

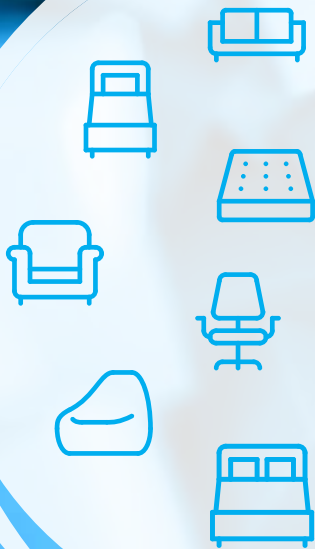


EUROPUR

European Association of Flexible
Polyurethane Foam Blocks Manufacturers

THE END-OF-LIFE OF FLEXIBLE POLYURETHANE FOAM FROM MATTRESSES AND FURNITURE

AN OVERVIEW OF REGULATORY
DRIVERS, RECYCLING TECHNOLOGIES
AND REMAINING CHALLENGES



About Europur

EUROPUR is the European Association of Flexible Polyurethane Foam Blocks Manufacturers. Our member companies produce foam in 28 countries in geographical Europe, from Ireland to Russia and Turkey.

About this document

A first brochure on end-of-life options for flexible PU foams was published by EUROPUR in 2015. Since then, many of the issues raised in that document have been addressed by the supply chain, the regulatory environment continues to evolve and recycling technologies have progressed. It has therefore become necessary to publish a new document providing an overview of the today's situation. This brochure is destined to allow a broad audience to understand the key factors influencing the end-of-life of polyurethane foam and its recycling.

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About Flexible Polyurethane Foam

Polyurethane (PU) *is a leading member of the wide-ranging and highly diverse family of polymers or plastics. Polyurethane can be a solid or can have a cellular structure, in which case it is called polyurethane foam... and polyurethane foam can be flexible or rigid. In this document, only flexible polyurethane foam is considered.*

Flexible polyurethane foam ("PU foam") is a thermoset polymer. It is used in a very wide range of durable applications, notably in mattresses, upholstered furniture and in vehicles. As an example, nearly 90% of mattresses produced in the EU contain PU foam (between 2 and up to 30 kg per unit) and almost all of furniture upholstery is made of PU foam. The PU foam supply chain has made great efforts already over the past decades to improve its resource efficiency at the production stage. Today, almost all PU foam production and conversion waste or scrap is sold by foamers and converters as trim foam (e.g. for pillow filling) and to produce PU bonded foam products (e.g. for carpet underlay). And between 2005 and 2015, our industry has reduced its energy consumption by 8% and CO₂ emissions by 24%¹.

The end-of-life (EoL) or post-consumer stage has however been historically challenging for flexible PU foam due to the fact that it is incorporated in complex bulky objects that are not collected for recycling, but were historically sent for incineration and/or landfill and due to some specificities of the material.

The flexible PU foam industry at large has been working at addressing this challenge over the past year. A first brochure on end-of-life options for flexible PU foams had been published by EUROPUR in 2015. Since then, many of the issues raised in that document have been addressed by the supply chain, the regulatory environment continues to evolve and recycling technologies have progressed. It has therefore become necessary to publish a new document providing an overview of the today's situation.

The present brochure is divided into three sections. The first one aims at setting the scene by providing an **overview of the flexible polyurethane foam markets in Europe** and an estimation of post-consumer PU foam volumes available in Europe, and by presenting the legal and regulatory environment regarding EoL solutions. The second part presents the **evolution of recycling technologies**: mechanical, chemical and thermochemical recycling, as well as energy recovery. The last section addresses the **remaining challenges for increased recycling** in the coming years.



PART I

Setting the Scene

1.1 An Overview of the Flexible Polyurethane Foam, Furniture and Mattress Markets in Europe

1.1.1 PU Foam Production

There are 109 plants in the European Economic Area and the United Kingdom producing flexible PU foam blocks in a semi-continuous process called slabstock foaming. Their combined production was of 1.1 million tonnes of foam in 2020, comprising ~1,035 kilotons of polyether slabstock foam and 63 kilotons of polyester foam. About 35% of the slabstock foam produced in Europe is used in mattresses, 50% in furniture and the rest in other applications.

Next to the slabstock foaming process, moulded parts of flexible foam are also produced for the automotive and furniture industries. It is estimated that about 35 plants produce such parts for furniture, about 35,500 tonnes per annum.

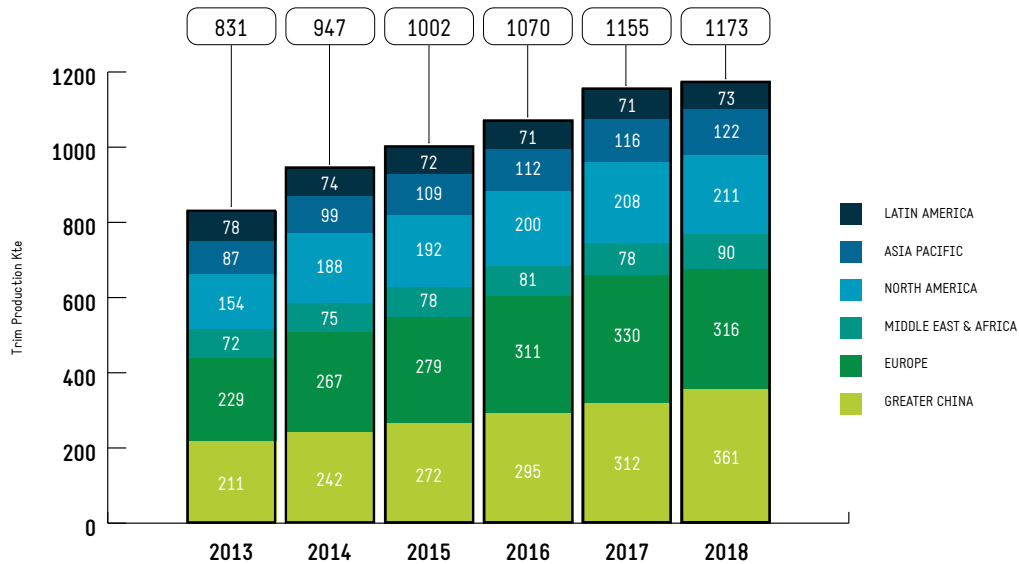
1.1.2 Bonded PU Foam Production

Polyurethane trimmings, resulting from converting large blocks of prime PU foam into smaller pieces (such as mattress cores or cushions), are referred to as “trim foam”. Trim foam is neither dirty nor contaminated with other materials and complies with the same specifications as the original polyurethane block materials out of which the converted pieces are produced. During the processing of foam blocks in the EU, up to 24% of the tonnage produced becomes trim foam². Global trim rates are slightly lower than EU rates at 22%, which provides for an estimated total of nearly 1.2 million tonnes of post-production trim foam generated globally in 2018, with forecasts of 1.3-1.5 million tonnes produced by 2023. The world demand for trim foam was estimated to be around 1.266 million tonnes in 2018. The largest producer of trim is China with 361,000 tonnes produced in 2018. Europe comes in second position with 316,000 tonnes produced the same year³. Trim foam is either used as such, or serves to produce PU bonded foam, which in turn is transformed into products such as carpet underlay or gym mats for example.

It is important to stress that the specifications of bonded foam are quite different compared to the specifications of prime PU foam. One of the major differences is the density. The density of prime PU foam (on average 20 to 40 kg/m³) is much lower than the density of PU bonded foam products (60 to 400 kg/m³).

As a consequence, the applications and the markets of bonded PU foam products are generally different from the markets of prime PU foam products.

Table 1 : Estimated Global Post-Production Trim Foam (Kte)



Source: Labyrinth Research and Markets Ltd, "Global Supply and Demand for Flexible Polyurethane Slabstock Trim Foam," November 2019.

1.2 Estimation of the End-of-life PU Foam Available in Europe

Research performed by Labyrinth Research and Markets Ltd⁴ in 2019 revealed that around 40 million mattresses currently reach the end of their life every year in the EU, compared to 30 million mattresses in 2012. If they were all stacked up, the pile would be 904 times the height of Mount Everest.

Taking into consideration foam production, average trim rates and the fact that EUROPUR members estimate that ~50% of slabstock PU foam goes to furniture manufacturing and ~35% to mattress production, it is fair to assume that potential post-consumer volume from furniture is between 350 and 400 Kt per year and between 250 and 300 Kt for mattresses. It should however be stressed that these figures only serve as a theoretical illustration since for such volumes to be effectively available for recycling each piece of furniture or mattress would need to be separately collected and recycled, which is far from being the case currently.

The reality today is that at the end of their useful life, both mattresses and upholstered furniture join the so-called solid municipal waste or "bulky" waste streams in Europe. It is difficult to obtain reliable public statistics on how bulky waste streams are treated. Research by the European Bedding Industry Association in 2020, however showed that 49% of mattresses are landfilled in the European Union today, 33% are sent to energy plants and 17% are recycled⁵. While little data is available for furniture, the European Commission estimates that less than 10% of furniture is recycled across the EU⁶.

For both mattresses and furniture, the status quo is not an option, as we already know that landfill and waste-to-energy will be reduced as waste management options. Indeed, the revised Landfill Directive imposes to EU Member States to reduce to 10% or less the

fraction of municipal waste that is landfilled by 2035. In parallel, waste-to-energy will also be significantly reduced in order to favour other end-of-life solutions, such as mechanical, chemical and thermochemical recycling.

This means there will be increased focus on separating solid municipal waste into different components and on processing and transforming of wastes that have been separated, also for post-consumer foams. The (evolution of the) regulatory framework influencing the end-of-life and recycling of flexible PU foam and foam containing products is outlined in the next section.

1.3 Legal and Regulatory Environment

Waste legislation in the EU and its Member States has been existing for decades and is evolving constantly. The current goal for all legislation covering waste is to reduce incineration and landfilling and to favour the conservation of resources, either via re-use or recycling. This section is addressing the Waste Framework Directive, Landfill Directive, chemical legislation and EPR schemes.

1.3.1 Waste Framework Directive (WFD)

In the EU, most waste is regulated under the Waste Framework Directive (WFD), also called Directive 2008/98/EC under its current numbering. Only a limited number of wastes in specific sectors, such as for example end-of-life vehicles, are regulated under their own sectoral legislation.

The WFD sets the basic concepts and definitions related to waste management, notably the definitions of waste, recycling and recovery. It specifies when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products.

One of the pillars of the WFD is the waste hierarchy. Waste legislation and policy of the EU Member States must follow the order of priority set by the waste management hierarchy. It is based on the principle of "Reduce, Reuse, Recycle", i.e. the best solution being to prevent the generation of waste, followed by reusing and recycling. The least preferable options are energy recovery and landfilling.



Source: European Commission⁷

EU institutions last revised the WFD in 2018. When doing so, they set new objectives requiring notably EU Member States to ensure that by 2025 55%, by 2030 60% and by 2035 65% of all municipal waste must be prepared for re-use or recycled in the EU. During this revision also, for the first time, a provision was introduced specifically mentioning mattresses and furniture as a waste stream to be tackled in the new definition of municipal waste.

Beyond these clear objectives, the WFD also contains provisions re-enforcing the concept of extended producer responsibility schemes with general requirements for their functioning, in order to encourage the setting up of such schemes for the separate collection, dismantling and recycling of products. It also foresees that Member States must reduce incineration and waste-to-energy to waste for which it delivers the best environmental outcome. Incineration and waste-to-energy should be discouraged progressively notably via increased gate fees.

1.3.2 Landfill Directive

According to the waste hierarchy in the WFD, landfilling is the least preferable option and should be limited to the unavoidable minimum. Where waste needs to be landfilled, it must be sent to landfills which comply with the requirements of Directive 1999/31/EC on the landfill of waste. In 2018, to support the objectives of the WFD, an amendment to the Landfill Directive (2018/850/EC) imposed to EU Member States to reduce to 10% or less the fraction of municipal waste that is landfilled by 2035.

1.3.3 Chemical Legislation

Like many industries, the flexible PU foam industry is using chemicals to make products. And when discussing post-consumer products, the particular issue of legacy chemicals arises. Legacy chemicals are chemicals that were used in foam formulation at the time of making products but may have seen their use restricted or banned since then. As foam containing products are very durable, they have a long lifetime (10-15 years for a mattress, often more for upholstered furniture), analysing this issue requires covering long periods of time.

The basic principle is that post-consumer foams can be legally placed on the markets and transformed into new products if they comply with chemical legislation and if legacy substances do not exceed legal thresholds. To check on the situation, EUROPUR decided to evaluate the presence of substances of concern in post-consumer foams from mattresses from The Netherlands, France and the UK. The study concluded that very few such substances were present in the analysed foams and never at levels exceeding legal thresholds. These findings were confirmed by the Dutch National Institute for Public Health and the Environment (RIVM). It is therefore perfectly possible to use post-consumer foams from mechanical recycling processes in products traditionally made with trim foam.

As list of SVHCs and of restricted substances are evolving over time, it is advised that - at reasonable intervals - foam recyclers perform the same type of study as EUROPUR did.

1.3.4 EPR Schemes for Mattresses and Furniture

Recycling foam requires that products containing large quantities of foam (such as mattresses or furniture) be first collected separately. This can take place at container parks or via a take-back system of the retailer. Then, in order to access the foam and other resources, products must be dismantled.

In order to facilitate the collection, dismantling and recycling of mattresses and upholstered furniture, extended producer responsibility (EPR) schemes are being implemented in several EU countries. They can be defined as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle."⁸

EPR involves not only a shift in responsibility from authorities to producers, but also an encouragement of producers to take environmental considerations into account when designing and manufacturing their products. EPR seeks to achieve a reduction in the environmental impact of products, throughout their lifespan, from production through end-of-life⁹.

Regarding the management of EoL PU foam, one notable evolution currently observed is the number of Member States considering setting up extended producer responsibility schemes for mattresses and/or furniture. The first operational scheme in Europe was Eco-Mobilier in France. Since 2013, Eco-Mobilier has been taking care of collecting, sorting, recycling and recovering end-of-life furniture and mattresses (as well as post-consumer pillows and blankets since 2018). The scheme is financed by an eco-participation fee paid by consumers when purchasing one of the new products above-mentioned. Between 2013 and 2017, more than one million tonnes of EoL furniture were collected in France for recycling and recovery. In 2019, Eco-Mobilier collected 874 KT of post-consumer furniture and mattresses, recovered at 93%, out of which 57% were recycled and reused¹⁰.

In Belgium, a scheme called Valumat, also financed by a fee paid by end-consumers, entered into force in 2021 for mattresses only. Part of the funds collected are used for supporting research into eco-design, innovative materials and recycling technologies besides creating a specific collection, dismantling and recycling infrastructure. Valumat also carries out the EPR-related legal obligations for all manufacturers and importers participating in its system. In addition, the final seller can accept discarded mattresses for free on a voluntary basis, when the consumer purchases a new mattress, and will receive a fee from Valumat¹¹.

In the Netherlands, an EPR scheme is being set up and has as objective to reach 75% mattress recycling by 2028, as well as transferring the financial burden over this time from the municipalities to the producers. It is worth noting that the Netherlands is already a world leader in mattress recycling, with an estimated 75% of mattresses being collected and recycled annually. The company Retour Matras announced that it handled 1 million mattresses in 2020 at 3 of its Dutch locations¹².

In Scotland, Zero Waste Scotland (supported by Eunomia and the National Bed Federation) is leading the process. Once a scheme is up and running in Scotland, it is expected that the whole UK will adopt the same system. The exact timeline for implementation remains unclear as of now however. For the moment, the discussions revolve around challenging topics for the UK: governance of the scheme, need for investment in infrastructures, as well as the fee model.



PART II

Evolution of Recycling Technologies

The industry has in recent years invested heavily into developing existing and new recycling technologies for flexible polyurethane foam, as part of companies' commitments towards reducing the impact of their products on the environment, but also as a logical consequence of the evolving legal framework

2.1 Mechanical Recycling

The obvious and in theory easiest way of recycling EoL PU foam is simply to reuse it or to recycle it into a new PU product (such as PU bonded foam). Mechanical recycling of polyurethane foam has been existing for decades. Indeed, the flexible PU foam industry is one of the few industries producing very little waste as our production cut-offs are transformed into so called trim (foam flocks), which in turn can become rebonded foam used in products such as: e.g. carpet underlay, gym mats, acoustic insulation.

From a technical point of view, post-consumer foams from discarded mattresses or furniture (or any other source that would be clean and dry) can perfectly be recycled that way too. There are however a number of issues to be considered:

2.1.1 Limitation of Output Markets

By collecting and separating materials, extended producer responsibility schemes (such as Eco-Mobilier in France and Valumat in Belgium) can ensure material is available for recycling. The main technology used to recycle EoL PU foam is mechanical recycling, which has increased significantly over the past few years.

As mentioned previously, Eco-Mobilier collected 874 KT of post-consumer furniture and mattresses in 2019, an increase of 200 KT compared to 2018. 93% of this waste stream was recovered, out of which 57% was recycled and reused. In the Netherlands, where 75% of EoL mattresses are being recycled, the company Retour Matras announced that it handled 1 million mattresses in 2020 at 3 of its Dutch locations.

There must be output markets available to absorb the recyclates. The reality is that if all EU countries were starting to recycle post-consumer foams, market outlets for the recyclates would not be able to absorb all the available volumes. Indeed, the EU is already today the world’s largest exporter of trim foam from virgin production, exporting over 300,000 tonnes annually. As the table below shows, the global trim market is just about in balance. If significant volumes of post-consumer foams were to become available as trim, it is unlikely that trim foam markets would be able to absorb them.

Table 1 : Estimated Global Supply and Demand for Trim Foam, 2015-2020 (Kte)

| Supply/Demand (Kte) | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|--------------------------|------|------|------|------|------|------|
| Post Production | 1002 | 1070 | 1115 | 1173 | 1231 | 1305 |
| Post Consumer | 136 | 139 | 144 | 148 | 142 | 145 |
| Total Trim Supply | 1138 | 1209 | 1259 | 1321 | 1373 | 1450 |
| Estimated Demand | 1041 | 1088 | 1155 | 1189 | 1224 | 1299 |
| Surplus | 97 | 121 | 104 | 132 | 149 | 151 |

Source: Source: Labyrinth Research and Markets Ltd, "Global Supply and Demand for Flexible Polyurethane Slabstock Trim Foam", November 2019. Updated for 2019 & 2020 by Belvedere and Partner Ltd.

2.1.2 Protocols to Manage Legacy Chemicals

As mentioned in the section on chemical Legislation, a study made by EUROPUR has demonstrated that no substances of concern were identified in post-consumer foam samples above their regulatory limit values from the Netherlands, France and the United Kingdom. This does not mean that such a presence can be ruled out systemically and companies making products with post-consumer foams should have a quality control and traceability system in place with reasonable testing frequency to address the possible issue of legacy chemicals.

2.1.3 Uncertainty of Global Market for Trim Foam

Global shipments of plastics wastes are under increased scrutiny since China closed its borders to plastics waste imports in 2018. In response, many plastics recycling companies started in countries near China. These companies produced mainly thermoplastics recyclates for the Chinese value chains and residuals were treated in sub-standard manners resulting in an increase in marine pollution and open burning practices in those countries. To counter this, amendments were adopted under the Basel Convention governing shipments of hazardous and other wastes to restrict green listed exports to those plastics wastes that are almost exclusively consisting of a single polymer and almost free from contamination.

While trim foam from virgin production should be considered as a by-product and thus not subject to the Basel Convention, there is increased scrutiny by countries of plastics shipments in general. It is not inconceivable that countries to which the EU exports its trim foam may request more assurances as to whether or not the trim foam is a (pre-consumer) by-product,

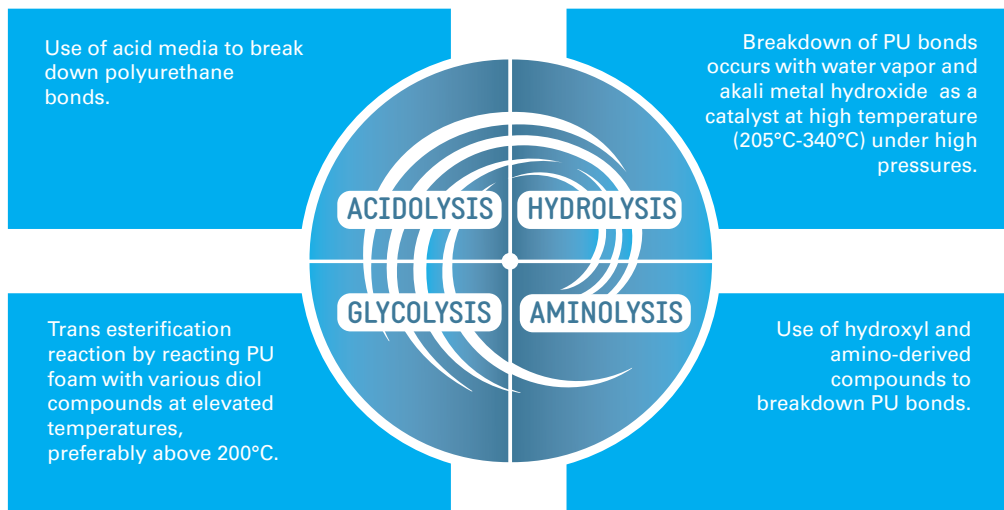
a product or a waste. This can become a factor contributing to the limitation or complication of the export markets.

In any case, mostly due to the limitations of end-markets for trim foam, there will always be a significant proportion of EoL PU foam that will need to be treated by other means. That is why other technologies need to be developed.

2.2 Chemical recycling

Chemical recycling is a process whereby flexible polyurethane foam is broken down into its specific constituent chemical raw materials, which can be used again to make fresh foam. The technology has been in use at an industrial scale in Europe since 2013 for trim foam from virgin production and has now evolved to also be able to recycle post-consumer foams. Chemical recycling is however more challenging for EoL PU foam due to the huge variation in types of foam collected and the absence of information on the chemical composition of these foams. But we are now getting there.

There are several **technologies available for the chemical recycling of PU foam** (acidolysis, hydrolysis, aminolysis and glycolysis) differentiated by the base material they use to dissolve PU foam :



Since the 2015 brochure, industrial scale or pilot plants for chemical recycling of flexible polyurethane foam have been planned or are under construction by our member companies, notably in France, the Netherlands, Spain, Germany and Belgium.

The company Dow Polyurethanes has launched a mattress recycling programme called RENUVA™ and is a partner in the construction of Europe's first chemical recycling plant for post-consumer polyurethane foam in Semoy (France). Foam Producer The Vita Group, which operates foam production plants across Europe, has been the first one to officially announce that they will use recycled chemicals from the plant to make new polyurethane foams¹³. In September 2021, the plant in Semoy was officially inaugurated and the first foams made with recycled polyols from the plant by The Vita Group obtained CertiPUR® and OekoTex® certification.

In The Netherlands, early December 2020, Retour Matras and its shareholders Ikea and Renewi Nederland announced plans to expand the company's recycling capabilities with chemical recycling, using technology developed by Ikano Industry in Poland. The first stone of the plant was laid in September 2021 and the plant is expected to come on stream in the course of 2022.

In Spain, Repsol announced that it plans to build the country's first plant for chemical recycling of polyurethane foam at its Puertollano Industrial Complex. The new recycling facility is expected

to be completed by the end of 2022. Once operational, the plant will be capable of processing around 2,000 metric tonnes of polyurethane foam per year. The recycled polyol will be included under Repsol Reciclex brand¹⁴.

In Germany, Covestro has developed an innovative process for the chemolysis of flexible PU foam from post-consumer mattresses. The new process enables the recovery of both main PU components at high yield: in addition to the polyol, the primary product of the other component formed during recycling – the isocyanate – can now also be generated. Covestro has now commissioned a new pilot plant for next-level chemical recycling, designed to expand recycling into an efficient industrial process. Furthermore, in collaboration with the companies Recticel and Redwave, the company has developed an intelligent sorting solution to efficiently separate the different PU foams from post-consumer mattresses. The software uses machine-learning algorithms for a proper recognition of the different types of foam, enabling clean material inputs for the subsequent recycling process. The innovative technology combining smart sorting with the new chemolysis process builds on Covestro's participation in the PUReSmart project, which is coordinated by Recticel¹⁵.

Also in Germany, BASF has developed a chemical recycling process for post-consumer mattresses and is currently running pilot tests at the Schwarzhilde site in Brandenburg. The process breaks down the flexible PU, producing an output of polyols. The target to recycle the materials from old mattresses in such a way that it enables the production of new mattresses from the recyclates¹⁶.

In Belgium, TripleHelix is working at providing end-of-life solutions in many areas including chemical recycling of flexible polyurethane foam for which the construction of a pilot plant is planned. The process that would be used is called split-phase glycolysis, which results in two fractions: polyols and a mixture of substances containing diamine, which can be sent to plants producing diisocyanates. The advantage of this process is that in the end both polyols and isocyanates are produced, which are the two basic components to create flexible polyurethane foam.

All of these projects on chemical recycling are currently making rapid progress, but that is not all. A number of publicly funded projects are also looking at chemical recycling across Europe, notably the Polynspire project and the Danish RePURpose project around mattress manufacturer Tempur which has recently published some conclusions¹⁷. And additional stakeholders, including Evonik, are working at initiatives for recycling too.

Together all these projects should result in a rapid roll-out of the technology across the continent in the coming years¹⁸.

Some players are also seeking to develop a new type of polyurethanes – called Covalent Adaptable Polyurethane (CAPU) – which would have the same properties as other plastics for easier recycling. This is also one of the objectives of the above-mentioned PUReSmart project.

In any case, while chemical recycling seems to be a promising prospect for the EoL treatment of PU foam in the future, more research needs to take place on this technology, in order to achieve higher conversion rates and higher quality for the recycled polyol.

2.3 Thermochemical Recycling

There are 3 main technologies for thermochemical recycling of polyurethane foam: pyrolysis, gasification and hydrogenation. The difference between the three technologies is that pyrolysis takes place in an oxygen-free high-temperature environment, gasification takes place in an environment with oxygen and hydrogenation takes place under hydrogen atmosphere.

Apart from this technical difference the underlying principle between the three technologies is that their goal is to transform the solid municipal waste (including EoL PU foam) into gas that can be further used, notably as raw material for the chemical industry or as fuel. For that, there is no need for separate collection. Besides, these technologies can help recover complex materials, such as polyurethane, latex and ticking, and keep them in the loop instead of simply landfilling or incinerating them, which constitutes a loss of resources.

Some investments into pyrolysis plants are currently taking place in Europe, which could accommodate solid municipal waste to produce gas serving as a raw material for the chemicals industry. Such plants have been operating in the past in Europe, but ultimately failed to be competitive.

There have been different pilot projects for gasification in Europe, for example at Schwarze Pumpe in Germany. While viable from a technical point of view, none of these projects have succeeded from an economical point of view. This may however be about to change in the coming years.

A consortium of leading companies is developing an advanced 'waste to chemicals' (W2C) plant in Rotterdam. The aim is that this will be the first plant of this type in Europe that make valuable chemicals and bio-fuels out of non-recyclable waste materials. That plant would produce syngas from waste for further transformation into methanol and ammonia¹⁹.

Koninklijke CBM – the trade association of the Dutch furniture industry- conducted a pyrolysis experiment combined with a Life Cycle Assessment (LCA) in 2018. The results were promising and led to the creation of a consortium of mattress producers, recyclers, knowledge institutes, chemical industry and pyrolysis providers. The goal was to valorise the possible roadmap on the recovery of PU, latex and ticking materials by using the pyrolysis technique. The project involved comparing a continuous screw pyrolysis reactor with a fed-batch process using radiolysis. Both techniques are promising to produce oil and syngas for latex²⁰.

2.4 Energy Recovery

In Europe, the vast majority of post-consumer mattresses and furniture are still being landfilled or sent to waste-to-energy plants. The latter technology will be an essential support to help divert products from landfills by 2035 as required by EU legislation, but it will also be increasingly discouraged as foreseen in the Waste Framework Directive. It will however have to remain part of the waste management solutions for post-consumer mattresses and furniture that are too dirty, too contaminated or too complex to dismantle and can therefore not be recycled otherwise.

Beyond usage for heat and electricity generation in waste-to-energy plants, flexible PU foam can also serve for the production of Refuse-Derived Fuel (RDF) and Solid Recovered Fuel (SRF).

RDF is a fuel produced by shredding and dehydrating pre-sorted municipal solid waste (paper, metal glass and wood are removed for recycling). Refuse Derived Fuels are used in the cement kiln industry and in a wide range of specified waste to energy facilities to produce electricity and thermal energy (heat/steam) for district heating systems or industrial uses.

SRF is a more refined resource from which energy can be recovered and produced to a defined quality specification European Standard EN 15359). It is used in cement kilns, paper mills and power stations as an alternative to fossil fuels. SRF has the potential to satisfy an important part of the global energy requirement.

Neither of these two products can account for recycling rates that are set by legislation and while they too are expected to remain part of the future treatment portfolio for post-consumer foams, it is not expected that they will become mainstream outlets for such foams.



PART III

Remaining Challenges

This section lists, in no particular order, some remaining challenges that are or should be addressed to further improve recycling of PU foam.

Getting Access to the Resource at Local Level

Calculations on the potential of mattresses, furniture and PU foam available for recycling are purely theoretical, based on estimated tonnages placed on the market. It is currently very difficult to find any reliable data on tonnages of mattresses or upholstered furniture produced, exported or imported and the calculations made are therefore to the best of our knowledge. More importantly, in the absence of infrastructure for the collection and dismantling of goods in most of Europe, accessing materials and recycling them is very difficult for individual companies. Research into mattress recycling companies made by EUROPUR shows that such companies mostly exist in France, Belgium, The Netherlands and the UK. While such companies can be found here and there in other countries, they are very few. This means that recycling rates of mattresses and furniture and hence of flexible polyurethane foam will only really increase if more initiatives around the collection and dismantling of products are launched, either by individual operators or by countries implementing extended producer responsibility schemes (EPR).

Getting Access to the Resource at Product Level / Design for Cost-efficient Dismantling

Post-consumer PU foam has a value estimated between 50 to 200 EUR²¹ per ton and is competing in roughly the same markets as virgin trim foam. For recyclers to be able to operate in an economically sustainable fashion, dismantling processes must focus on the products that are the easiest to dismantle and offer the highest material yields. And this is exactly what we are seeing today. All recycling initiatives currently focus on mattresses because dismantling is relatively easy and the yield in valuable materials such as foam is high. Some companies have

even adopted automated machinery in certain parts of the dismantling process. Currently, very little recycling of upholstered furniture takes place, not because the material yields would not be high, but because too much manual intervention would be required to dismantle the product. And this while about 50% of the flexible PU foam produced in Europe goes into upholstered furniture. To increase recycling rates in the future, it is essential that products are made that are easier to dismantle at the post-consumer stage. It is expected that future product policies for furniture launched by the European Union will seek to address this issue, to complement initiatives already taken by individual operators in this area.

Creating a Market for Recyclates

The markets for recyclates from mechanical recycling are well established already, although there may be some growth prospects in some applications where they are little used for the moment, such as furniture for example. The real challenge is however to create a market for foams made with recycled content from chemical recycling processes. In that context, it is essential that outputs of chemical recycling are recognized by EU Institutions as qualifying to count towards recycled content.

In that context, it is also important that stakeholders along the supply chain work together to create a market for recyclates from chemical recycling processes. The use of recycled polyols for example will influence the colour and some mechanical properties of the foam produced and will require adaptation of foam formulations. Customers of foam producers can help creating a market for recyclates by reviewing their specifications and where possible or desirable adapting them.

From Pilot to Industrial Plant / Creating the Conditions for Investments

Linked to need to create a market for recyclates, favourable conditions must be created to encourage companies to invest into the several dozens of chemical recycling plants that will be needed to replace landfilling and waste-to-energy. As can be seen in some countries where plants are being built today, EPR scheme and local authorities can play a useful role financing some R&D, facilitating the building of the plant or ensuring that the post-consumer feedstock for the plant is readily available.

Sorting of Foams for Better Recycling

Some recycling processes – whether mechanical or chemical - work better when foams are sorted by so called foam families (e.g. visco-elastic foams, standard foams, high resilience foams...). Also legacy chemicals can be identified by efficient sorting processes, allowing to remove foams that contain them from recycling processes. For a sorting process to work in a cost-efficient manner, it must be automated. Some stakeholders are working at applying technology inspired from sorting thermoplastics to polyurethane foams with first results that are encouraging. Current work on forms of foam identification or blockchain technology can also be useful in that regard, although – taking into account the generally long lifetime of products made with PU foam – tangible benefits of such technologies could take a long time to materialize.

Recycling all Foam Components

For the moment, most chemical recycling projects focus on recycling the polyol component of foams. The resulting product is a polyol containing a certain amount of amines, which will allow to use less virgin diisocyanates when foam is made with the recycled polyol. Some companies are working at alternative technology that will deliver on one hand recycled polyol and on the other hand diamines, which can then in turn be integrated into chemical production processed to produce diisocyanates with recycled content.

Harmonization of (End-of-life) Legislation / Interpretations

Currently, different public authorities across Europe sometimes have different view on what can be considered a by-product and how to interpret end-of-waste criteria. Only Spain has to date clear legislation in place to define the conditions under which trim foam can be qualified as a by-product. In the same vein, certain countries seem fairly lenient when it comes to accepting end-of-waste declarations from individual companies, while others are extremely stringent and require a hefty amount of proof (especially on the chemical safety side, criteria in article 6.1.c and 6.1.d WFD). Greater harmonization in these fields and ideally EU implementing legislation detailing the by-product status and End-of-Waste criteria could be beneficial.

Recycled Content Certification

For packaging plastics, there are already organisations that certify recycled content of final products. This is not the case yet for polyurethane foam since until recently recycled polyols were just not available commercially. With the emergence of polyurethane foams made with recycled content, and knowing that in most recycling processes also virgin material must be added, it becomes important that the supply chain reflects on putting in place some credible recycled content certifications schemes to avoid misleading claims in the future.



Conclusion

Our last brochure on recycling options for flexible PU foams dated back to 2015 and had become outdated thanks to the tremendous progress achieved by stakeholders in the PU supply chains. With the current high level of development and innovation, chances are that this brochure will be outdated in less than 5 years and this is something we are looking forward to.

In September 2021, the first chemical recycling plant in the world processing foams from post-consumer mattresses was inaugurated in France. No less than 5 other plants are under construction or have been announced in The Netherlands, Spain, Germany and Belgium. Some companies performing mechanical recycling operations in the countries that were among the first to discuss EPR schemes are starting to expand to other countries, recycling ever larger volumes. There seems to be a great appetite in the supply chain to use more recyclates and some large players in the furniture and mattress industry are leading the way.

Clearly, anybody who had question marks about the recyclability of PU foam 5 years ago should now reconsider their opinion. Industry has proven over the past years that PU foam is recyclable and can offer sustainable solutions for the mattress and furniture industry for the next decades. The industry has sought to address technological challenges, as it does since the 1950's, with a continued proven track record of innovation and unequalled product performances.

This does not mean the PU foam industry can rest on its laurels. It now needs to move from pilot projects to technology rollout across an entire continent. But it cannot do that alone. It means that companies using flexible polyurethane foam, including mattress, furniture and car manufacturers, must join the journey and make use of recyclates where possible. It also means that public authorities must play their role by accompanying the technology rollout by creating favourable conditions for substantial investments to be made.

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