EUROPUR

European Association of Flexible Polyurethane Foam Blocks Manufacturers

FLEXIBLE POLYURETHANE FOAM IN MATTRESSES AND FURNITURE

AN OVERVIEW OF POSSIBLE END OF LIFE SOLUTIONS

CONTENTS

INTRODUCTION

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 15 kg per unit) and over 90% of furniture upholstery is made of PU foam.

The PU foam supply chain has made great efforts already to improve its **resource efficiency at the production stage.** Today, most of 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) stage is somewhat more challenging due to the specificity of the material. The use of Eol PU foam for the production of bonded foam products is only possible in a limited number of cases for practical reasons. This means that other Eol solution have to be explored, taking into account the fact that, contrary to most plastics, which are thermoplastics, PU foam decomposes rather than melts at elevated temperature. ***Eol PU foam can therefore not be melted to make new products.***

A number of recycling technologies however exist or are under development, which will be looked at in the course of this document, the objective of which is to discuss end-of-life options for flexible polyurethane foam, also considering various legal, economic and technical parameters.

[1] *Ecoprofile of Flexible Polyurethane Foam, Thinkstep, August 2015.*

1. AN OVERVIEW OF THE FLEXIBLE POLYURETHANE FOAM MARKETS IN EUROPE

1.1 PU foam production

There are 107 plants in the EU28, Switzerland and Norway producing flexible PU foam blocks in a semi-continuous process called slabstock foaming[2]. Their combined production was of 926,161 tonnes of foam in 2015[3] . About 35% of the slabstock foam produced in Europe is used in mattresses, 50% in furniture and the rest in automotive and other applications.

In addition, over 50 plants produce moulded flexible PU foam for furniture (about 35,500 tonnes per annum)[4] and for the transport sector (about 350,000 tonnes per annum). However, the latter tonnages will not be considered in this document since the end of life of automobiles is dealt with under a specific piece of waste legislation, the End-of-Life Vehicles Directive[5]. This Directive sets specific rules and targets for the automotive sector and organizes a specific waste management infrastructure.

1.2 PU bonded foam production

Polyurethane trimmings, resulting from converting large blocks of prime PU foam into smaller pieces (such as mattresses), are referred to as (PU) "trim foam".

Trim foam is neither polluted 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, around 15 to 20 % of the tonnage produced becomes trim foam[6].

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 (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 completely different from the markets of prime PU foam products. This means that trim foam does have an economic value and is effectively being re-used already in various markets.

The world demand for trim foam was estimated to be around 1.006 million tonnes in 2013. The largest producer of trim is China with 325,000 tonnes produced in 2013. Europe comes in third position with 186,000 tonnes produced the same year.

[2] *For more information on the production process, please visit:* ***https://www.youtube.com/watch?v=u9Sj1KmmzQI***

[3] *Labyrinth Research and Markets, Statistical Report for EUROPUR, June 2016.*

[4] *Labyrinth Research and Markets, article published in PU Magazine, issue 04/2016.*

[5] *Directive 2000/53/EC.*

[6] *Industry sources indicate that scrap rates in flexible PU foam production plants are of around 8-12% and of up to 22% in PU foam converting plants.*

unit: ***thousand tonnes***

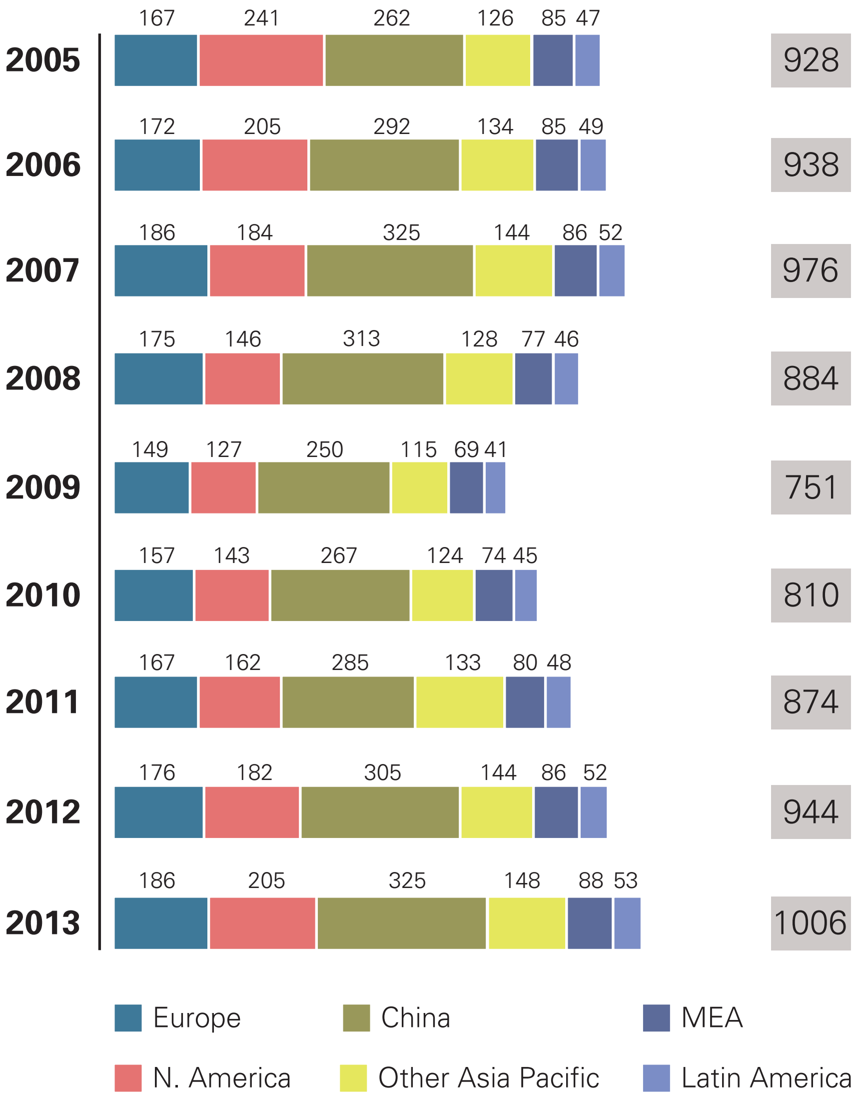


Table 1:

The Global Supply of Polyurethane Trim 2005-2013, The Vita Group

2. ESTIMATION OF THE END-OF-LIFE PU FOAM AVAILABLE IN EUROPE

Research performed by EMPA Consult (Belgium) in 2012 for EUROPUR revealed that around 30 million mattresses currently reach the end of their life every year in the EU. This represents around 460 Ktons of PU EoL material. The annual estimate for end-of-life upholstered furniture is of around 1450 Ktons.

A breakdown of this tonnage by components of mattresses and upholstered furniture is provided in the table below:

Table 3:

Volumes and Material Mix, Mattresses and Furniture, EU 28

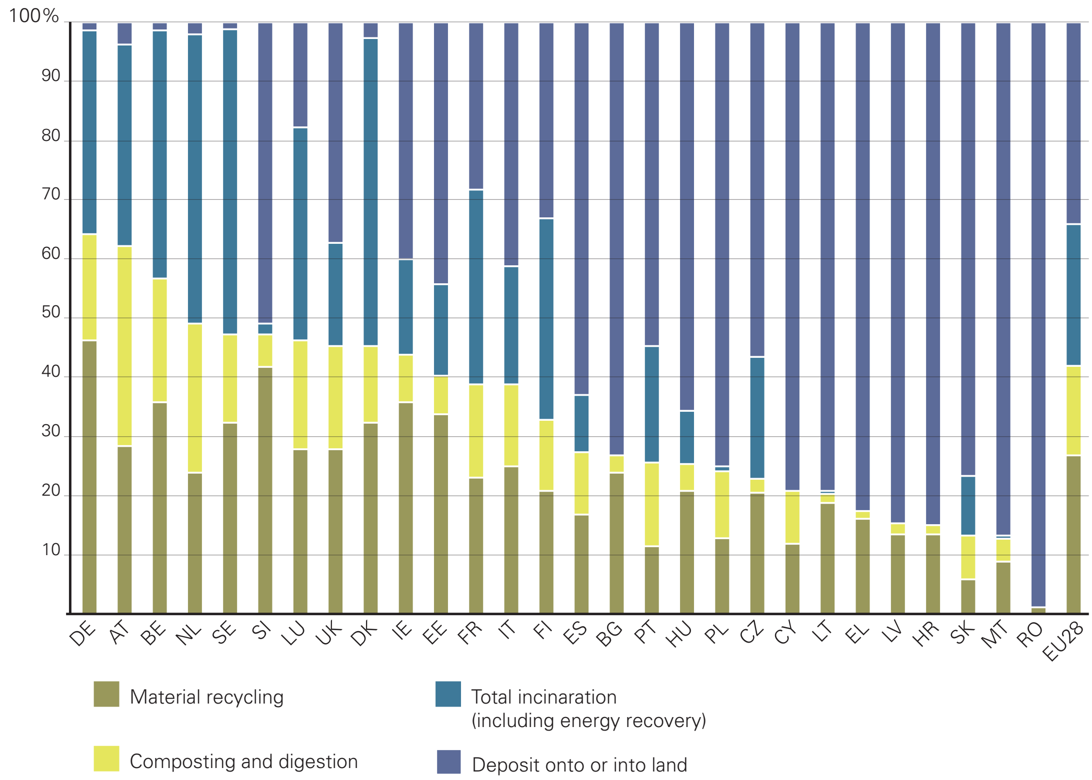
End of Life Material			
Mattresses (ktons)		Furniture (ktons)	
PU foam	160	PU foam	450
Latex	60	Wood/Steel	700
Steel	90	Fibers/Fabrics	200
Fibers / Fabrics	120	Leather	80
Non-woven	15	Other	20
Other	15		
Total	460	**Total**	1450

Both waste mattresses and upholstered furniture join the so-called solid municipal waste or "bulky" wastestreams in Europe (together with the rest of waste furniture and solid household waste for example).

The municipal waste industry has four components: recycling, composting, waste-to-energy via incineration and landfill.

Table 4:

Solid municipal waste by treatment in the EU28, EUROSTAT 2014



The waste technologies in case of waste mattresses and upholstered furniture, as part of solid municipal waste, are today mainly incineration and landfill.

In Europe in 2012, it was estimated that 40% of the combined EoL mattresses and upholstered furniture tonnage (760 Ktons) was incinerated (including energy recovery) and 60% (1140 thousand tonnes) was landfilled.

Considering the volume of EoL mattresses only, this represents around 1920 olympic swimming pools of waste being landfilled. The situation is however greatly variable from country to country, with landfilling of solid municipal being virtually phased out in Northern Europe but remaining the main way of waste disposal in Southern / Eastern Europe.

The landfilling of waste that could otherwise be re-used or recycled or serve as a valuable source of energy does not make sense from an environmental point of view nor from an economic point of view and is less and less accepted by society. In addition, the EU is considering to almost phase out of the landfilling of recoverable waste as part of the European Commission's Circular Economy Package proposals of December 2015.

This means more focus on separating solid municipal waste into different components and processing and transforming of wastes that have been separated. In particular, Eol PU foam from old mattresses and furniture must be separated and processed.

Recent legal initiatives are meant to help this process. A number of countries have put in place or are considering the setting-up of *Extended Producer Responsibility (EPR) Schemes* to facilitate separate collection and support recovery/recycling of materials. In order to avoid that companies are confronted with a huge variety of such schemes across Europe, the European Commission is trying to impose a number of minimal rules that all EPR schemes in Europe have to comply with as part of its Circular Economy Package.

The PU foam industry, in line with the other stakeholders in the plastics supply chain, has for many years been in favour of the ban of landfilling of energy-rich materials. That being said the options envisaged for treatment of PU EoL foam must be viable both from a technical and economical point of view and need to be able to overcome a number of challenges linked to output markets or material contamination.

3. CHALLENGES FOR THE TREATMENT OF END-OF-LIFE PU FOAM

3.1 The availability of output markets in case of recycling

Recycling material implies that there is a market for the recyclates. Either already existing or to be created. In the case of polyurethane foam however, market demands that could be answered by recyclates are either very small (e.g. synthetic sport pitches) or already saturated.

The best example of this challenge is the trim foam market. Any volume of EoL PU foam that would be diverted to this market would effectively enter into direct competition with waste, from production processes, that is currently being recycled.

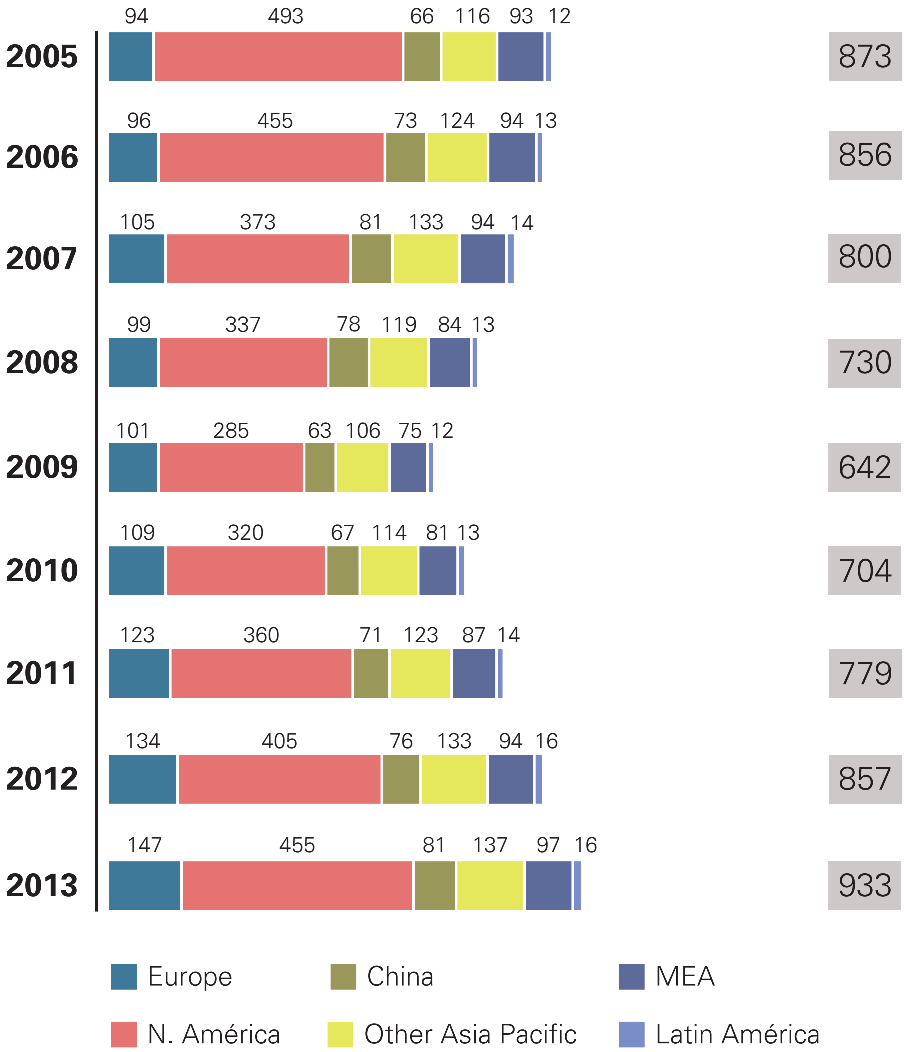
The issue is however that the global PU foam trim market is in structural imbalance as demand is lower than supply. Demand of PU foam trim was of 933,000 tonnes in 2013. North America is by far the largest consumer of trim foam with 455,000 tonnes in 2013 or more than half the world's production.

In other words, this means that while EoL PU foam can in theory be easily transformed into PU trim foam, finding an output market for this new trim will be very challenging. The volume of EoL PU foam from mattresses and furniture from the EU alone (610 Ktons) is greater than the demand of trim foam from North America and Europe combined. And also in the United States, more specifically in California, Connecticut and Rhode Island, programmes are being put in place to diver EoL PU foam from landfill. The share of US consumption of trim foam that can be satisfied by local resources is therefore expected to increase in the coming years.

Table 2:

The Global Demand of Polyurethane Trim 2005-2013, The Vita Group

unit: ***thousand tonnes***



3.2 The composition of EoL PU Foam Material

Contrary to most plastic products, which have in most cases a rather short use-phase, the average lifetime of a mattress in Europe is over 10 years and is much longer for upholstered furniture (up to several decades).

From a sustainability point of view, products with a use-phase of 10 years or more are very interesting. In fact, extending the use-phase to ten years or more is a challenge for most products.

But unfortunately, products with such a long use-phase do have an important disadvantage. The materials, composing these products, may have been produced with substances that have been banned, restricted or phased out during the use-phase (so-called legacy substances). Either simply because production processes improved or because a ban or restriction was put in place by legislation.

In the case of PU foam, the following substances were for example widely used in production over 10 years ago and have been phased out in the meantime:

Substance	Past Usage
Tris(2-chloroethyl)phosphate	Plasticizer, Viscosity regulator, Flame retardant
Pentabromiddiphenylether	Flame retardant
Dibutyltinlaurate	Catalyst
Tributyltinmaleate	Biocide
Azo **colorants** and azo **dyes**	Colorants/**dyes**
Phtalates	Plasticizers

When a substance has been banned by legislation, it means that (Eol) PU foam containing such substances must not be placed on the market anymore[7]. One can conclude that the longer the use-phase the more difficult it is to re-use or recycle the Eol material. A use-phase of many years could even make it impossible to re-use or recycle the Eol material.

As a batch of EoL PU foam may contain a mix of PU foams of different origins and ages, one can hardly guarantee that the said batch does not contain any banned substance. This, in practice, today closes the output market for a large part of recyclates that may be composed of EoL PU foam in Europe.

The issue of legacy substances is a continuous process, as substances used today may be subject to restrictions or even be banned in the future. Some flame retardants or colorants currently allowed for use in PU foam production will for example be evaluated by EU Member States or the European Chemicals Agency (ECHA) in the coming years. It is not possible to know what the result of those evaluations may be.

[7] *This is a simplified summary statement. The issue is more complex than this as substances may be restricted for certain uses only. More information on REACH can be found on the website of the European Chemical's Agency: https://echa.europa.eu/.*

It is therefore important for industry to get a clear view from authorities on what is possible and what is not possible in terms of mechanical recycling due to the issue of legacy chemicals. The European Commission is aware of this issue and has announced that it intends to clarify the situation of legacy substances in recyclates as part of the Circular Economy Package[8]. It is to be seen whether its proposals, expected for 2017, will allow the placing on the market of recyclates that may contain banned or restricted substances.

3.3 Performance of EoL PU Foam Material

Like for most materials, except metals, there is a limitation in the number of times one can mechanically recycle or re-use PU foam. It is the cellular structure of the foam that allows the material to provide comfort or absorb vibrations and sounds. Over time the cell walls get distorted or broken, reducing the material's ability to perform its function. After many years of service, and possibly after an additional lifecycle as recycled product, PU foam will therefore inevitably reach the end of its life and will need to be disposed of.

3.4 Logistics of EoL PU Foam Material

Flexible PU foam being a cellular material has a very important volume compared to its weight (around 20-40 kg/m³ on average). This means that transporting bulk or compressed PU foam is equivalent to transporting important amounts of air. This in turn means that cost and environmental impact will be a limiting factor for the long-distance road transport of a material such as EoL PU foam that does not have an important intrinsic economic value. This very practical logistical factor will thus be encouraging the co-existence of EoL solutions for PU foam as there will be a natural incentive to ship foam to the closest treatment facility rather than to distant ones.

[8] *COM(2015)614*

4. IDENTIFIED END-OF-LIFE SOLUTIONS FOR FLEXIBLE PU FOAM

4.1 Re-use and Mechanical Recycling

The obvious and in theory easiest way of recycling EoL PU foam is simply to re-use it or to recycle it into a new PU product (such as PU bonded foam). There are however a number of challenges to be overcome that are highlighted in section 3 of this document:

- There must be output markets available to absorb the recyclates;
- The presence of legacy chemicals must be kept within legal limits;
- The performance of the foam must still be good enough;

But that is not all. There are additional conditions that must be met too:

- Consumers should accept to purchase new products with "old foam" that in the case of mattresses has been biologically contaminated by previous users, even if in the meantime it has been cleaned;
- Products containing large quantities of foam (such as mattresses or furniture) must first be collected separately. This can take place at container parks or via a take-back system of the retailer (see also the introduction of ***Extended Producer Responsibility (EPR) Schemes).***
- Then, in order to re-use the foam, products must be dismantled. This is very often a high-cost and labour intensive activity, which may be complicated by the presence of dust or by biological contamination. While some funding by EPR schemes of such operations can be considered, there will always be instances where the ***dismantling of products*** will be either too difficult (e.g multi-material products that are glued together) or simply too expensive.

There are a lot of initiatives currently taking place in Europe to foster the separate collection and the dismantling of products containing large quantities of PU foam. Some are private initiatives, some are steered by local authorities in EU Member States and the European Commission itself is seeking to address some of the issues listed above. While it is not widely developed today, one can therefore expect that the mechanical recycling of EoL PU foam will increase in the coming years. In which proportion will however depend on how some of the challenges listed above will be addressed.

The PU foam supply chain acknowledges that reality. But it also insists that products made out of recyclates need to be absolutely safe and must comply with the same technical requirements as new foam. If legally possible, a sensible way forward may be to allow the use of EoL PU foam for applications the end consumer is not in direct contact with in buildings or industry (e.g. acoustic insulation, vibration dampening…) while ensuring that products the consumer is in direct contact with for a large part of his life such as mattresses or furniture are made out of clean, prime material.

In any case, due to the above challenges, even if re-use increases, there will always be a significant proportion of EoL PU foam that will need to be treated by other means.

4.2 Energy Recovery

4.2.1. Waste-to-energy

As part of the energy recovery process, PU foam can either enter conventional waste-to-energy plants (to produce heat and electricity) or can be transformed into pellets used notably in cement factories.

Energy recovery today (or waste-to-energy) is the **preferred technology** for the treatment of EoL polyurethane foam and is the one that is immediately able to divert great volumes of organic waste from landfills.

There are different reasons to that:

- Waste-to-energy plants are widely available in the Northern parts of Europe (482 in 2014[9]) and are able to absorb a large share of the volumes of solid municipal waste available.
- (Dry) solid municipal waste is a welcome feedstock in waste-to-energy plants where its high energy content can be recovered. It also avoids burning gas to counter the low calorific value of (wet) household waste.
- There is no need for dismantling products. Shredding is sufficient in most occasions.
- EoL PU foam may contain legacy chemicals or – especially when originating from mattresses – may be biologically contaminated, in which case incineration is the safest and most hygienic way of disposal.
- Energy recovery reduces the volume of PU foam waste by 99% (foam being composed essentially of air) and renders the final waste fraction manageable.
- The waste fraction after incineration can be used e.g. in road construction

As a consequence, energy recovery is expected to remain the main technology for the EoL treatment of PU foam in the foreseeable future, while other technologies will develop and gain in maturity. It is anyway the only suitable solution to divert the huge volumes of solid municipal waste from landfill.

4.2.2. Pellets (RDF and SDF).

Due to its high caloric value, PU foam waste plays a very important role in the production of Refuse-derived fuel (RDF) and Solid Recovered Fuel (SDF).

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.

SDF 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.

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[9] *http://www.cewep.eu/information/data/studies/m_1488*

The repolyol plant at Dendro Poland.

4.3 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 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.

There have been different pilot projects for gasification in Europe, for example at Schwarze Pumpe[10] 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 building a large scale plant in Rotterdam in the Netherlands the opening of which is planned for 2018. That plant would produce syngas from waste for further transformation into methanol and ammonia[11].Similarly, a Saudi company, Energy Recovery Systems, has announced an investment in the Port of Antwerp in order to build a plant aimed at producing ammonia and urea from waste plastics[12].

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[10] *The SVZ (Sekundärrohstoff-Verwertungszentrum) at Schwarze Pumpe was in operation between 1995 and 2004 and failed for financial reasons.*

[11] *http://www.duurzaambedrijfsleven.nl/recycling/6009/commerciele-partners-haen-aan-bij-duurzaam-synthesegas*

[12] *http://www.portofantwerp.com/en/news/new-billion-euro-investment-port-antwerp*

4.4 Chemical recycling

Similar to thermochemical recycling 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.

The only chemical recycling plant for PU foam operating in Europe today is operated by the company Dendro in Poland. It is operating on the basis of the acidolysis technology, whereby PU foam is dissolved in a mixture of carboxylic acid and basic polyol to produce fresh polyols. The process is however based on recycling production trim of which the chemical composition is known and not of EoL foam. Also the variation in foam types and grades entering the recycling plant is limited. Within a 12-hour cycle, the plant produces 5 tonnes of recycled polyol (so-called repolyol) from 2 tonnes of production trim. The polyol can then be mixed with fresh polyol in a proportion of up to 20% in order to produce fresh PU foam. Since the company installed the plant in 2013, they have recycled over 1,600 tonnes of foam[13]. One can therefore state that under given conditions, chemical recycling of PU foam is possible both from a technical and economic point of view[14].

Chemical recycling is however more challenging for EoL PU foam due to the huge variation in types of foam collected, the absence of information on the chemical composition of these foams and the possible presence of legacy chemicals. There are research and pilot projects being carried out to establish chemical recycling as a valid technology for the recycling of EoL PU foam.

H&S Anlagentechnik (Germany) has carried out a pilot project in 2015/16 on the recycling of EoL flexible PU foam from mattresses. Flexible PU foam was chemically recycled using an optimised acidolysis technology. The result of the recycling process is a short-chain polyether polyol that can be used for the production of rigid PUR/PIR insulating foams, pre-polymers for compound materials (rubber mats, covering materials), glues and/or pre-polymers for the wood industry, rigid PU block foam, sprayfoam or compound materials for automotive industry. This recycled polyol has for the moment been tested with a leading rigid foam producer and the results do seem promising.

Within the URBANREC project financed by European Commission, research will be carried out on glycolysis of EoL PU foam. The project was approved in 2016 and its conclusions should be published in 2019. The project notably focuses on re-using recycled polyols for the production of adhesives.

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. This research should concentrate on taking the step to move from pilot projects to industrial-scale applications but also to solve a number of issues that have been addressed in previous sections of this document, not least the interest of the technology from a lifecycle point of view as compared to other EoL treatments and the issue of legacy chemicals.

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[13] *Data given by Dendro Poland. Reference Period : 2013-April 2016.*

[14] *More information on the process in use at Dendro Poland is available here : http://www.hs-anlagentechnik.de/index.php?article_id=63&clang=1*

CONCLUSION

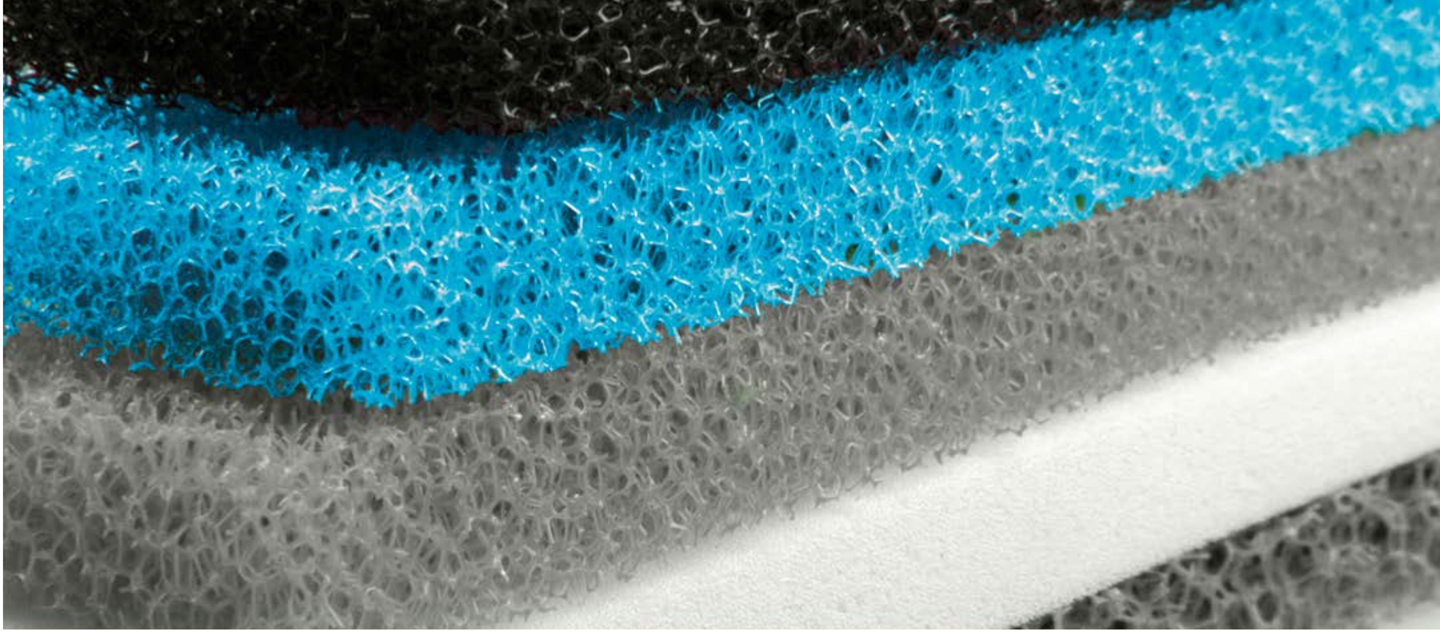
The way in which products containing large quantities of PU foam will be treated at the end of their life in Europe is expected to change drastically in the coming years. The first and most welcome of these changes will be to divert vast tonnages from landfills. While these tonnages will have to be absorbed by energy recovery in the foreseeable future, there are a number of stakeholders across the European Union that are working at finding other ways to treat individual materials such as PU foam at the end of their life.

It is the PU foam industry's belief that in the mid-term a number of end-of-life options will coexist. As for all plastics, energy recovery will remain part of the solution for the proportion of PU foam that will not be re-used or recycled otherwise or that cannot be recycled anymore because it has reached the end of its usable life.

Some of the technologies considered have been available for quite some time but still need to find the proper economic model to operate, while others are still under development or need to demonstrate their value in terms of lifecycle improvement. There are also a number of technical and legal challenges that must be overcome. It is therefore difficult to predict which technologies will allow for the successful recycling of EoL PU foam in the future and at which pace. But clearly, the number of EoL treatment options available will be much more diverse than today.

Public authorities at EU level and in the Member States have a strategic role to play in creating the framework in which recovery and recycling technologies can develop and thrive: via research funding and promotion of pilot projects, via the creation of a stable investment environment and by tackling some of the legal challenges highlighted in this document.

The PU foam supply chain has since the very beginning of the industry in the 1950's worked hard to re-use waste at the production stage. It has considerably reduced its environmental footprint over the past decades. The use of raw materials from renewable sources is increasing drastically as new technologies are being put on the market. With this state of mind, it confidently also looks forward to improving the ways it product is addresses at the end of its life.



ABOUT EUROPUR

EUROPUR is the European Association of Flexible Polyurethane Foam Blocks Manufacturers. Our members produce flexible polyurethane foam in 24 countries in Europe.

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Acknowledgements / Disclaimer

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