WOOD
KPLUS

Bacterial Cellulose Emerging as Novel Material for Advanced Applications

Michael Egermeier, Christoph Unterweger, Tom Distler
BNN Annual Forum, 07.10.2025

Competence center
for wood chemistry
and renewable resources

Research volume 2024: € 12,5 M

appr. **130**

PEOPLE

24

YEARS IN BUSINESS

Founded based on a joint research program in 2001

>100

PARTNER COMPANIES on

3

CONTINENTS

North America, Europe, Asia

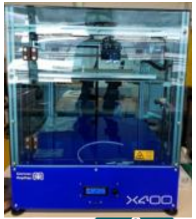
European leading research organization with a broad range of expertise & excellence

Materials research and process technology **along the entire value chain**

Basics and applied research projects at the economy-science interface

Strong **customer & partner relationships** with academic and industrial partners

Acquisition of national and EU funding to minimize partner risks of innovative research

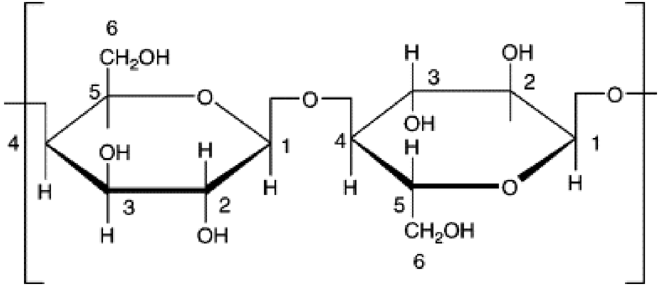


What is Bacterial Nanocellulose?

- Biopolymer of β-1,4-D-glucose units

  → chemically identical to plant cellulose

- Produced in nature by bacteria on fruits, juices: "mother of vinegar"
- Serves: protection against UV and drying out, oxygen supply (BC floats)
- Free of lignin and hemicellulose → very pure
- Advantages: biocompatible, non-toxic, water-rich, sustainable



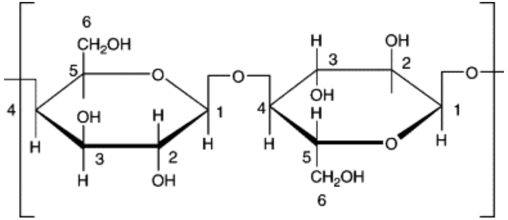
Source: Naomi et al., International Journal of Environmental Research and Public Health; 2020

Properties of Bacterial Cellulose

Nanostructure: highly porous, very large surface area

Mechanical strength: high tensile modulus, humidity-dependent

Crystallinity: >60 %, cellulose I structure



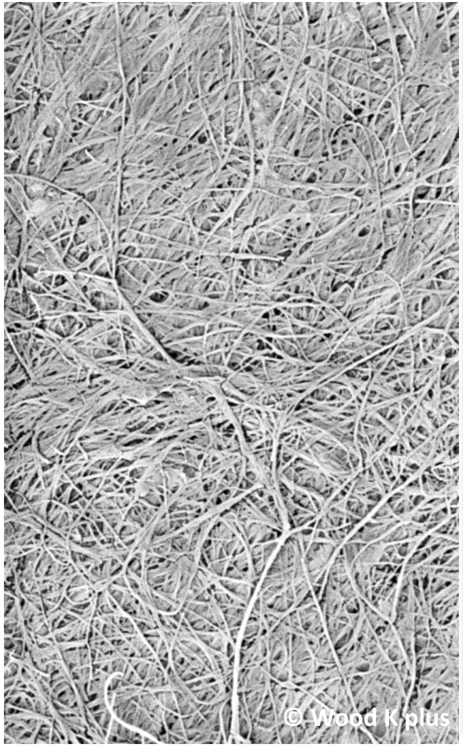
Hydrogel behavior: excellent water retention

Biocompatibility: non-toxic, degradable, cell-friendly

Chemical flexibility: easily modifiable (esterification, TEMPO, composites)

Source: Naomi et al., International Journal of Environmental Research and Public Health (2020)

Why use bacterial cellulose?



Property	Bacterial Cellulose (BC)	Plant Cellulose (PC)
Purity	~99% (no lignin or hemicellulose)	80–90% (contains lignin, hemicellulose)
Fiber diameter	20–100 **nm**	1–100 **µm**
Crystallinity index	60–90%	40–70%
Degree of polymerization	2000–6000	1000–15000
Tensile strength	Up to 250 Mpa	~50–150 MPa
Cost	High	Low
Biocompatibility	Naturally biocompatible	After the removal of contaminants
Water retention	Up to 100× water retention of PC	Lower water holding capacity than BC

Source: Naomi et al., International Journal of Environmental Research and Public Health (2020)

Bacterial cellulose history

- **1886**: A. J. Brown discovers cellulose production by acetic acid bacteria
- **1949**: First production of Nata de coco 1949 by *Teódula Kalaw*
- **1954**: Hestrin & Schramm establish standard growth medium
- **1970s**: structural studies, first industrial uses
- **1990s**: boom in medical & cosmetic applications
- **2010s**: Modification/functionalization; startups are emerging

Source: Brown, Journal of the Chemical Society (1886); Hestrin, The Biochemical Journal (1954); Moradi et al., International Journal of Biological Macromolecules (2021)

Functionalized Bacterial Cellulose

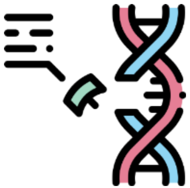
How is BC functionalized?

- **Chemical modification** (TEMPO oxidation, acetylation)
  → introduces carboxyl/acetyl groups
  → improves **hydrophilicity, reactivity**

- **In-situ composites** (nanoparticles, graphene, metal ions)
  → nanoparticles incorporated during biosynthesis
  → **antimicrobial, conductive, bioactive**

- **Enzymatic** (proteins, peptides, enzymes)
  → surface functionalization with biomolecules
  → **biocompatibility, bioactivity**

- **Genetic engineering** (of *Komagataeibacter spp.*)
  → engineered bacteria produce BC with fused proteins
  → **smart materials**



Source: Kaczmarek et al. Journal of Nanobiotechnology (2025); Malci et al., ACS Synthetic Biology (2024). Icons from flaticon.com

Icons: flaticon.com

Global Players & BNC Production

BIOWEG (Germany)

- Pilot plant in Quakenbrück, capacity up to **6 t/year** (AgroPages, 2023).

CELLUGY (Denmark)

- Pilot plant several **t/y** in Søborg (4.9m€ investment, 2024).
  -> Applications: cosmetics, microplastic replacements.

Polybion (Spain)

- Producer of Celium™
- Applications: fashion, footwear, sportswear, and automotive applications
- Production of 3500 sqm cellulose/year

Global Estimate

- Total global BNC output (2023): **~2,800 t/year** (high-value applications).

Asia – Nata de coco (food-grade BNC) as sweet dessert

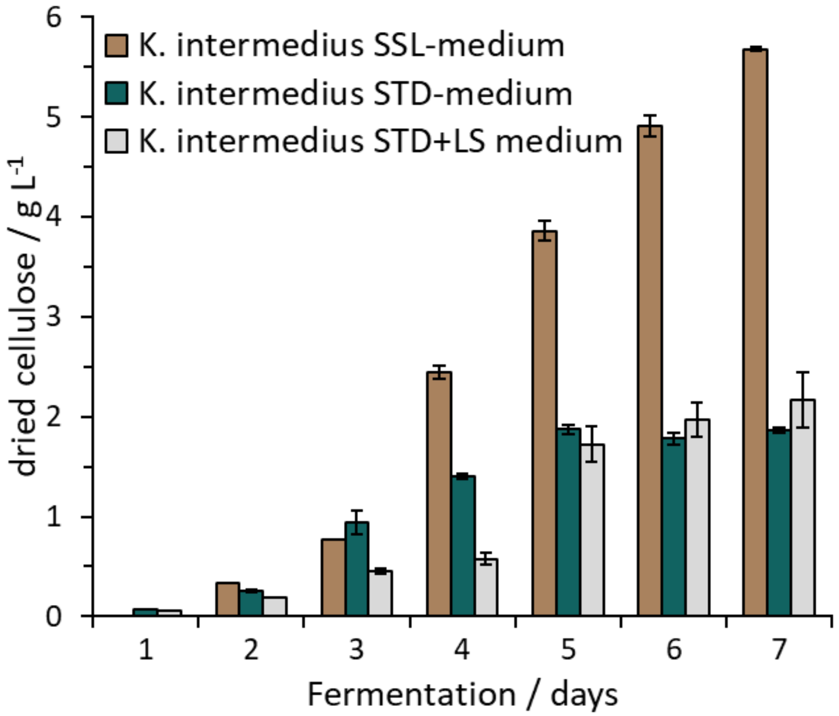
- Nata de coco industry in Vietnam, Thailand, and Indonesia
- **~15,000 t/year** raw nata de coco

https://www.cellugy.com/our-offerings/ecoflexy-color

https://coconutvietnam.com.vn/news/nata-de-coco/475.html

Source: bioweg.com (2025); polybion.bio (2025); marketgrowthreports.com-Report ID: 112720 (2025); Phisalaphong et al., Bacterial Nanocellulose (2016).

Cellulose production on spent sulfit liqour media



- Highest yield on sulfite media

STD-Medium	STD+LS Medium	SSL-Medium
1.86 g L^{-1}	2.17 g L^{-1}	5.68 g L^{-1}

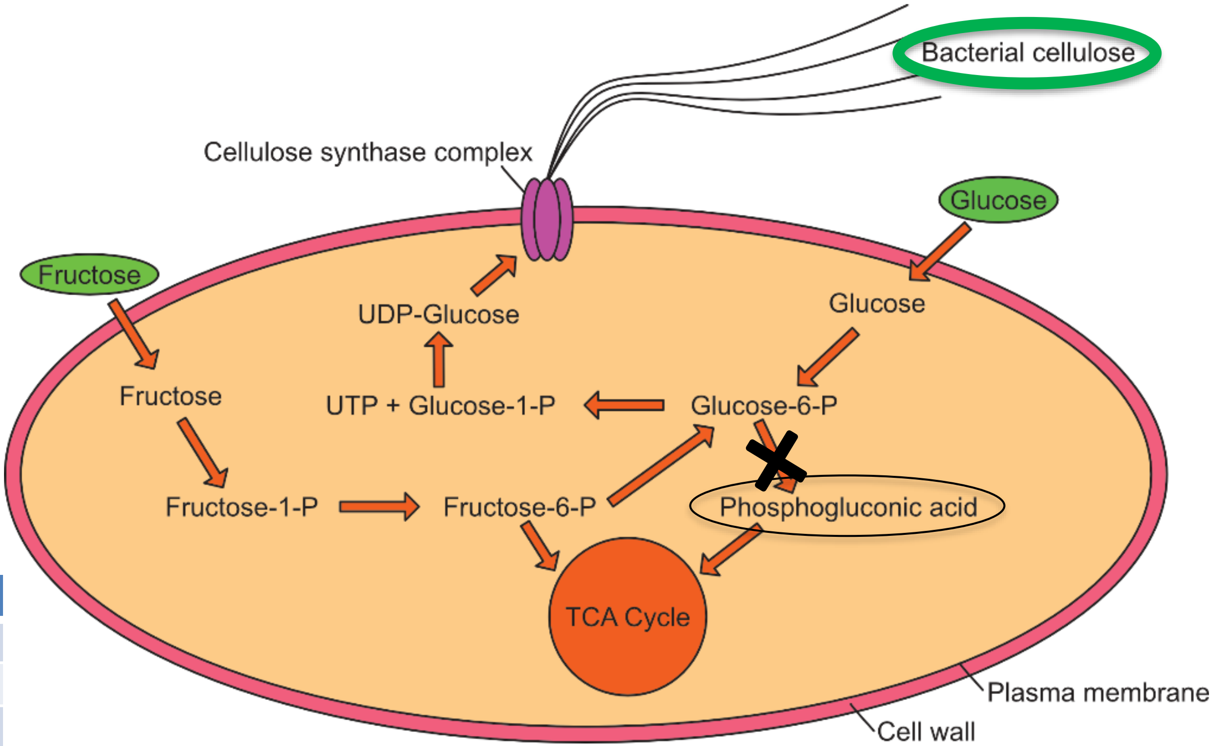
- Why does the sulfite media boost cellulose production?

Source: Distler et al., Bioresource Technology Reports, (2023). Keshk et al., Enzyme and Microbial Technology (2006). Tyagi et al., Journal of Cleaner Production (2016).

Inhibition of gluconic acid pathway

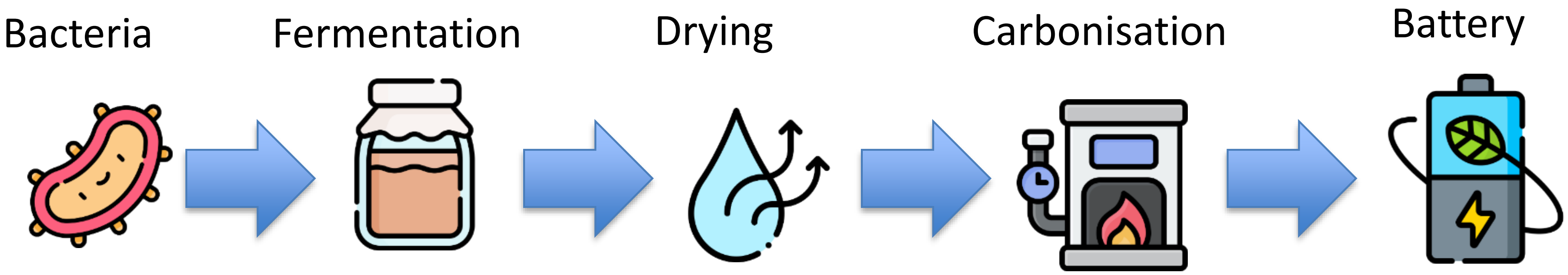
- Blocking gluconic acid pathway improves cellulose production
- Has already been postulated in other papers
- No inhibition when pure Lignosulfonates were added

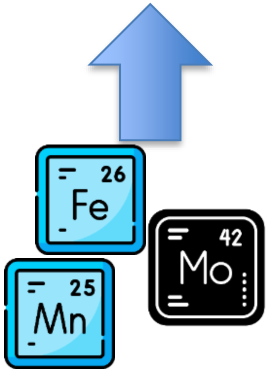
	Δ pH	gluconic acid [g/L]
STD-Medium	1.25	1.28
STD+LS Medium	1.51	1.69
SSL-Medium	0.48	0.01



Source: Distler et al., Bioresource Technology Reports, (2023).

From bacteria to battery





- Growth medium contains Mn, Mo etc.
- Metal ions accumulate in cellulose
- No extraction steps necessary

Icons: flaticon.com and Biorender

From bacteria to battery

- In situ Addition of metal salts to fermentation media
- Metal ions incorporated directly into cellulose
- Direct carbonization of functionalized celluloses (no further treatment steps)

Goal

- Produce conductive carbon from bacterial cellulose
- Use in-situ functionalization for simplified synthesis
- Use functionalized cellulose as battery component

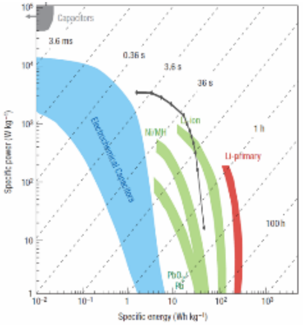
Bio-based Fibers & Carbon Materials

HT equipment

- Chamber furnaces (vacuum, Ar, N_2, air) (6 L, 2300 °C / 160 L, 900 °C)
- 3 tube furnace + fiber transport (5 zones, 300 °C / 5 zones, 1000 °C / 2 zones, 1600 °C)
- Rotary tube furnace (1100 °C, activation in CO_2 or steam)

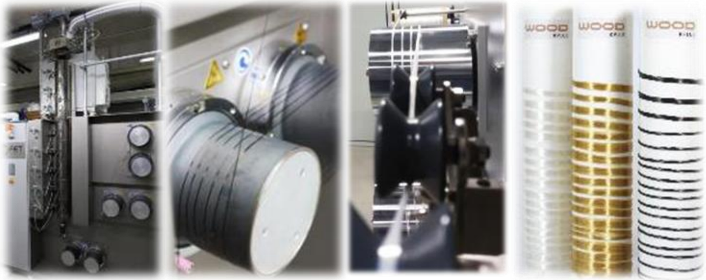
- Chemical labs incl. comprehensive material characterization & testing

Bio-based functional carbons / carbon fibers



- Activated carbon, hard carbon, conductive fillers etc.
- From cellulose, lignin, wood, cork, waste biomass
- Controllable pore size distributions – specific surface areas up to 3400 m²/g
- Tunable interlayer spacing and crystallite size by variation of precursor and temperature (max. 2300°C)
- Catalytic graphitization using Fe & Ca compounds
- Heteroatom doping & surface modification
- Electrodes for supercaps, Na-ion batteries, Li-S batteries, fuel cells etc.
- Filters for waste water or air treatment

Bio-based continuous carbon fibers



- From cellulose (commercial) or lignin filaments (melt spun at Wood K plus)
- Material development & process optimization
- Prepared CF successfully used in CFRP 3D printing

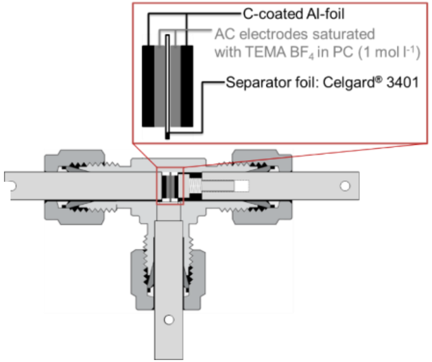
Bio-based SiC ceramics

- From wood, novolak + LDPE
- Extrusion, injection molding or 3D printing followed by carbonization and Si infiltration
- Tunable C content → conductivity

Preparation of Activated Carbon Fibers

Viscose fibers

8 mm



Precursor → Pre-treatment → Carboni-zation → Activation → Electrode preparation → Building of test cells

Precursor
- Washing
- Drying

Pre-treatment
- Treatment with DAHP solution (impregnation)
- Drying

Carboni-zation
- Under nitrogen atmosphere
- Variation of heating rate and temperature

Activation
- Variation of time, temperature, and gas flow
- Activation agents: CO_2, H_2O, KOH

Electrode preparation
- Grinding
- Kneading with PTFE & graphite (80/10/10)
- Rolling & punching out

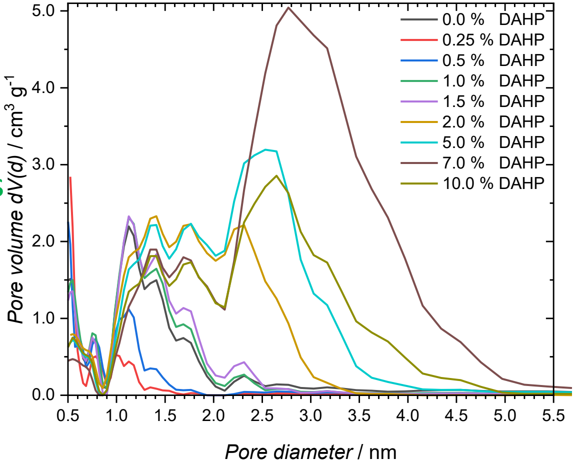
Building of test cells
- Under argon atmosphere

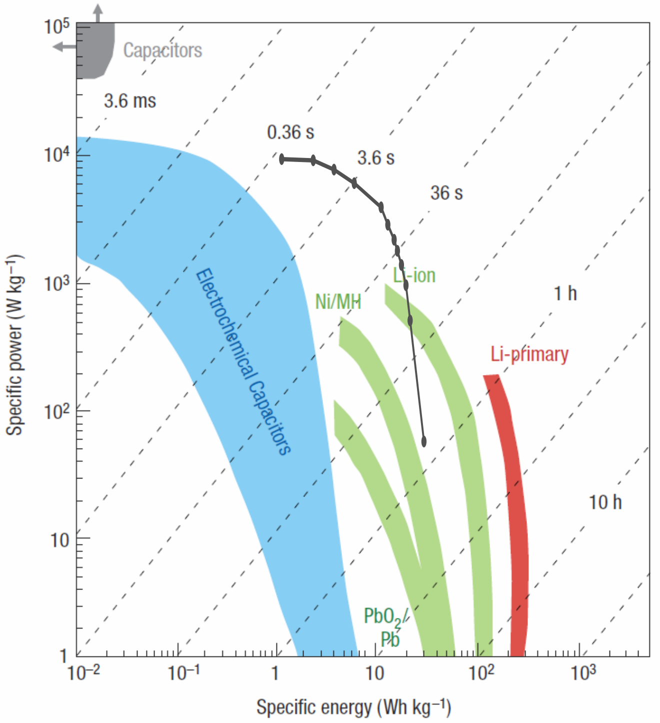
Previous Results – Motivation

- Activated carbon fibers with optimized **pore size distributions** can be prepared from cellulose fibers
- Supercapacitors with activated carbon **fiber** electrodes have **low internal resistance**
- Significant outperformance over commercial activated carbon

- Drawbacks
- - Pre-treatment needed
- - binder & conductive additive
- - grinding of fibers
- - just 80% „active“ material

- → doped cellulose nanofibers
- → self-standing electrodes

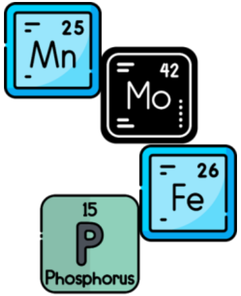


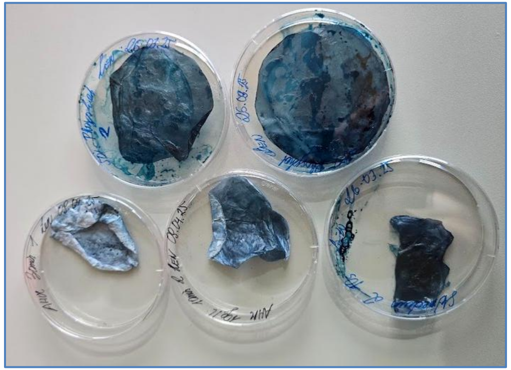


P. Simon, Y. Gogotsi, Materials for electrochemical capacitors, *Nature Materials* **7** (2008) 845–854.

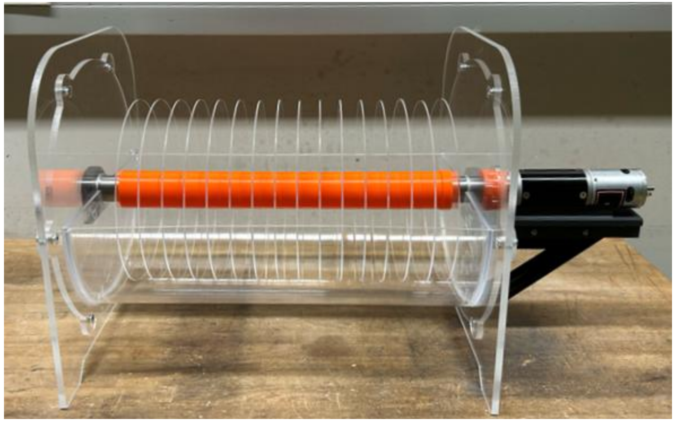
Functional carbons from bacterial cellulose

- Bacterial cellulose produced in rotating disc reactor (RDR). Scale-Up to 5-litre with 16 discs.
- Functionalization and carbonization of obtained cellulose layers for novel battery applications.

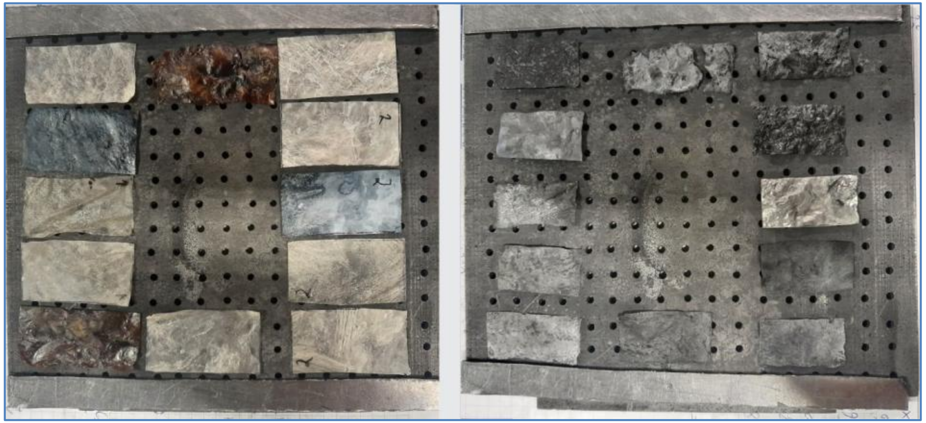




Functionalisation of bacterial cellulose using heteroatoms to increase conductivity.



5-L rotating disc reactor for bacterial cellulose production.



Functionalised bacterial cellulose before/after carbonisation procedure.

Visit us at JKU Science Park

Dr. Michael Egermeier
Bioprocess Technologies

Tel.: +43 (0)732 2468 6781
m.egermeier@wood-kplus.at

Dr. Christoph Unterweger
Biobased Fibers and Carbon Materials

Tel.: +43 (0)732 2468 6758
c.unterweger@wood-kplus.at

Kompetenzzentrum Holz GmbH
Altenberger Strasse 69
A-4040 Linz
www.wood-kplus.at

This presentation has been designed using images from Biorender and Flaticon.com

Kofinanziert von der Europäischen Union

Acknowledgement: *This work is part of the EFRE project IBW 2021-2027 Sus2C and funded by the European Union and the province of Upper Austria.*