institute specializing in R&D and troubleshooting industrial challenges in petrochemicals and polymers.

For the SMEs, DOE conducted targeted roadshow, bringing in local and international industrial experts, to provide them guidance and reassure them the advantages of converting to more sustainable technologies. These roadshows also provide SMEs with information on available government support, such as financial and technical assistance under HPMP, as well as the long-term benefits of adopting low-GWP alternatives. These has been instrumental in the success of PU foam sector technology conversion projects under HPMP.

## Awareness activities conducted in accordance to HPMP

### 27-29 February 2012

Regional workshop on understanding links between ozone depletion and climate change, UNEP Ozone action, AIBD

Kuala Lumpur, Malaysia

### 4-5 March 2012

Seminar on ozone layer protection and global warming counter measures

Tokyo, Japan

### 28 August 2012

Launching of the HPMP Stage 1

Cyberjaya, Malaysia

### 18-20 February 2013

Study visits to ODS destruction facility in Indonesia

Java, Indonesia

### 3-14 March 2013

Study visit and seminar on Ozone layer protection and global warming counter measure

Tokyo, Japan

### 29-30 June 2013

Advancing ozone and climate protection technologies: Next steps-second international conference

Bangkok, Thailand

### 6-9 November 2013

4th Ozone2Climate technology roadshow and industry roundtable

Manila, Philippines

### 29 April 2014

Seminar on alternatives for foam sector

Putrajaya, Malaysia

### 29 September 2015

Award ceremony to 17 foam sector companies participated and completed the project under HPMP Stage 1 during Ozone Day Celebration 2015

Putrajaya, Malaysia

### 8 May 2017

Seminar on Hydrochlorofluorocarbon Phase-out Management Plan (HPMP) Stage II

Kuala Lumpur, Malaysia

### 20 - 24 August 2017

Consultative Workshop with International Experts in Foam Sector HPMP II

Selangor, Malaysia

### 12 - 16 March 2018

Study Tour PU Foam Sector SMEs in China

China

### 17 January 2020

Consultative workshop for foam sector

Putrajaya, Malaysia

### 17 February 2020

Workshop on Foam Alternatives and Hand Holding Activities to System Houses and PU Foam Companies under HCFC Phase-out Management Plan Stage II

Selangor, Malaysia

### 30 April 2021

Consultative Meeting for Foam Sector

Online

### 12 October 2021

Webinar entitled PU Foam Conversion Project Under the HPMP Stage II

Online

### 21 September 2021

Webinar foam sector-Technology choice

Online

### 1 March 2022

A virtual seminar on HCFC-141B Conversion to Alternative Technologies in Foam Sector

Online

### 4 - 6 September 2023

Consultation visits with PU foam expert Zhang Peng to 8 enterprises

- MSM Equipment Manufacturer Sdn Bhd
- Syarikat Kejuruteraan Elektrik Food Mei Sdn Bhd & Ocean Parade Sdn Bhd
- Power Cool Equipment Sdn Bhd
- Alps Polymer (M) Sdn Bhd
- Wincool Refrigeration & Air Cond Sdn Bhd
- Kim Refrigeration Industries Sdn Bhd
- NKR Continental Manufacturing Sdn Bhd

Malaysia

### 8 September 2023

Seminar on Safety and Sustainability in Polyurethane Foam

Putrajaya, Malaysia

### 28 April - 3 Mei 2024

Study Visit to India PU industry and Research Institute

India

*Figure 7.1: World Ozone Day Celebration 2024*

Every year, World Ozone Day (WOD) serves as a platform for the government to promote awareness about the critical importance of protecting the ozone layer while celebrating the achievements of industries that contribute to this cause ***(Fig. 7.1)***. Among these, the PU foam industry is prominently recognized for its efforts in reducing ozone-depleting substance (ODS) usage. These celebrations include the presentation of awards to companies that have successfully transitioned to environmentally friendly practices, highlighting sustainability as both a national commitment and a catalyst for industrial progress.

In 2015, as part of the World Ozone Day celebrations, Ozone Awards were conferred upon 17 companies that had completed their technology conversion projects under the first phase of the HCFC Phase-out Management Plan (HPMP Stage I). Similarly, during the 2023 celebration, eight foam manufacturing entrepreneurs were honoured for their successful implementation of technology conversion projects under HPMP Stage II ***(Fig. 7.2)***. These recognitions not only highlight the industry's pivotal role in environmental protection but also inspire continued efforts toward adopting sustainable practices across the sector.

*Figure 7.2: Honouring foam manufacturers for successful technology conversion under HPMP Stage II, World Ozone Day 2023*

## Continuous Research and Development

Research and development have been the driving force for the transformation of PU foam industry, particularly in finding innovative alternatives to ODS. One of the key areas of focus is the development of alternative blowing agents which contributes to the foam desired structure and properties. Research into hydrocarbons (HCs) and hydrofluoro olefins (HFOs) has yielded promising results, as they are able to meet performance standards, non-ODS and have zero / low GWP. HCs such as isopentane and cyclopentane are widely used in rigid and flexible foam applications. HFOs are also used in rigid foam insulation applications.

Additionally, the use of carbon dioxide ($CO_2$) and water as blowing agents offers even more sustainable options, as both have no ODP and low environmental impact. $CO_2$ is especially suited for high-pressure systems, while water and water-based agents (such as diluted formic acid) are effective in producing rigid foams with minimal environmental impact.

Research is also ongoing for bio-based polyols, from plant oils or natural resources such as agricultural biomass, which could potentially reduce reliance on synthetic chemicals and lower the overall environmental footprint on foam production. These bio-based alternatives offer promising potential sustainable benefits, especially as companies are shifting towards eco-friendly, circular economy practices that prioritize renewable resources and waste minimization.

In addition to research and development on alternative blowing agents, optimizing foam formulations to reduce the overall amount of blowing agent required can also be a sustainable approach. This can involve enhancing foam processing technologies or incorporating additives that improve foam properties without relying heavily on blowing agents. PU additives, including surfactants and catalysts, have evolved through multiple generations of modifications in order to be compatible with the whole PU system. Formulation development in the polyol blend has been extensively researched to meet specified industrial foam standards. Additionally, innovations in foam processing technologies allow for more efficient use of materials, reducing waste and energy consumption during production. The shift towards optimized formulations ensures that manufacturers can maintain high product quality and performance standards while contributing to global sustainability goals, particularly in reducing greenhouse gas emissions.

## Future Outlook

The polyurethane (PU) industry has a promising future, driven by sustainability, technological innovation, and expanding applications across various sectors. One of its most significant advancements lies in the move towards a circular economy, with innovations such as discovery of a few auxiliary blowing agents; chemical recycling and the development of bio-based polyurethanes from renewable resources like plant oils. These efforts not only reduce dependency on fossil fuels but also minimize environmental impact. Additionally, the integration of carbon capture technologies into PU production highlights how the industry is contributing to global efforts to reduce greenhouse gas emissions.

Smart materials are another exciting frontier for PU. Self-healing polyurethanes and materials responsive to heat, light, or moisture are being developed for use in coatings, wearables, automotive components, and adaptive insulation in buildings. These advancements promise to enhance product durability, efficiency, and adaptability. Moreover, the PU industry continues to expand its applications in construction, automotive, healthcare, and 3D printing. For example, lightweight PU materials are key to improving fuel efficiency and extending the range of electric vehicles, while biocompatible PU formulations are revolutionizing medical devices and prosthetics.

**The success in the greening of PU foam industry in Malaysia offers valuable lessons for other sectors. Its emphasis on innovation-driven growth, sustainability, and adaptability to evolving regulations demonstrates how industries can unlock new markets and thrive amidst challenges.**

By prioritizing R&D, fostering public-private partnerships, and adopting circular economy principles, other industries and emerging economies can replicate this success. Investments in green technologies and workforce development are also critical for building a competitive and sustainable industrial ecosystem.

Looking ahead, the PU industry is set to drive further breakthroughs. Artificial intelligence is being leveraged to accelerate material discovery, while PU's role in renewable energy infrastructure, such as wind turbines and hydrogen storage, is growing. Multifunctional coatings with properties like antimicrobial resistance and energy harvesting are on the horizon, alongside modular and biodegradable products that align with environmental priorities. The PU industry is poised to lead the way in sustainable material science, offering a blueprint for innovation, adaptability, and responsible growth, leading the way in creating solutions for a greener and more efficient future.

Malaysia's proactive approach has yielded multiple benefits. Environmentally, it has contributed to the restoration of the ozone layer and a reduction in greenhouse gas emissions. Economically, the transition has enhanced the competitiveness of Malaysian PU products in global markets that demand eco-friendly materials. The success in phasing out HCFCs demonstrates the effectiveness of coordinated policy implementation, industry collaboration, and capacity building.

The transition to environmentally friendly blowing agents in the PU foam industry is a complex undertaking, yet significant progress has been achieved through structured initiatives such as the HPMP. By addressing technical challenges, providing financial aid, and fostering collaboration, the program has paved the way for a smoother, more sustainable shift. As the industry continues to innovate and adopt sustainable practices, Malaysia is positioned to lead by example in reducing environmental harm while maintaining high-quality production standards.

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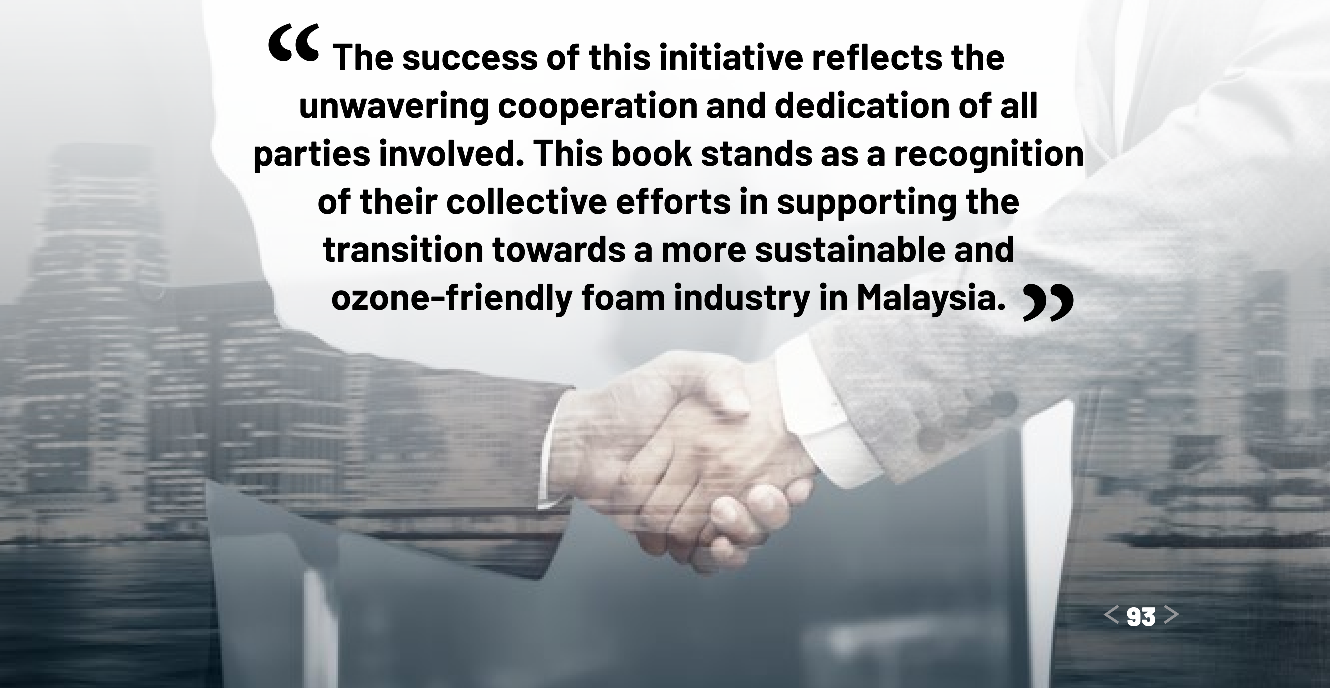

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