Deliverable 3.6

DELIVERY OF PRINTED EMG ELECTRODES INTEGRATED INTO TEXTILES

Dissemination level: Public

Date: 02/07/2024

The project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 952941.

Document control sheet

Project	BIOMAC – European Sustainable Biobased Nanomaterials Community
Call identifier	H2020-NMBP-TO-IND-2020-twostage
Grant Agreement N°	952941
Coordinator	Aristotelio Panepistimio Thessalonikis - AUTH
Work package N°	3
Work package title	Pilot Plant Supreme Hub (PPSH) Services
Work package leader	LIST
Document title	D3.6 Delivery of printed EMG electrodes integrated into textiles
Lead Beneficiary	PRECURE
Dissemination level	Public
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Reviewer(s)	
Issue date	02/07/2024

DOCUMENT HISTORY

Date	Version (n.)	Summary of changes
26/06/2024	1	Initial version
28/06/2024	2	List of pilot lines and figures for process flows added along with a few other minor changes.
28/06/2024	3	List of pilot lines updated, process flow diagrams updated, 2 new process flow figures

		added, description of the process flows added and a few other minor changes.
28/06/2024	4	Process flow figure and description removed
02/07/2024	5	Figures and description of process added.

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List of acronyms

H2020	Horizon 2020
OITB	Open Innovation Test Bed
TeC	Test Case
WP	Work Package
PPSH	Pilot plant supreme hub
MSD	MusculoSkeletal Disorder
TPU	Thermoplastic PolyUrethane
PL	Pilot Line
PUD	PolyUrethane Dispersion
CNC	Cellulose NanoCrystals
PU	PolyUrethane
BNC	Bacterial Nanocellulose

BPUS	Biomac PolyUrethane Substrate
NIPU	non-isocyanate polyurethane
REx	Reactive extrusion

List of pilot lines

PL1: Semi-continuous organosolv-steam explosion pre-treatment, Luleå University of Technology (LTU),

https://www.biomac-oitb.eu/en/static/pl_1

PL2: Hydrolysis of fibre sludge and BNC production, Research institutes of Sweden (RISE),

https://www.biomac-oitb.eu/en/static/pl_2

PL3: Sugar derived polyols and diols by catalytic hydrogenation/hydrogenolysis, ARISTOTELIO PANEPISTIMIO THESSALONIKIS (AUTH),

https://www.biomac-oitb.eu/en/static/pl_3

PL7: Enzymatic Hydrolysis & Microbial Fermentation for SA and LA, Leibniz Institut Fuer Agrartechnik Und Biooekonomie Ev (ATB),

https://www.biomac-oitb.eu/en/static/pl_7

PL8: Biomass carbonization, The University of Edinburgh (UEDIN),

https://www.biomac-oitb.eu/en/static/pl_8

PL9: Continuous Reactive Extrusion for TPU, Luxembourg Institute of Science and Technology (LIST),

https://www.biomac-oitb.eu/en/static/pl_9

PL12: Resins, Fraunhofer Institute for Wood Research Wilhelm-Klauditz-Institut (FH-WKI), https://www.biomac-oitb.eu/en/static/pl_12

PL13: Mechanical treatment to produce NFC and / or CNC, Instituto Tecnológico del Embalaje (ITE), https://www.biomac-oitb.eu/en/static/pl_13

PL14: Coating Formulation, Instituto Tecnológico del Embalaje (ITE),

https://www.biomac-oitb.eu/en/static/pl_14

PL16: Printed electronics, Danish Technological Institute (DTI),

https://www.biomac-oitb.eu/en/static/pl_16

Executive Summary

The present report constitutes deliverable 3.6 "Delivery of printed EMG electrodes integrated into textiles" within the framework of the H2020 OITB BIOMAC project (European Sustainable BIO-based nanoMAterials Community)

The work presented is from Test Case 5 (TeC5) whose activities were developed under the framework of WP3 – task 3.6.

The goal of TeC5 has been to redesign the EMG electrode part of PRECURES "MLI ELBOW" product to be able to print the electrodes and to develop bio-based materials that can be used in the printed electronics processes.

The work was carried out from M18-M42 and resulted in functional prototypes of the PRECURE "MLI ELBOW" products where the electrode part has been produced with printed electronic processes and bio-based materials produced by the BIOMAC pilot lines (PLs). The report presents the materials and processes used in final delivery of prototypes to PRECURE. Details about all the work performed is presented in the periodic reports and D3.7.

Introduction

PRECUREs "MLI ELBOW" is an elbow sleeve with EMG sensors that is used for measuring muscle strain in the lower arm. The purpose of the product is to try to prevent musculoskeletal disorder (MSD) in the elbow (tennis elbow) by monitoring the strain in different work processes and thereby being able to detect critical processes and develop procedures to minimize strain. MSD is the number one work-related health problem in the world. 58% of all workers in the EU report MSD complaints, and the cost related to this is estimated to 39 billion Euro.

Figure 1 shows the current design of the EMG part of the product.

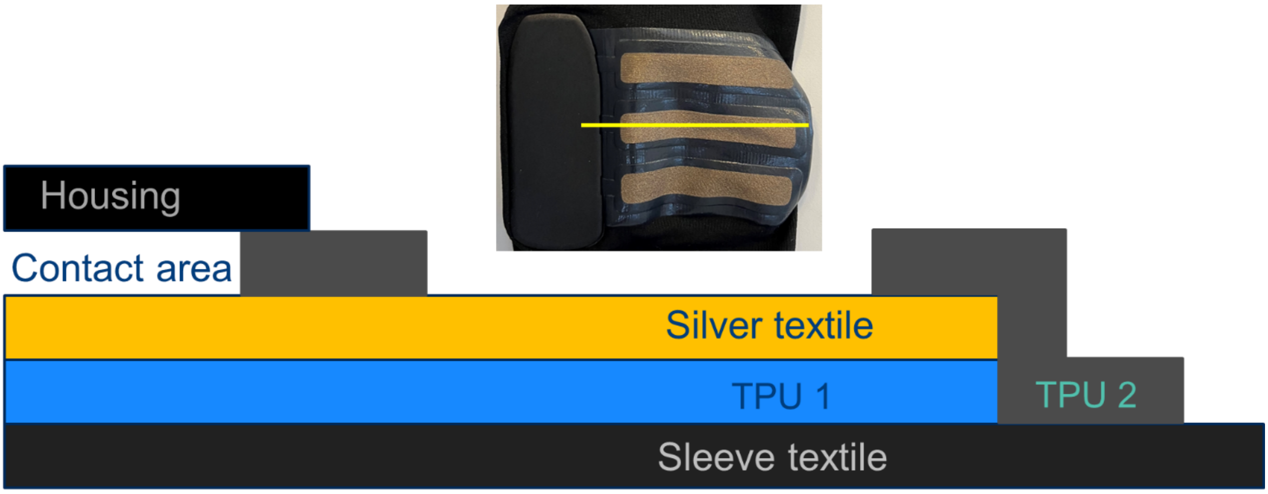

Figure 1: Picture of the EMG electrode part of MLI ELBOW, and a scematic of the design along a line indicated on the picture. TPU (Thermoplastic PolyUrethane) is a highly stretchable polymer.

The current design can be changed in different ways:

- The silver textile can be substituted by printed stretchable conductive ink/inks
- Some or all the current TPUs can be substituted by biobased TPUs or other stretchable substrates with similar characteristics
- Some or all the current TPUs can be substituted by printed stretchable dielectric inks

Materials and process flow

The BIOMAC produced materials used for the final prototypes can be accomplished with several different process flows as several pilot lines (PLs) produce similar materials. Examples are given below.

Polyurethane dispersions (PUDs) are used as a basis for both the inks and substrates used in the prototypes. They are prepared by PL12 and incorporate several materials like diols produced by PL3, and succinic acid from PL7. In the production of PUDs, PL12 also use externally sourced biobased monomers, and petrobased diisocyanates. The process flow for the BIOMAC materials is shown in Figure 2.

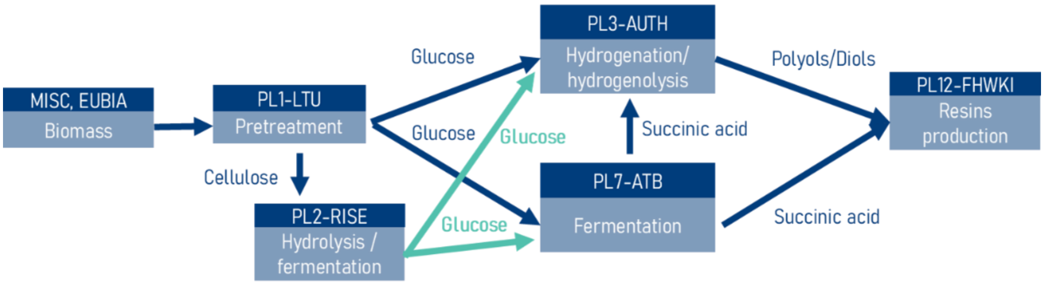

Figure 2: Process flow for the diols and succinic acid used by PL12 in the production of PUDs.

Cellulose NanoCrystals (CNC) produced by PL13 are used for the screen printable inks produced by PL14 and PL16. The process flow for the production of CNC is shown in Figure 3.

Figure 3: Process flow for the cellulose used by PL13 in the production of CNC.

Bacterial Nano-Cellulose (BNC) was produced by PL2 and sent to PL16 in order to produce the conductive inks. Also, PL8 produced biochar that also incorporated to the inks. The process from is shown at the Figure 4.

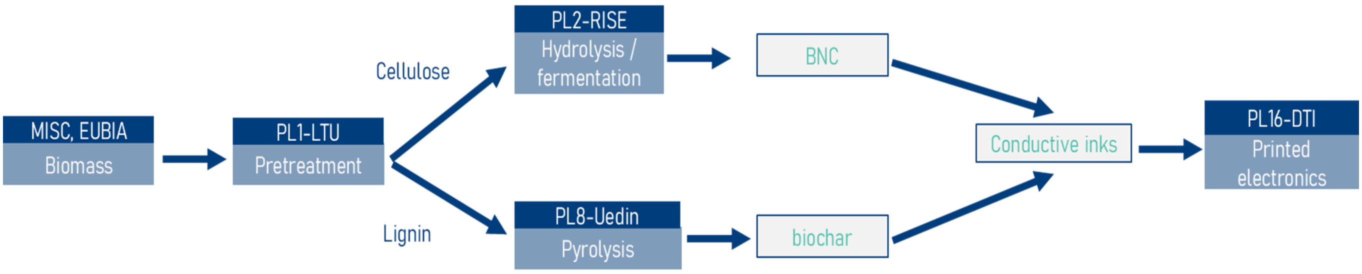

Figure 4: Process flow for the production and use of BNC and biochar

As part of PL9 two different approaches have been evaluated to produce biobased flexible non-isocyanate polyurethane (NIPU) by reactive extrusion (REx). The first option corresponds to the step-growth polyaddition of cyclic dicarbonates and diamines, while the second option was the step-growth polycondensation of polycarbonates and diamines. However, both of those approaches led to limitations when the molecular weight are concerned. Indeed, while some side reactions seem to be limiting the first option, leading to low molecular weights in the range of only 15 kDa; the second option was limited by a lack of reactivity which could not be compensated by catalysis, though the polycarbonate end chains were reacting.

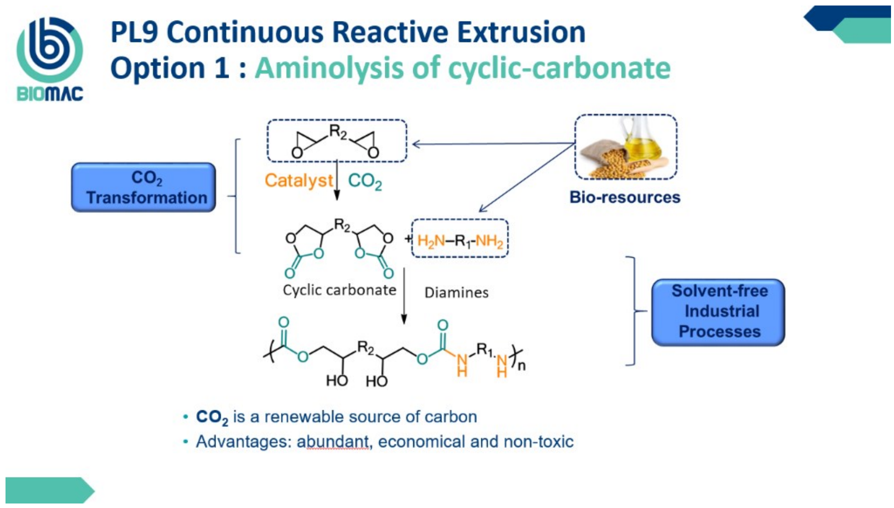

Figure 5: First approach evaluated to synthezise biobased NIPUs: step-growth polyaddition of cyclic dicarbonates and diamines.

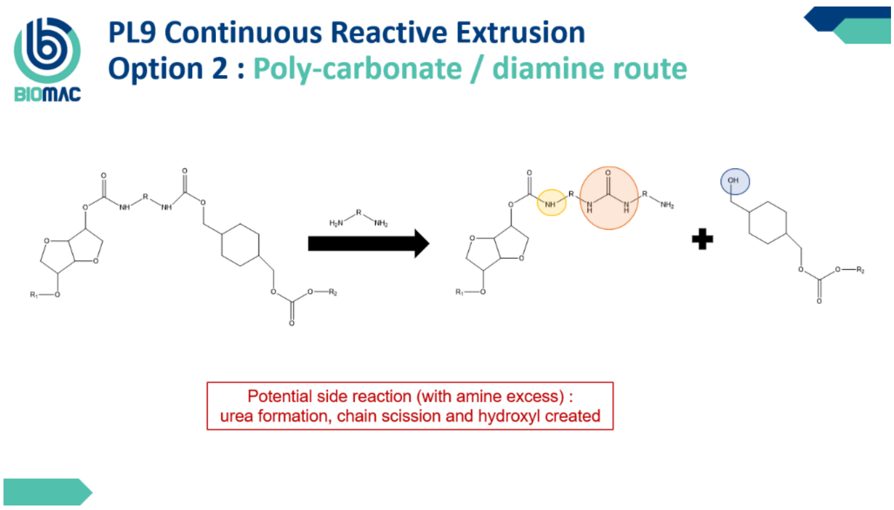

Figure 6: First approach evaluated to synthezise biobased NIPUs: step-growth polycondensation of polycarbonates and diamines

The bio-based materials used in the final prototypes were:

Substrates: BPUS (Biomac PolyUrethane Substrate)

The polyurethane (PU) substrates were produced using film casting of PUDs, using a doctorblade and screen printer from PL16. They were cast on top of transfer substrates that act as carrier in the subsequent processing of the films. Figure 7 shows a picture from the casting process and a picture of a piece of substrate.

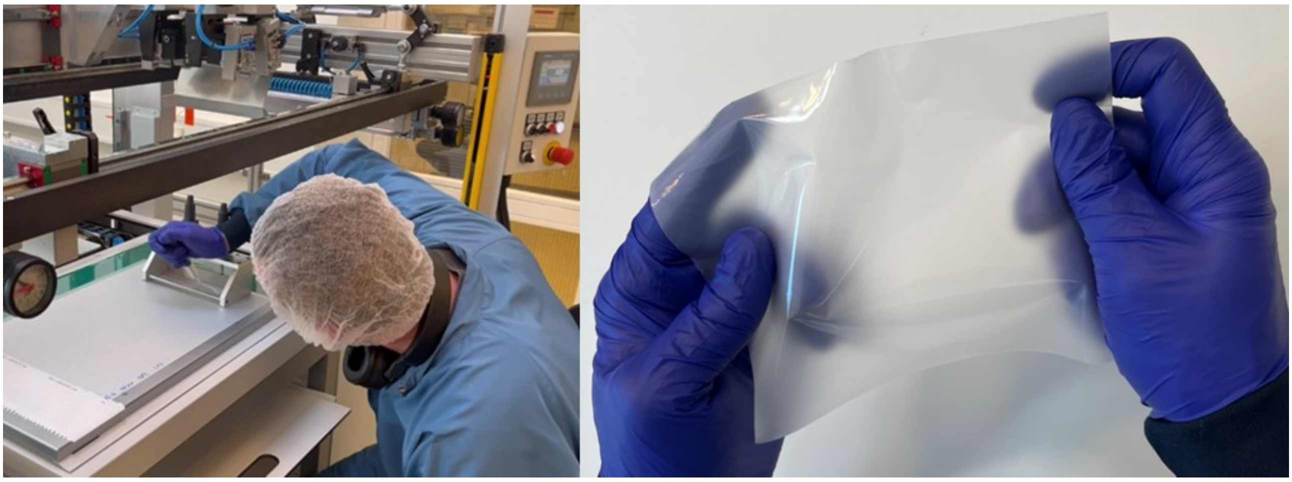

Figure 7: To the left a picture from the production of a substrate and to the right a picture of a piece of substrate.

The substrates can replace TPU 1 and TPU 2 of the current design. In both cases an additional adhesive is needed.

Barrier ink: BC80

A screen printable barrier ink was produced by PL14. It is formulated using PUD from PL12, modified CNC from PL13, water, co-solvents and additives. Figure 8 shows a picture of a print of BC80.

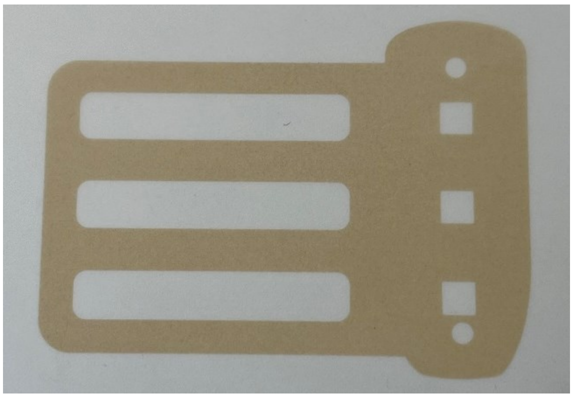

Figure 8: Picture of a single layer print of BC80 on a transfer substrate.

The barrier ink can be used to replace TPU 2.

Conductive ink: ATR-136

A screen printable conductive ink was produced by PL16. It is formulated using PUD from PL12, CNC from PL13, carbon black and ethylene glycol. Figure 9 shows a picture of a print where ATR-136 was used as the conductive ink.

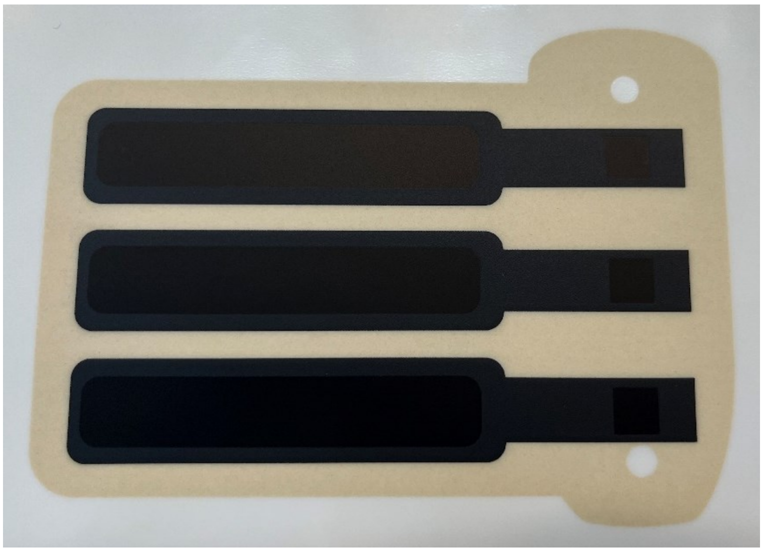

Figure 9: Picture of a product, consisting of 3 layers of ATR-136 and 3 layers of BC80 screen printed on BPUS.

The conductive ink can be used to replace the silver textile.

Material properties

For material characterization we have been using both BIOMAC and commercial materials in different combinations to investigate how the different BIOMAC materials perform in different combinations. Only a few commercial materials were tested and thus, the conclusions are probably not true for all commercial alternatives. Even so, the matrix was large, and that was without varying parameters like heat press temparature and pressure. Figure 10 shows pictures of some of the samples made for wash durability testing.

Figure 10: Pictures of samples used in wash durability testing. Pictures taken after 15 wash cycles.

Substrates: BPUS

Bio content is high compared to commercial biobased TPUs (around 70% compared to 20-40% for the commercial alternatives we have found)

Can stretch several hundred % without breaking (break at +500% in a few experiments)

When stretching substrates 20%, 600 times, the permanent stretch deformation is around 3-4% which is comparable to what we typically see using commercial TPUs.

The commercial stretchable inks we have tested print well on BPUS and have good wash durability when printed on BPUS.

BPUS tends to stick to itself during washing, more than commercial TPUs. How much depends on the PUD used in the production of the BPUS.

Barrier ink: BC80

BC80 prints well on both commercial TPUs and BPUS.

The wash durability is good on BPUS and ATR136

The wash durability is bad when printed on the commercial TPUs and conductive ink we tested it on (it slowly peels off).

Conductive ink: ATR-136

Prints well on both the commercial TPUs and BPUS.

Can tolerate stretching 20% more than 500 times.

The wash durability is medium when printed on BPUS.

The wash durability is good when printed on the commercial TPUs we tested it on.

Prototypes

In the first part of the project, PL16 developed fabrication procedures for the electrode part of the "MLI ELBOW", using printed electronics processes and based on commercial materials. Prototypes using the processes developed, and a current version for reference, were produced and handed over to PRECURE for validation of the printed electronics version of the product. At the same time, the biobased materials were being developed for later replacement of the commercial materials used.

In June 2024, prototypes P8 and P9, incorporating BIOMAC materials, were produced at PL16. In both cases TPU 1 was replaced by BPUS + commercial adhesive, the silver textile was replaced by ATR-136, and TPU 2 was replaced by BC80 in P8 and BPUS + commercial adhesive for P9.

Figure 11 shows pictures of the prototypes and, below them, pictures of a few seconds of EMG measurements made with PRECURE's app. The value is close to zero when the hand is resting on a table and high when the hand is bent upwards and the muscle strain is high. This shows that the prototypes work as intended.

Figure 11: Pictures of prototypes at the top. and pictures of EMG measurements from PRECUREs app below. P8 is to the left and P9 to the right.

Conclusions

Design and fabrication process developed that enabled the production of EMG electrode part of PRECUREs "MLI ELBOW" using printed electronics processes.

Several biobased materials were developed, that could successfully replace conventional materials used in the current design of PRECUREs "MLI ELBOW".

Prototypes were produced using the biobased materials developed.

Prototypes were tested and worked as intended.

Further validation of the prototypes will be performed by PRECURE in H2.