REVERSE SUPPLY CHAIN FOR THE CIRCULAR PU FOAM FROM APPLIANCE. CHALLENGES AND BARRIERS

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Abstract

The actions of the European Commission, as well as the sustainability goals developed by the UN, are forcing companies to take steps towards a circular economy. One such product that can be potential reused is PU foam from appliance equipment. The introduction of appliance PU foam into the circular economy involves a reorganisation of the reverse supply chain. This requires the involvement of different stakeholder groups that are involved in the entire process. The aim of this paper is to present the current reverse supply chain for appliance-derived PU foam and to propose a new reverse supply chain concept to build a new closed-loop ecosystem for PU foam. Based on a survey among different groups of stakeholders, the challenges and barriers of designing a reverse supply chain for closed-loop PU foam will be presented.
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Keywords: Reverse supply chain, circular economy, PU foam

1. INTRODUCTION

Recent years have been characterized by increased environmental concerns inducted by environmental, social and economic concerns about a lack of resources and increasing amounts of global waste due to accelerating consumption in the world. On the one hand, it influences the creation of legislation to improve the environment, on the other hand, to build and increase the environmental awareness of producers and consumers, which strongly determines the relationship between production-consumption of products, environmental protection and sustainability. Manufacturers, influenced by legal conditions and pressure from consumers and social organizations, must pay attention to the environmental consequences of production processes, including waste prevention, reuse and recycling as a part of a potential solution for efficient resource management. By providing products and services with limited negative environmental impact, manufacturers have discovered opportunities to build competitive advantages based on the circular economy (CE), which has been referred to as one of the main strategies to achieve sustainable development [1]. Within the circular economy discourse, pertinent definition is developed by Kirchherr et al. [2] The authors undertook the labor-intensive task of canvassing literature proposing 221 definitions of CE appearing between 2017 and 2021, all published in academic articles. They then used their analysis to propose their own definition: the circular economy is a regenerative economic system which necessitates a paradigm shift to replace the *end-of-life concept* with reducing, alternatively reusing, recycling and recovering materials throughout the supply chain, with the aim to promote value maintenance and sustainable development, creating environmental quality, economic development and social equity, to the benefit of current and future generations. It is enabled by an alliance of stakeholders (industry, consumers, policymakers, academia) and their technological innovations and capabilities. It should be pointed, that implementation of this concept is a major economic and technical transformation that can only work if the different actors collaborate smoothly [3]. CE enable the

reuse of materials thereby minimizing the use of virgin materials and eliminating unnecessary wastes of end-of-life products [4]

From the CE perspective, the reverse supply chain (RSC) is essential to “close the loops” of end-of-life products, with regenerative and restorative features. [5,6] The RSC definition considered in this paper is the efficient and effective management of a series of necessary activities to recuperate a product from the consumer to dispose of it or recover the residual value [6].

Plastics are essential components of a circular economy. To build CE on their potential, current challenges around plastic like products design, collection, sorting and end-of-life management must be addressed. As the report's *The Circular Economy for Plastics. A European perspective* note, a lack of appropriate waste management infrastructure, policy incentives and business models mean that the full value of plastics waste is currently not being captured. Plastics waste that is not disposed of correctly most often ends up into the environment while they should be kept as a resource in the circular economy. The plastics CE is a sustainable model where plastics remain in circulation longer and are reused and recycled at the end of their life span.[7] According to the European Parliament the most common way to dispose of plastic waste in Europe is energy recovery, with recycling coming in second. About 25% of all plastic waste generated is landfilled and 50% of the plastic collected for recycling is exported to be treated outside the EU caused by the lack of capacity, technology or financial resources to treat the waste locally.[8] This problem concerns circularity of high-performance plastics because until now, not adequately recycled waste stream coming from rigid polyurethane (PU) foam used as insulation material in refrigerators.

Based on these premises, the paper aims to propose a new reverse supply chain concept to build a new closed-loop ecosystem for PU foam and present the challenges and barriers identified during the survey among different groups of stakeholders.

2. CURRENT AND NEW REVERSE SUPPLY CHAIN FOR APPLIANCE-DERIVED PU FOAM

What needs to be emphasized is that currently almost 100% of PU waste from electrical and electronic equipment is managed through energy recovery, it does not currently go for recycling. In Poland, there are 2,279 municipal points to which residents can give their used appliances (including refrigerators) [9]. Collection is also often carried out directly from the property and through stores. In the country, there are 6 plants for demolition of used refrigerators, each of which recycles between 500 and 1,000 refrigerators per day, depending on demand (from each refrigerator comes about 10 - 12 kg of used PU foam of large volume).

As indicated in Figure 1, there is a network of municipal collection points in Poland, and it is well developed. These points receive used appliances including refrigerators. They are then transported to municipal installations where they are collected in larger batches and sent to installations that deal with the targeted demolition of refrigerators. These installations send the materials obtained from demolition for recycling (metals, precious metals, plastics, glass) and energy recovery (primarily PU foam). In order to obtain a reverse supply chain for circular PU foam from appliances, additional activities are required. As presented in Figure 1, the concept of a new reverse supply chain for PU foam will include chemical preparation for electronic appliance producers from refuse derived fuel obtained from WEEE Processing Plants for electro-waste. That is, PU foam that is not currently recycled, but used as a fuel for power generation in a new reverse supply chain for circular PU foam will be recycled and after chemical preparation will be delivered to the electronic equiepment producers. It is worth to mention, that refrigerator demolition facilities incur costs in allocating PU foam for energy recovery and are interested in seeking cheaper methods for its management, such as chemical recycling. Refrigerator manufacturers, on the other hand, are looking for secondary raw materials to produce their goods to colder their environmental footprint and to achieve production-related savings (understood also as the cost of primary raw material interruptions).

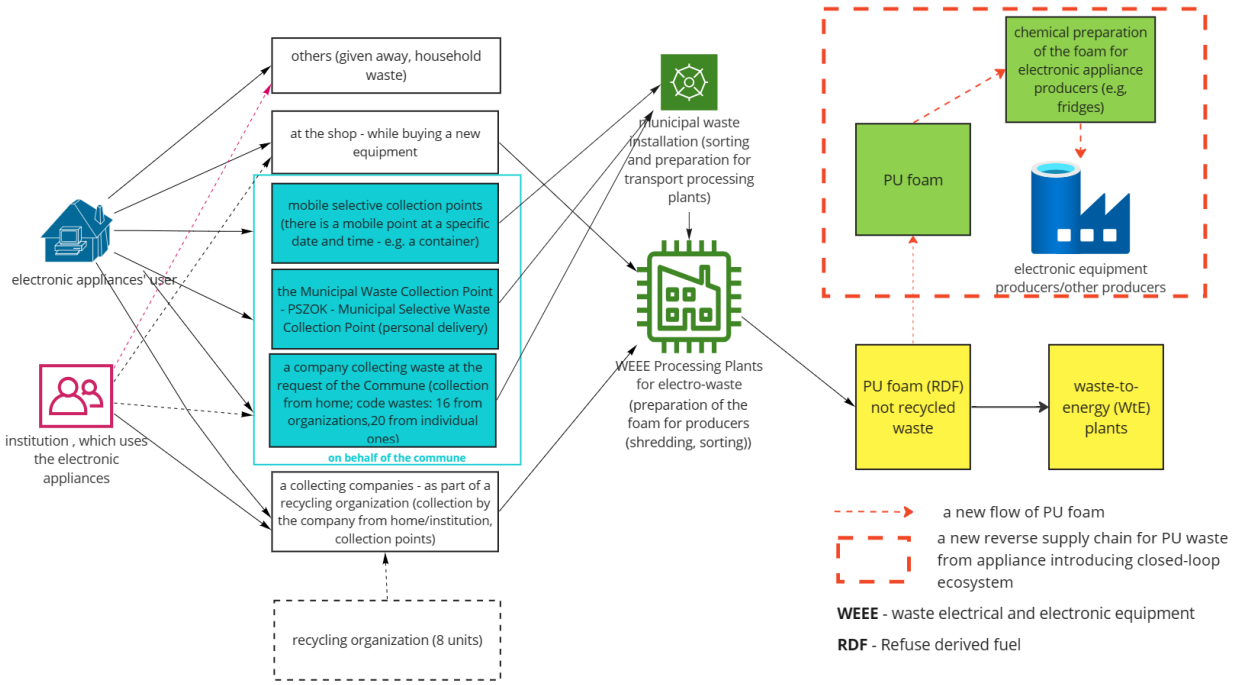

Figure 1 Reverse Supply Chain for PU waste from appliance – current status and a new, introducing closed-loop ecosystem

3. METHODS

To investigate challenges and barriers of implementing a reverse supply chain for close - loop PU foam we conducted quantitative and qualitative surveys among stakeholders, both using a survey method for data collection. Stakeholders were divided into two groups. The first group was consumers, the second waste stakeholders involved directly and indirectly in PU foam collection and its recycling.

A quantitative survey was conducted among consumers in the first step. Data was collected by using the Computer Assisted Web Interview (CAWI) method. The survey was conducted in the second quarter of 2023. The group of respondents from Poland consisted of 1001 people, including 662 women (66.13%) and 337 men (33.67%). In order to gain a deeper understanding of the attitudes that potential consumers have toward recycled polyurethane, two Focus Group Surveys (FGI) were conducted (during May and June 2023). Each FGI consisted of 10 people (representative of young and elder generation of consumers). At the same time, an in-depth survey was conducted within stakeholders involved directly and indirectly in PU foam collection and its recycling, using a categorized interview questionnaire. The survey included 11 experts representing local government (2 interviews), scientific and research institutions (4 interviews) and waste collectors (4 interviews).

4. RESULTS AND DISCUSSION - CHALLENGES AND BARRIERS OF DESIGNING A REVERSE SUPPLY CHAIN FOR CIRCULAR PU FOAM

The reverse flow of the supply chain is important for companies to be capable of recycle and remanufacture PU foam and for consumers who will be the users of appliances with recycled PU foam. According to the surveys, the results in table 1 can provide an insight of the important barriers and challenges of reverse logistics of the companies in the PU foam industry and waste collectors.

Table 1 Challenges and barriers of designing a reverse supply chain for circular PU foamFOAMS

Areas	Barriers	Challenges
Technical, technological and infrastructural	Lack of a sufficient number of chemical recycling plants in the market Difficulties in obtaining an adequate amount of PU waste stream for the future plant	Low efficiency of the collection system can be improved in the future, primarily through introducing new technology Lack of innovation/technology for PU in current recycling plants will require additional investments
Legislative	Unclear conditions and management for PU waste (large number of different legal acts) Three-level administrative division in Poland hinders cooperation between stakeholders.	Lack of legislative support for scaling up circular models will require the introduction of new legal regulations
Economic	The high cost of preparing PU foam for transport (after demolition of the refrigerator), transporting and development PU foam (due to its low density and lack of recycling facilities outside WtE facilities).	Lack of financial support for scaling up circular models will require some programs enabling to provide this kind of support
Socio – cultural	Some consumers are not willing to change their behavior in terms of waste segregation, CE and recycling	Low consumers' knowledge about CE, waste segregation and recycling can be improved through education and information campaigns

A lack of experience in plastics recycling is prevalent among stakeholders, but some are considering investing in this area mainly due to the lack of a sufficient number of recyclers in the market. A prerequisite, however, is the availability of preferential external funding. They see the potential for PU recycling mainly in refrigerators - here, the PU recovery process is automated and not time-consuming.

Experts also indicate that CE is related to efficient recycling, the longest possible use of raw materials and the design of products that allow this. The state of transformation towards a closed loop economy is in its infancy - some steps have already been taken, but they are not sufficient or the pace of implementation is too slow and they are a reaction to top-down legal regulations (EU and then governmental). In plus the waste collection and treatment system is considered to be developed. Recycling of metals, plastics, organic bio-waste is evident. Education and information campaigns and new legal regulations are noticeable, but there are not enough of them and more action is needed in this direction. Experts believe that it is not possible to implement a full RSC for PU foam due to high costs and the unavailability of suitable technology. Also three-level administrative division of Poland, into voivodships, councils and communes defines the competences of the public administration. These competencies are not always convergent - in consequence three-level administrative division hinders cooperation and may be a significant barrier to the implementation of a circular economy uniform system in the long term. Introduction of closed-loop economy solutions for municipal waste is not treated comprehensively and there is a lack of consistent action as well as legal regulations in this regard.

Stakeholders perceive the potential of Poland as a possible PU recycling centre in the future, pointing out, among other things, its convenient geographical location, transport accessibility, the high level of industrialisation in Poland and the potential of waste management and recycling operators. The idea of such a centre is also seen as an opportunity to attract funding to support the environmental policy and promotion of the Region. Unfortunately, according to stakeholders, there are currently no suitable cooperation structures on which to base the PU recycling system in Poland. Among the most important barriers to the development of such cooperation are those of an organisational, legal, economic and logistical nature. The scale of the

necessary actions and the lack of presence, according to the experts, of factors conducive to the development of cooperation causes that stakeholders do not expect a radical change in the process of establishing a closed loop economy for PU.

Surveys conducted with consumers have shown low level of knowledge in CE and a lack of knowledge about the recyclability of appliances. For the same price and quality, respondents are willing to choose an appliance that has recycled components. However, they are unwilling to spend more money on products that are recycled compared to non-recycled products. Instead, consumers prefer to redirect their daily activities to areas where they have an impact, such as reducing plastic consumption. According to respondents, manufacturers should be primarily responsible for introducing recycled products and there should be legal regulations mandating the use of recycling in the production process. It would be worthwhile for the introduced products to display information that certain components are recycled. This could be an important factor for them to make a purchase decision. In addition to systemic measures, respondents also pointed to education of the public as a form of the process of building environmental awareness.

5. CONCLUSION

The main differences between current, and circular supply chains of PU foam lie in their origin of material resources. Current supply chain extracts the material from the primary resources and produces large amount of waste, circular supply chains bring back recovered from used and/or broken appliances PU foam to the producers of electronic appliances. We propose that circular supply chain of PU foam adopts an approach that is closely connected to the circular value chain for chemical recycling, including: waste collection, sorting and processing, two chemical recycling technologies, the production of new waste-based materials and the demonstration of their use in new refrigerated appliances, the eco-design of new materials and products for the future, with additional emphasis on stakeholder cooperation for a closed loop. Nor is it the case that a circular economy system for PU foam must be built from scratch. After all, it is possible to implement new conditions into existing infrastructure. This allows involved companies to maximize their use and generate savings for the environment. By using the infrastructure that already exists, we save the time associated with the process of building a new collection system and the financial resources that can be allocated to new innovations at the stage of waste management and reuse in the economy. The ideal place to change from a current to a circular supply chain of PU foam is when the equipment is handed over to facilities for demolition. Instead of dedicating PU foam to energy recovery, installations will be able to transfer PU foam to a chemical recycling plant for processing back into intermediates used in the production of new refrigerators. In such a model, both refrigerator demolition facilities and refrigerator manufacturers are faced with a win - win situation, which is what the idea of CE as a new economic model is all about.

Among the most significant barriers to implementing a new closed-loop supply chain of PU foam can be distinguished:

- Lack of chemical recycling technology for PU in recycling plants,
- Difficulties in obtaining an adequate amount of PU waste stream for the future plant (in order to ensure adequate economic efficiency).

There are also unclear legal conditions for PU waste and the high cost of preparing PU foam for transport. Among challenges, which shows difficulties in introducing circular supply chain for PU foam, but which can be overcome can be distinguished:

- Low efficiency of the collection system can be improved in the future, primarily through introducing new technology
- Lack of legislative support for scaling up circular models will require the introduction of new legal regulations
- Lack of financial support for scaling up circular models will require some programs enabling to provide this kind of support

Research shows also that consumers' knowledge about CE and recycling is low. Therefore, to introduce a closed-loop supply chain of PU foam, education and information campaigns are required.

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