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REACT

RECYCLING OF WASTE ACRYLIC TEXTILES

D6.4: Recommendation on Eco-Design

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Abstract	Recommendations about Eco-Design of products and potential new market niche and/or possibilities of use of scraps/post-consumer/un-recyclable waste of acrylic textiles in open loop recycling
Keywords	Eco-Design, Waste, Acrylic fibres

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EXECUTIVE SUMMARY

This deliverable has been created in the context of the WP 6 (LCA and recommendations) of the H2020-funded project REACT (Grant No. 820869).
The document provides an overview of the work done in the whole project and the recommendations to transfer the existing technology and develop a production chain of recycled acrylic fabrics. The document provides indications on how to manage waste generated in the production phases and recovery systems of the material at the end of its life, the technology used to remove the chemicals, the disposal and treatment of hazardous substances and the modification of mechanical recycling process to treat the acrylic fibres.

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ABBREVIATIONS

CE	Circular Economy
CRMs	Critical Raw Materials
DfD	Design for Disassembly
DfM	Design for Modularity
DfR	Design for Recycling
EOL	End-of-Life
LCA	Life Cycle Assessment
MDD	Material Driven Design
NIR	Near Infrared Spectroscopy
PAT	Process Analytical Technology
SDG	Sustainable Development Goals (obiettivi di sviluppo sostenibile)

1 INTRODUCTION

REACT was born with the objective of filling the existing gap in the application of the principles of the circular economy (CE) in acrylic awning, until now mostly conceptualized only under technical requirements and in order to support the overall textile sector in its decarbonization.
This objective implies the development of an integrated solution aimed towards alignment with the Sustainable Development Goals, SDGs, specifically the 9th (Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation) and 12th (Goal 12: Ensure sustainable consumption and production patterns) with particular reference to the 5 principles of Circular Economy as defined by webster.
Thus, ecodesign is arguably the cross-cutting factor that connects the research development activities of the React project through identifying new ways forward in order to maximize and improve the performance of the products and processes under consideration, adopting improvements focused on simultaneously reducing environmental impact and external costs, maximizing benefits and increasing product value, expanding the potential for material use, and leaning secondarily toward forms of upcycling and open loop recycling.
The results of the project/task will generate new references on eco-sustainable and responsible product design and will identify new potential opportunities in terms of alternative and high value-added uses, in line with CE principles.
The manufacturing process has been designed for the fulfill of product specifications, but the recommendations outlined in this task could lead to changes to improve the recovery and recollecting of materials in order to achieve higher recycling rates toward "out of waste" philosophy.
The perspective is toward the end of the production chain with physiological waste generation and moving toward systems thinking in which materials will be cyclical.
Finally, the approach taken and recommendations that emerged could be used by similar companies or adapted to other industries with similar production processes.

2 THE ECODESIGN APPROACH

2.1 From strategies to actions

Ecodesign can be defined as a method and process that considers environmental aspects at all stages of the product development process, striving for products which make the lowest possible environmental impact throughout the product life cycle[1].

Ecodesign considers the integration of multiple aspects which stem from environmental, social, and economic motivations targeting a sustainable product in the early stages of design. This approach considers the entire life cycle of the product, not only the in-use phase also the manufacturing and end of life phases which are evaluated in terms of, among other aspects, energy and resource consumption. Key concept of eco-design is *life-cycle thinking*, which requires consideration during the design and development process of the significant environmental aspects of a product in all life cycle stages. The life cycle stages usually include the processing of materials, manufacturing, distribution, use, maintenance and end-of-life management (including reuse, recycling,recovery and final disposal).

In the textile industry, such approach must deal with numerous influencing areas which lead to a complex process due to the complexity of system and life cycle thinking and the holistic approach needed.

One of the firstly principle to consider is to avoid that a choice in one phase performed in order to reduce a particular environment impact could lead to a more environment trouble in another phase of the whole life cycle of product.

For this reason, is important to refer to eco-design norms (ISO 14006; ISO 14062 and IEC 62430) and LCA standards (ISO 14040, 14041, 14042, 14043 and 14044).

In addition, it is crucial to refer to the principles of the circular economy, because Ecodesign fundamentally integrates harmoniously the design actions with these principles.

According to Webster, the circular economy is based on five principles:

- Design out waste. This means taking waste as raw material, and thinking how it could be dismantled and reused so that it is not discarded again. With this approach, waste is turned out into biological (biodegradable) or technical (reusable) material. Products are usually divided into a biological trace component and a reusable material component.
- Build resilience through diversity. We should stop looking for efficiency in the current models and think out of the box, working in process adaptability, modularity, and versatility based on diverse, interconnected systems.
- Use renewable energy. Minimize the use of fossil fuels and ensure the efficient use of energy.
- Think in systems. The key to apply or implement the circular economy is to think in systems. Understanding the influence and interconnection of the parts and the whole is critical.
- Think in cascades. This means to get the highest value out of products and materials in every step of the process.

2.2 Meanings of EcoDesign

Eco-design appeared in the early 1970s as a reaction to emerging considerations of the unsustainability of production patterns in place in the Western world, and that the tendency in would lead toward inevitable collapse in less than a century. According to V. Papanek, the role of the industrial designer would be central in connecting the emerging environmental awareness with the shift toward sustainable production patterns through ecological and social design.

The 1980s were devoted more to the theorization and discussion of the concepts of sustainable development and low-impact design. But it was in the 1990s that ecodesign began to gain strong societal support, with the development of various regulations and manuals by institutes, governments and researchers around the world.

[1] Source: European Environment Agency

One of the most important manuals is the one published by UNEP in 1997, based on the Dutch "Promise:Manual for Ecodesign" , which proposes an eco-design methodology consisting of seven steps:

1. Organization of the eco-design project;
2. Product selection;
3. Definition of the eco-design strategy;
4. Idea generation and selection;
5. Detailing the concept;
6. Communication and product launch;
7. Definition of monitoring activities. Definition of monitoring activities.

In addition, the manual is complemented by specific modules on some of the tools needed for EcoDesign, including design strategies, life cycle assessment methods, and eco-labels.
The model is, with some evolutions, still adopted in EcoDesign processes, and constitutes a line of implementation of an EcoDesign process there are some parallels with other systems, which will be addressed later (in particular Uni EN ISO 14062 and IEC62430, explained in subsequent Chapters).
Since it is necessary to identify a strategy by choosing among several possible options, the model identifies a methodology for evaluating and selecting possible strategies: the "LiDS wheel"
The LiDS wheel is an ecological design tool that recommends ways to rank the different strategies used in the field of ecological design into eight main approaches. This tool was originally created to evaluate the relative environmental impact of different products. The standard use of this tool is to evaluate a new product using the old product as a kind of benchmark.
Although LiDS provides a basic framework that can be used to examine the entire lifecycle of a product, it is not a method that can be used to determine the actual environmental impact of a product, because LiDS wheel analyses are inherently qualitative and are based on an arbitrarily defined evaluation system. When using this tool, the eight LiDS approaches are represented in a radar diagram, like the evolutionary potential tool, but in this case instead of showing the state of evolution in terms of device novelty, the results refer to its evolution in terms of ecological parameters.

2.3 The relationship among them Technologies and strategies

Even before focusing on technologies, it is important to focus on material cycles; the focus must be on the "product system." With the ecodesign method adopted, it becomes clear that the vision must focus on the product system before focusing on technologies.
In fact, when defining product concepts, it is appropriate to investigate several different approaches, even delving into different technologies.
To give an example, in previous experiences in centrocot projects (from the C-tex project) the initial research on recycling technologies led to the definition of certain common processes, but only after having reached the mainly objective, new needs and stimuli could emerge. A second phase of research, focused on the new specifications brought out several other recycling hypotheses that were not known before. Some because the scope of the analysis on technologies was more circumscribed, some because they were published during this time frame.
Technological solutions in other words are subordinate to strategies of EcoDesign adopted. In fact, a good ecodesign approach makes it possible to identify potentially viable strategies and subsequently investigate and outline the relevant technological solution thact could be employed. In some cases this can be a systemic and serial approach, that is, one that is constantly repeated over time, as required by the Deming cycle.
The main advantages of this method are that it allows one to identify solutions and evaluate them and to continue the research by focusing it on the aspects that emerge step by step, recalibrating the research on the needs that emerge as it progresses.
Going into the most promising technologies that nowadays it is necessary to keep a close look at Recycling Technologies both with a close loop perspective (i.e., textile to textile) but especially open loop (textile to other sectors), because / taking into consideration:

1. In line with the 2nd principle of circular economy (webster, ilibid),
2. the landscape is broader;
3. cannibalism is avoided; and
4. looking for solutions that are consistent and symbiotic with the company's values by going to create proposals that allow it to increase its volume of business.

It is necessary to specify that it is not meant industrial symbiosis in the strict sense, but a market positioning that is kindred and proactive to the company's core business, in simple words the objective is to seek any situations in which the byproduct obtained by recycling the non-recyclable fraction with close loop is a product that in the market facilitates or improves the main product.

In the curent deliverable, it is intended to adopt the present approach as a model for identifying possible strategies to be pursued in the future as a continuation of the REACT project.

In fact, the project demonstrated the effectiveness of removal treatments, classification of available waste types, but also revealed values of non-recyclable material with the method employed, specifically:

- around 13% of the material sent to shredding (see D4.1)
- around 3 to 4 % of the material sent to spinning (see D4.2

2.4 EcoDesign: norms and it's integration in Environment Management System: ISO 14006, 14062 and IEC 62430

There are two standards covering EcoDesign and its integration into environmental management systems, and they deal with different aspects:

- ISO 14006:2020 provide guidelines for the relationship between business functions and EcoDesign, effectively indicating how EcoDesign should be embedded and contextualized within the organization,

- ISO 14062:2007, recently replaced by IEC 62430 in 2019, provides guidelines for implementing sustainability criteria within the design process.

It should be emphasized that although it only mentions environmental aspects, actuality Ecodesign can cover a wide range of actions, from risk management, new product design, supply chain and production asset redesign to brand repositioning or redefinition of the company's vision and mission, depending on which objectives it refers to.

In other words, Ecodesign is a method and thinking that fits corporate frameworks with a distinct philosophy, and can influence choices and the dna on multiple levels, from marginal choices to the core identity of an organization.

Based on ISO 14001, which links the environmental management system (EMS) with the design and development phases of ecodesign, one can assess the areas of improvement to be provided and any innovation plans to be implemented as necessary to improve the product/service with regard to environmental aspects.

By its nature, EcoDesign must be multidisciplinary, especially to fulfill the requirements of ems. In fact, certain core competencies must be considered, mainly:

- A critical assessment of environmental aspects and impacts in the various phases of the product/service system, considering their significance and identifying hot spots, potential critical issues and opportunities;
- Understanding the proper aspects of product design and development, in order to integrate considerations of environmental aspects and impacts within the design, identify effective forms of response to the needs that have arisen, and integrate the results with the EMS system.

UNI 14006:2020 is a general standard that can be used by any organization that aims to document, implement and continuously improve ecodesign as part of the environmental system in accordance with the ISO 14001 family of standards. The environmental aspects covered are related to products and the organization of activities.

Ecodesign is a systematic approach that considers environmental aspects during design and development with the intent of decreasing impacts on the environment throughout the product life cycle; enhancing environmental performance, but it can also be seen as a way to manage risks and opportunities.

Finally, the standard also considers aspects related to staff training:

- Central point is environmental awareness. this must be the starting point for knowledge development and a fundamental objective for product life cycle development.
- the organization must ensure ongoing training of personnel involved in product design and development in awareness of environmental aspects and impacts and knowledge of product life cycles. In this regard, it specifies that skills should also indentify measures and information to improve the entire product life cycle and decrease the extent of environmental risk.
- Finally, the communication strategy employed should push different points, and should be specifically developed depending on whether it is:
    - INTERNAL: to all interconnected levels and functions;
    - EXTERNAL: from and to different stakeholders to support collaboration and facilitate information sharing. In addition, all parties should be aware of the actions needed to improve the product life cycle with the goal of improving environmental performance.

IEC 62430 – Environmentally Conscious Design (ECD)

In order to harmonize the Ecodesign method into a common practice to be included in business organizations and not to consider it a technical obstacle, the EU commissioned the Comité Européen de Normalisation Electrotechnique (CENELEC) (European Committee for Electrotechnical Standardization) to develop an Ecodesign standard for its implementation in the Ecodesign directives (the first one was established with the first European Ecodesign standards covering the household appliance sector, and later adopted to other sectors as well); CENELEC brought the standardization task into the international arena through IEC. In 2005, IEC created TC 111, the environmental technical committee, which initiated the environmental standards development projects. ECD standard IEC 62430 was published in 2009.
The standard IEC 62430 define Eco-design as a systematic approach which takes into account environmental aspects in the design and development process with the aim to reduce adverse environmental impacts.

The key point of IEC 62430 is the Ecodesign process for the conformity assessment of products, either for the internal design control or the management system. In either case, the same Ecodesign process applies. The Ecodesign process consists of

1. Analysis of the regulatory and stakeholders' environmental requirements
2. Identification and evaluation of environmental aspects and corresponding impacts
3. incorporation of Environment Concious Design into design and development
4. Review and continual improvement
5. information exchange

The Ecodesign process steps can fit into the Plan-Do-Check-Act (PDCA) cycle of a management system, in particular it is addressed to the first 4 items: the early Steps (1st and 2nd) correspond to Plan, then step 3rd involve the "Do" phase, and finally step 4th regard Check and Act.

It is important to emphasize the parallelism with the methodology defined in the handbook "Promise:Manual for Ecodesign" , and especially that a similar scheme is proposed , consisting of 3 general macro stages: a basic research to contextualize the product/process to be implemented, a generation of hypotheses to be pursued, and then the development of concepts down to the details of the same, followed by testing and analysis.

It clearly emerges that the focus of the activity is the generation of hypotheses, and on this the standard specifies that *"The organization shall establish, implement and maintain a process to ensure that the following tasks are carried out during design and development",* fa riferimento a "*c) determine improvement strategies for the environmental parameters" e " f) create solutions to realize the specification while taking into account other design considerations.*", but does not mention a method for concept generation, the notes also describe that *"The product solution resulting from design and development should achieve a balance between the* *various environmental aspects including relevant stakeholder requirements (se 5.2) and other requirements such as function, technical requirements, quality, performance, safety, economic aspects, ethical and social value, and technical and business risks.".*

For this reason, LiDS is considered to be a reference tool for formulating development hypotheses, as it allows potential development strategies to be addressed.

A Key point for the implementation of an EcoDesign process is the allignement with life cycle thinking, in fact it is assumed that in steps 1 and 2 significant environmental parameters are identified. These parameters become the target for the environmental improvement.

A design solution to improve the environmental performance of the parameter is developed during the design and development step. Once the environmentally improved product is developed and put on the market, any feedback from the market is reflected to the redesign of the product for further improvement of the environmental performance.

A Key point for the implementation of an EcoDesign process is the allignement with life cycle thinking, it is important to move from product design to life cycle system design based on the principles of Circular Economy. Lifecycle thinking adopted in design practice becomes important in two key aspects of the development process. The initial assessment and the planning of possible solutions that can be identified.

Key elements of life-cycle-thinking are:

1. Having an objective to minimize the overall detrimental environmental impacts of the product
2. Identifying, qualifying and where feasible quantifying the significant environmental aspects of the product
3. Identifying new potential solution available (or almost available) for the use of materials as feed for new cycles/sectors

In theory, this should be done as early as possible during the design and development process because there are maximum opportunities to make improvements and changes to the product that affect its overall environmental performance throughout its life cycle. In particular 1st and 2nd key element are related to this approach.

Therefore and in particular for 3rd key element, there is no exclusion that EcoDesign procedures can also be applied once a solution has been identified and implemented in any new system, as is the case with the current React project.

One of the benefits of this approach is that by having potentially new secondary raw materials available that can be integrated into virtuous forms of recycling, new opportunities for their use can then be identified.

This means that if with the project it is demonstrated to recover the material at the end of its life and make it suitable for recycling by eliminating the chemical risk, in addition to the closed loop recycling forms described and explored in detail in the previous deliverables ... , new virtuous forms of recycling can be searched through the EcoDesign approach. The process can be virtuous if circular economy criteria are taken into consideration, in particular:

<u>Design out waste.</u>

It can be deployed in various forms of approach: one of the most feasible can be focusing on recycling of non-recyclable fractions, or finding alternatives that can potentially create uses for the same materials. Material maximization, i.e., the elimination of physiological waste, is also addressed by this approach. One of the promising paths, and sometimes prioritized, is to find solutions to waste that proves difficult or not recyclable at all. In this way, such fractions can be valorized, increasing the recovery rate of the materials themselves.

In addition, it is necessary to try to prefer solutions that do not create additional problems for the subsequent recycling of materials (as defined by UNI 14006), but that can lead to virtuous forms of circularity, i.e., with minimal downcycling or upcycling, in this way new processes and new business models can be described that allow the second principle to be met:

Build resilience through diversity.

The identification of new technological solutions of processes for materials, also makes it possible to identify new applications or new target sectors. In some cases these can be actual new market niches which are distinct from the core business and can generate new potential business cases for organizations. To do this, it is necessary to refer to the two missing principles:

Think in systems.

The approach employed operates on progressive scales: first some conceptual and broadly defined solutions are identified, then the most promising hypotheses are selected and defined in detail, finally the most promising hypotheses are "accepted" to practical experimentation.

Sometimes it is necessary to experiment "blindly," that is, without having available a predictive analysis of the results that may emerge, because basically it is experimenting with uncertain elements. In some cases it is precisely necessary to do empirical experimentation on which the theoretical model can be reconstructed, and the collection of data and final analyses, including negative results, enables to draw the border of "feasible solutions" with accuracy.

Taking into account that each single transformation step includes several process variables, it is clear that the landscape of potential solutions tends to be infinite and made up of many slightly different variants. Therefore, it is necessary to be able to define general outlines for possible applications while at the same time being responsive and identifying positive and negative aspects. Sometimes only through initial experimentation can unknown opportunities be identified. This approach also makes it possible to connect different sectors or those that do not normally talk to each other, this element helps a lot for the last principle to be considered:

Think in cascades.

This means to get the highest value out of products and materials in every step of the process: at every single step it should come down to knowing precisely how to handle waste, and avoiding all forms of material loss. The development criteria expressed in the above points delineate the development process.

3 REACT CURRENT OUTPUT

3.1 Application of Ecodesign in REACT project

Thanks to the results of the REACT project and its successful removal process, it was demonstrated that the material is suitable to be reintroduced into the recycling process, thus avoiding the chemical risk.
The above mentioned LiDS wheel is a tool for eco-design that suggests a way of classifying the different strategies used in the field of eco-design into eight main blocks.
Those blocks are:

0) New Concept
1) Selection of low-impact materials
2) Reduction of materials usage
3) Optimization of production techniques
4) Optimization of distribution system
5) Reduction of impact during use
6) Optimization of initial life-time
7) Optimization of end-of-life system

The main REACT project is focused on 7th strategies (enabling by the chemical removal process the optimization of end-of-life system), and it is also addressed on 3rd approach (Optimization of production techniques).
Since the eco-design process is part of a well-established production system, research is therefore oriented towards identifying solutions that can be adopted to improve the same eco design approaches As seen in WP4, the feasibility of the "close loop" recycling process was demonstrated, i.e. reintroducing the material into the process itself.

3.2 EU Ecolabel Product

The EU Ecolabel covers a wide range of product groups, from major areas of manufacturing to tourist accommodation services The REACT Project focused on the removal of the finishing touches on the awnings. If this product were entirely produced by industrial partners, it would be included in the Supplies category[2].
The advantages of having a product - a tent - with the EU Ecolabel marking are identifiable. Good reasons have been identified for choosing the EU Ecolabel:

- *Help protect the environment*: EU Ecolabel products produce less waste and pollute less throughout their life cycle than similar products on the market.
- *Help minimize the use of hazardous substances*: EU Ecolabel products prohibit the use of many substances that are dangerous for the environment and for your health.
- *Choose a brand of environmental excellence*: Attributed by independent competent bodies which verified compliance with ecological criteria established, at European level, on a scientific basis.
- *Savings*: The restrictive performance criteria that the products. EU Ecolabel must meet guarantee its effectiveness and, helping you to reduce energy and water consumption.
- *Choose consciously*: You have a wide range of ecological products and services available to choose from

In this context, if all the partners were industrial, it will be possible to insert the Ecolabel practice and the product will be advertised on the European Commission website: http://ec.europa.eu/ecat/

[2]2014/350/EU: Commission Decision of 5 June 2014 establishing the ecological criteria for the award of the EU Ecolabel for textile products (notified under document C(2014) 3677) Text with EEA relevance

3.3 Optimization of end-of-life system

As described above, ecodesign actions are undertaken to increase the recycling rate of recovered materials.
Physiological losses of material that is unsuitable for processing were observed, specifically, as described in D4.1, in the preparatory stage, shredding, 13 % of the material is lost.
A further 3-4 % loss arises in the spinning phase.
It can be assumed that in the weaving phase the same loss occurs as in the original process, which could be reintroduced in subsequent recycling cycles, which must be checked
The characteristics of the waste are, as demonstrated in the literature, fibre fractions, powders or off-cuts that are too poor in performance to be processed by the traditional mechanical method.
Nevertheless, it can be inferred that the performance of the intimate material remains, namely, as stated in the Grant agreement:

- UV resistance;
- Chemical resistance;
- Excellent mechanical properties
- Resistance to weathering in general

It follows that by adopting an open-loop recycling approach, in line with the principles of the circular economy, a range of alternative solutions can be identified in which to reintroduce the material.
In general, the best solution seems to be to evaluate destinations and processes in which its resistance is an added value.
With reference to the polymer's intrinsic performance, it is inferred that waste could be used in the following sectors

- outdoor, thanks to its sunlight resistance characteristics, in fact the same reason why it is adopted for awnings.
  Hence, this points to a second opportunity: to focus (by following the principles of thinking in systems and cascading, creating resilience through diversification) on related sectors where the material is used for the production of complementary goods to awnings. For example, if rigid supports were to be created, for the construction of the frames of the awning, or used for the support structures of the awnings themselves.
- Resistance to chemicals and mechanical performance in general: another area of investigation may focus on identifying optimal ways in which the material can 'deliver' intrinsic performance, perhaps as a substitute for virgin materials.

One hypothesis considered valid to adopt is thinking of employing the material as a filler in the production of traditional products.
For example, it could be investigated as:

- alternatives to WPC
- STL powder 3D printer

A further hypothesis for the application of waste stems from the analysis of the use of different materials in powder form, where some possible alternatives were identified:

- use of powders as colouring agents instead of pigments
- use of powders as flock material

3.3.1.1 Using PAN powders and fibres as alternatives in composites derived from WPCs

Wood Plastic Composites are man-made materials that are well established in the market and are produced from a variety of raw lignocellulosic materials and an appropriate binder.
They are used in a variety of sectors, including outdoor furniture, but generally also offer the possibility of customising the end product according to the area of application. Extruded WPCs are formed into both solid and hollow profiles. A wide range of injection-moulded parts are also produced, from car door panels to mobile phone covers.
Their advantages include easy design for various applications, including structural applications, often as an alternative to solid wood.

WPCs are produced by blending wood particles or fibres with thermoplastic resins. They are typically extruded into profiles that are used in various sectors both as decorative and structural elements. Alternatively, they can be used in injection moulding.
WPCs can be produced from virgin or recycled thermoplastics, including high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), acrylonitrile butadiene styrene (ABS), polystyrene (PS) and polylactic acid (PLA).

Fig. 1,2: exaples of WPC panels and final outdoor products [3]

The simplicity of the process makes it possible to simplify the design of artefacts, but there are potentially several benefits to be gained from replacing the traditional ligno-cellulosic filler with acrylic fibres or powder, which would allow an aesthetic and performance variant due to the material's inherent UV resistance.
Since additives such as dyes and UV stabilisers are used during their production, the use of PAN fibres suitably processed to make them suitable for the traditional WPC production process could replace the above-mentioned fillers, and confer new aesthetic properties to the final product, thus creating a diversification from the standard product.
The treatment to make the PAN waste arose from recycling of awning suitable for the WPC production process should consist of selecting the colours to be used and homogenising the particle size according to the effects to be achieved.
Finally, it can be assumed that the final product will be recyclable continuously through standard plastic recycling processes (grinding, pelletising and extrusion).

3.3.1.2 Use of PAN powders in 3D printing processes: selective laser sintering

The Selective Laser Sintering (SLS) process enables the production of functional and durable parts by using a high-power laser to sinter small polymer powder particles and transform them into a solid structure based on a 3D model.
Developed in the mid-1980s, selective laser sintering was one of the first additive manufacturing techniques and today enables the production of products with complex shapes from a wide range of materials, including plastics, metals, glass, ceramics and various powder compounds. In a simplified form, the process is based on the concept of a 'powder bed melt': an additive manufacturing process in which thermal energy melts selected areas of a powder bed, where layers of powder are progressively spread out.
Today, the main polymer used are polyamides, but it is not excluded that PAN powders may be used, either as a filler to provide the polymer's properties (in particular UV resistance, chemical resistance and mechanical properties), or with increasing percentages until, hypothetically, it can be used as the main matrix or pure products.
Studies are currently underway aimed at evolving the SLS process to achieve both better flexibility of the polymers that can be used and a reduction in fixed and operational costs.

[3] Courtesy: https://www.pavimentieparquet.com/pavimento/legno-composito-wpc-per-esterni-decking-wpc-alveolare/ and https://www.solostocks.it/vendita-prodotti/arredo-urbano/panchine/panchina-melpignano-con-doghe-in-wpc-12775132

Fig. 3: exaple of SLS product[4]

3.3.1.3 Use of PAN powders as printing pigments

During the research, a study emerged: 'Coloured powder from coloured textile waste for fabric printing application'[5].
It was studied the feasibility to use a dyed cotton fabric as pigment for screen printing on a virgin fabric.
The dyed cotton fabric was first powdered and the resulting powder was used as pigment in screen printing on a virgin fabric.
The process was conducted using a common formulation used in industrial printing processes.
The study shows that the powdered textile material can be used as a substitute for virgin pigments used in printing.
By adopting this method, it is possible to make prints on textiles by recycling non-recyclable PAN powders and waste.
Further, the technology required simply involves the normal industrial printing process, thus the possible use in awnings will have to be evaluated, or it could be used as a form of finishing secondary recycled products for other sectors.

3.3.1.4 Use of PAN fibrils in flock production

Another potential potential application emerged during research into possible alternative uses could be the use of the waste to create flock.
This is a well-known and consolidated industrial technique that gives to soft and hard surfaces a velvet-like coating.
The process exposes particles of natural, artificial or synthetic fibres to a surface coated with adhesive (and in an electrostatic field). The adhesive layer of the surface absorbs the fibres, generating an effect similar to velvet, although it is not the well-known fabric but this technique is being appreciated for its tactile characteristics.
The normal industrial process involves the pulverisation of fabrics into fibre fragments that are subsequently functionalised to be reintroduced into production processes.

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[4] Courtesy: https://formlabs.com/it/blog/sinterizzazione-laser/

[5] "Coloured powder from coloured textile waste for fabric printing application", GanZhiheng L., ZhangJin X, et al. Springer, January 2021.
https://www.researchgate.net/publication/345795845_Coloured_powder_from_coloured_textile_waste_for_fabric_printing_application ,

A range of products (both soft and hard) could then be refined and, thanks to the intrinsic properties of the polymer (the aforementioned UV and chemical resistances in general) would be rewarding, high-performance elements.

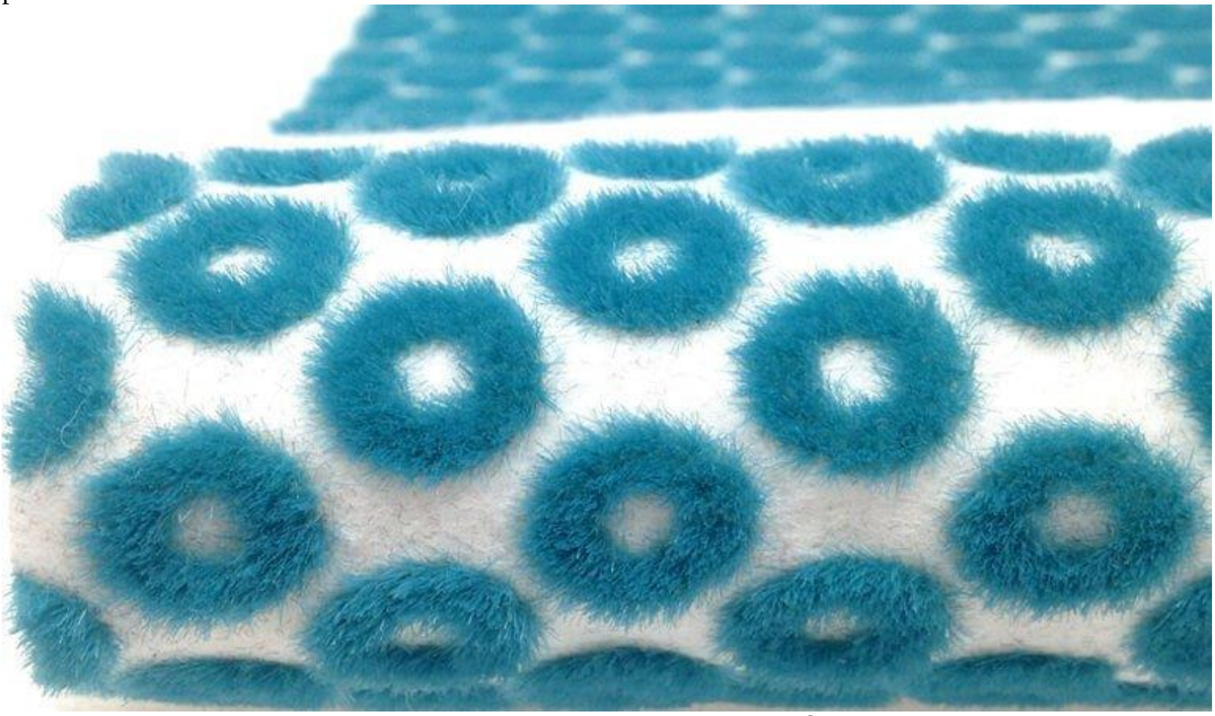

Fig. 4: exaple of a flocked product[6]

3.3.1.5 Other potential uses of PAN in various sectors

The search for possible solutions was carried out through literature studies, identifying possible sectors and/or applications in which the material could be used.
Research has identified a number of solutions in which PAN polymer has been studied in applications of various kinds.
These are stimuli that identify potential outlets, which, if found interesting, will require further specific investigation, however, it is shown that, with a broader perspective, some solutions not initially considered are possible and that the intrinsic properties of PAN polymer can be exploited.

Some studies[7] are deepening knowledge on the use of PAN polymers as binders in battery production, although further investigation is needed, the use of PAN recycling waste could be investigated as such materials.

Several studies have investigated the use of PAN with the electrospinning production process. Although these studies do not specify the origin of the polymer, hence it can be assumed that they refer to virgin material, it can also be assumed that the material may derive from the non-recyclable scraps that emerged during the REACT project and as described in the introduction could be done by chemical dissolution, a process that is already necessary for its application in electrospinning. However, this remains a field to be explored at the moment.

Some particularly interesting approaches have been identified because of their potential for upcycling:

[6] Courtesy: https://floccaturaflockbalmar.it/cosa-e-il-flock/
[7] Understanding the capacity fade in polyacrylonitrile binder-based LiNi0.5Mn1.5O4 cells. Mathew A, Misiewicz C, Lacey M., Sept 2022, https://chemistry-europe.onlinelibrary.wiley.com/doi/abs/10.1002/batt.202200279

- A study[8] investigated the possibility of creating composite nanofibres of polyethylene glycol (PEG) as a phase change material (PCM) and polyacrylonitrile (PAN) as a support matrix for the production of thermal energy storage materials. During the process studied, a membrane with a suitable phase transition temperature range and high thermal enthalpy values was produced by electrospinning, demonstrating its potential for thermal energy storage applications.
- Several studies[9] show the possibility of using PAN polymer for wound dressing products, which are produced by electrospinning. Some research shows that using PAN wound dressings as a replacement for traditional fibres (cotton, wool, cellulose, rayon and polyester) could allow an improvement in critical aspects.

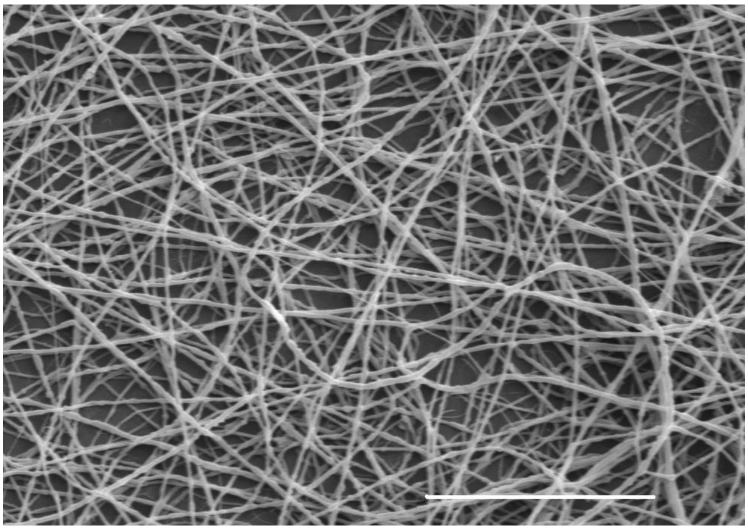

Figure 1: exaple of a elettrospinning wound product, sem image

[8] Fabrication and characterization of polyacrylonitrile and polyethylene glycol composite nanofibers by electrospinning. Xing L, Chaoming W, Zhenyu C.. The Journal of Energy Storage 53:105171, September 2022 https://www.researchgate.net/publication/361626064_Fabrication_and_characterization_of_polyacrylonitrile_and_polyethylene_glycol_composite_nanofibers_by_electrospinning

[9] Recent Progress in Electrospun Polyacrylonitrile Nanofiber-Based Wound Dressing. Huang C., Xu X., Fu J., Yu D-G, Liu Y. Polymers 2022, 14, 3266. https://doi.org/10.3390/polym14163266

4 CONCLUSION

This Deliverable aims to show that it is possible to identify forms of recycling of the resulting non-recyclable fractions, as emerged in the previous project WPs.

This therefore allows the results of the project to be aligned with the criteria of the circular economy, with a view to future continued development, in order to fully demonstrate the sustainability of the sector.

Several opportunities emerged that can be pursued in the future as further fields of investigation.

The multi-discipline approach and a holistic view made it possible to identify both solutions that are easier to implement and others that have more unknowns to deal with but show potential upcycling cases, thus making the processes theoretically more economically feasible.