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FibreNet - A Training Network on Designing Novel Bio-based Fibre Products for Targeted Advanced Properties and New Applications

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Partner organisations:

Educell podjetje za Celično Biologijo doo, Tetra Pak packaging solution, Billerudkorsnas AB, Mondi AG, Bcomp Ltd, ITA Technologietransfer GMB, Universitaetsklinikum Aachen

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1 Introduction

FibreNet project was an innovative EU-funded H2020-MSCA-ITN project that trained PhDs in the field of bio-based fibres. It was a consortium of 15 European academic and industrial organizations, striving to bridge the knowledge-gap between the properties of fibres and fibre-based products in order to enable product tailoring, products with new functionalities and brand-new fibre products.

The work in the project was carried out in six Work Packages (WP)—three scientific WPs (WP2-WP4) and WPs for management (WP1), training (WP5) and dissemination & outreach (WP6). For administrative purposes, two additional WPs were included in the project: ethical issues (WP7) and data management (WP8). In practical day-to-day project management, WPs 7 and 8 were included in WP6.

The scientific WPs were selected according to three important application areas of bio-based fibres, namely biocomposites, paper & packaging, and biomedical applications as shown in Figure 1 below. The 15 IRPs of FibreNet were divided to these three WPs such that each WP contains activities related to functionalization and modification of fibres, characterization, modelling and production. Furthermore, life cycle analysis (IRP5) spans over all the scientific WPs. In this section, the activities and the main results are presented for each WP.

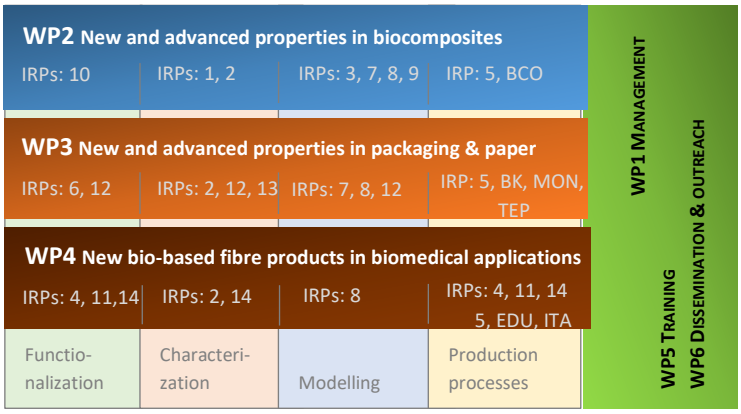

Figure 1. Overview of FibreNet's scientific WPs and different research methodologies.

2 Objectives

The FibreNet objectives for long-term impact in the different application domains are:

1. to boost the competitiveness of biocomposites in the composites sector and improve their strength and durability properties by enhancing the fibre-matrix interface properties,
2. to improve the price-competitiveness and functionality of paper and fibre-based packages by developing new modification, characterization and modelling methods and tools,
3. to improve biocompatibility, extend the linear drug release period and increase pilot production capabilities in fibre-based wound healing and tissue engineering applications.

The main research aim was to produce a toolbox of methods suitable for different application fields including methods related to functionalization, modification and characterization of bio-based fibres as well as to modelling, production and life cycle analysis of bio-based fibre products, as illustrated in Figure 2. These higher-level objectives then translate into more specific IRP-level objectives. IRP-level

objectives are summarized in Section 3 together with descriptions of main outcomes in each IRP during project duration.

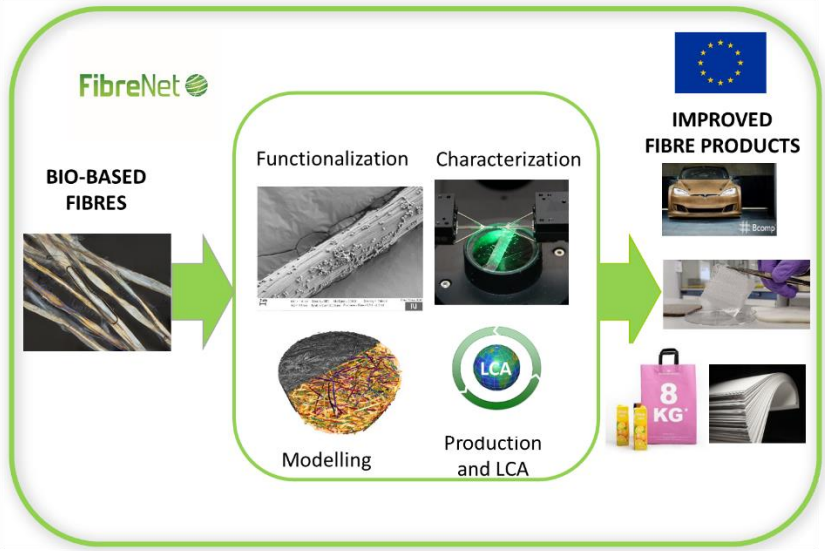

Figure 2. Illustration of different research methodologies applied in FibreNet.

The training objectives were as follows:

a) to gain multidisciplinary, multi-method & multi-application understanding and capability for cross-sectional innovation,
b) to gain research skills needed to obtain an internationally recognized PhD,
c) to gain an entrepreneurial and innovation-oriented attitude,
d) to gain experience in applying own research in the non-academic sector,
e) to gain transferrable skills,
f) to encourage a mindset towards open and reproducible research, through open publication of research papers, data, and software,
g) to encourage a mindset towards sustainability as a natural part of the product development process and life cycle,
h) granting open access to our educational material,
i) sharing our training experiences and best practices and by developing and publishing curricula recommendations.

3 Explanation of the work carried in WP4 related to UM

WP4 - New bio-based fibre products in biomedical applications

was contributed by three IRPs - doctoral students at Univerza v Mariboru (UM): IRP11, IRP14, and IRP15. These IRPs aimed for developing foundations for new bio-based fibre products in biomedical applications including 1) textiles with far infrared activity (IPR11), 2) wound dressings (IPR14), and 3) 3D printed cell scaffolds (IPR15).

The IRPs developed various fibre processing and functionalization methods for the methodological toolbox. Processing and functionalization methods include for example wet spinning, solution blowing

spinning, electrospinning, supercritical CO_2 drying, 3D printing, succinylation, aqueous exhaustion, and dip-coating.

Summary of the main results of the WP4:

- Fabrication of a novel and multi-functional biobased wound dressing prototype through fibre electrospinning, CO_2 supercritical drying, surface modification, and drug impregnation process.
- Production of nonwoven electrospun wound dressing mats having antibacterial and non-cytotoxicity properties using synthesized betaine, choline and carnitine containing polymers.
- Development of nano- and microparticle coating materials for surface modification of cellulose fibres to provide far infrared absorbing and emitting properties for biomedical applications.
- Production of surface modified 3D printed polysaccharide derivative scaffolds having optimized mechanical, physical, and biological properties for vascular graft application.

IRP11: Surface modified regenerated cellulose textile fibres with far infrared (FIR) activity for bio-medical applications (Özkan Yapar)

Objective

- The objective was to develop and investigate the modification of regenerated cellulose fibres with durable nano- and microparticle coatings, which have far infrared (FIR) absorbing and emitting properties.

Main results

- Various polyelectrolyte and polymer coatings were applied on viscose textile fibres. The conditions for these coatings have been optimized at the 100 g scale.
- Most of the polymer coatings do not cause significant alteration of the fibres` mechanical properties.
- Various amounts of ZrC and TiC could be successfully applied on the fibre surfaces in a reproducible manner.
- Coated fibres can be shaped into non-woven by a wet-lay process and blended with uncoated fibres to adjust IR properties. Particle coatings are stable against washing and rubbing conditions.
- Optical properties of fibres significantly change with the deposition. Absorbance and emission of near/mid/far IR radiation increases with the amount of deposited ZrC particles.

Development beyond the SoA when compared to the proposal

- The coating conditions were already at an early stage designed in a manner to allow for an upscaling towards the production of yarns or non-woven. This was achieved through the avoidance of organic solvents or hazardous substances in the coating stage. The coating methods for the efficient and durable immobilization of IR emissive particles, the measured properties of IR activity, and the availability of functionalized fibres for further processing into yarns or non-woven represent a clear progress beyond the SoA at the proposal phase.

Thesis title and estimated month of graduation

- Surface Modified Regenerated Cellulose Fibres with Far Infrared Activity for Biomedical Applications
- July 2024

Scientific impact

The coating methods and the coated fibrous material can be spun into yarns by the beneficiary Litia in the next stage of development. These yarns can be blended with unmodified fibres of cellulose or synthetic origin. The yarns can be woven into fabrics by European textile companies in the form of prototypes in the kilogram scale. Those fabrics can be investigated with respect to their infrared emissive properties in the biomedical, but also in the technical fields (e.g., thermal insulation). We expect that such a process can be completed within 1-2 years. Alternatively, we have demonstrated that fibres can be shaped into non-wovens in wet-lay processes. These fabrics can be expected to be manufactured on a larger scale in shorter times, if consumer demand exists.

IRP14: Nano fibrous systems morphology study for advanced biomedical applications—wound healing (Lucija Jurko)

Objective

- The objectives were to prepare electrospun, antimicrobial cationic material to be used as a wound dressing and to develop cationization of cellulose derivatives and synthetic polymers, to investigate their antimicrobial and cytotoxic properties and shape them into non-woven mats.

Main results

- Succinylation of polyamines can be performed in aqueous solution with a gradual decrease of the cationic charge. With a higher degree of succinylation, biocompatibility increases while the antimicrobial activity decreases.
- Betaine and choline chlorides can be condensed to a Gemini type compound with low cytotoxicity against mouse fibroblasts but also with low antimicrobial effects. Pending investigations include the use as acetylcholine esterase inhibitor.
- Betaine and choline can be used to introduce cationic charge to hydroxyethyl cellulose (HEC) and polyvinyl alcohol. From the betaine and choline derivatives, only HEC choline shows antimicrobial properties.
- All materials can be electrospun into non-woven mats in combination with polyvinylalcohols or polyethylene oxides.

Development beyond the SoA when compared to the proposal

- A significant number of new cationic compounds and polymers have been developed and they are now available at the gram scale and fully characterized.
- The Gemini cationic compound has, to our knowledge, not been described earlier in the literature. Some selected materials showed antimicrobial properties and most of them are not cytotoxic.
- Practically all developed polymers could be shaped into non-woven mats using electrospinning, opening the possibility to be used as topological wound dressing.

Thesis title and estimated month of graduation

- Synthesis of betaine, choline and carnitine containing polymers for dermal wound healing
- July 2023

Scientific impact

Practically all compounds produced by the IRP can be shaped into electrospun nanofiber webs to be used as wound dressings. They can also be used as cationic coagulants or as paper coatings when the upscaling issue and the avoidance of organic solvents can be solved. Furthermore, they can be used as antimicrobial coatings.

IRP15: Functional 3D printed and porous polysaccharide derivative scaffolds for regenerative medicine (Fazilet Gürer)

Objective

- The objective was to prepare micro- and nanostructured cellulose/polysaccharide materials compatible with 3D printing (hydrogels or thermoplastic polymers) methods and tailoring their surface and chemical composition to positively influence and control the growth, viability and migration of human umbilical cord endothelial cells.

Main results

- A one-step aqueous method for the synthesis of isolated and purified polysaccharide-amino acid conjugates was developed with carboxymethyl cellulose and knowledge was transferred to synthesis of HA-small peptide conjugates. By switching to a more stable crosslinking agent, side product free HA-small peptide conjugates were obtained.
- Surface active scaffolds were produced via 3D printing and Schiff base chemistry. All composite PCL-HA conjugate scaffolds were cytocompatible in a long term (7 days) cell culture, with PCL-HA-Tri-Gly-OEt showing the most promising results.

Development beyond the SoA when compared to the proposal

- Proteoglycan-peptide conjugates were used to modify the surface of the material, resulting in customized mechanical and physical properties as well as biocompatibility.
- Surface attachment on 3D printed material was found to improve biocompatibility and cell spreading which is beneficial for further applications.

Thesis title and estimated month of graduation

- Functional 3D printed polysaccharide derivative scaffolds for vascular graft application
- July 2023

Scientific impact

The results of the IRP can be utilized by universities and other research organizations, medical faculties, pharmaceutical industry working in the field of regenerative medicine.

4 Explanation of the work carried in WP5 related to UM

Organisation of 3rd Network Wide Training Event (NWTE) at UM – Deliverable 5.6

The 3rd NWTE of FibreNet took place at, and was organized by the beneficiary University of Maribor, Slovenia with support from the coordinator and aimed at providing ESRs with an in-depth training of technical, transferable and social skills by an intense program of five days (02.-06.09.2019). The program of the event included:

A) transferable skills on intellectual property rights (IPR) and career development (day 1)

B) an open “science for the public day” in which results of ESRs’ research were presented to a public audience and recorded on video (day 2)
C) a laboratory course on surface and material science of bio-based fibers (day 3)
D) specialized lectures on the surface and material science of renewable polymers given by renowned invited lecturers (day 4)
E) transferable skills/excursion to the beneficiary, spinnery Litija or the Innorenew Renewable Materials and Healthy Environments Research and Innovation Centre of Excellence, a project financed by H2020 WIDESPREAD-2-Teaming: #739574 and the Republic of Slovenia at which ESRs could also present their research and the coordinator of FibreNet presented the project

ESR workshop on visibility and data management

Before the 3rd NWTE, ESRs accomplished a two-days’ workshop (Friday 30.08.2019 - Saturday 31.08.2019) on project visibility and data management with practical training using data from FibreNet at the beneficiary, University of Maribor, Slovenia. The coordinator team of FibreNet, Pasi Kallio and Mariaana Savia were introducing the important topic of visibility for project management. On the second day, ESRs performed group works and presentations suggesting measures to increase visibility of FibreNet. This was followed by an introduction on how to manage research and project related data by the coordinator and the demonstration of the Zenodo repository with research data from the ESRs.

5 Explanation of the work carried in WP6 – lead by UM

WP6 - Dissemination / outreach

WP6 produced and submitted to the portal all the planned deliverables: Dissemination, Exploitation and Communication Plan, Data Management Plan (officially in WP8), project website (to be updated at least three years after the project), online platform for networking, dissemination, communication and training, compilation of training material, and report on dissemination, communication and exploitation activities. As the report on dissemination, communication and exploitation (Deliverable D6.4) thoroughly presents the activities and results related to WP6, in the following, only some of the highlights are summarized.

- 31 scientific publications in peer-reviewed journals and several more are under preparation
- 1 innovation disclosure
- 47 lectures promoting FibreNet in conferences and other events
- 16 poster presentations in conferences

FibreNet also arranged an international online workshop with high-profile keynote speakers and with all ESRs presenting their work and results. The two-day event attracted an international audience (159 participants on Day 1 and 98 on Day 2).

The consortium enhanced dissemination activities by promoting open access both in training and in practice; in addition to training in NWTE1, a specific workshop on visibility and data management was arranged in the third NWTE, all FibreNet scientific papers are open access, mostly by self-archiving in institutional repositories. Dissemination was also enhanced by opening part of selected NWTEs for public. Furthermore, initial steps towards open data were taken as FibreNet participated in the open

data pilot. The undeveloped peer-review practices and absence of clear link to scientific merits related to open data limited the interest of the researchers to openly publish data.

Highlights of FibreNet's communication and outreach activities included

- participation to the Science is Wonderful! event in 2020 organized by the Commission (the whole consortium),
- participation to Researcher's Night in 2019 and 2021 (the University of Maribor team),
- website where the monthly number of visitors has settled to around 1100 (highest peek: 3000 visitors per week),
- six published ESR videos in FibreNet's YouTube channel,
- 20 published expert interviews in the FibreNet website,
- 57 blog texts prepared by the ESRs and other project participants with varying contents, (from scientific pieces to experiences as a student in an ITN project),
- a popularized magazine article about FibreNet project and its research in 2019 (SciTech) – another one is currently under preparation,
- FibreNet project's appearance in Slovenian national TV in 9/2019.

The deliverable also lists local activities related to newsletters and networking with, e.g. COST Action.

6 Future activities

The consortium continues the **dissemination** by publishing the results of on-going doctoral theses in open access journals, presenting the results in conferences and providing open access to completed theses. The dissemination activities will be promoted through the project's web pages which will remain active at least for three years after the completion of the project, and through the LinkedIn channel of the project and individual members of the network. The software development was shared along with the publications whenever applicable, and several software packages have already been made openly available. This will be continued with the coming publications as well.

In joint **doctoral training activities**, collaboration in thesis supervision will be continued. Furthermore, information about coming PhD dissertations, on-line courses and intensive courses such as summer schools will be shared to the FibreNet community through the website. LinkedIn will be used as the promotion channel. In addition to the doctoral training, the FibreNet results will be used in BSc and MSc education.

The FibreNet project has created a large amount of new knowledge that has already provided and will provide basis for **new research initiatives** which include consortium members but also new partners. This momentum in progressing the research and development in the field of biobased fibres is indicated by the enrolment of new PhD students, preparation of joint publications beyond the scopes of the current ESRs' PhD theses, R&D activities in industry and the intense activity in submitting new project proposals.