Laboratoire de Génie des Procédés pour la Bioraffinerie, les Matériaux Bio-sourcés et l'Impression Fonctionnelle

Laboratory of Process Engineering for Biorefinery, Bio-based Materials and Functional Printing

UMR 5518

YEAR BOOK 2026

lgp²

lgp2.grenoble-inp.fr

All editions of the Yearbook

Few words from the head of the lab

Anne BLAYO,
Head of the LGP2 lab

We are particularly pleased to present the 2026 edition of the LGP² *Yearbook*. This publication features a collection of mini-posters prepared by the laboratory's doctoral and post-doctoral students, summarizing their research topics and the progress of their work.

Rather than serving as a conventional annual activity report, the 2026 *Yearbook* offers a snapshot of all the topics currently being studied within the laboratory.

In line with previous editions, it underscores the strong focus of LGP² on biobased materials, the recovery of lignocellulosic resources, and functional printing, with an ever-increasing emphasis on sustainable development, recycling and eco-design.

The 2026 edition is special for several reasons. It will be widely distributed during two major international scientific events hosted by LGP² : the Cellulose International Summit in July, followed by the IARIGAI and IC international conferences in September. This presents an excellent opportunity for doctoral and post-doctoral students to showcase their work.

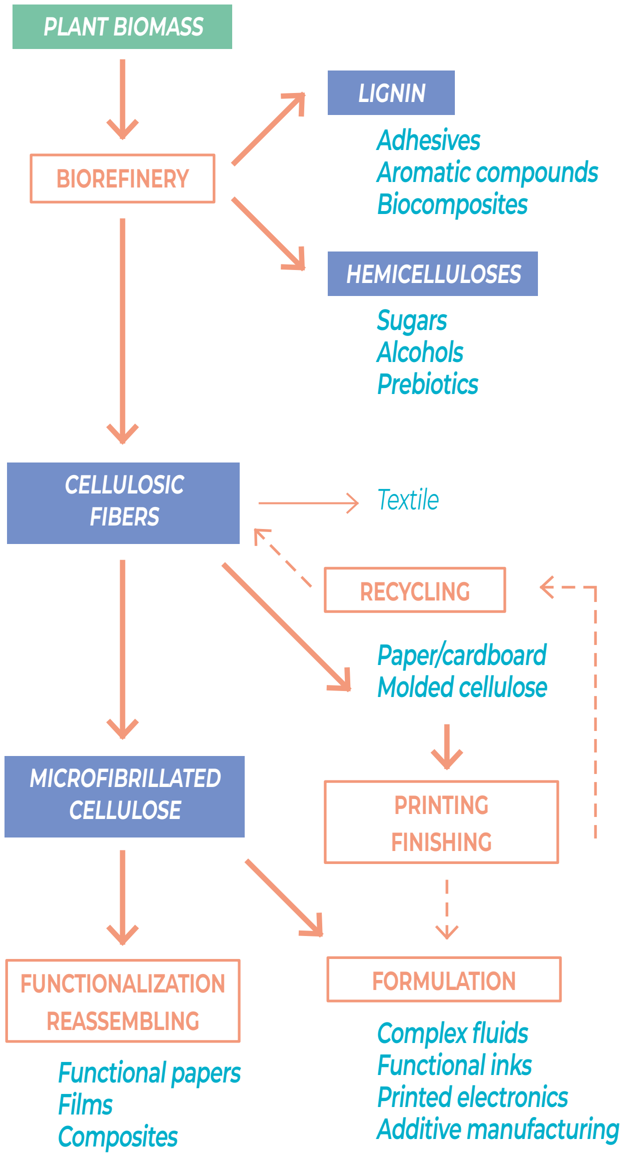
Furthermore, this marks the final edition signed under my directorship at LGP²; December 2026 will indeed conclude my mandate.

I am delighted to witness, year after year, the quality and breadth of the research presented in this document. I am equally pleased to note the diversity of collaborations between LGP², other research laboratories and industrial partners, as well as the variety of ways in which projects are funded.

I would like to extend my warmest thanks to all the young researchers who have kindly contributed to the 2026 *Yearbook*, and and made the effort to present their work in such a concise format. Many thanks to Dr. Aurore Denneulin, Deputy Director of LGP² and head of the Funprint team, who coordinates the collection of the mini-posters from researchers every year, and to Antoine Julien, LGP²'s Communication Manager.

We hope you enjoy reading this issue and discovering the research topics currently being pursued at LGP² in 2026.

An overview of the LGP2



At the very heart of sustainable development

LGP2 has built up a reputation in France and abroad for its research in the **valorization of plant biomass**, the development of **biobased materials** (paper, cardboard, composites), recycling processes, **nanocelluloses**, **printing processes for surface functionalization** and printed electronics.

In line with the **principles of eco-design** and **the challenges of sustainable development**, these research projects help to reduce the impact of human activities on the environment.

High-quality collaborative research

European projects, **ANR**, Idex and numerous direct industrial partnerships.

Member of the **LabEx Tec21**, **Institut Carnot PolyNat** and **Bioeconomy for Change** networks.

Strong synergies with the **Grenoble INP - Pagora, Graduate School of Engineering**.

Quality, Safety and Environment certified (ISO 9001, ISO 14 001, BS-OHSAS 18 001).

60 PUBLICATIONS EACH YEAR | **2 / 3 PATENTS EACH YEAR** | **2 RESEARCHERS ARE MEMBERS OF THE INSTITUT UNIVERSITAIRE DE FRANCE** | **60 RESEARCHERS AND PH.D STUDENTS** | **10 PH.D THESES EACH YEAR**

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ORGANIZATION : 3 RESEARCH GROUPS

BioChip

Biorefinery: chemistry and eco-processes

Dr N. Marlin (HDR)

- Plant biomass fractionation processes
- Valorization of plant biomass fractions

MatBio

Multi-scale bio-based materials

Pr J. Bras

- Building blocks extracted from plant biomass
- Suspensions & blends: material process engineering
- Composites and fiber-based materials for packaging, healthcare and transport

FunPrint

Surface functionalization by printing processes

Dr A. Denneulin (HDR)

- Formulation and characterization of complex fluids
- Design and characterization of structured functional systems and components

Young Researchers' research projects description

Ph.D. students

Audrey DRIEUX
Ph.D. thesis (2025-2028)
LGP2 (N. Belgacem; C. Sillard; B. Michel)

Chemical and physical modifications of lignocellulosic fibres for superabsorbency in biodegradable menstrual napkins

Modifications chimiques et physiques de fibres lignocellulosiques pour une application de super-absorption dans les serviettes menstruelles biodégradables

BioChip MatBio

Context

Napkins

Around 15 000 menstrual protections used per menstruated person[1]

Petrosourced composition

Harmful for the environment

Menstrual precarity

Biobased biopolymers

Biodegradable

Affordable

Local resources from parts of the world with limited access to disposable health care products

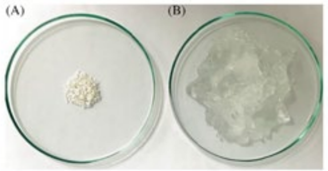
[1] Bae J. et al. Safety Evaluation of Absorbent Hygiene Pads A Review on Assessment Framework and Test Methods 2018

Funded by:

Objectives

Superabsorption

Water absorption capacity of 1000g/g
High swelling capacity
Create a highly hydrophilic network



[2]

Antibacterial properties

From materials of the top sheet or the foam
Brought by modification of the core

Biodegradability

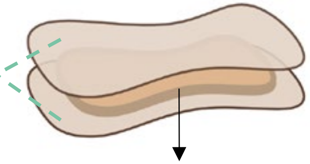
Implementation of tests in water and in soil

[2] Arredondo R. et al. Performance of a novel, eco-friendly, cellulose-based superabsorbent polymer (Cellulo-SAP): Absorbency, stability, reusability, and biodegradability 2022

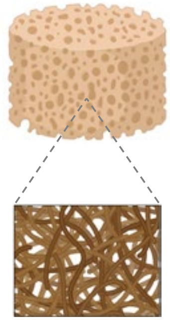
Methods

Superabsorption

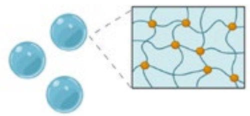
L. Caban



Absorbent core



V. Gemin



Superabsorbent polymers (SAPs)

OR

Fiber chemical modifications

Abdullah JAVED
Ph.D. thesis (2025-2028)
LGP2 (N. Reverdy-Bruas;
M. Robert De Saint Vincent;
C. Martin); LRP (F. Pignon)

Microstructuration of complex fluids for screen printing

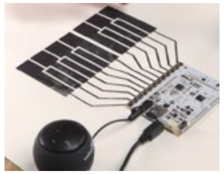
Microstructuration de fluides complexes pour l'impression sérigraphique

FunPrint

Thèse confidentielle

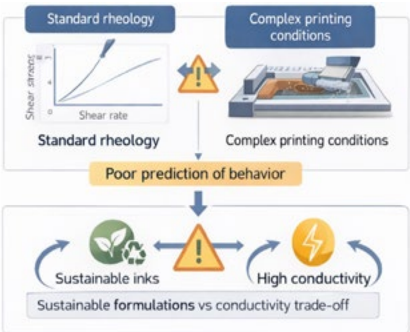
Context

Printed electronics enable low-cost, flexible devices via additive manufacturing approaches.



Screen printing enables scalable deposition of functional layers.

Conductive inks (particles, binders, solvents, additives) govern flow and performance.



Funded by: UGA Université Grenoble Alpes; UGA Collège Doctoral ED I-MEP²; lgp²; Laboratoire Rhéologie et Procédés

Objectives

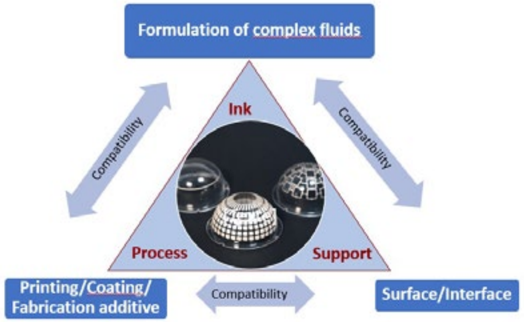
High-performance conductive inks
High conductivity + High precision + Low cost

Understand ink behavior during screen printing

- **Formulation** (composition)
- **Rheology** (flow)
- **Printability** (deposition)

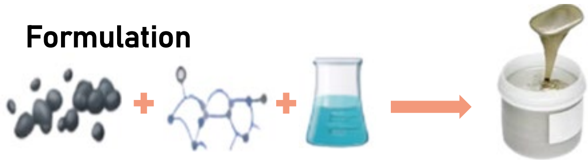
Microstructure formation during drying

Functional performance
(Conductivity)



Methods

Formulation



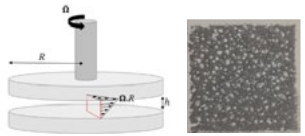
Conductive Materials + Binder + Solvent → Ink Formulation

Rheology & Printing

Viscosity, Flow and Thixotropic Tests

Deposition behaviour

Substrate interaction

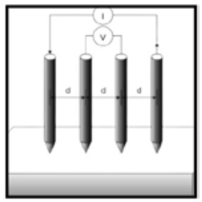


Characterization & Performance

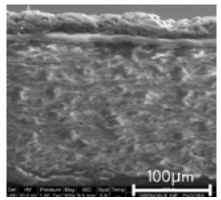
Optical microscopy / SEM

Conductivity measurement

Morphology-property relation



4-point probe test



SEM Micrograph

Juliette LACROIX
Ph.D. thesis (2026-2029)
LGP2 (J. Bras, Q. Charlier, A. Dufresne)
Arkema (J. Flat, Q. Jean)

Optimization of the interface and of the distribution of natural fibers and nanofibers in a bio-based composite matrix.

Optimisation de l'interface et de la distribution de fibres et nanofibres naturelles dans un composite à matrice biosourcée.

MatBio

Thèse confidentielle

Context

Polyamide 11 is a 100% bio-based polymer produced from castol oil. Reinforcement with **glass fibers** enables to reach high mechanical performance, for sports and leisures applications.

However, glass fibers have a high carbon foot print and are not bio-based. The goal is to **substitute glass fibers** to develop a 100% bio-based material.

→ **natural fibers** and **cellulose** are good candidates !

But, there is a **poor interfacial adhesion** between PA-11 and natural fibers.

→ This leads to a **strong decrease of the ductility**, the material becomes **fragile**.

Funded by: Cifre, ANRT, ARKEMA

Objectives

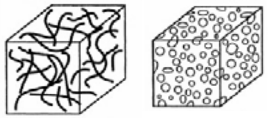
Development of a ductile material 100% bio-based, using PA-11 matrix

1. Overgo the poor interfacial adhesion of the material via <u>processing</u> and <u>functionalization</u>.

→ To enhance the fillers dispersion

→ To enhance the interface quality fillers / matrix

2. Study of the influence of the multi-scale

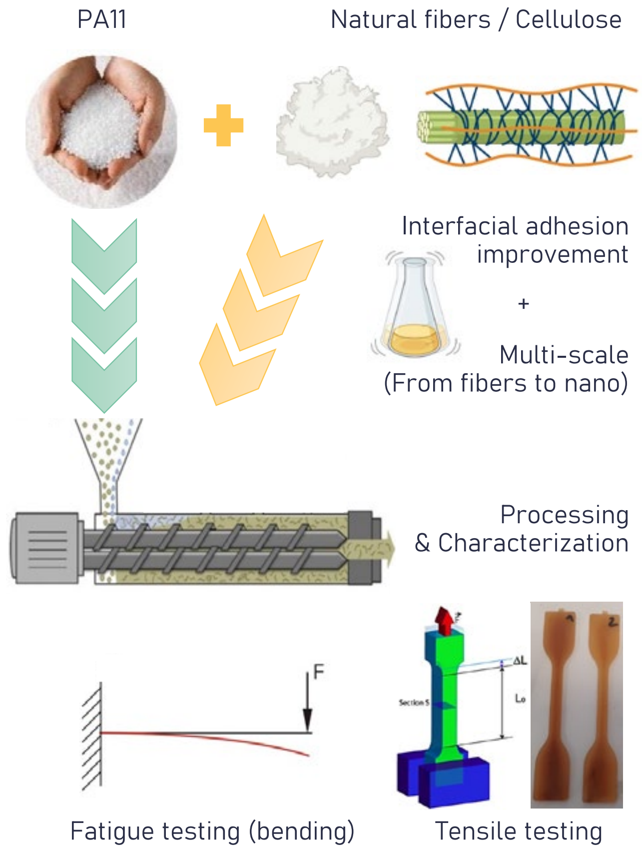


→ Short-fibers or particle reinforced composite

3. Characterization of the composite

→Mechanical & Thermal analysis,...

Methods



Alexis SUCHET
Ph.D. thesis (2026-2029)
LGP2 (J. Bras; J. Viguié; C. Rey)
Cellulose Valley

Towards Sustainable Packaging: Processing Strategies for Lightweight and Functional Cellulosic Materials

Vers des emballages durables : stratégies de transformation pour des matériaux cellulosiques légers et fonctionnels

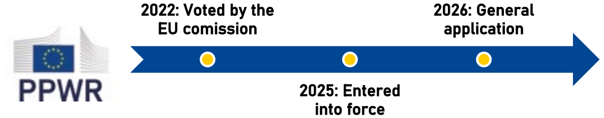
MatBio

Thèse confidentielle

Context

In the EU, the production of **plastic packaging waste** is estimated at 15.8 Mt in 2023[1], while its **recycling rate** is estimated at only **42.1%**. The rest is either incinerated, landfilled or leaked in nature. In comparison, the production of **paper and cardboard packaging waste** is estimated at 32.3 Mt in 2023, and its **recycling rate** is estimated at **79.3%**.

Packaging and packaging waste regulation



To answer this problem, the Cellulose Valley was created in 2022:

An Excellence Chair working to:

- Upgrade cellulosic materials
- Propose new innovative and high performance solutions

Funded by: Ahlstrom, Andritz, Aptar, Chanel, Citeo, Fondation Grenoble INP, ctp, Decathlon, DS Smith, Fibre Excellence, #weprotectyourfood, Marie

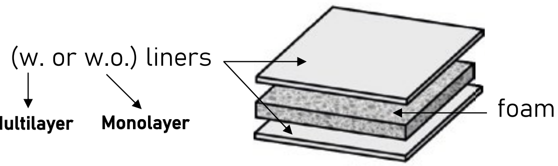
[1] According to Eurostat, ec.europa.eu/eurostat

Objectives

PPWR 2025/40 Chapter 1, article 10:

« By 1 January 2030, the manufacturer or importer shall ensure that the packaging placed on the market is designed so that ***its weight and volume is reduced to the minimum necessary*** to ensure its functionality, taking account of the shape and material from which the packaging is made. »

To create a lightweight cellulosic material with high mechanical properties



Main objectives
- Low density / High porosity
- High mechanical properties
- Biodegradable & recyclable

New properties exploration
- Low thermal conductivity
- Sound absorption
- Cushionning

Methods

FOAM MANUFACTURING

Formulations:

› Paper pulp (w. or w.o. MFC)

› Bio-based additives

↓

Foaming processes

↓

Drying step
(in-line or out-line)

↓

Cellulosic foam

Loïc VOISIN
Ph.D. Thesis (2026-2029)
LGP2 (A. Denneulin; J. Bras)
LEGI (F. Ayela)

CAVITOSE: Use of Cavitation to produce cellulose nanofibrils and simultaneously its functional suspension

Utilisation de la cavitation pour produire des nanofibrilles de cellulose et simultanément sa suspension fonctionnelle

FunPrint MatBio

Context

Growing demand for scalable, **low-energy**, eco-friendly alternatives to petro-plastics

→ **CNF**: promising bio-based material but high production energy

Current processes: multi-step, energy-intensive homogenizers

→ **Hydrodynamic cavitation (HC) "on-chip"**: scalable, low-energy method enabling cellulose fiber fibrillation for CNF production

CNF + **Microfluidic HC**

CNF	Microfluidic HC
High barrier properties	Low energy consumption
Strong entanglement	High shear rates + shock
High mechanical strength	Minimal material damage
High specific surface area	Scalability potential
Complex rheological behavior	Direct optical flow observation capability

→ **CAVITOSE**: An innovative way to produce CNF and functional suspensions

Funded by: UGA Université Grenoble Alpes, tec21 the engineering of complexity

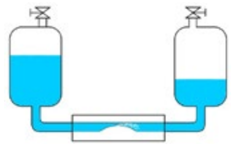
In collaboration with **LEGI**: LEGI Laboratoire des écoulements géophysiques et industriels

Objectives

Develop low-energy hydrodynamic cavitation for CNF production and surfactant-free functional suspensions for inks/coatings.

1. Lignocellulosic materials selection and **pretreatment strategies**

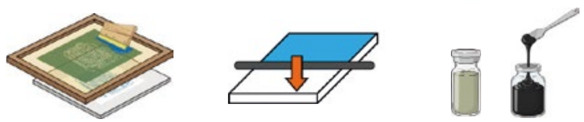
2. Optimize **HC on-chip** for low-energy CNF from viscous suspensions (properties characterized).



3. Demonstrate in-situ **co-exfoliation** CNF + functional nanoparticles (surfactant-free).

4. Validate **functional suspensions** for inks and coatings for **scale-up** pathways.

5. Deposition processes for **high material performances**

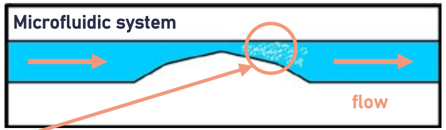


Energetic evaluation of a new process

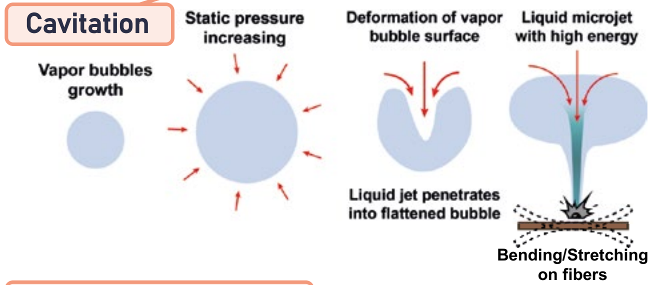
Methods

New low-energy method

Cavitation exfoliation in microfluidic systems (low Δp)
Localized shear, high compression, efficient de-agglomeration, liquid-phase dispersion

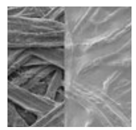


Cavitation



CNF characterisation

Morphology, surface properties, rheological behavior, multiscale microscopy, particle network imaging



Fluid formulation and material assessment

Functional performance, coating/printing processes, conductivity, barrier efficiency, mechanical strength, colloidal stability

Iqra ZAHID
Ph.D. thesis (2025-2028)
LGP2 (C. Chirat; C. Quesada Salas)
Institut Pascal (G. Christophe)

Valorization of Hemicelluloses as Oligo and Polysaccharides in an Integrated Biorefinery

Valorisation des hémicelluloses sous formes d'oligo et de polysaccharides dans une bioraffinerie intégrée

Biochip

Thèse confidentielle

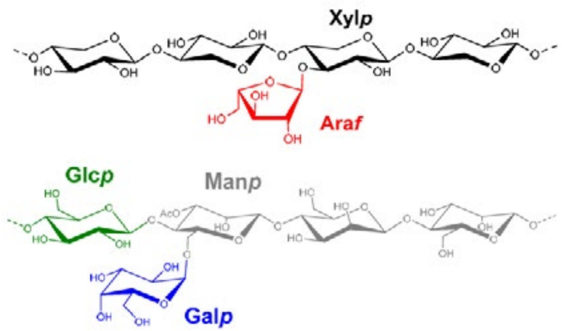
Context

Hemicelluloses:

They are the second component in wood and annual plants (20 to 30% in mass), composed of five different sugars: Xylose, Arabinose, Galactose, Mannose, Glucose.

They are today not valorised other than for energy production

Structure: Commonly exist as Arabinoxylan and Galactoglucomannans.



Funded by :
BIORAF
(ANR-24-CMAS-0004)

Objectives

Extraction of hemicelluloses from pulp by a combination of chemical and biochemical processes

Fully bleached pulps contain from 15 to 30% of hemicelluloses depending on the wood species and the pulping process used.

Combination of sustainable chemical and biochemical processes, will be applied on pulps to collect different fractions of hemicelluloses.

Reasons for the recalcitrance of some hemicelluloses fractions to be extracted will be looked for.

Advanced characterisation of the extracted hemicelluloses

- High Performance Anion Exchange Chromatography for composition
- Mass Spectrometry for side groups and structure of oligosaccharides
- Size Exclusion Chromatography for Molecular Weight Distribution
- NMR spectroscopy

Methods

Bleached pulps

↓

Chemical and or biochemical pre-treatment to modify hemicelluloses structure

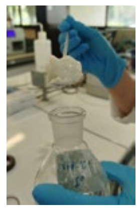
↓

Cold Caustic Extraction

→ High purity cellulose pulp

↓

Fractionation and Purification



Water Insoluble polysaccharides

Water soluble oligosaccharides

Nassim AFIOUNI
Ph.D. thesis (2024-2027)
LGP2 (B. Michel; G. Mortha; C. Quesada Salas)

Processes for the Oxidation of Lignin kraft for the Integration of Antibacterial Nanoparticles in the Papermaking Process

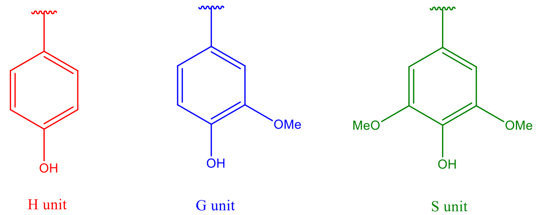
Procédés d'oxydation de la lignine Kraft pour l'intégration de nanoparticules antibactériennes dans un process papetier

BioChip

Context

What is Lignin?

- **Origin:** One of the three main components of wood
- Currently mainly valorized for energy production by combustion
- **Structure:** Highly heterogeneous polymer, constituted of monolignols with phenolic nature:



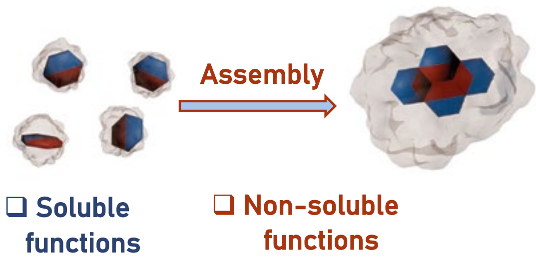
Lignin Nanoparticles (LNPs)

- Benefits: increased surface area, homogeneity and reactivity.

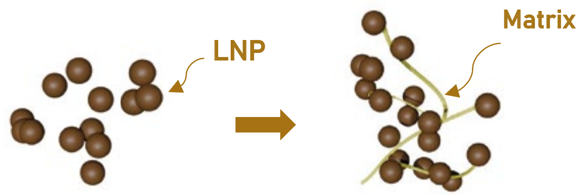
Funded by: Grenoble INP UGA; UGA Collège Doctoral ED I-MEP²

Objectives

- **Transform** raw kraft lignin into uniform nanoparticles (LNPs)
- **Synthesize** LNPs with controlled size, morphology, and surface properties.

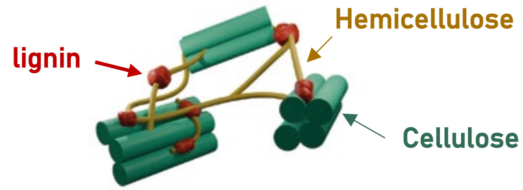


- **Investigate and modify** to bring specific antibacterial properties by chemical modifications
- **Integration** of LNPs on a ligno-cellulosic matrix



Methods

Lignin extraction from Kraft black liquor



- *Characterisation:*
  - Phenolic, carboxylic, methoxy content
  - Molecular weight and sugar content
  - Antibacterial properties

Lignin nanoparticle formulation by self assembly using an antisolvent with and without chemical modification

- *Characterisation:*
  - Shape, size and morphology via DLS, AFM and TEM
  - Antibacterial properties

Elsa BIHEL
Ph.D. thesis (2024-2027)
LGP2 (A.Denneulin; A. Blayo)
ICCF (D. Boyer)

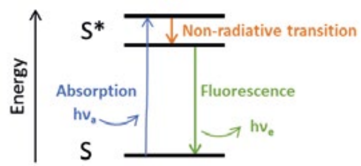
LUMNI – Luminescent nanoparticles design for the development of high-performance luminescent functional inks.

Synthèse de nanoparticules luminescentes pour le développement d'encres fonctionnelles luminescentes hautes performances.

FunPrint

Context / Objectives

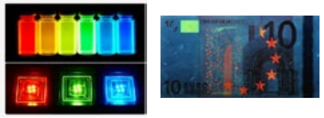
Fluorescence: unique property of emission of a lower energy photon after absorption



Usually:
$h\nu_a \neq h\nu_e$
UV → Visible

Growing demands for numerous applications:

- Anti-counterfeiting
- LED display
- LDS in PV



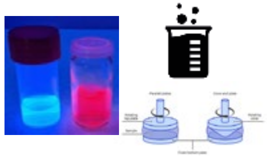
Need for simplified deposit: additive processes

Need for more sustainability: non-toxic components and processes

Funded by: Grenoble INP UGA; UGA Collège Doctoral ED I-MEP²

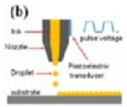
In collaboration with ICCF: Institut de Chimie de Clermont-Ferrand

Methods

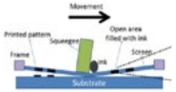


Fluid formulation:
Formulation and mixing
Rheology and physico chemistry properties

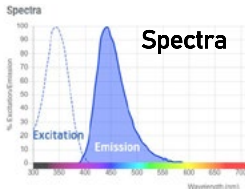
Processability:
Deposition processes
Surface and interface properties



Inkjet

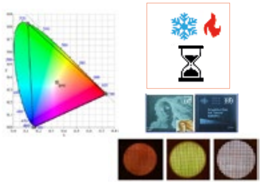


Screen printing

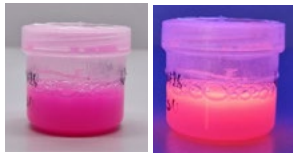


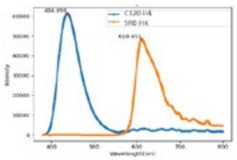
Optical characterization:
Excitation-Emission spectra / Quantum Yield / Stability

Post-printing properties:
Time stability
Color management
Applications



Results



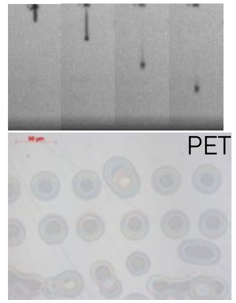


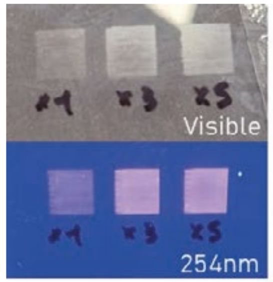
Ink formulation:

Ink formulated with Sulforhodamine B, obtaining the physicochemical properties of inkjet ejectability and the highest fluorescence.

Inkjet printing:

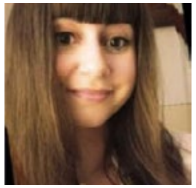
Influence of the inkjet parameters on the drop ejection. Observation of single drops on PET.





Deposit analysis:

Printing on different substrates (PET, paper and tracing paper).
Impact of the layer thickness on the fluorescence intensity.



Lilou BOUTARIN
PhD. thesis (2025-2028)
LGP2 (A. Denneulin; J.Bras)
LMGP (D.Bellet)

Eco-design of optically active multi-layered systems by full printed approach: materials-process correlations

Eco-conception de systèmes multicouches optiquement actifs par approche totalement imprimée : corrélations matériaux-procédés

FunPrint MatBio

Context / Objectives

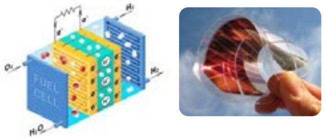
Electrochromic devices

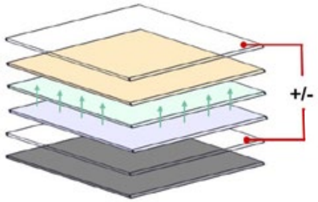
Device that can change its color when a electrical potential is applied (reversible action)

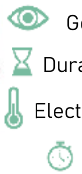
Smart windows
Planes, cars, buildings

Flexible displays
Solar cells, captors

Other technologies
Fuel cells, printed battery







- Good optical properties
- Durability after cycles of use
- Electrical and thermal stability
- Low switching time

Printing technologies advantages
- Low production's cost
- Compatible with eco-friendly components
- Large deposition surfaces
- Flexible surfaces

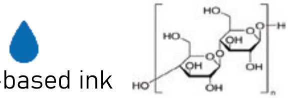
Funded by / in collaboration with:
icmcb, lgp², anrt

Methods

Stacking of different printed layers using 3 inks:
- Electrochromic ink
- Electrolyte ink
- Transparent conductive ink

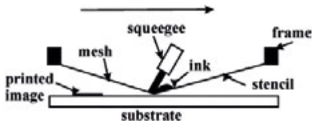
Complex aqueous-based fluids formulation

Water-based ink

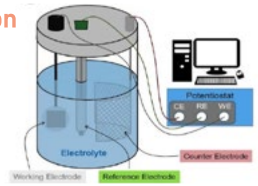


Nanocellulose and cellulose derivatives as binder and viscosity modificator

Printing with screen-printing process
- Rheological properties
- Characterization of unique layers



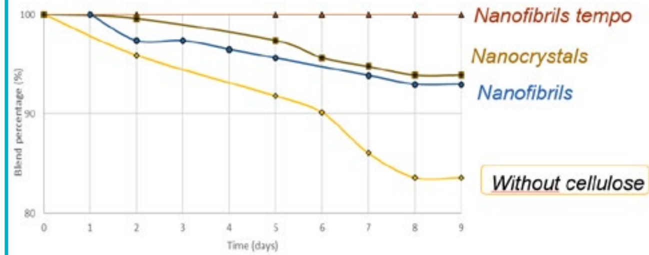
Physico-chemical characterization
- Three-electrode system for electrochemical analysis



Results

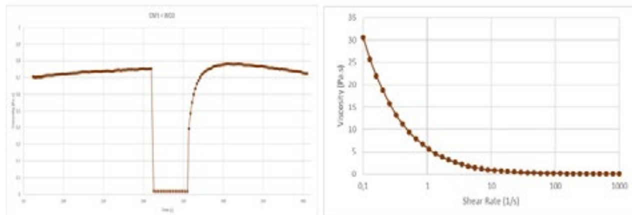
Colloidal stability of inks

Collloidal stability thanks to the addition of nanocellulose



Only one grade of cellulose allows high colloidal stability

Assessment of flow properties



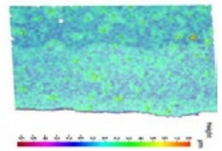
Thixotropic ink
Meeting of screen printing requierements

High shear-thinning behavior

Printed layer

Thickness : 4µm

Homogeneity of the printed layer



Léa CABAN
Ph.D. thesis (2025-2028)
LGP2 (Q.Charlier)
3SR (R. Peyroux)

Development of absorbent and waterproof veils made from lignocellulosic fibres to manufacture 100% bio-based and biodegradable menstrual pads

Développement de voiles absorbants et imperméables élaborés à partir de fibres lignocellulosiques pour la fabrication de serviettes menstruelles 100% biosourcées et biodégradables

MatBio

Context

500 to 1500 periodic protections thrown away in the lifetime of a menstruated person[1]

« Risky » products for health in the event of prolonged skin contact[2]

Environmental issues: petroleum-based materials, non biodegradable, soil contaminant...

500 millions of menstruated persons cannot afford to buy adequate supplies[2]

€ €

Absenteeism from work, school, social activities[4]

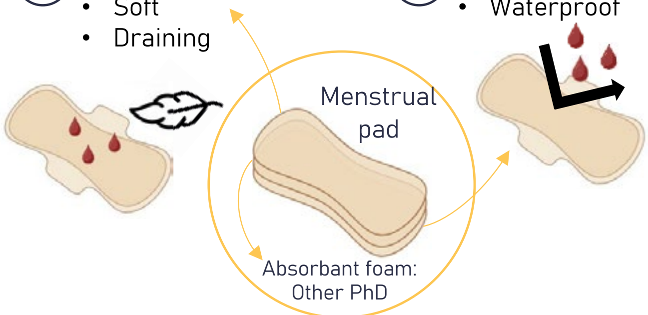
[1] National Geographic, sept 2025
[2] J. Bae, et al. 2018
[3] Médecins du Monde, sept 2025
[4] UNICEF, sept 2025

Funded by: anr Napkins

Objectives

Production of bio-based and biodegradable menstrual pads

1. **Upper veil :**
   - Soft
   - Draining
2. **Bottom veil :**
   - Waterproof

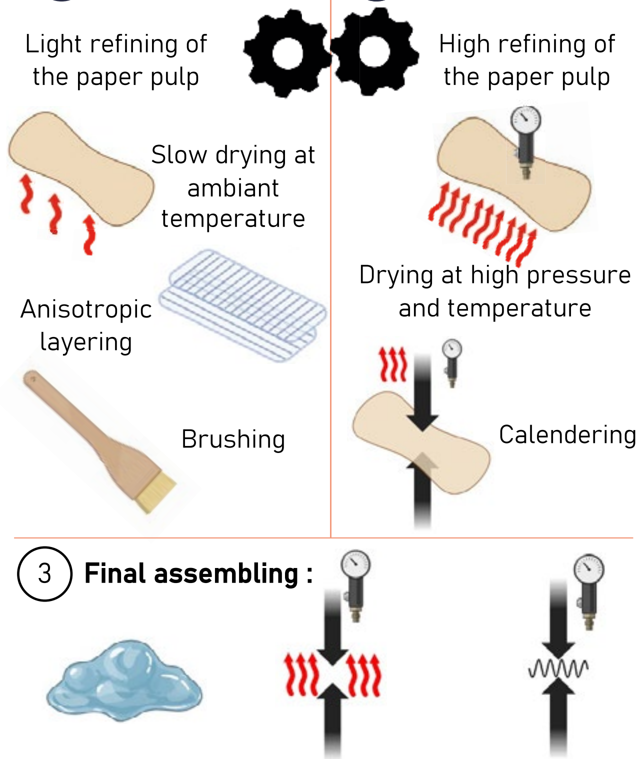


3. **Final assembling:** Without petroleum based glue

Materials:

Methods

1. **Upper veil**
   - Light refining of the paper pulp
   - Slow drying at ambiant temperature
   - Anisotropic layering
   - Brushing
2. **Bottom veil**
   - High refining of the paper pulp
   - Drying at high pressure and temperature
   - Calendering
3. **Final assembling :**
   - Glueing (bio-based)
   - Hot-sealing
   - Ultrasonic welding



Julien CLAUZON
Ph.D. thesis (2024-2027)
LGP2 (R. Passas; Q. Charlier)
3SR (S. Rolland du Roscoat)

Multiscale Characterization of the Hygro-Mechanics of Papers

Caractérisations multi-échelle de l'hygro-mécanique des matelas fibreux

BioChip MatBio

Context / Objectives

Paper

It is an **alternative to plastics** but is strongly limited by its **weak ductility**.

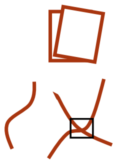
To face the growing demand while limiting its environmental impact**, the paper industry must reduce its consumption of energy, water and raw materials.**

Goal of this project

Using a multiscale approach to better understand the influence of fiber bonds properties depending on the fiber type and refining methods.

Study paper at different scale

- **Macro scale**: paper sheet
- **Micro scale**: fibers and fiber bonds



Funded by:
anr FiberBond ANR 2024-2028
ANR-23-CE43-0014

Methods

Sample preparation

- 6 g/m² and 75 g/m² handsheets

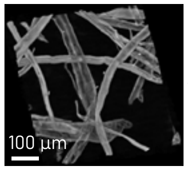
Macroscopic Hygro-mechanical Properties

- Varimass, Varidim, tensile testing at 20-80% RH
- Using different pulp: BEKP, NBSKP
- Different refining methods

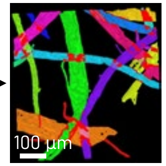
Microsctructural Chrarecterization by X-ray microtomography

Fiber and contacts Identification

Quantification of surface contact area

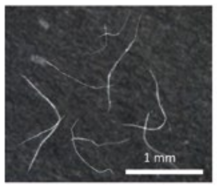


Gray level 3D image

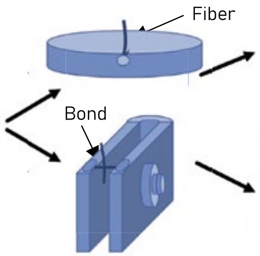


Segmented 3D image

Mechanical properties of single and single fiber-fiber bond



Fibers & bonds



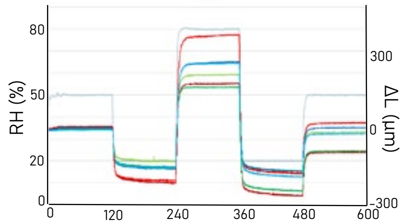
Supports

(Femtotools MTA03)

Results

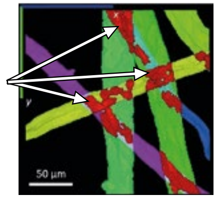
Macroscopic Hygro-expansion

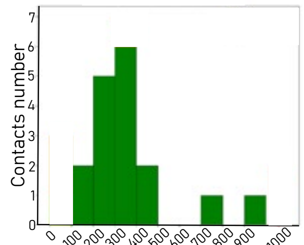
Varidim results showing the effect of pulp type and drying methods



3D images segmentation

Contacts (red)

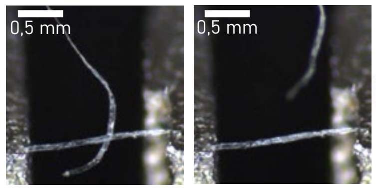




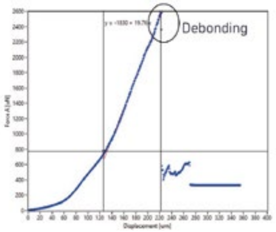
>75% of well identified contacts

Tensile behavior of single fiber-fiber bond

Single bond tensile test



Bonded Debonded



Valentin GEMIN
Ph.D. thesis (2024-2027)
LGP2 (N. Belgacem; C. Sillard; J. Viguié)

NAPKINS, Structure-properties relationships of wet and dry fiber foams for absorbent and retentive menstrual pads

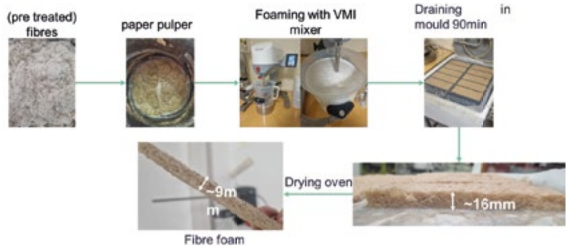
NAPKINS, étude propriétés-structures des mousses fibreuses liquides et solides pour la fabrication de mousses absorbantes et rétentives

Thèse open-source

MatBio

Context / Objectives

Evaluate a fiber foaming process to produce 100% bio-based & biodegradable absorbent core to replace superabsorbent particles in menstrual pads.



Study the effects of surfactant concentration and fiber type on the foaming process along with the structural evolution of foams from wet state to dry state.

Understand the interplay between mechanical properties, intrinsic fiber absorption and capillary properties on absorption and retention performances of the dry foams.

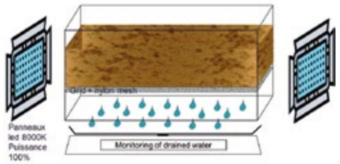
Funded by:

ANR-24CE43-6826-01

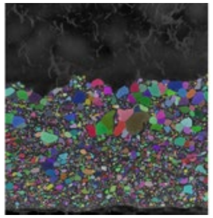
Methods

Characterization of the fibers/surfactant system: Morfi, Capillary rheometer, Pendant & oscillating bubble tensiometry, Zeta potential

Liquid foams: Air uptake during foaming, bubble size and air fraction evolution during drainage and drying

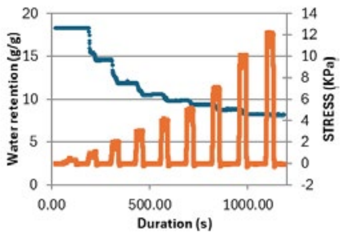


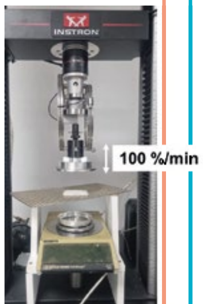
Monitoring of foam



Bubble segmentation

Solid foam: Dry and humid mechanical properties, tomography, capillary wicking, Dripping absorption performance, Cyclic retention performances

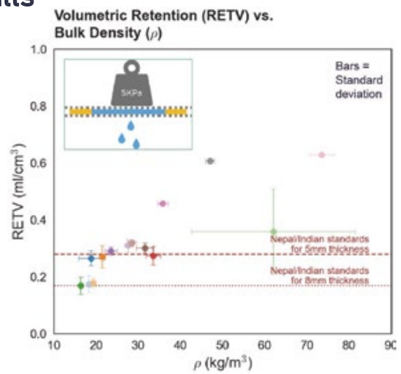




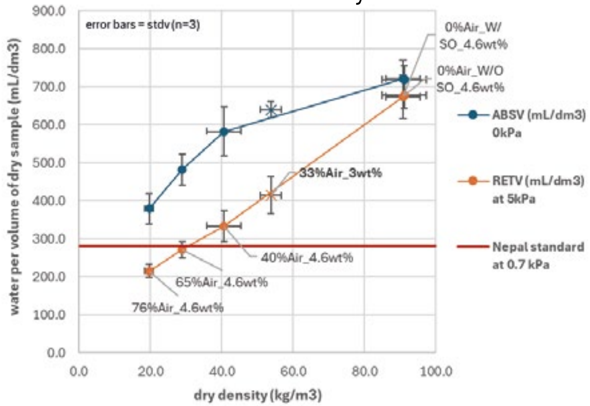
Results

Preliminary results

Performance benchmark for different types of fiber-foams



Volumetric performances of RMP fiber-foams versus density



Sarp KÖLGESİZ
Ph.D. thesis (2025-2028)
LGP2 (N.Belgacem; D.Beneventi)
PoliTO (R.Bongiovanni)

Use of natural wood and biobased polymers as base materials for the elaboration of fuel cells components by additive manufacturing

Utilisation du bois naturel et des polymères biosourcés comme matériaux de base pour l'élaboration de composants de piles à combustible par fabrication additive.

MatBio FunPrint

Thèse confidentielle

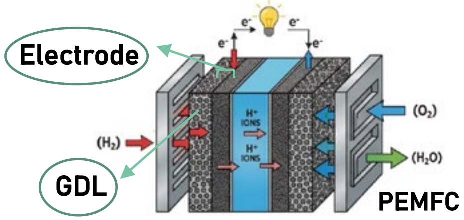
Context / Objectives

Sustainable energy materials play a critical role in enabling the widespread adoption of green energy systems.

Utilization of Bio-sourced precursors
(such as waste wood and bio-based polymers)

are commonly used as structural and functional materials in conventional devices like **capacitors, batteries, and sensors**.

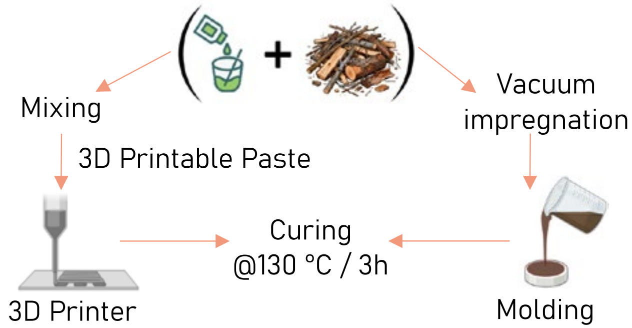
In this thesis:
Gas Diffusion Layer (GDL) and **electrodes** will be elaborated from bio-sourced materials for PEMFC.



Funded by:
MSCA Unite!Energy/EU

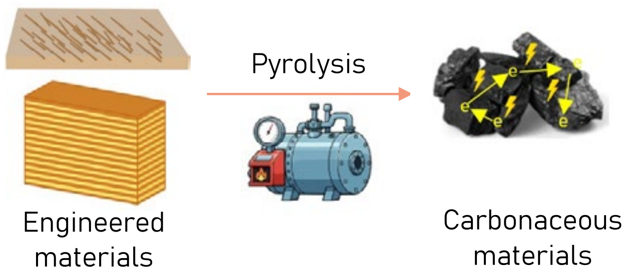
Methods

Bio-sourced Composite Material Preparation:



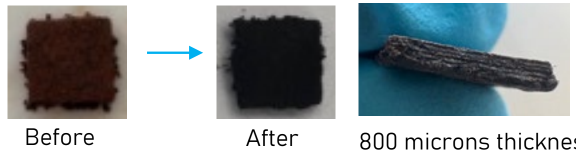
Pyrolysis:

After pyrolysis at 950 °C of engineered bio-sourced materials;
High electrical conductive and tunable **porous carbonaceous materials**

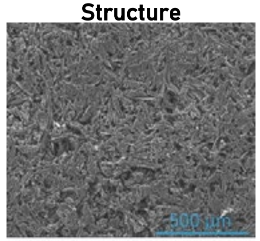


Results

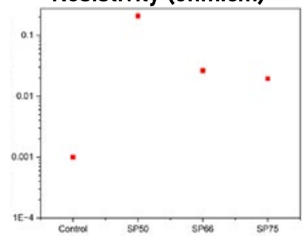
Engineered carbon materials after pyrolysis



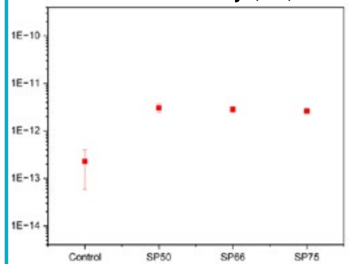
SEM Image of Porous Structure



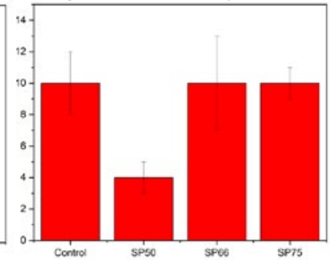
In-plane Electrical Resistivity (ohm.cm)



Gas Permeability (m^2)



Compression Strength (MPa)



Conclusion: Porous high electrical conductive and durable self standing ordered/order biocarbon materials were produced.

Suzy RUANO
Ph.D. thesis (2024-2027)
LGP2 (J. Bras ; N. Belgacem)
Gascogne Paper (J. Desmaisons; A. Pinsolle)

Development of new biobased barrier solutions for flexible packaging

Développement de nouvelles solutions barrières biosourcées pour emballages flexibles

MatBio

Thèse confidentielle

Context / Objectives

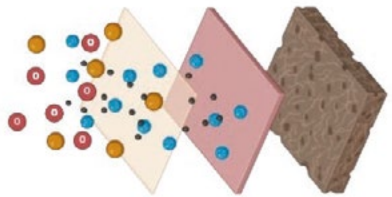
Regulations

SUP directive – AGEC law – PFAS regulation

- Imminent need to find **plastic and PFAS – free** solutions
- Solutions such as petro-based coatings or laminated papers are emerging, but at **detriment of the packaging's end-of-life.**

Challenges

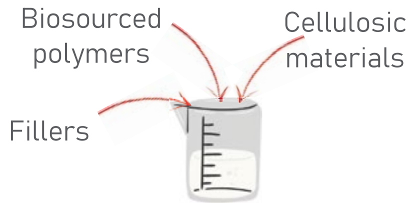
- Formulation of 100% biobased solution
- Optimize and adapt coating processes
- Improve and adapt barrier characterization methods



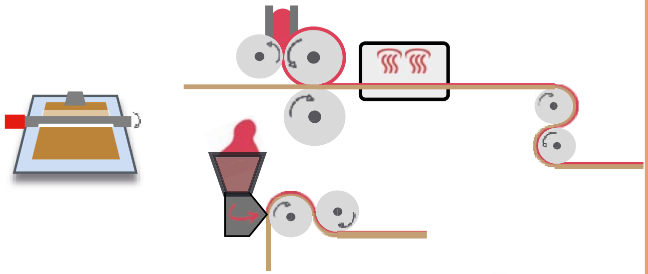
Funded by: Gascogne – ANRT Association Nationale Recherche Technologie

Methods

Formulation



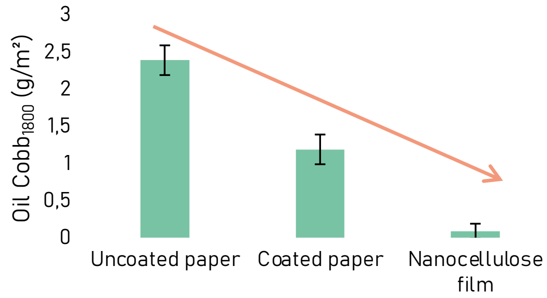
Coating processes : from lab to pilot and industrial scale devices



Barrier characterization

Results

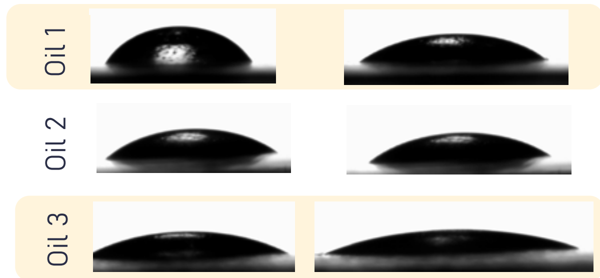
Oil Cobb measurements



Liquid oil behavior onto paper substrate

→ Depending on the oil used, the substrate doesn't react the same way

→ Each oil has its own characteristics: viscosity, surface tension, density



Océane AVERTY
Ph.D. thesis (2023-2026)
LGP2 (C. Martin; J. Bras; Q. Charlier)

Cellulose substrate functionalisation for barrier & sealing solutions in beauty packaging

Fonctionnalisation de substrat cellulosique pour des emballages barrières et scellables dans le domaine cosmétique

Thèse confidentielle

MatBio

Context / Objectives

World Plastic pollution:
- Regulations in Europe: SUPD (2019) & PPWR (2024)
- Society expectations to have less plastic packaging

Replace flexible plastic packaging by water vapour barrier paper packaging with bio-based coating

Reach the **barrier performance** required for high moisture products

Be **sealable**

Be **recyclable and 100% biobased**

In collaboration with: Unilever

Methods

1. From bio-based material to barrier paper

Suspensions formulation

Paper selection and coating and drying parameters monitoring

Barrier performance against water vapour

2. From barrier paper to packaging

Sealability (Heat, Ultrasound, Mechanical)

A multilayer strategy to reach all the targets

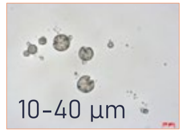
3. Characterisations of the packaging

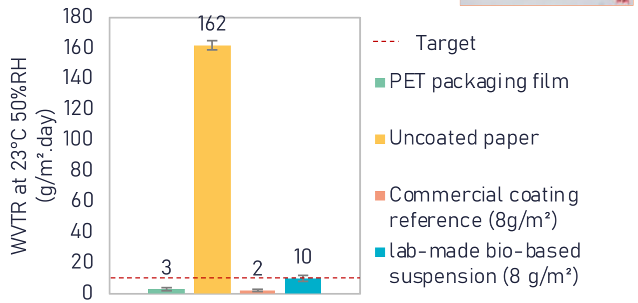
Recyclability

Converting resilience

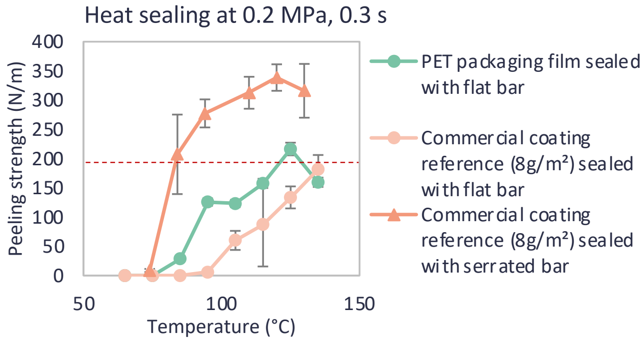
Results

Stable bio-based suspension with nanocellulose achieved with an industrialisable technology





Serrated geometry provides better peeling strength than flat bar for a paper coated with a sealant, especially at low temperature (90-100°C)



Eliott BONNET MARTIN
Ph.D. thesis (2024-2027)
LGP2 (D. Beneventi, A. Denneulin)
FCBA (M. Lecourt)

Set-up of an innovative wood-based biocomposite for processing by 3D LDM printing and wood panel adhesion

Elaboration d'un biocomposite innovant à base de bois et développement de sa mise en forme par procédés d'impression 3D LDM et thermopressage

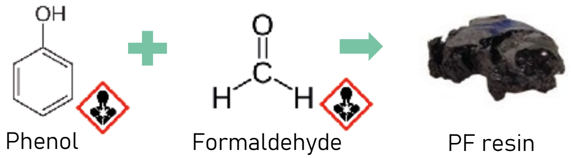
Thèse confidentielle

FunPrint

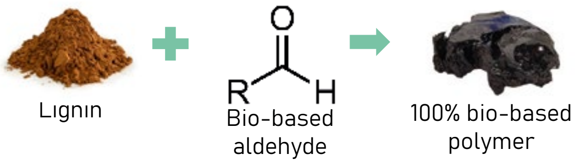
Context / Objectives

Substitution for phenol formaldehyde (PF) resin

Around 500 kT of phenol formaldehyde is produced per year for **wood panel adhesion**.



Bio-based and **non toxic** substitutes for phenol and formaldehyde are needed.

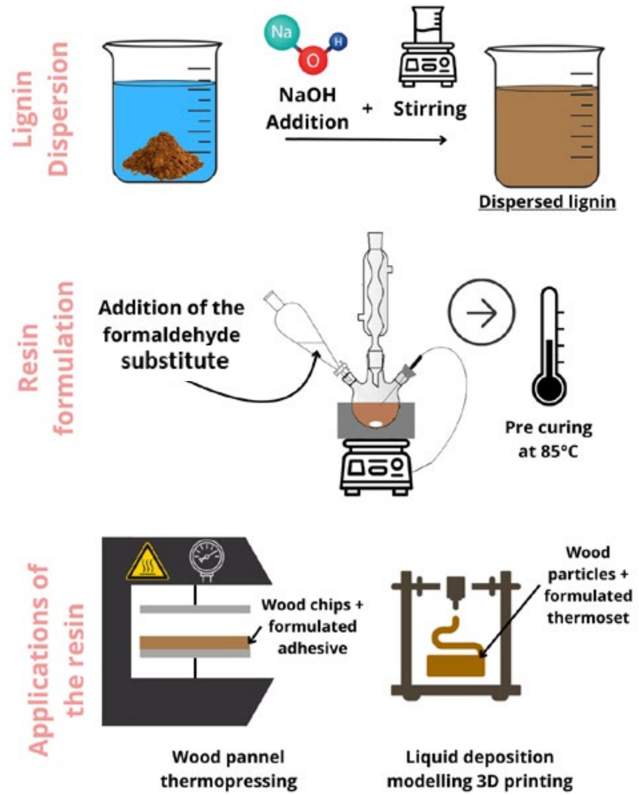


Lignin as a phenol substitute

- Abundant, cheap and bio-based chemical with phenolic structure.
- Potential to enhance performances of adhesive (UV resistance, thermal stability…)

Funded by: FCBA INSTITUT TECHNOLOGIQUE, ANRT ASSOCIATION NATIONALE RECHERCHE TECHNOLOGIE

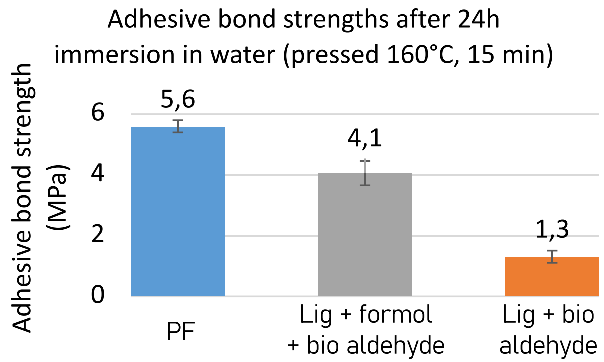
Methods



Results

Process optimization

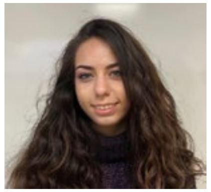
- Substitution of phenol by lignin 70 % ↗ to 100 %.
- Substitution of 100 % of formaldehyde with bio-based non toxic aldehydes achieved.



- After 24h immersion in water adhesive bond strength >1MPa => water resistant

Limitations after 2 years

- Cure temperature higher than PF adhesives (around 160°C).
- Weaker adhesive bond strength.



Laura BERNARD
Ph.D. thesis (2023-2026)
LGP2 (A.Denneulin; N. Reverdy)
CEA-Leti DTIS (P. Mailley; P. Marcoux)

Printed electronics for early detection of bloodstream infections

Electronique imprimée pour le dépistage rapide des infections sanguines

FunPrint

Context / Objectives

Bloodstream infections

- Every 2.8 seconds, someone dies from a bloodstream infection in the world.
- After 6h, the survival rates decrease by 7.6% each hour
- Increase in antibiotic resistance, leading to the leading cause of death by 2050.

Handmade to a standardized product

Previous work have been made by manual deposit of ink. This PhD study various parameters to standardized the process of manufacture.
Requirements :

- Autoclave-proof (130°C/18 min/2 bar)
- Rigid, resistant to breakage during septum perforation
- Biocompatible
- Electrically insulating
- Electrochemical sensor

Funded by:
In collaboration with LGP2

Methods

Electrochemistry-based

- Hypothesis of ink reduction by bacteria measured by a potentiostat (OCP method)

Experimental setup

Printing processes of sensor

Print on PCB sensor with 2 techniques :

- Screen-printing of viscous ink
- Manual deposit of liquid inks

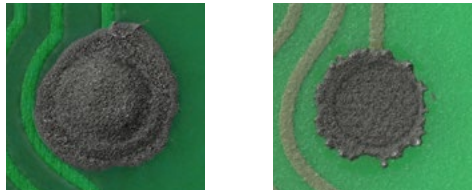
Characterisation:

- Rheology
- Microscopy
- pH sensitivity and bacterial detection (OCP electrochemistry)

Results

Screen-printing impact :

Improved reproducibility, controlled thickness and shape



Manual ink deposition *Screen-printing*

	Manual ink deposition	Screen-printing
Average (µm)	54,4	19,4
S.D (µm)	25,6	5,9

Keyence Optical Shadow Effect Mode of depositions & corresponding thickness of ink measured with Keyence

Towards a plug-and-play device

Optimising sensor design using 3D-printed prototypes and developing an integration guide

Optimized shape of sensor and integration assistance guide

Mathilde BERNARD-CATINAT
Ph.D. thesis (2023-2024)
LGP2 (E. Mauret; J. Bras)
Cellulose Valley

Development of innovative process for 3D cellulosic packaging.

Développement de procédés innovants pour l'obtention
de matériaux cellulosiques tridimensionnels.

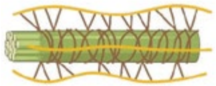
MatBio

Context / Objectives

Climate change and single use plastics: modern issues leading to various legislations push towards bio-based materials.

→ **Cellulose**

- Bio-based and biodegradable.
- Easily available.
- Recyclable.



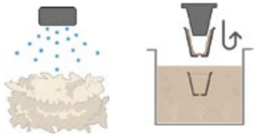
→ **Rigid 3D Cellulose-base packaging challenges:**

- Innovative 3D Shaping processes
- Waterless surface functionalization
- Combination of both steps

Funded by:

Methods

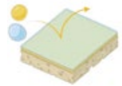
3D shaping processes:



- Wet molded fiber.
- Dry molded fiber.

Surface functionalization:

- Innovative coating process.
- Multilayered barrier structure.



Characterization

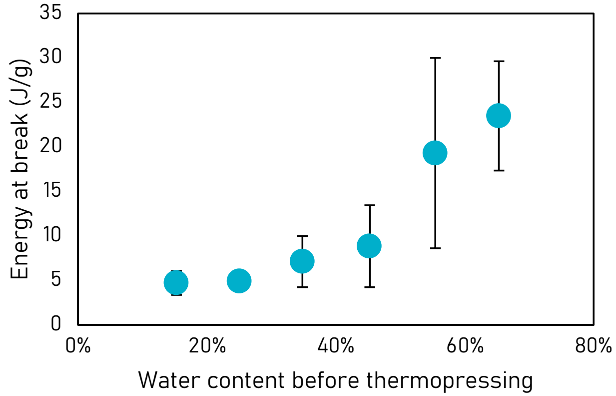
- Mechanical characterization (Traction, Bending).
- Surface characterization (Roughness).
- Barrier properties (Cobb, WVTR, Air permeability, Contamination monitoring after filling).

LCA

- Alternative fiber sources.
- Processes.

Results

Mechanical resistance of dry formed substrates increases with water content.



Barrier solution protecting tray during food storing.

Susie GUEHENNEUX
Ph.D. thesis (2024-2027)
LGP2 (G. Mortha)
IMP (F.Dalmas; F.Mechin)

Formulation of high-performance bituminous binder, mostly biobased, with a low environmental footprint

Formulation de liants « de type bitumineux » hautes performances, majoritairement biosourcés et à faible empreinte environnementale

Thèse confidentielle

BioChip

Context / Objectives

Global challenge: Reducing fossil fuel reliance (ex: **bitumen**) by 2050, following IRENA recommendations.

Solutions: Substitution of bitumen by **bioresources** – in road (85%) and roofing (15%) applications

Global bitumen production/yr

100 Mt = 53 Mt CO_2eq/yr

Development of a new biobased blend:

Bitumen: *Asphaltenes + maltenes* → **Biobased blend**

- With the same **rheological properties**
- using **sustainable bioresources** available on a large scale

Funded by:
EIFFAGE
SOPREMA Building for Life

Methods

Materials:

Aphaltenes — *Substitued by* → **Bio polymer**

Maltenic matrix — *Substitued by* → **Bio maltenic matrix**

Methods:

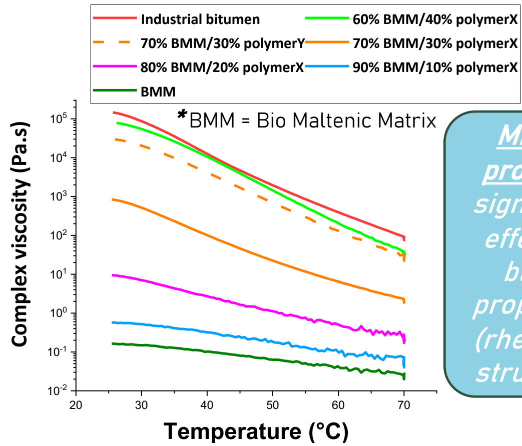
- **Selection & Screening** of bio polymer and bio Maltenic matrix
- **Preparation of colloidal dispersions**

Optimization of the mixing protocol (polymer type and content, temperature and mixing time) to match the properties of commercial bitumen.

- **Dispersions characterisations**
  - Rheology
  - Microscopy
- **Understanding physico-chemical interactions**
  - NMR, SEC, SAXS

Results

Rheological properties: Polymer type and content



Mixing protocol: *significant effect on blend properties (rheology/ structure)*

- **Impact of polymer type**: Depending on the type of polymer, the rheological properties of the blends are different
- **Impact of polymer content**: A blend with 40% of polymer X can mimic the rheological properties of industrial bitumen *(with a specific protocol)* **Outlook:** Are the blends stable ? More sustainable ? Suitable for applications ?

Annabelle JULIEN
Ph.D. thesis (2024-2027)
LGP2 (J. Bras; Q. Charlier)

Dry processing methods to manufacture low environmental-footprint bio-based materials

Fabrication en voie sèche de matériaux biosourcés à empreinte environnementale diminuée

MatBio

Context / Objectives

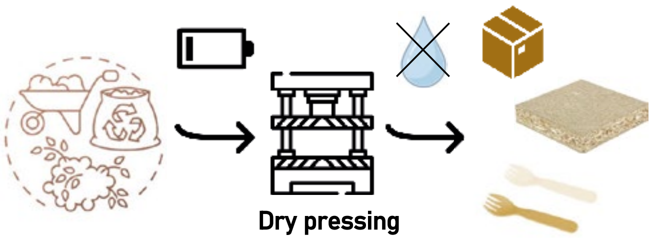
1 Environmental issues
Plastic industry

- **CO2 emission**
- **Not biodegradable** so a lot of wastes finds itself in landfill or ocean (6900 Mt[1])

2 Disadvantage of current biobased solutions

- Hight **energy and water consumption**
- The use of **petroleum-based adhesives**
- **Low biodegradability** or recyclability for bioplastics

Goal : Substitute plastic by producing material from biomasses with more sustainable dry processes that uses less energy, less water, no petroleum based adhesives and that can leads to biodegradable solutions !



Understanding adhesion phenomena is key

[1]Tony R. Walker et al. Trends in Analytical Chemistry 2023

Funded by:
Drybiomat - ANR-23-CE43-0002
https://anr.fr/Projet-ANR-23-CE43-00
anr agence nationale de la recherche AU SERVICE DE LA SCIENCE

Methods

Lignocellulosic material

- Wood industry by-products
→ *For circular economy*
- "Model raw material"
→ *To control and understand*

Functionalisation and modification

- Biobased polymers
- Green chemistry
- Delignified wood
→ To tune the mechanical properties

→ Different type of material shaping (powder, fiber, particle)

Dry process

- Thermocompression
- Ultrasonic compression molding

→ Design of experiment (Central Composite Design)

→ Adjust **input parameters** to tailor final properties

Iterative work

Multi-criteria analysis
Creation of a global performance index

Performance

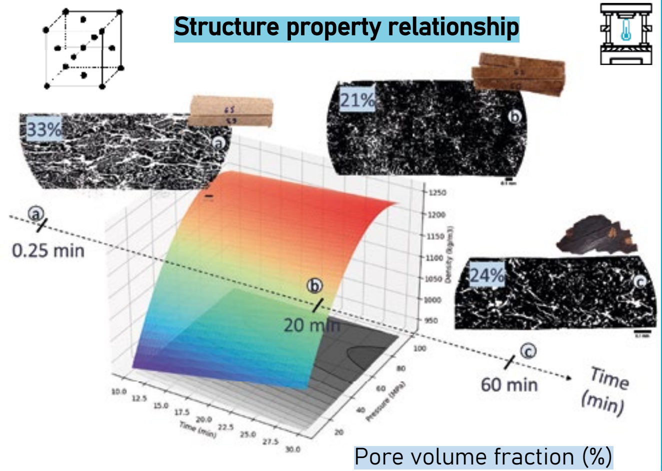
- Mechanical properties
- Surface roughness
- Internal structure
- Water resistance

Environment

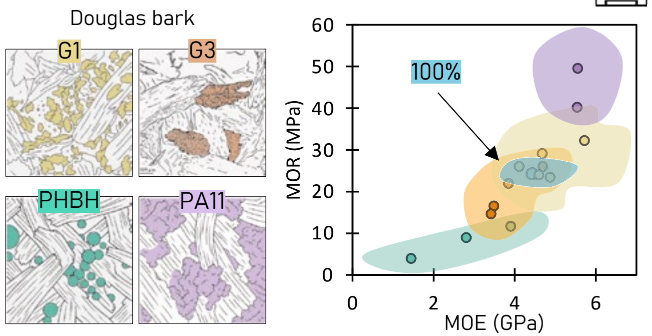
- Energy consumption
- Biodegradability
- Fragmentability
- Dry recyclability

Results

Structure property relationship



Biopolymers blends with soft wood particles



Amélie LEFEVRE
Ph.D. thesis (2023-2026)
LGP2 (N. Marlin; G. Mortha)
CERMAV (L. Heux)

Sustainable chemical treatments to improve recycled fibers bonding ability

Amélioration de la capacité de liaisons des fibres recyclées par procédés chimiques durables

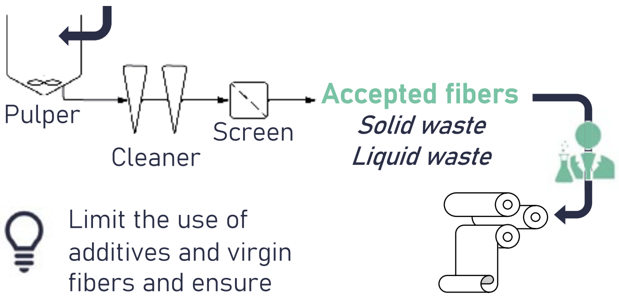
BioChip

Context / Objectives

PEPR **PAC3R** « Recycling, Recyclability, Re-use of Paper and cardboards »

- Add more value to paper and board recycling products
- Recycle all types of paper and board
- Valorize recycling waste

Recycled papers and boards



Limit the use of additives and virgin fibers and ensure paper quality

To develop new sustainable chemical process to upcycle recycled fibers for packaging applications

Funded by: anr agence nationale de la recherche; France 2030 Programme de recherche Recyclage

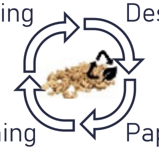
Methods

Raw materials

Test Liner
Recycled fibers
Contaminants
Fillers

Refined UKP
Softwood kraft fibers, high kappa
Contaminant-free

Evaluate the impact of recycling



Assessing paper properties

Restore the fibers' bonding ability

Ozone treatment – oxidative process
CHO or COOH groups creation mainly on lignin

Grafting process
Interaction between added molecules and lignocellulosic fibers

Refining – mechanical process
Low-intensity to avoid excessive degradation

Characterizations

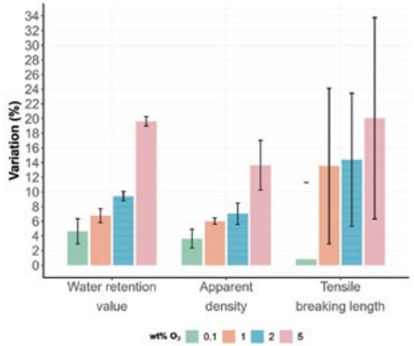
Traction, Burst, Water retention value, Contact angle, Air permeability, Kappa Number, COOH content, DP_v

Results

Test Liner

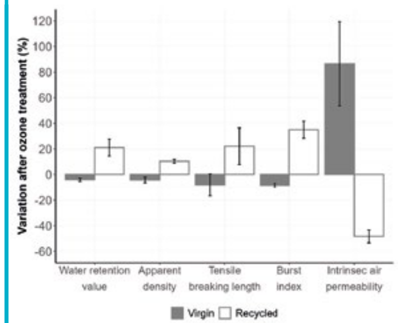
Improvement
5% - 20% of mechanical properties

Presence of contaminants
⇨ difficulties for chemical characterizations



Refined UKP

Recover 20 to 45% of mechanical properties lost through 3 successive recycling operations while **preserving lignin and cellulose**



Destruction effect

Reconsolidation effect

Maxime LEGAY
Ph.D. thesis (2023-2026)
LGP2 (D. Beneventi;
I. Desloges; J. Viguié)

Printing stiffeners on the surface of folding or corrugated boards: a bio-inspired approach to lighten packaging and optimize resource consumption

Impression de renforts à la surface d'emballages cartons: une approche bio-inspirée pour alléger les emballages et optimiser la consommation des ressources.

MatBio FunPrint

Context / Objectives

Paper industry consumption

- 15-25 m^3 of water / ton of paper
- 2.9 kWh / ton of paper
- 2-3 ton of wood / ton of paper

Two approaches to reduce the use of resources :

1. Lighten packaging
2. Increase the use of recycled pulps in packaging

→ **But how to keep good mechanical performances?**

3D printing polymer ribs on cardboard packaging boxes

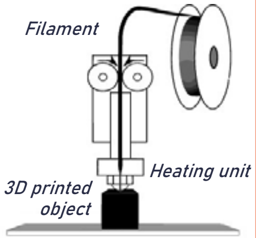
Ribbed structures = high bending stiffness to weight ratio
→ Printing polymer ribs on cardboard is a promising idea to increase packaging strength adding a reduced weight

- **Finding a suitable deposited material**
- **Characterizing** the behavior of printed cardboard
- **Optimizing** the geometries of the ribs patterns to maximize the strength to weight ratio

Funded by: UGA Collège Doctoral, ED I-MEP²

Methods

3D Printing



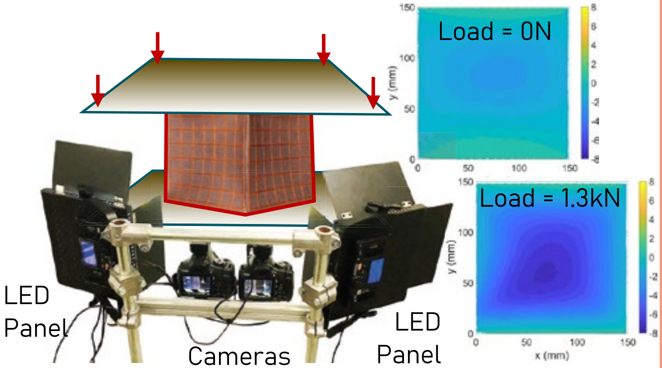
- **PLA** used as a demonstrator, Fused Deposition printing from
- Ongoing work on **cellulosic paste** cold extrusion

Mechanical characterizations

Comparison of printed and unprinted cardboard by
→ **4 points bending** of plates
→ **Compression tests** of boxes

Monitoring the boxes' deformation

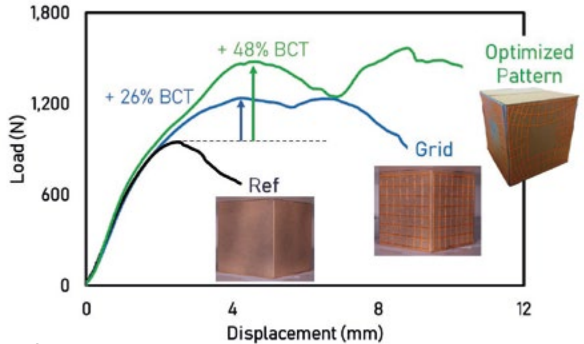
→ **Digital Image Correlation (DIC)** to measure the displacement fields of the boxes' surfaces during compression tests



Results

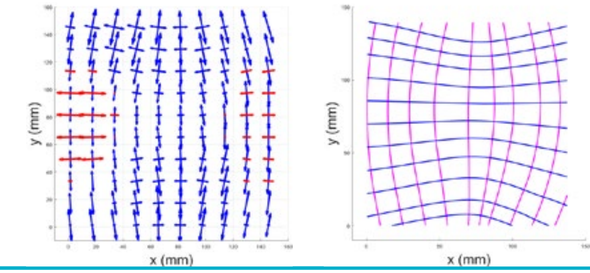
Improvement of the mechanical performances

Up to **+48% strength for +28% mass** for optimized pattern boxes so far



DIC analysis

- Fine monitoring of **buckling**
- Currently devellopping an **optimization tool** calculating the most efficient pattern to print based on the **deformation vectors maps**



Julie LUNEAU
Ph.D. thesis (2023-2026)
LGP2 (R. Passas; C. Martin)

Influence of the drying conditions on the surface properties of end-products during Roll to Roll surface functionalisation : comparison between copper and fiber-based strips

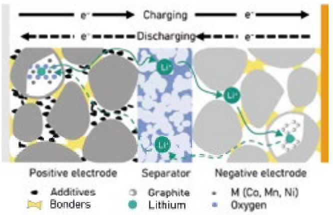
Influence des conditions de séchage sur les propriétés de surface des produits finis lors de la fonctionalisation de surface Roll to Roll : comparaison entre les bandes à base de cuivre et de fibres

MatBio BioChip

Context / Objectives

Context: Lithium-ion battery

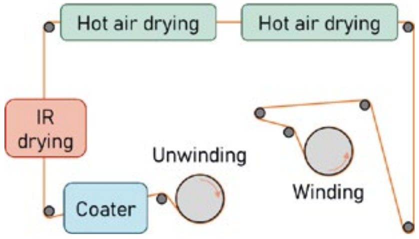
- Need to store energy produced
- production increasing of electrical cars
- Need to improve the manufacturing process



Schematic drawing of the components and operation of a lithium-ion battery cell – Marcel Schmitt

The electrodes are manufactured by coating an active material on the current collector, copper, for the negative one.

Objectives: Adaptation of a paper functionalization driver for lithium ion battery negative electrode manufacturing.



Schematic drawing of the functionalization driver

Funded by:
AMI – CMA, L'école de la batterie, Grenoble-INP UGA

Methods

Slurry characterisation:

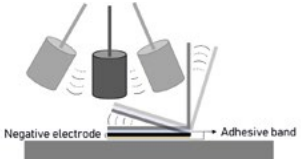
- 3 slurries formulations
- Rheological characterisation
- Surface tension measurement

	V-50:50	A-50:50	A-25:75
Graphite %	53,60	52,62	52,62
Carbon black %	0,80	0,79	0,79
CMC %	0,60	1,50	0,75
SBR %	0,60	1,50	2,25
Water %	44,40	43,59	43,59

Slurries composition

Electrode manufacturing:

Electrode characterisation:

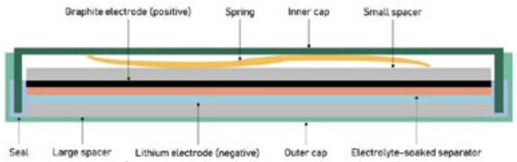


Scott Bond adhesion test

- MEB imaging: cross sectioning and surface
- Electrical characterisation
- Mechanical characterisation
- Adhesion to the substrate

Coin Cell manufacturing and electrochemical characterisation:

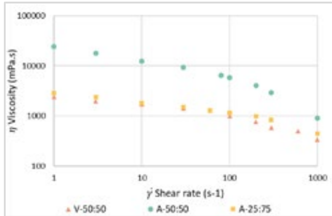
- "Half cell": Lithium-graphite
- EIS: Electrochemical impedance spectroscopy
- GCPL: Galvanostatic cycling with potential limitation



Cross-sectional diagram of a coin cell

Results

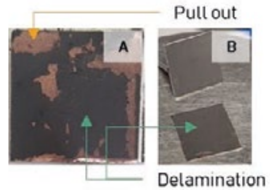
Rheological behavior of the slurries



Viscosity curves

- Shear-thinning slurry
- CMC acts as a thickening agent

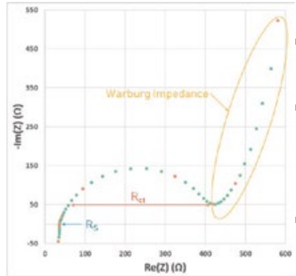
Scott Bond adhesion test



Electrode delamination after tensile adhesion test on A) uncalendered and B) calendered electrode

	Pull-out	Delamination
Uncalendered	→	→
Calendered	X	→

EIS results for V-50:50 electrode, Nyquist plot:



Viscosity curves

- RS = 36 Ω : Electrolyte and cell resistance ⇒ should be below 10 Ω
- Rct = 385 Ω : Diameter of the semicircle: resistance to load transfer ⇒ slow kinetics, limited electrochemical reaction
- Warburg impedance : lithium ion diffusion

Zelda MONTEIL-OCHS
Ph.D. thesis (2023-2026)
LGP2 (D. Beneventi)
STPE - CEA Liten (G. Furia ;
JF. Blachot ; M. Heitzmann)

Development of conductive bio-based composites for printed PEMFC

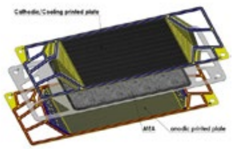
Développement de composites biosourcés conducteurs pour les PEMFC imprimées

FunPrint

Context / Objectives

Printed PEMFC* developed by CEA

**Protonic exchange membrane fuel cell*



Advantages of printing: lightweight, compact, roll to roll industrialization, flexible in implementation.

Printed bipolar plates in PEMFC

Printing of fluidic channels to distribute gases and cooling, conduct electrons, water management and mechanical strength of the cell

Carbon composites printed on carbon coated foils
But based on harmful fluoropolymer incompatible with potential European legislation

Objective : Replacing the fluoropolymer in the composite with a bio-based polymer

Composite specifications

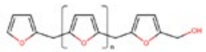
Bio-based binder + carbon fillers ;
Resistant in PEMFC environment (heat, water/moisture and acids) ;
Areal specific resistance < 0.01 Ω.cm² and low deformation under 1 MPa

Funded by: cea liten

Methods

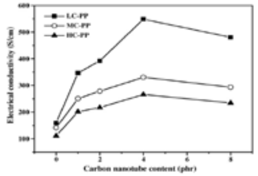
Biobased polymeric bider compatible with PEMFC environment, with printing processes, and good resistance to heat:

Polyfurfurylic alcohol (PFA)



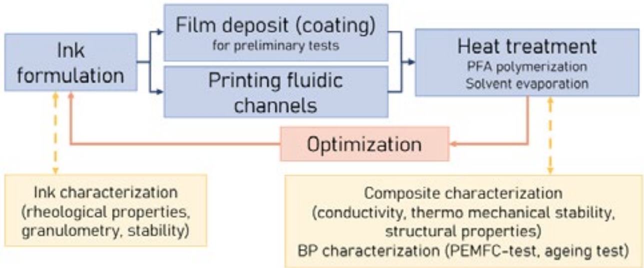
Carbon fillers to provide electrical conductivity to composite. Multi-charge composite to increase the number of percolation paths and create a maximum for conductivity:

Graphite (G)
+ Carbon Nanotubes (CNT)

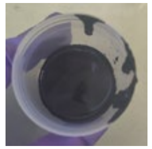


Conductivity for bipolar plate: optimum for 20%wt PP binder, 80%wt G and 4 phr CNT (Liao and al. 2008)

Process and characterization



Results

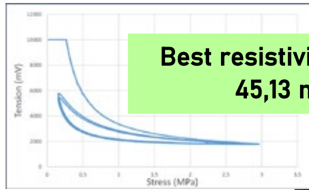


1) Ink formulation

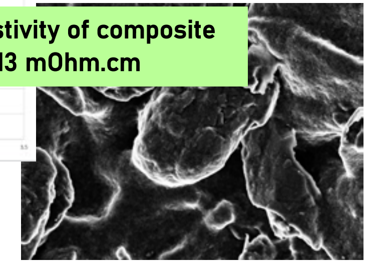
PFA + G + CNT

2) Film coating on carbon foil
+ Cured 90°C – 130°C

3) Composite characterization



Best resistivity of composite
45,13 mOhm.cm



SEM structural observation

Perspectives

- Printing bipolar plates and characterization
- Understanding interactions between components within the ink and composite
- Identifying percolation phenomena
- Implementing standard conductivity measurements

Chloé PARISI

Ph.D. thesis (2023-2026)
LGP2 (J. Bras)
SIMAP (E.Blanquet)
CILKOA (E.Giquel)

Atomic Layer Deposition (ALD) optimization into cellulosic substrate for barrier properties

Optimisation du traitement ALD sur supports cellulosiques

MatBio

Thèse confidentielle

Context / Objectives

New legislation on plastic packaging

Reduce Reuse Recycle

- Single Use Plastics Directive (2019)
- Packaging and Packaging Waste Regulation (2018)

Green alternative

Cellulosic materials

Abundant, Recyclable, Biodegradable & Renewable

☒ Permeable, Low barrier & Hydrophilic

CILKOA

Develop an innovative hydrophobic barrier treatment for cellulose substrates with few nanometers of ceramic

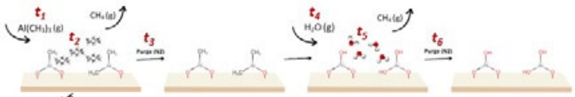
Objectives

☐ Study the influence of substrate density, roughness and chemistry on ALD deposition
☐ Study adhesion of different layers
☐ Determine converting resilience for specific applications

Funded by: RÉPUBLIQUE FRANÇAISE, ADEME
In collaboration: SIMaP, cilkoa The barrier solution for paper packaging

Methods

Atomic Layer Deposition (ALD)



Different reactors
Different treatments (temperature, precursors, exposure…)

Cellulose substrates

Different Chemistry / Roughness / Porosity

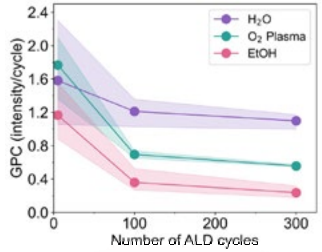
Characterizations

Ellipsometry, X-Ray Fluorescence, ICP-MS, SEM-FEG, AFM, XPS, ToF-SIMS…
Properties: Water Vapor, Water, Oxygen, Fire resistency, Mechanical resistency…

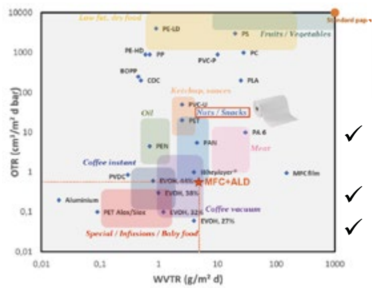
Results

ALD deposition

- ✓ Exact composition
- ✓ Influence of parameters
- ✓ Influence of reactors
- ✓ Understanding surface phenomena



Cellulose substrates

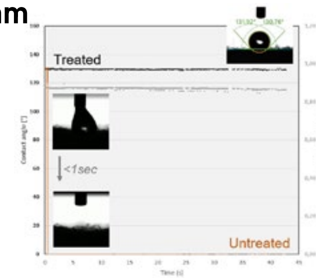


- ✓ Characterization of ALD penetration
- ✓ Influence of chemistry
- ✓ High barrier properties (WVTR, OTR, WCA)

Example of ALD on foam

for building application

- ✓ Super-hydrophobicity
- ✓ Humidity regulator
- ✓ Fire retardant…



Juliette SEIGNARD
Ph.D. thesis (2024-2027)
LGP2 (N. Reverdy-Bruas; D.Curtil)
Tageos (T. Germann)

Active and Flexible Hybrid Electronics at an industrial scale

Système électronique actif hybride et flexible à l'échelle industrielle

FunPrint

Thèse confidentielle

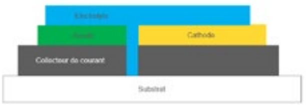
Context / Objectives

In today's connected world:

Battery life cycle = ☹

BECAUSE dangerous and scarce raw materials + less than 48% of batteries are recycled, often done under deplorable conditions, etc.

One solution? → **Printed batteries**
The challenge → Successfully design a battery **on paper** (=bio-based materials)



At industrial scale!

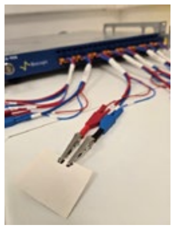
Funded by: Cifre lgp² TAGEOS FEDRIGONI

Methods

Characterization of materials
> Substrates: paper (permeability, dimensional stability, processability)
+ inks (viscosity, conductivity, etc.)

Battery printing
> Deposition process investigation for each layer
> Sizing process investigation

Characterization of batteries produced
> Electrical performance: capacity, internal resistance, lifetime

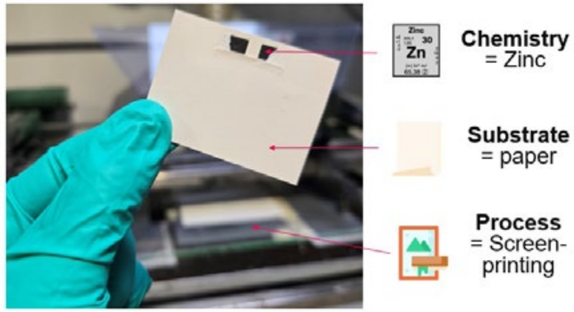


$$Capacity(mAh) = \text{time(h)} * \text{discharge current (mA)}$$

$$Rint(\Omega) = \frac{U1\,(V) - U2(V)}{I2\,(A) - I1(A)}$$

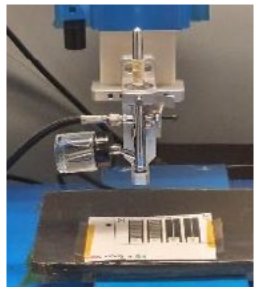
Results

Successful production of printed batteries (<2mm of thickness) on paper with electrical performance **corresponding to the targeted applications**



Design adaptation according to **requirements**

Promising industrial trial results



Alicia TESTON
Ph.D. thesis (2023-2026)
LGP2 (C. Chirat; N. Marlin)

Biorefinery integrated in paper/board recycling : extraction of starch from recycled cellulosic fibers and its valorization into high value-added products

Bioraffinerie intégrée au recyclage des papiers et cartons : extraction de l'amidon des fibres cellulosiques de récupération et sa valorisation sous forme de produits à haute valeur ajoutée

BioChip

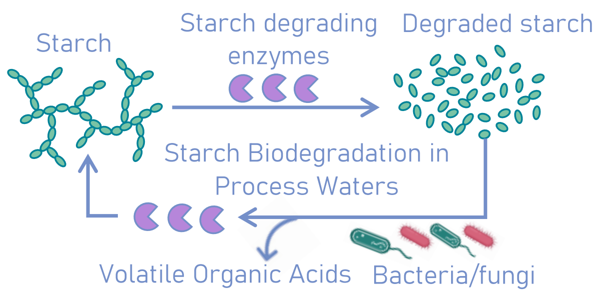
Context

Use of Starch in Papermaking

- Versatile additive : dry strength agent, retention aid, coating binder, adhesive for corrugated boards
- The paper industry consumed 1.6 million tons of starch in Europe in 2023, according to CEPI

Issues Related to Starch

- When recycled papers/boards are used to produce new paper/board grades, part of the starch contained in them ends up in the process waters, leading to microbiological, process and environmental issues

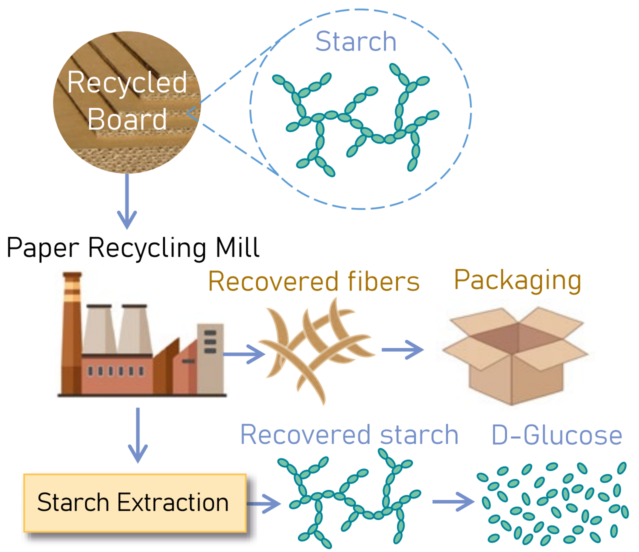


Funded by:

In collaboration with

Objectives

Development of a Starch Extraction Process at the Beginning of Paper/Board Recycling Operations

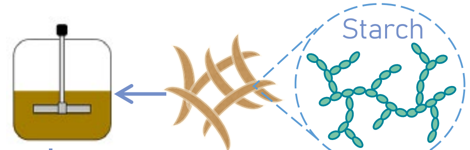


Development of a bioeconomy-compliant approach to :

- ✓ Minimize the amount of starch released in process waters during papermaking operations
- ✓ Valorize starch (considered up to now as a contaminant) into high value-added products

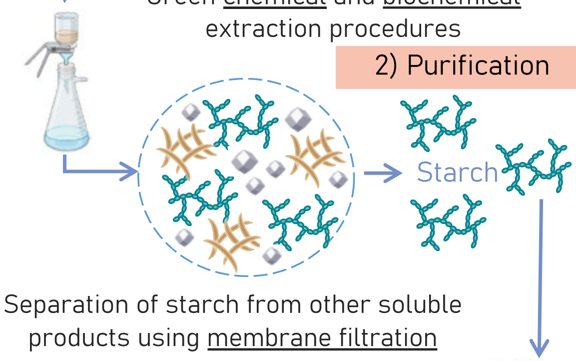
Methods

1) Extraction of Starch from Recycled Fibers



Green chemical and biochemical extraction procedures

2) Purification



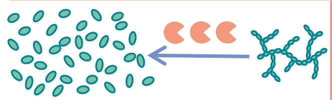
Separation of starch from other soluble products using membrane filtration

3) Characterization

Determination of the macromolecular features of the recovered starch using AF4-MALS-dRI

4) Depolymerization

Enzymatic hydrolysis of starch into D-Glucose



Arthur VALENCONY

Ph.D. thesis (2023-2026)
LGP2 (G. Mortha; N. Marlin)
Institut Technologique FCBA
(S. Tapin-Lingua)

Lignocellulosic biorefinery: Development of a new pulping process to produce high-quality fibers from underexploited resources

Bioraffinerie lignocellulosique : Développement d'un nouveau procédé de mise en pâte pour la production de fibres de haute qualité à partir de ressources sous-exploitées

BioChip

Context / Objectives

Underexploited biomass:
Huge quantities are available

- Wastes of industrial biomass
- Underexploited sources: hemp, nettle and poplar residues available in local areas

The Kraft process is a strongly alkaline process
Large plants with limited flexibility

- Soft alkaline pulping processes are in the trend
- Total Chlorine Free (TCF) bleaching sequence is a must
- Smaller cooking units for smaller biomass quantities

MicroFibrillated Celluloses (MFC) are in current development for their good properties

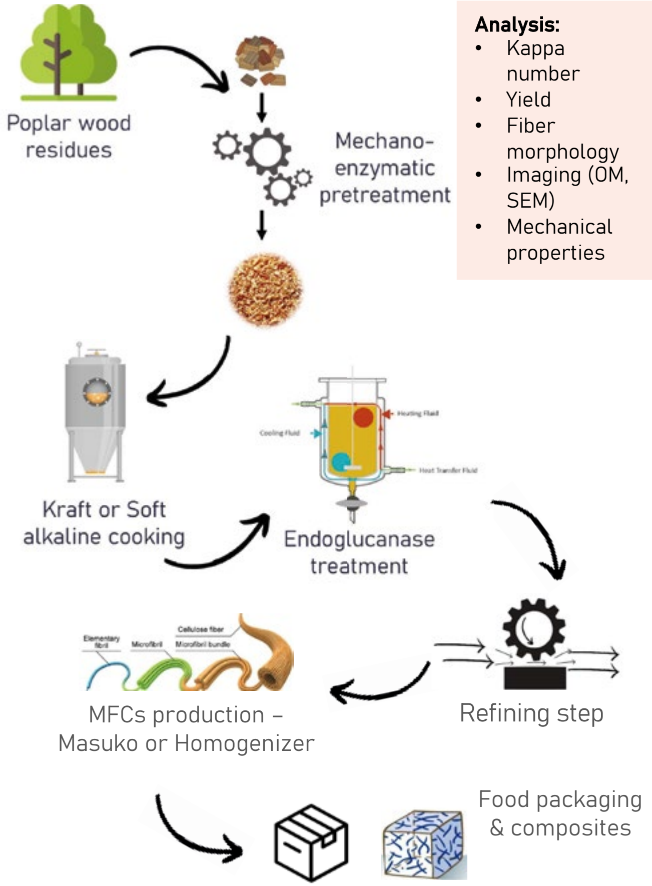
- Reinforcement in composites
- Packaging applications for barrier properties
- Textile utilization

Funded by: FCBA Institut Technologique, Cifre, ANRT, Bio-LUSH

Methods

Analysis:

- Kappa number
- Yield
- Fiber morphology
- Imaging (OM, SEM)
- Mechanical properties

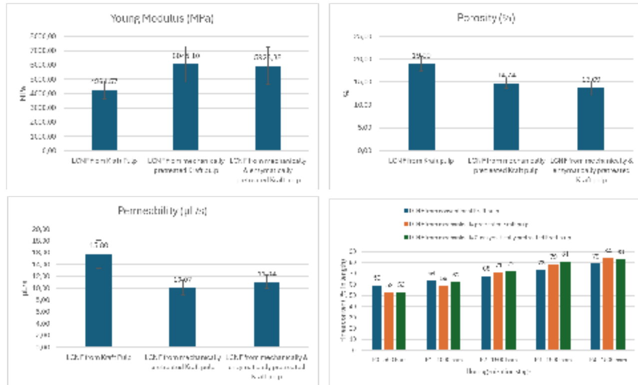


Results

3 different Lignified nanocellulose (LCNF) produced from:

- Conventional Kraft pulp
- Kraft pulp from wood chips mechanically pretreated
- Kraft pulp from wood chips mechanically & enzymatically pretreated

Nanopapers of 65 gsm produced on 0,65µm nitrocellulose membrane



→ Positive impact of mechanical pretreatment of wood chips on LCNF properties: higher energy absorption during tensile, lower air permeability and more fine elements

Arnel BRZOVIC
Ph.D. thesis (2023-2026)
N. Reverdy-Bruas; N. Marlin (LGP2)
L.Svecova (LEPMI)

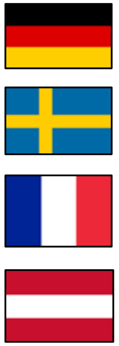
Recycling of multilayered electronic devices printed on cellulosic substrates

Etude de le recyclabilité de modèles complexes d'électronique imprimée sur papier par adaptation de lignes de recyclage papier existantes.

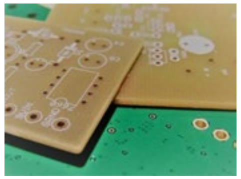
BioChip FunPrint

Context / Objectives

European Circel-paper project

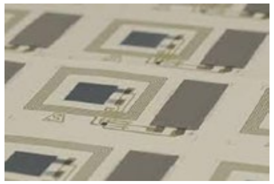


Only **17.4 %** of the e-waste is documented to be collected and formally recycled worldwide.



FR4 PCB

→

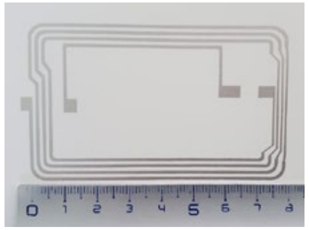


Paper PCB

Challenges:
1) Recover the fiber fraction with minimum contaminants.
2) In a second fraction recover functional materials.

Methods

1. Paper printed electronics



Powercoat XD200
- Silver conductive Ink
- Coated paper
- 200 g/m^2

2. Conventional paper recycling line

Pulping → Screening → Centrifugal cleaning → Flotation →

Units are optimized individually and tested sequentially as part of the process.

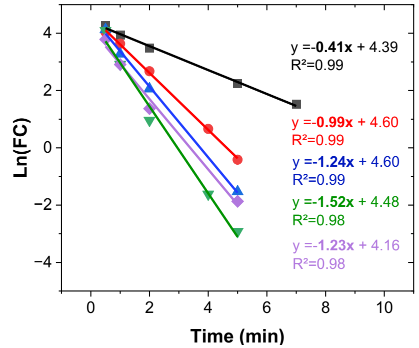
3. Atomic Absorption Spectroscopy (AAS)

Objective: silver tracking

Ash + silver → Leaching in Nitric acid → Solvated silver Ag^+ → (AAS)

Results

1. Pulping optimization



The optimization involves monitoring the flocs content in the pulp which gives the disintegration kinetics.

2. Silver Recovery

Centrifugal cleaning emerges as a highly promising unit operation for the separation of silver from fibers.

Ag= 100 % → inlet → **Centrifugal cleaning** → accepts → Ag= 2-3%
rejects → Ag= 90 %

→90 % of the silver can be recovered from the pulp.

Mathilde DAVID
Ph.D. thesis (2022-2026)
LGP2 (Q. Charlier, J. Bras)

Manufacturing of bio-based materials using ultra-sonic compression molding

Élaboration de matériaux biosourcés par compression ultrasonore

MatBio

Context / Objectives

Manufacturing of 100% biosourced materials

Environmental footprint reduction

Bio-sourced materials can have a significant environmental impact :

- Use of petroleum-based resins (wood panels)
- High energy consumption during production (papers and boards)
- Low recyclability (bio-based composites)

New process and material development

1. Use of Bio-waste as raw material in order to get into a *circular economy model*
2. Dry process in order to *reduce water and energy consumption*
3. Manufacturing of molded composites via powder compression using ultrasonic vibrations

→ 100% Composite materials made derived from cellulosic fibers and natural binder (lignin and others)

Funded by: GRENOBLE INP UGA; UGA COLLÈGE DOCTORAL ED I-MEP²

Methods

Ultrasonic compression

High frequency acoustic vibration under compression

Compaction of dry powder into bulk

Composites materials

Figure : Ultrasonic Press - Sonimat

Characterization methods

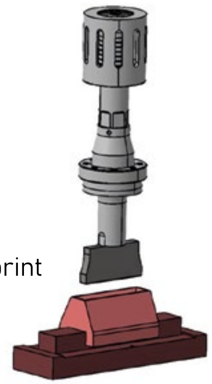
Analysis :

- Microstructural

- Resistance to water and humidity

- Mechanical properties

- Energy consumption



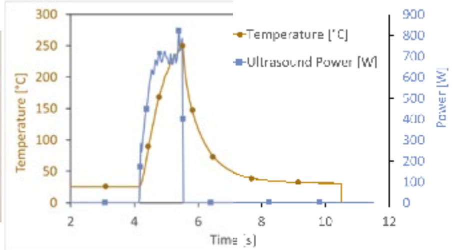
Impact assessment

- Multicriteria analysis to associate material properties and energy footprint
- Toward scale up (TRL 4+)

Results

Key process parameters :

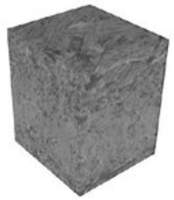
- Power and transmitted energy
- Pressure



Process development :

- Molds (for dry materials)
- Spring tooling system for US molding
- Temperature monitoring

In-situ monitoring of material formation



Key raw material characteristics :

- Influence of chemical composition
- Shape and Size of bio-elements
- Influence of humidity content
- Elements hardness

Clément TURPIN
PhD thesis (2023-2026)
LGP2 (N. Reverdy-Bruas, J. Viguié)
3SR Lab (L. Orgéas)

Architecturing papers and boards with bio-based grid printing: a low-cost approach to lightweight packaging

Papiers et cartons architecturés par impression de renforts bio sourcés : développement d'une approche à bas coût pour alléger les emballages.

MatBio FunPrint

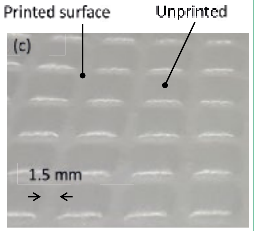
Context / Objectives

Reducing the weight of paper-based packaging

- Paper production demands substantial ressources:
  - ✓ 15-25 m^3/ton of water,
  - ✓ 2.9 MWh/ton of energy,
  - ✓ 2-3 ton/ton of wood

Idea: architecturing papers and cardboards

- Embossing paper sheets to increase their bending stiffness
- Low cost biodegradable route:
  - ✓ Printing patterns with starch suspensions
  - ✓ Sheet embossing induced during suspension drying



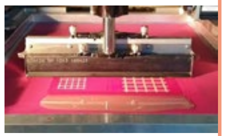
Thesis objectives

- Optimization of the printing process
- Multiscale analysis of :
  - ✓ Drying, shrinkage, buckling phenomena
  - ✓ Induced meso and microstructures
  - ✓ Induced hygro-mechanical properties

Funded by: GRENOBLE INP UGA; ctp centre technique du papier

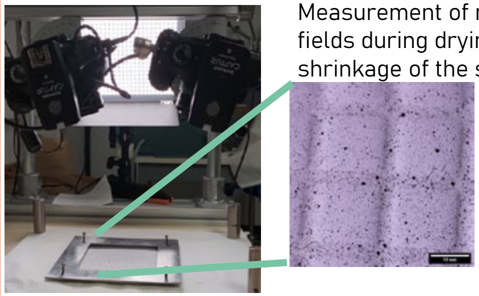
Methods

Materials & Processing route



- Handmade model paper sheets:
  - ✓ Softwood kraft bleached pulp
  - ✓ Rapid Köthen former
  - ✓ Basis weight: 80-120g/m²
- Aqueous suspension with 40 wt% of low molecular weight corn starch
- Screen printing

Monitoring the drying/embossing



Measurement of meso kinematic fields during drying and shrinkage of the starch.

Mechanical test:

Cantilever strip of paper

Bending stiffness measurement based on image analysis

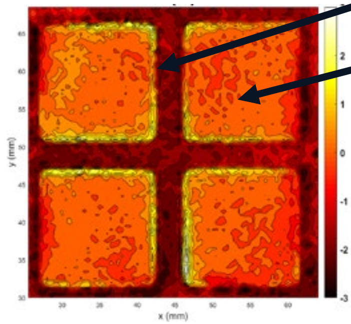
Microstructure observations :

ESEM

Results

Embossing phenomenon

Mean surface strain

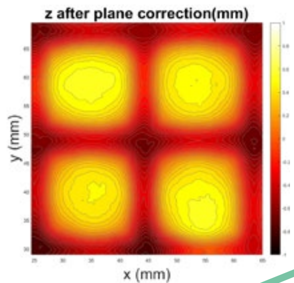


Printed line

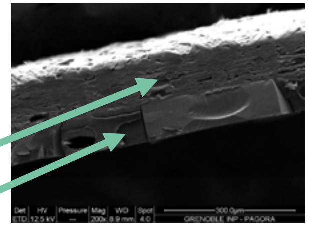
Unprinted

Digital Image stereo-correlation quantifies the out of plane displacement induced by the strains due to the shrinking of starch

Out of plane displacement (mm)



Structured surface shows altitude variation about 1mm. Paper is 110µm thick



Fibers

Starch layer (≃80µm)

Printed starch presents good adhesion, homogeneous thickness and many cracks due to its brittleness

Conferences: Turpin, C et. al. (2023). 8th EPNOE International Polysaccharide Conference, Graz

Young Researchers' research projects description

Post-doctorates and Research Engineers

Lorette BRAULT
Post-doc (2024-2027)
LGP2 (N. Marlin, G. Mortha)
Cermav (L. Heux,
S. Molina-Boisseau)

Valorization of the fibrous rejects from paper and cardboards recycling process

Valorisation des déchets fibreux issus de la filière de recyclage papier-cartons

BioChip

Context

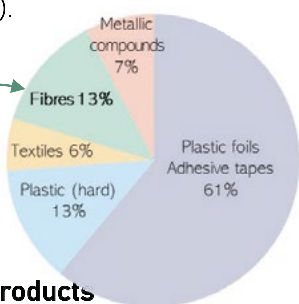
Paper and cardboards (PC) recycling process[1]

- 4.9 Mt of recovered PC in France/year, including

4 Mt for packaging sector (2020).
↳93% recycled into PC
Among the 7% waste:

13% of fibrous rejects

= 36 kt of non-valorized fibres per year in France.



Lignocellulosic high value products

- EU directives (Green Deal) on reducing consumption and replacing of petroleum-based products.
- High demand of cellulose and lignocellulosic compounds for ubiquitous applications.

= high demand of virgin fibers and pure bio-compounds representing high energy and chemical consumption.

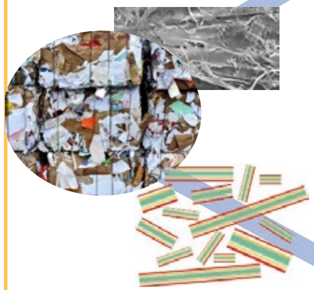
However, for some applications, non-pure and damaged cellulose from paper recycling process could be used.

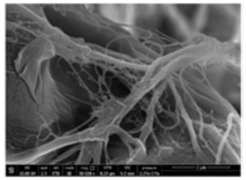
Funded by:
agence nationale de la recherche
FRANCE 2030 PROGRAMME DE RECHERCHE RECYCLAGE
RECYCLAGE RECYCLABILITE RÉUTILISATION MATIÈRE PEPR

Objectives

Development of valorization methods tailored to the fiber quality and contaminant nature

Damaged fibres



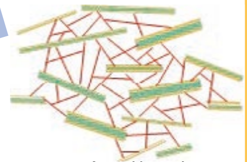


MFC

Applications

Mechanical reinforcement (paper coating, composites)
Rheological additive

Resin



Applications

Adhesives, sealing, coating, composites,...

Caption:
Cellulose
Hemicelluloses
Lignin

Methods

Characterization of rejects

Chemical: %cellulose, %hemicelluloses, %lignin, %stickies,... functional groups analysis (COOH, CHO, phenol,...)

Physical: Fibres morphologies and specific areas.

Extraction of lignocellulosic fraction

Rejects → Physico-chemical separation / Mechano-chemical treatment / Direct dissolution

Processing of fibrous-rich rejects

Rejects or model compounds → Fractionation/purification → Oxidative pretreatment → Foaming / Fibrillation / Hot-pressing

Characterization of materials

Mechanical, thermical, chemical and optical characterizations.

[1] K. Guiltaux, et al., ADEME 2023. Perspectives d'évolution de la filière papiers-cartons en France. 79 pages

Emilien FREVILLE
Alice DUTHOIT
Research engineer (2024-2026)

injectose

Injection-molding of cellulose based material for packaging applications

Injection-moulage de matières cellulosiques pour des applications d'emballage

MatBio

Context / Objectives

Alternative solutions to plastic packaging

SUPD
Single Use Plastics Directive (2019)

→ Progressive ban of SUP

PPWR
Packaging and Packaging Waste Regulation (2024)

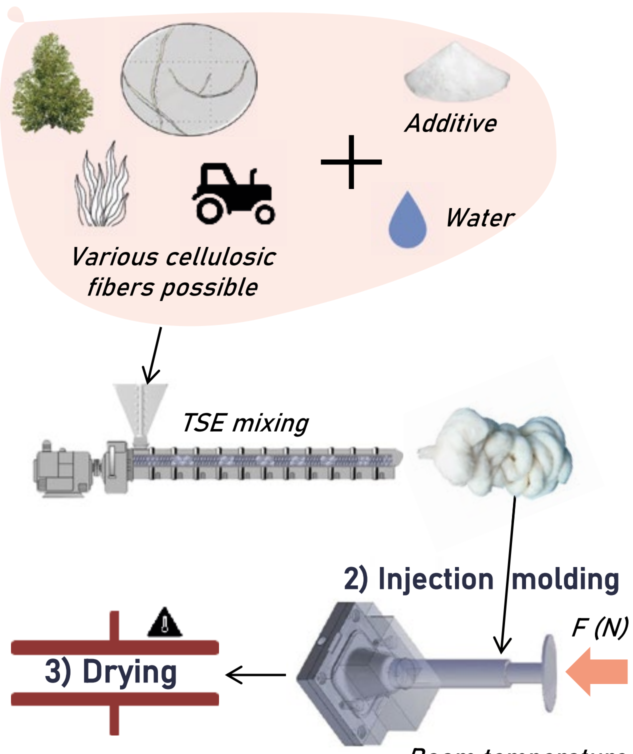
→ All packaging must be recyclable by 2030

→ End of SUP by 2040

AGEC
Loi anti-gaspillage pour une économie circulaire (2020)

Methods

1) Injectable cellulosic paste production by twin-screw extrusion



Results

Injection-molding of 3D objects containing at least 90% of cellulosic fibers

Daniella MORGADO
Post-doc (2025-2026)
LGP2 (J. Bras; N. Belgacem)

High yield grafted nanocellulose via use of mechanochemistry and natural deep eutectic solvents (DES)

Production à haut rendement de nanocellulose greffée via mécanochimie
et utilisation de solvants eutectiques profonds naturels (DES)

MatBio

Thèse confidentielle

Context

Conventional CNC production

- acid hydrolysis of amorphous cellulose →complex washing and isolation steps, which limit scalability and generate environmental concerns

Greener and more energy-efficient process

- goal of extracting CNCs → a few steps, obtaining a high yield and using an energy-efficient process

strong acid
batch process
high energy
large amount of water

new approach from cellulose fibers:
extract nanocellulose
+ modify it in one-step

Funded by: Pôle universitaire d'innovation Grenoble Alpes; Grenoble INP UGA

Objectives

Confirm the promising results obtained at laboratory scale through pilot and semi-industrial trials

Optimize yield and processing parameters for two types of nanocellulose (CNC and CNF)

Demonstrate the technical and economic feasibility of the patented process at larger scale

Develop demonstrators and prototypes to attract industrial and financial partners

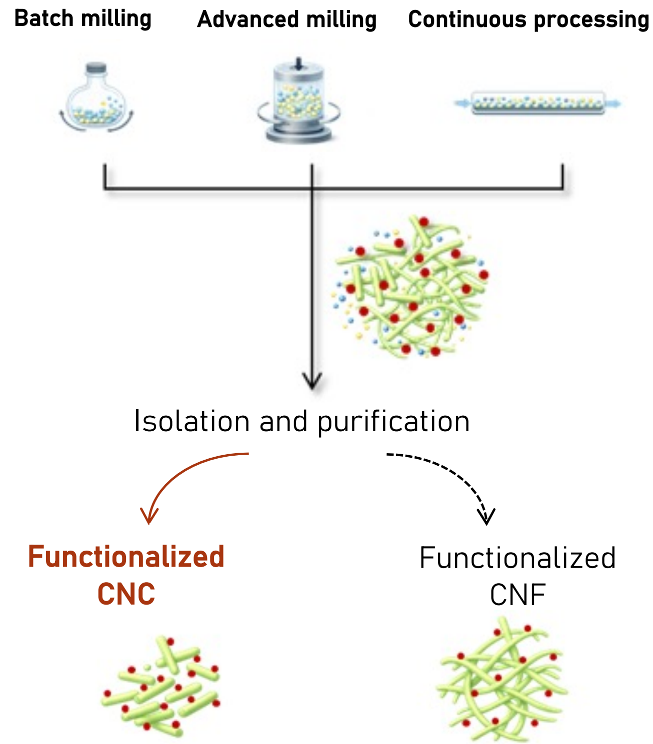
Prepare the groundwork for technology transfer and start-up creation in the regional innovation ecosystem

Lab-scale innovation ⇒ Start up creation

New company creation

Methods

NADES-assisted mechanochemical scale-up



Emma PIGNERES
Post-doc (2025-2026)
LGP2 (J. Bras; N. Belgacem; C. Sillard)

Innovative Packaging and edible coatings to guarantee post-harvest Durability of Mediterranean fruits and vegetables production

Emballages innovants et enrobages comestibles pour garantir la durabilité post-récolte de la production de fruits et légumes méditerranéens

MatBio

Context / Objectives

- **30-60% of fruits and vegetables are wasted** every year[1].
- European legislation is evolving towards **ban of single-use plastics**[2].
- **Edible coatings** are growing as plastic packaging alternatives to enhance fruits and vegetables quality[3].
- This research is part of PRIMA project **DurInnPack**, regrouping eight partners from the Mediterranean basin.

➔ **Objective : Better understand the adhesion and interface phenomena between polysaccharide-based edible coatings and fruits and vegetables.**

References

[1] FAO (2015). Global Initiative on Food Loss and Waste Reduction.

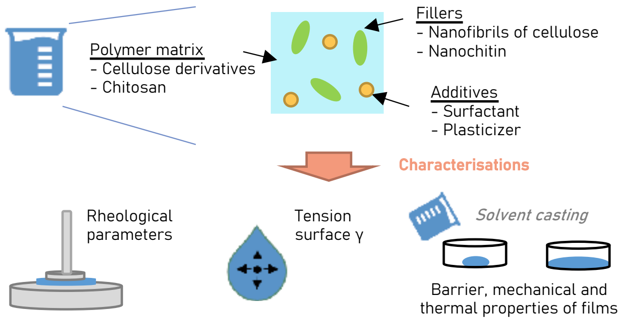
[2] Regulation (EU) 2025/40

[3] Martins, V. F. R. et al. (2024). Recent Highlights in Sustainable Bio-Based Edible Films and Coatings for Fruit and Vegetable Applications. Foods, 13(2). https://doi.org/10.3390/foods13020318

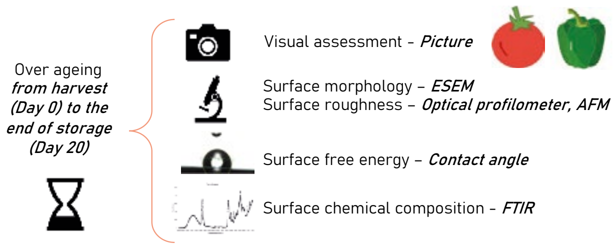
Funded by: anr agence nationale de la recherche – PRIMA

Methods

Coating formulation & characterization



Fruits surface characterization



Adhesion assessment

Results

Coating formulation & characterization

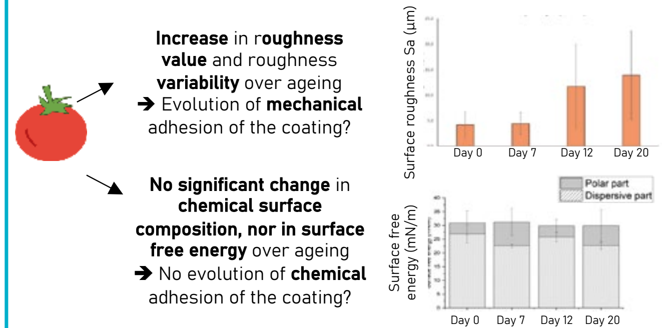
HPMC 1% w/w	TOCNF 1% w/w	HPMC/TOCNF (50:50) - 1% w/w
- Newtonian fluid	- Shear-thinning fluid ✓	- Shear-thinning fluid ✓
	- Thixotropic ✓	- Thixotropic ✓
- Low surface tension ✓	- High surface tension	- Low surface tension ✓

HPMC: Hydroxypropyl methylcellulose
TOCNF: TEMPO-oxidized cellulose nanofibrils

Fruits surface characterization

Increase in **roughness value** and roughness **variability** over ageing
➔ Evolution of **mechanical** adhesion of the coating?

No significant change in **chemical surface composition, nor in surface free energy** over ageing
➔ No evolution of **chemical** adhesion of the coating?



Adhesion assessment

Contact angle

Contact angle **tends to be lower when HPMC is present**, with **low evolution** of the contact angle **over fruit ageing**.

Candice REY
Research Engineer (2023-2030)
Cellulose Valley Chair
LGP2

Cellulose Valley Co-directress: innovation for cellulose-based high performance packaging with sustainable end-of-life

Co-directrice Cellulose Valley : emballages innovants en cellulose, performants et durables.

MatBio

Context / Objectives

A story of Single-use plastics regulations to limit global warming:

- 2018: SUP (Single Use Plastics) directive for European countries.
- 2024: PPWR (Packaging and Packaging Waste Regulation) for European countries.

Need for sustainable packaging solutions:

- Cellulose is a 1st choice candidate to design bio-based packaging.
- Biodegradable, recyclable in paper/carboard stream, naturally present on earth.
- **Need improvement to meet packaging and PPWR requirements**

Cellulose Valley chair: Innovation to serve society expectations for packaging applications.

Methods

5 years project (2026-2030)

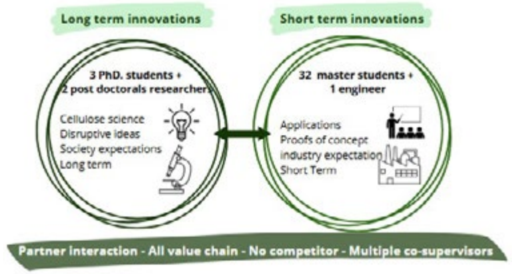
1,8 million euros, industrial sponsorship

Long-Term innovations team:

- **3-5 PhD students.**
- **2 study engineers.**

Short-term innovation team:

- **40 Proofs of concept to design bio-based packaging, resistant, biodegradable and recyclable.**



Scientific communications:

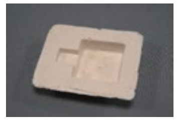
- Webinaire (CELLIENCE), 500 suscriptions.
- Disseminations in special events and congresses (Tech&Fest, Pint of Science)
- International Conferences

Results

Mid-term Chair report:

- Discover and understand all our applications and concerns in our mid-term report.

- Since 2022: 40 innovative bio-based packagings development.


Erwan TROUSSEL
Post Doctoral (2026)
LGP2 (Davide Beneventi)
LS2N (Elodie Paquet)
Co-de-iT (Andrea Graziano)

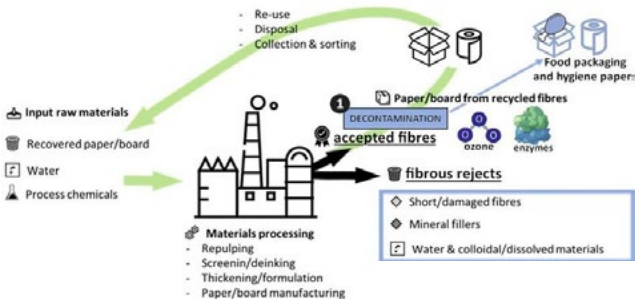
DEFI2R – Formulation of cellulosic paste composed of rejects from paper mills for LDM printing

Formulation de pâte cellulosique à base de fibres recyclées pour des applications d'impression 3D (LDM)

FunPrint

Context

Recycling of 5 millions tons of paper and cardboard annually:



7% of the recycle elements are rejected with the presence of short fiber, mineral fillers and various additives.

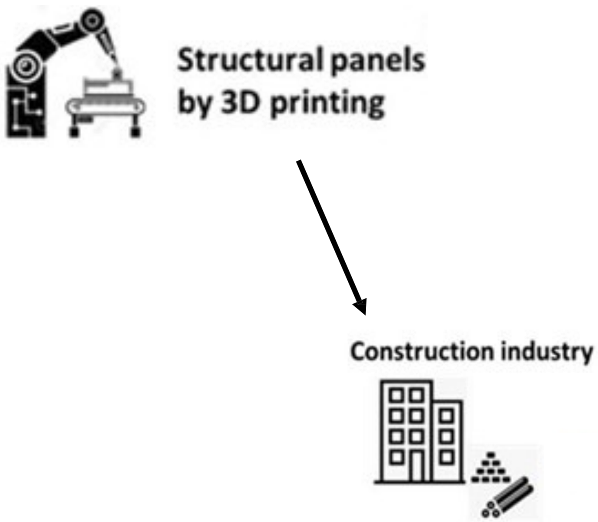
The objective is to find innovative valorisation routes for underutilised by-products like screening rejects.

Funded by:
anr agence nationale de la recherche
FRANCE 2030 PROGRAMME DE RECHERCHE RECYCLAGE
RECYCLAGE RECYCLABILITE RÉUTILISATION MATIÈRE PEPR

Objectives

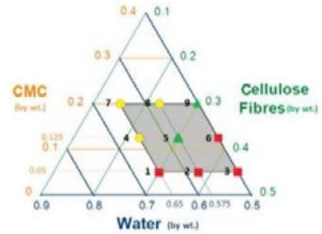
Sludges rejects from paper mills valorization:

Development of novel 3D-printable materials by cold extrusion (LDM) for structural applications in construction and furniture manufacturing



Methods

Formulation of model formulation with recycled fiber and cellulosic additives



Printing characterization with 6-axis Staübli robot

Process upscaling for board panel manufacturing

[1] C. Thibaut, et al., Carbohydrate polymer, 2019

Laboratoire de Génie des Procédés pour la Bioraffinerie, les Matériaux Bio-sourcés et l'Impression Fonctionnelle

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