Research & Development project

for the upcycling of closed-cell rigid polyurethane foams

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Executive summary

The widespread use of polyurethane foams in processing technology leads to high volumes of excess waste. Proper handling of this waste is of paramount importance for environmental, social, and economic reasons.

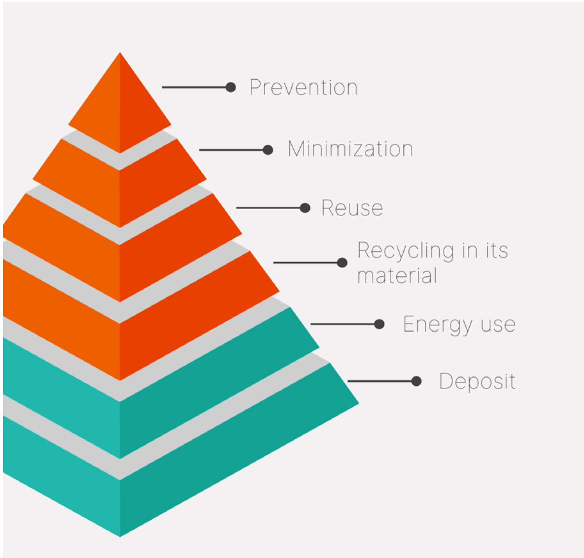
In order to reduce waste, our project aims to solve the mechanical recycling of closed-cell, rigid, cross-linked polyurethane foams. The rigid foam waste generated in our plant is subjected to a special grinding process. Grinds are mixed with a custom-formulated binder in a ratio of 70-30%, to produce upcycled polyurethane foam sheets.

During the research, we first identified the upcycling opportunities of closed-cell polyurethane foam materials and purchased the necessary machinery. Later, we started the production of polyurethane foam and finally developed the prototypes.

By upcycling polyurethane foam during production, we aim to reduce and perhaps even eliminate the waste produced by our company and other market players within the Central European region.

Treatment of polyurethane foam waste

The widespread use of polyurethane foams in processing technology leads to the accumulation of large amounts of waste, such as production residues from housing construction, refrigerator production, and cold room building, or demolition waste. The automotive industry also uses a significant amount of rigid polyurethane foam, which is also still a challenge-to-be-solved due to its volume. Proper waste management is of utmost importance for environmental, social, and economic reasons.



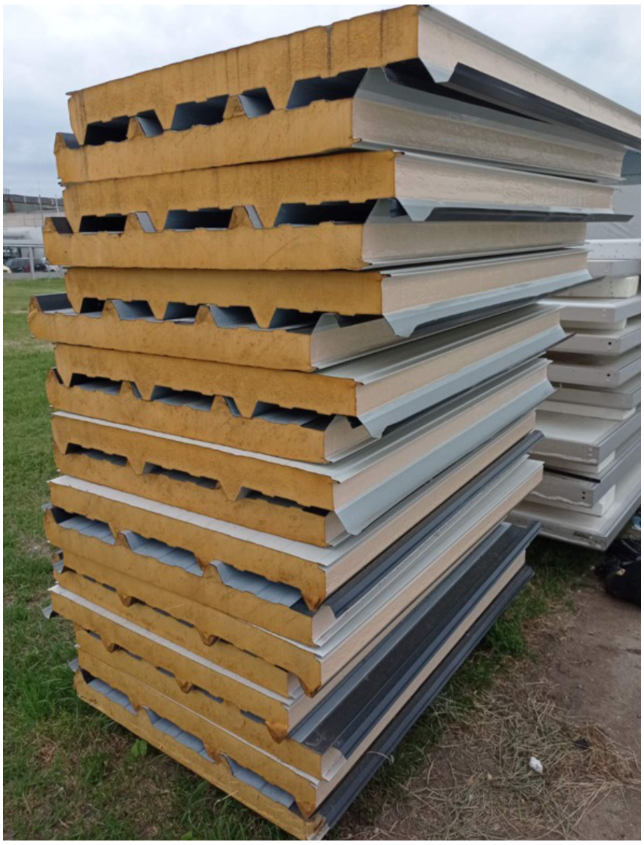
Nowadays, several solutions are in use to treat the accumulated rigid polyurethane foams. According to the waste management pyramid, these are from worst to best: deposition, energy use (incineration) in power plants and recycling as base material.

The project fits in the framework of both a resource-efficient economy and the national focus on energy and climate. Rigid polyurethane and polyisocyanurate foam waste is usually managed through energy use or deposition. Due to their low density, deposition is the worst option from an environmental point of view. Foam waste has a high volume and stable structure, therefore it does not completely decompose even after a long period of time. Burning foam waste can generate large amounts of energy (7000 kcal/kg), but the process can also release harmful greenhouse gases (COx, NOx) and other pollutants into the atmosphere. Desipite these negative effects, these waste management methods are still the two most frequently used, especially to treat rigid polyurethane foam.

Increasingly stringent environmental regulations are also encouraging the industry to recycle PU foam. To address this problem, our project aims to find a solution for the mechanical recycling of closed-cell, rigid, cross-linked polyurethane foams.

Rigid polyurethane foam waste generated in our plant is to be subjected to a special grinding process, after which the grinds are mixed with a custom-formulated binder to produce upcycled polyurethane foam sheets. We aim to reuse these upcycled products in our existing production technology for insulation, thus reducing or even eliminating the waste stream of rigid polyurethane foam produced by our company and in the Central European region.

About polyurethane foams



Polymeric foams are two-phase systems in which the polymer matrix contains gas bubbles of variable size and statistical distribution. Foam products have several advantageous properties, such as low density, good sound- and thermal insulation properties, and excellent energy absorption that have led to a widespread application in various industries. This is also proven by the fact that the global polymer foam market has reached $90.7 billion by 2020, with a compound annual growth rate of 4.8%. The growth of the market is mainly driven by polyurethane (PU) foams, with sales of these materials accounting for 41.7% of the total market, and polyurethane foams growing at an estimated annual compound growth rate of 7.5%.

Polyurethanes include substances containing a urethane linking group (-NH-C(=O)-O-), which are produced by a polyaddition reaction between di- or polyisocyanate and di- or polyol units. PU foams account for the largest proportion of the total urethane production, reaching 68%. PU foaming can be carried out using both physical and chemical foaming agents. Previously, various hydrochlorofluorocarbons (HCFCs) were often used as physical foaming agents, although their use was banned due to their ozone-depleting effects (Montreal Protocol, 1989). At present, HCFCs have been completely replaced by various pentanes (n-, iso-, and cyclopentane), while the most widespread chemical foaming agents are various carboxylic acids and water. These react with the isocyanate group to form carbon dioxide, giving the characteristic cellular structure. Due to the wide range of raw materials available, the properties of the produced foam can be modified over a wide range, from soft foams to integral foams and rigid foams. Production can be carried out both in a batch (e.g. reactive injection molding) or in continuous operation.

Rigid polyurethane foams are widely used as thermal insulation elements in the construction industry, however, they do not meet strict fire safety standards. This has given way to polyisocyanurate (PIR) foams, which contain urethane (carbamate) bonds along with isocyanurate groups formed by trimerization of isocyanate groups. The obtained ring structure and higher cross-linking density contribute to improved heat and fire resistance of PIR foams. PIR foams can be considered as a subtype of rigid polyurethane foams, and therefore the term polyurethane foam is used hereafter to refer to conventional PU and PIR foams.

Chemical and mechanical recycling of polyurethane waste

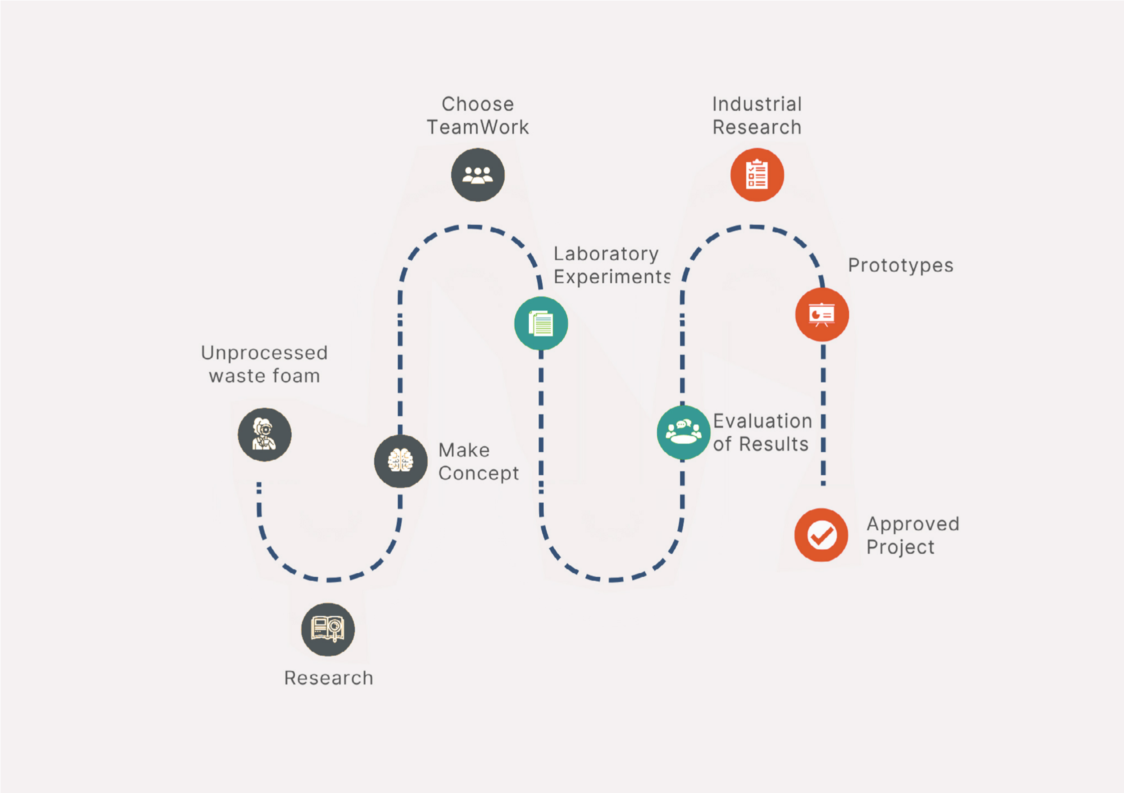
According to the current state of science, both chemical and mechanical methods for upcycling polyurethane waste are available. Due to the chemical degradation of polyurethanes, a number of different methods (hydrolysis, glycolysis, aminolysis, alcoholysis) have been developed in the past years. These processes typically require high temperature and pressure, different chemicals and catalysts, and complex equipment, which hinders their widespread application. At the end of the degradation process, secondary raw materials (polyols, amines) are produced, which can partially replace the primary raw materials in the production of PU.

Mechanical upcylcling of polyurethane foams is also available. For example, flexible foams are often recycled by the furniture industry as a material for bed mattresses, where reformation after static loading is important; by the sports industry for an inner layer for sports mats, providing excellent shock absorption; or by the automotive industry for noise damping purposes.

Currently, there is only one common method for the mechanical upcycling of rigid polyurethane foams. This process consists of grinding the waste foam into a fine powder and using it as a filler (max. 20%) in polyurethane products. At present, the rigid PU foams recovered from disposed household refrigerators and freezers are recycled in this way. However, it is important to note that most rigid PU and PIR foam waste is typically treated by incineration for energy use or deposited.

In addition to developing the new technology and testing its feasibility for industrial application, the project is also expected to deliver important scientific results, as the mechanical recycling of rigid polyurethane foams has still remained an unexplored area of research to this day.

Identification of recycling opportunities of closed-cell polyurethane foams, purchase of machinery



The first phase of development involves selecting and purchasing the machinery and equipment needed to implement the project. Also during the first phase, the required binder materials for the laboratory pre-tests will be selected and procured on the basis of the available information. In the meantime, we begin a comprehensive characterization of the polyurethane foam waste generated at our plant. Microscopic methods are be used to investigate the cell structure of the foams and the average size of the cells inside them. A key parameter of foams is their density, which we determine by a buoyancy-based method. The mechanical properties to be investigated include the compressive strength of the foam structures, which is determined using a universal materials testing device, a tearing strength tester.

In the second phase, we produce recycled rigid polyurethane foams in the form of flat sheets in a laboratory scale. This involves grinding the waste foam to a particle size that meets the specifications of the production line to be supplied. The reconstituted foam sheets will be produced using a laboratory hydraulic press. The properties of the upcycled PU-foams will be analysed under laboratory conditions.

As our plant generates both polyurethane (PU) and polyisocyanurate (PIR) foam waste, we need to study the effect the various proportions of PIR and PU waste foams have on the properties of the reconstituted foams. By the end of this phase, we aim to have a production technology that can be adapted to the processing equipment and is to be fine-tuned in the next stage, based on the results of the in-plant experiments. All results of the laboratory phase are to be included in the protocol.

Production of upcycled polyurethane materials

During the third phase of the project, we aim to test the scalability of the formula defined in the laboratory phase for industrial applications. We first need to study the technical characteristics of the production line, its exact operation, the types, and the ranges of parameters that can be adjusted on the equipment. Next, the industrial processing and upcycling tests can begin, where the aim is to reproduce or exceed the product quality established under laboratory conditions.

During the fourth phase, we are to analyse the industrial-scale produced foam blocks, in view of the starting materials and the laboratory results. All of the findings are to be included in the protocol, with the main factors affecting the properties of the final product described. Using this knowledge, we finalise the type and dosage of the binder and optimise the production parameters in view of the intended usage of upcycled foams. By the end of this phase, we aim to achieve the final formula and manufacturing parameters to produce high-quality reconstituted foams in a reproducible way for mass production.

When our development reaches a phase when the research results are ready for use, we would like to organise demonstrations - primarily for our customers - where we can showcase the results of our development and the properties of the materials. We also aim to make a presentation of the research results, which we want to make available online on our own website and on the websites and publications of professional associations and interest groups of our industry.

Development of product concepts

The final stage of the product development is to use the upcycled material in different industrial forms and moldings. The product prototypes are to be tested in our on-site test chamber, which has already been used for development during clean room door production. Our ultimate goal is to produce as many upcycled products from secondary raw materials as possible.

Prototypes

Our development project focuses on various areas. Rigid polyurethane foams can be found and are used in all areas of life, many of which could be made of upcycled products. To reach this goal, we want to offer sustainable alternatives for a wide range of industrial applications.

Our vision

Our project aims to create real value for industrial application from upcycled foam waste, reducing COx and other harmful emissions. With the growing demand for green solutions both locally and globally, innovation is a key element of evolving technology. Our goal is to achieve 100% upcycling of waste from our operations and other companies instead of relying on environmentally damaging incineration or landfill.

Sustainability

One of the key principles of sustainable development is that it takes a complex approach to environmental concerns, social needs, and economic development. Our project aims to address all sustainability issues. We are working on a production and waste management solution that reduces the amount of PUR foam and microplastics released into the environment, therefore contributing to human well-being, health, and economic development.

Have a look at our project descriptions in English and Hungarian on our website!

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