FUNDING PROGRAMME from PN IV: Programme 5.8. – European and International Cooperation
SUBPROGRAMME: 5.8.1. – Horizon Europe
PROJECT TYPE: ERANET

PROJECT TITLE/ACRONYM: Biobased Degradable Flame Retardant Printed Eco-Electronics / BEATRICE

CONTRACT NO.: 15/2024

TOTAL PROJECT BUDGET: 1.184.500 Euro — **INCDTP'S BUDGET:** 100.000 Euro

PROJECT STARTING DATE: (01/04/2024) — **PROJECT ENDING DATE:** (31/03/2027)

WEBSITE: https://www.htw-dresden.de/en/luc/forschung/chemieingenieurwesen/translate-to-english-technische-chemie/polymere/translate-to-english-beatrice

PARTNERS:
Partner 1 (CO) - HTWD University of Applied Sciences, Germany;

Partner 2 - Budapest University of Technology and Economics, Hungary;
Partner 3 - National Research and Development Institute for Textiles and Leather – Division: Leather and Footwear Research Institute, Romania;
Partner 4 – SC Monofil SRL, Romania.

GENERAL OBJECTIVES

1. **Development of biodegradable and sustainable composite materials for electronic circuit substrates**, based on natural polymers and natural protein fibers.
2. **Replacement of traditional non-recyclable materials (such as FR4)** used in printed circuit boards, with ecological alternatives compatible with standard industry equipment.
3. **Integration of design for recycling principles**, aiming at the efficient recovery of strategic metals (e.g. Cu, Ag, Au) through controlled biodegradation processes of the composite matrix.
4. **Evaluation of the functional performances of the developed substrates** under real or simulated operating conditions (temperature, humidity, mechanical/electrical stresses).
5. **Creation of a demonstration model of biodegradable electronic substrate** for sustainable electronic applications and heterogeneous integration.
6. **Increasing the European contribution in the field of sustainable electronic materials**, by generating applicable knowledge and support for environmental policies and circular innovation.

EXECUTION PHASES:

Stage 1 (01.04.2024-31.12.2024)
Stage Name: Processing natural fibers into bio-fire retardant and PLA using ecological methods

Stage 2 (01.01.2025-31.12.2025)
Stage Name: Obtaining the new green electronic substrate at laboratory scale

Stage 3 (01.01.2026-31.12.2026)
Stage Name: Demonstrating the functionality of the methods and technologies used to obtain circuit traces. Assembling electronic components on the new PCB at laboratory scale.

Stage 4 (01.01.2027-31.03.2027)
Stage Name: Obtaining new Beatrice materials using industrial equipment

SCIENTIFIC CONCEPT:

The BEATRICE project addresses one of the most pressing current challenges in the electronics field – the alarming increase in the volume of electronic waste, caused by the short life cycle of electronic devices and the use of non-recyclable materials in the manufacture of printed circuit boards (PCBs). Currently, most PCB substrates are made of thermosetting resins derived from petroleum, often containing brominated flame retardants with negative environmental impact, and their recycling is difficult, due to the impossibility of efficiently separating metallic and organic components.

BEATRICE proposes an innovative and sustainable solution by developing demonstrators of electronic assemblies manufactured on substrates made of environmentally friendly and biodegradable composite materials. These substrates will be obtained from natural polymers reinforced with protein fibres of natural origin, which will allow recycling through biodegradation, significantly reducing the carbon footprint and costs associated with the recovery of strategic metals such as copper, silver and gold.

The project aims to manufacture these substrates using standard industrial equipment, to ensure compatibility with existing industry processes. In addition, BEATRICE aims to develop advanced, rigid, flexible and wearable composite materials with optimised thermal, electrical and mechanical properties for electronic applications, in line with current heterogeneous integration trends. The ultimate goal is to initiate the sustainable production of PCBs in Europe, capable of replacing conventional materials (such as FR4), thus promoting a new design of electronic devices based on the principles of "design for recycling" and "eco-design", with the potential to transform the value chains of the European electronics industry in a sustainable and circular way.

EXPECTED EXPLOITABLE RESULTS:

To achieve the general objectives of the project, the following exploitable results, with scientific, technological and applicative value, are expected:

1. **Development of new formulations of bio-based composite materials**

Development of innovative compositions based on natural polymers, reinforced with biodegradable protein fibers, which can replace conventional thermoset materials used in printed circuit boards (e.g. FR4). These materials will be optimized for thermal, electrical and mechanical performances suitable for use in advanced electronics.

2. **Manufacturing technology compatible with industrial standards**

Definition of a scalable technological process compatible with existing industrial equipment, for the production of electronic substrates based on bio-materials, with direct applicability in the production of rigid, flexible or portable PCBs. The technology will be validated at laboratory scale (TRL 4).

3. **Integrating circular economy principles**

Designing materials and products in accordance with circular economy principles: compostability, recyclability, easy disassembly and reduction of toxic substances. This will contribute to increasing the sustainability of the value chain in the electronics sector.

4. **Developing a multi-criteria evaluation methodology**

Developing and applying an integrated framework for analyzing material performance, including: life cycle analysis (LCA), cost-benefit analysis (CBA), life cycle cost calculation (LCC), to substantiate decisions regarding the ecological and economic feasibility of new materials.

5. **Demonstrating the functionality of developed products**

Creating prototypes of electronic assemblies (e.g. printed circuits or integrated components), using the developed composite materials, and testing them under conditions representative of real applications (ambient, electrical load, accelerated aging, etc.).

6. **Generating transferable knowledge and disseminating results**

Publishing scientific results in specialized journals and participating in international conferences, along with developing technological guides, etc.

7. **Strengthening the technological base for European reindustrialization**

Creating the premises for the relocation of sustainable PCB production in Europe, through the development of know-how, materials compatible with market requirements and technological processes compliant with the environmental and public health regulations of the European Union.

OBTAINED RESULTS:

- **1 study from the specialized literature** on the current state of the art in the processing of PLA/wool or keratin fiber composites and their potential applications;
- **Development of a methodology for characterizing** natural fiber (by FTIR), modified PLA, as well as the new green electronic substrate (HDT, impact);
- **5 Variants of keratin** extracted by alkaline treatment, either using the combined enzymatic/reducing agent treatment in the presence of two denaturing agents (SDS and EDTA);
- **6 Variants of wool fibers** modified by enzymatic treatment, respectively combined enzymatic/silane coupling agent or enzymatic/stearic acid in order to improve the interaction and dispersion in the PLA mass;
- **Establishing parameters** for processing PLA, flame-retardant PLA, injection-modified PLA, Brabender and electric press;
- **Production of mixtures and plates** by the compression method based on PLA/wool or keratin fibers that will be laminated with copper foils and tested as substrates for PCBs.

Figure 1. Samples of flame-retardant PLA in the form of granules and sheet (A) respectively granules obtained by extrusion-granulation based on PLA modified with additives and dyes (images B and C)

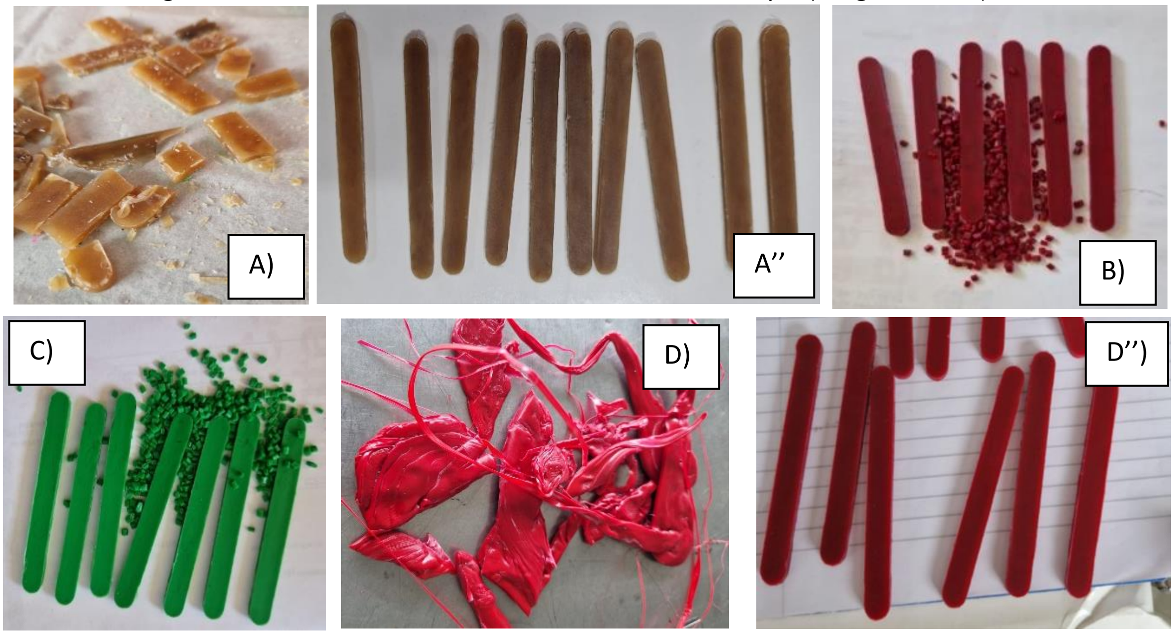

Figure 2. Images of test specimens obtained by compression: A) flame-retardant PLA obtained at 182°C and A'') at 170°C; Images B and C specimens made from PLA modified with 2 and 3% dispersion/compounding additive; Image D (Mixture based on PLA/flame retardant PLA/dispersant additive/dye obtained on the Brabender mixer) and image D'') samples made by compression

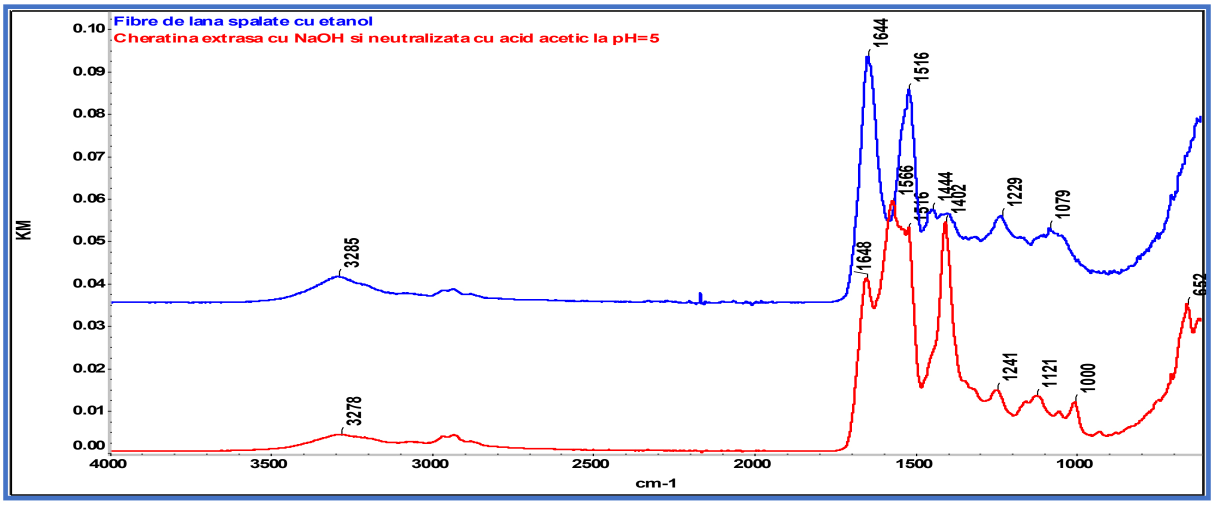

Figure 3. FTIR spectra of wool fiber and keratin obtained by alkaline hydrolysis

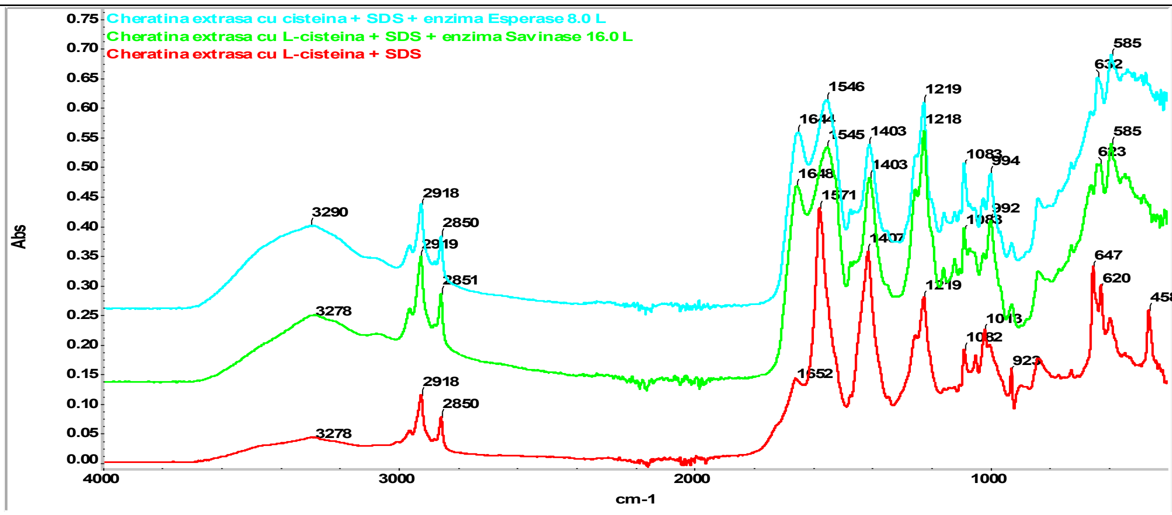

Figure 4. Superimposed FTIR spectra of keratin obtained from wool fibers in the presence of: reducing agent/surfactant SDS (red spectrum); reducing agent/SDS/Savinase enzyme (green) respectively keratin extraction in the presence of reducing agent/SDS/Esperase enzyme (turquoise)

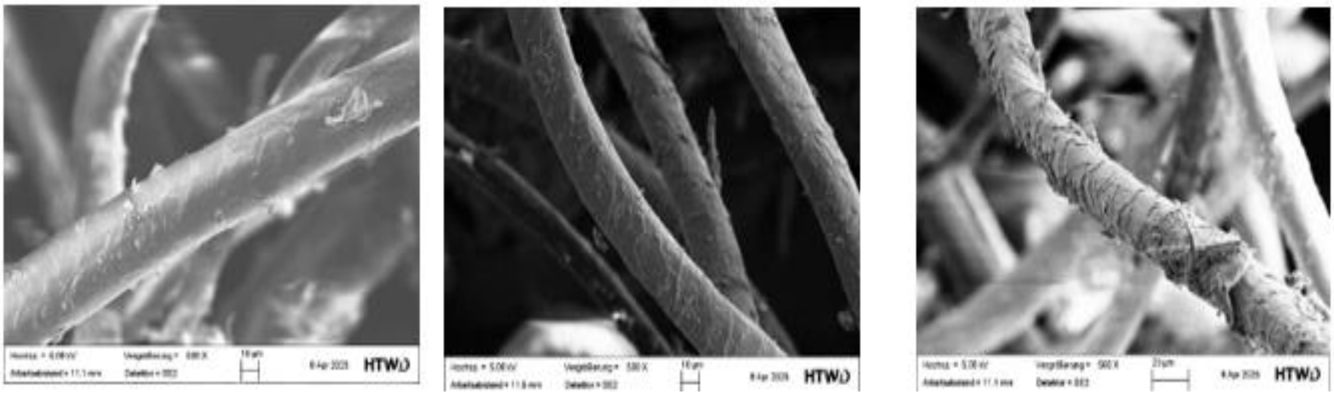

Figure 5. SEM images of: raw wool fiber (left), ethanol-washed fibers (center) and respectively treated with enzyme/APTMS (right)

Figure 6. PLA-based composites reinforced with peroxide-treated wool fibers obtained by extrusion-granulation (image A) respectively by compression (B and C)

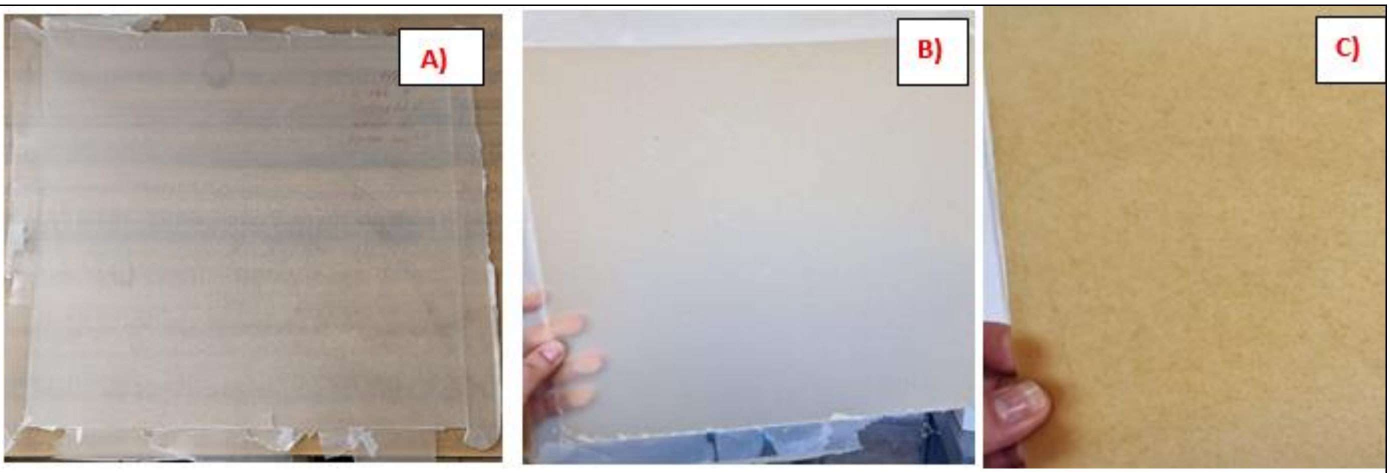

Figure 7. Plates obtained by compression method: **A)** PLA, **B)** PLA/untreated wool fibers and **C)** PLA/keratin

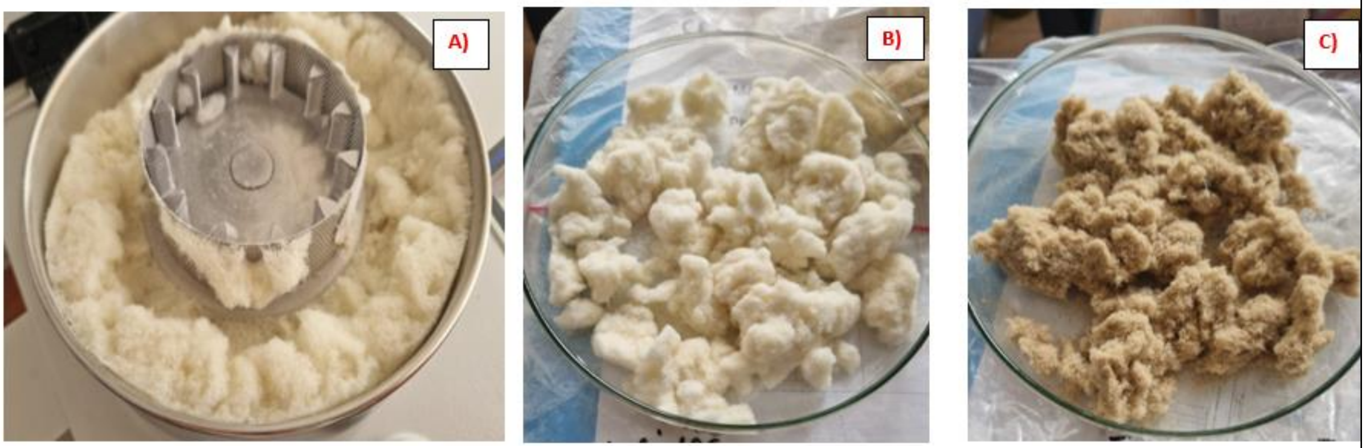

Figure 8. Turcana and Merino wool fibers treated with stearic acid (images A and B) respectively wool fibers treated with Savinase/APTMS

DISSEMINATION, PATENT APPLICATIONS, AWARDS:

- **WoS published papers:**

1. Dan Xiao, Katharina Knez, Yue Qi, Uwe Gohs, Kathrin Harre, Richárd Berényi, **Maria Sonmez, Dana Gurau, Mihai Georgescu,** Doina Constantinescu, Attila Géczy, Development of sustainable printed circuit board constructions based on Polylactic Acid (PLA) substrates: review of processing and manufacturing technologies, 2025, Journal: Materials Science & Engineering B, Manuscript Number: MSB-D-25-02979 - **Submitted for publication**.

- **IBD published papers:**

1. **Mariana Daniela Berechet**, **Maria Sönmez**, **Maria Daniela Stelescu**, **Demetra Simion**, Doina Constantinescu, Short review on keratin synthesis and its application as a bio reinforcement and flame retardant agent in polymer composites, DOI: https://doi.org/10.2478/9788367405805-006, 2024, pp. 45-52, published in Proceedings of the International Conference on Advanced Materials and Systems.

- **Scientific communications:**

1. **Mariana Daniela Berechet**, **Maria Sönmez**, **Maria Daniela Stelescu**, **Demetra Simion**, Doina Constantinescu, Short review on keratin synthesis and its application as a bio reinforcement and flame retardant agent in polymer composites, ICAMS 2024, 10th International Conference on Advanced Materials and Systems, 30-31 October 2024, Bucharest, Romania – oral presentation.

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