Strategies for Next Generation Biomolecular Engineering with Nanopolysaccharides

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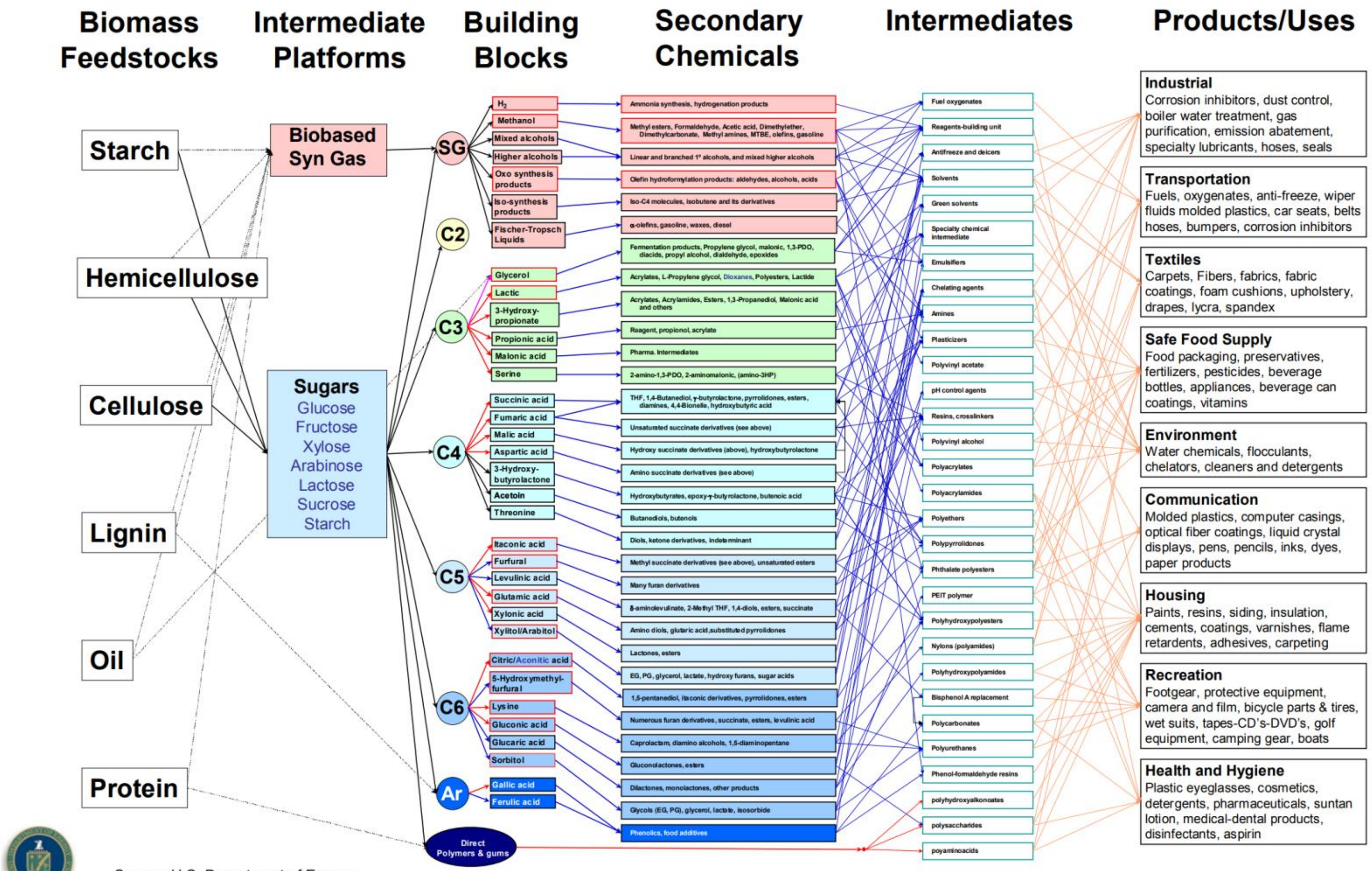
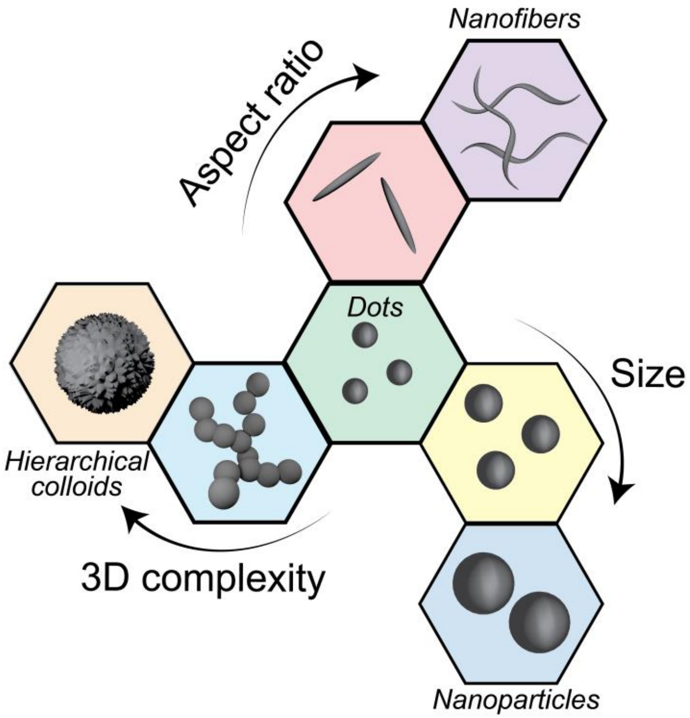
FinnCERES Materials Cluster

Natural Diversity: a challenge or an opportunity?

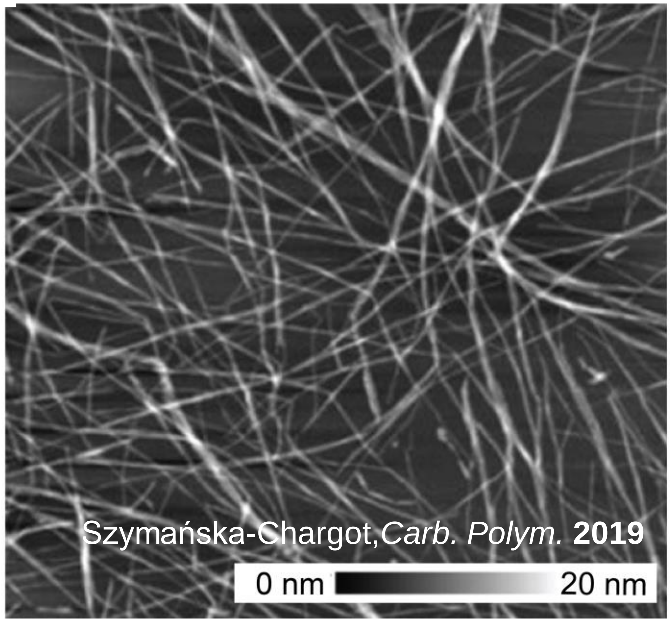


Source: U.S. Department of Energy.

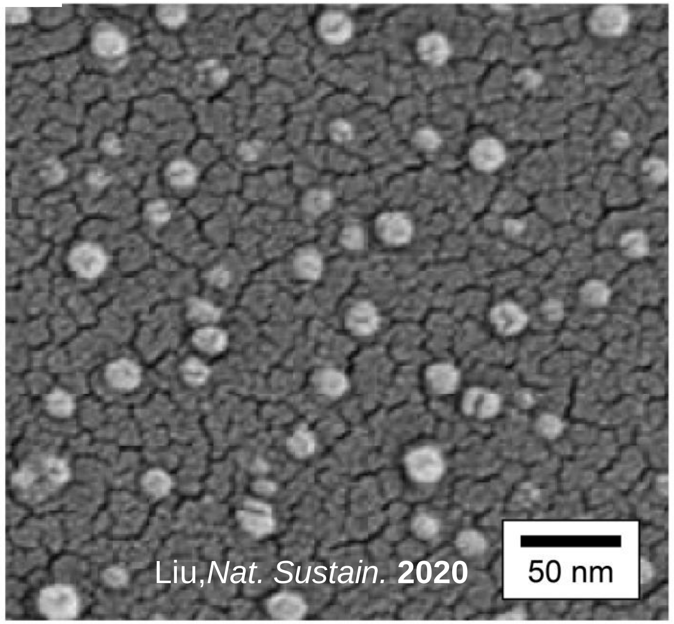
USDA (2008) "U.S. Biobased Products Market Potential and …2025."United States Department of Agriculture.OCE-2008-1.



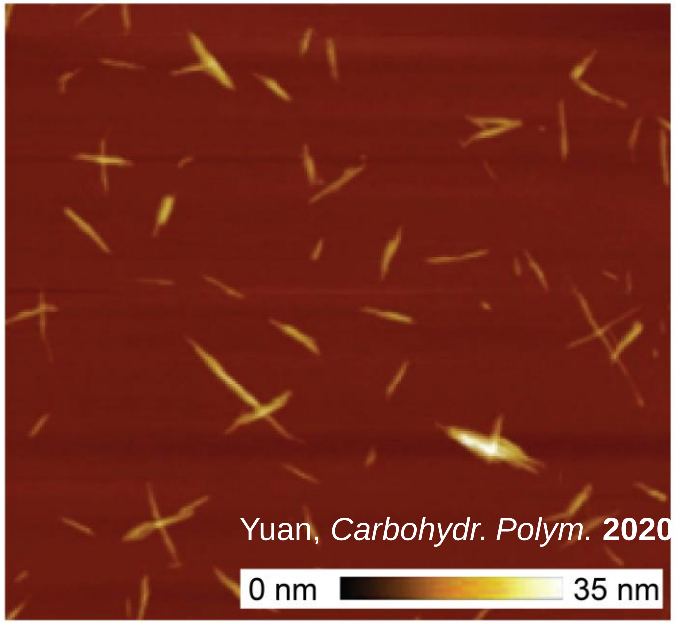
Cellulose nanofibrils: Apple pomace



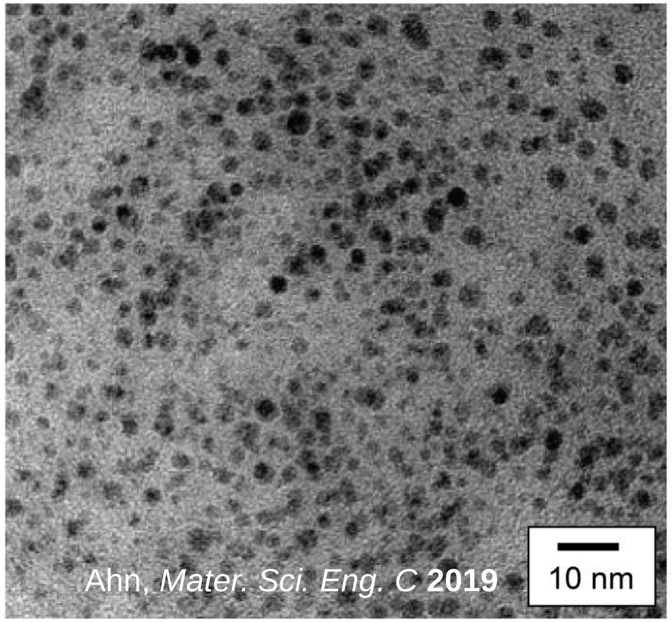
Cellulose nanospheres: Corncob



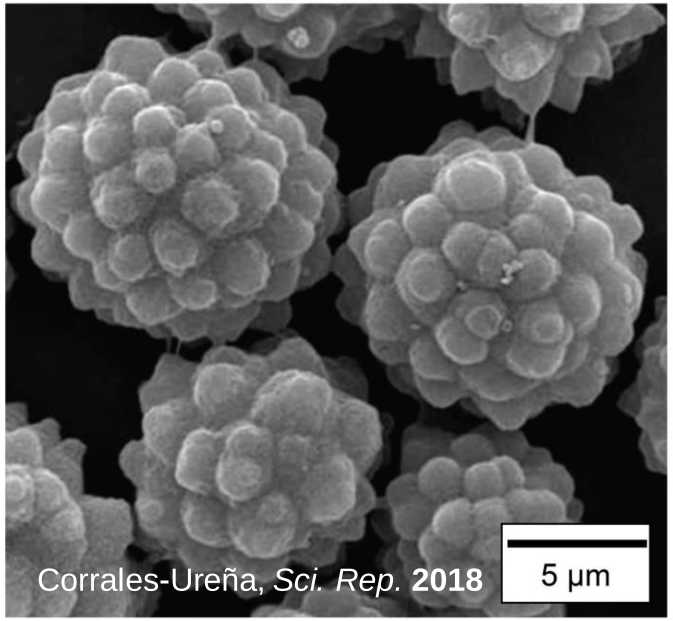
Chitin nanocrystals: crab shell



Carbon QDs: various sources



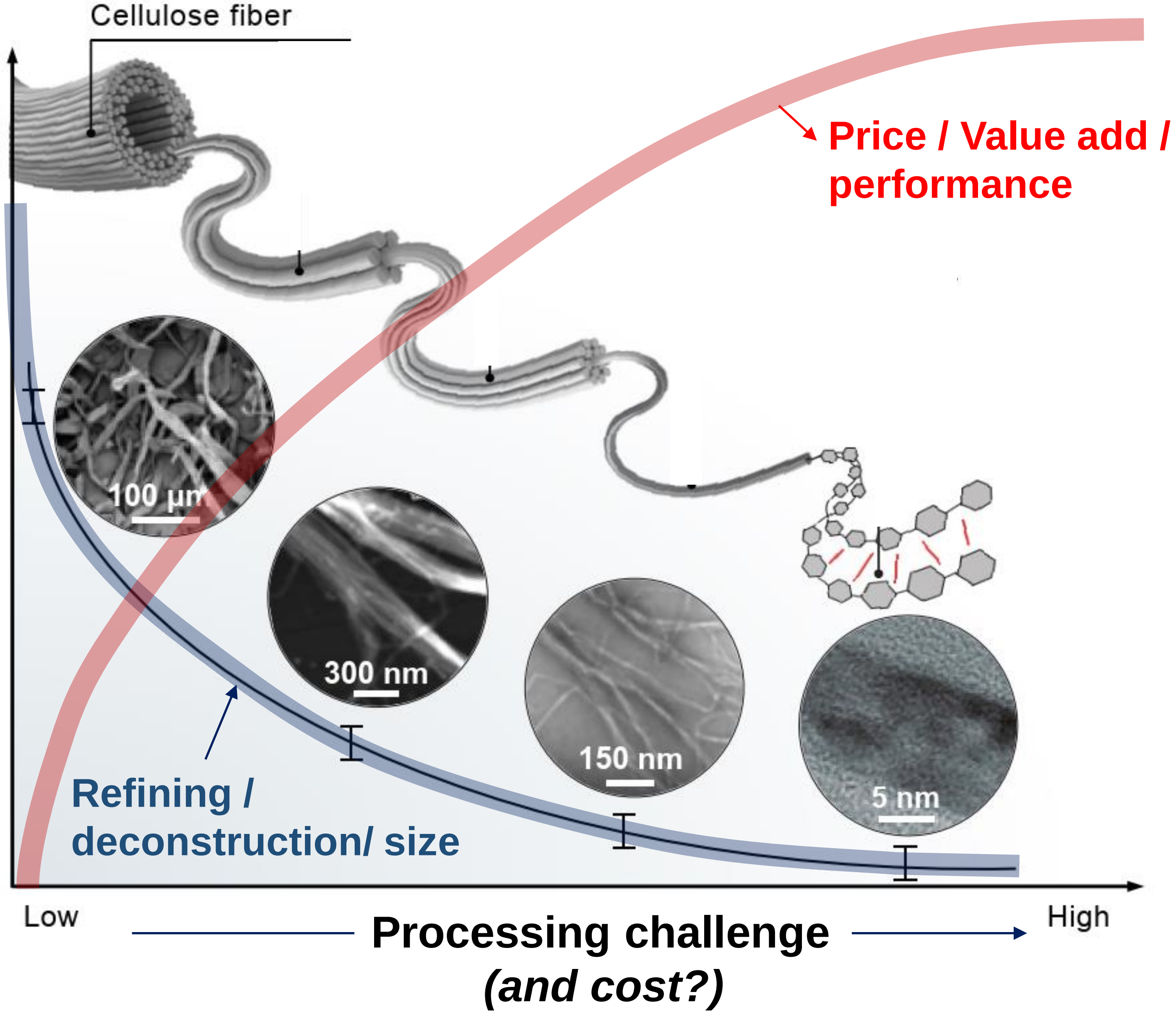
SiO_2: Pineapple peel



Otoni, Azeredo, Beaumont, Correa, Rojas, *The Food-Material Nexus: Agri-Food Residues as Precursors for Advanced Bioplastics*, **Advance Materials** (2021)

Hierarchal structure and manufacturing challenge

Nature 590, 47 (2021). DOI: 10.1038/s41586-020-03167-7

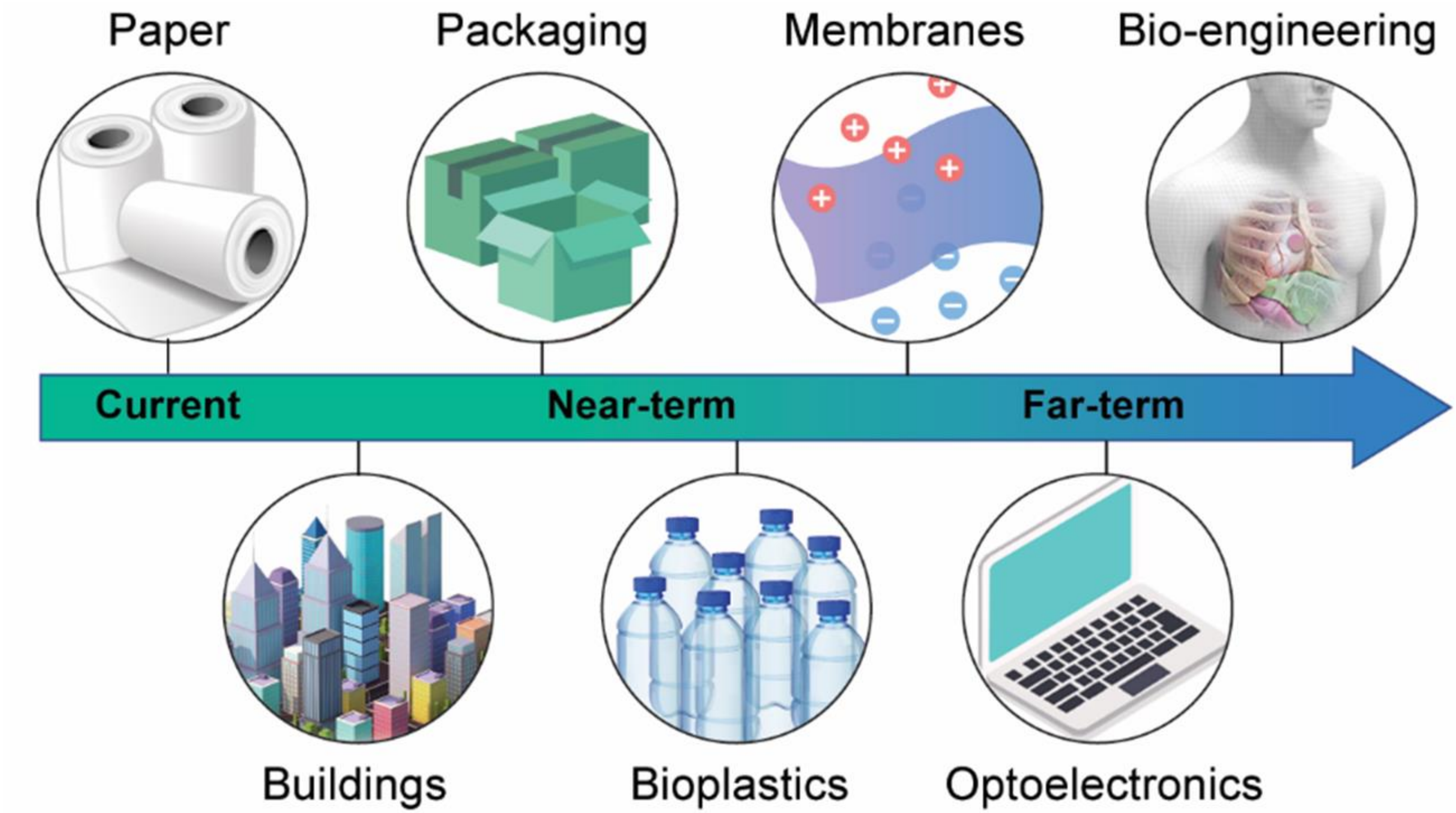


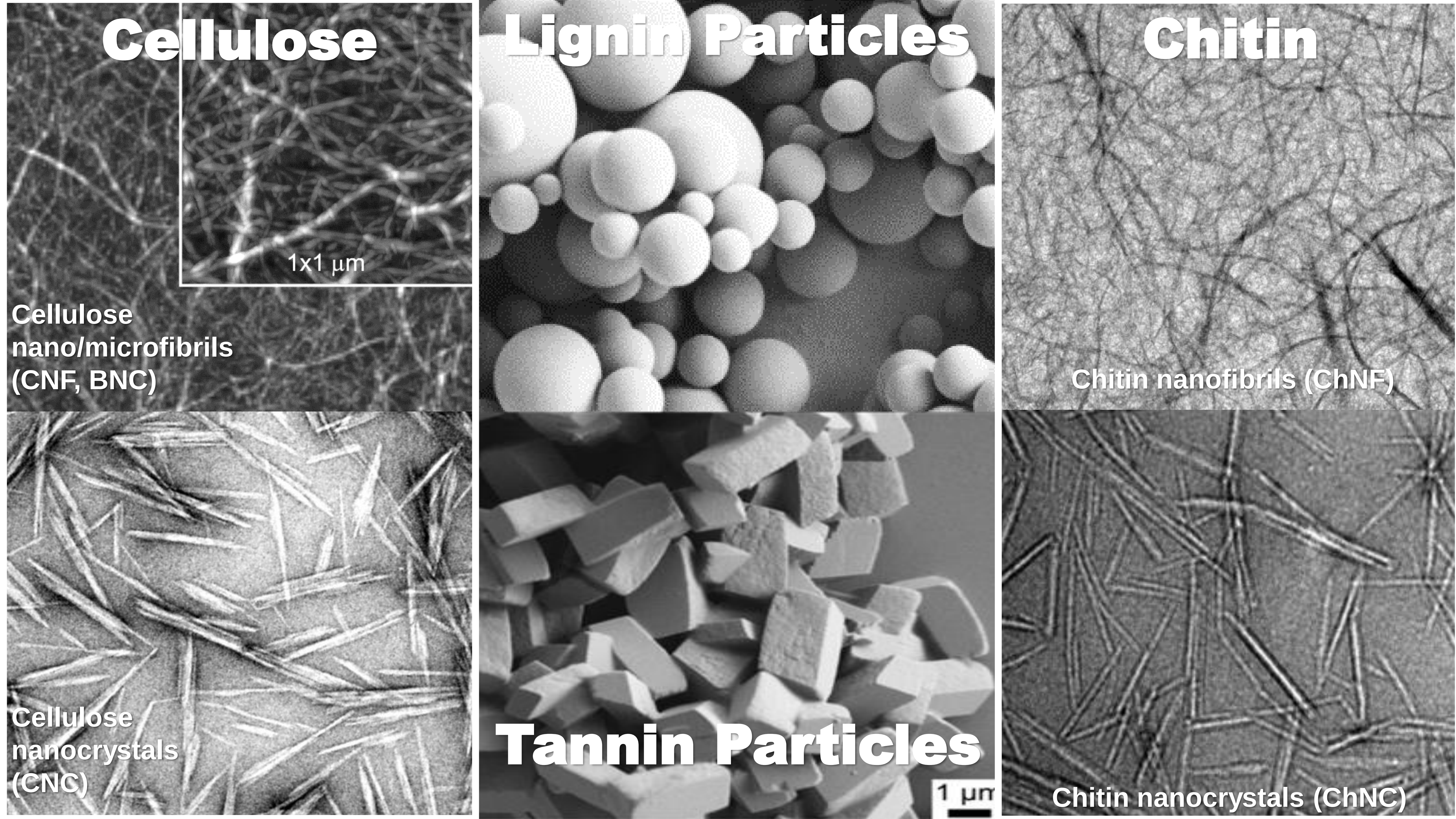
Key Enabling Technologies for the future Bioeconomy

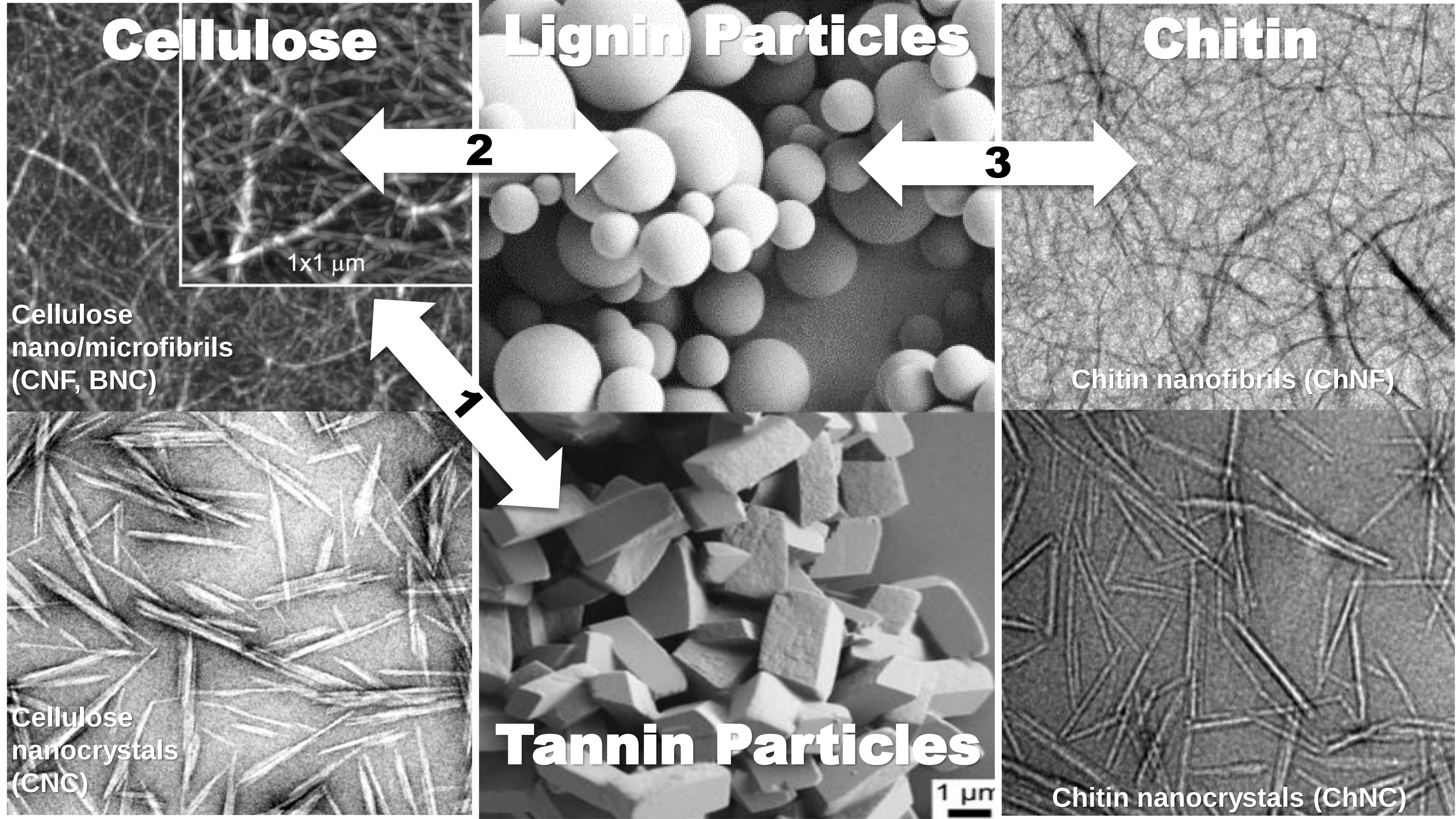
- Advanced Manufacturing Technologies
- Advanced Materials and Nanotechnology
- Life Sciences Technologies
- Micro-, Nano-electronics and Photonics
- Artificial Intelligence
- Digital Security and Connectivity

The prospects of fibrillar cellulose

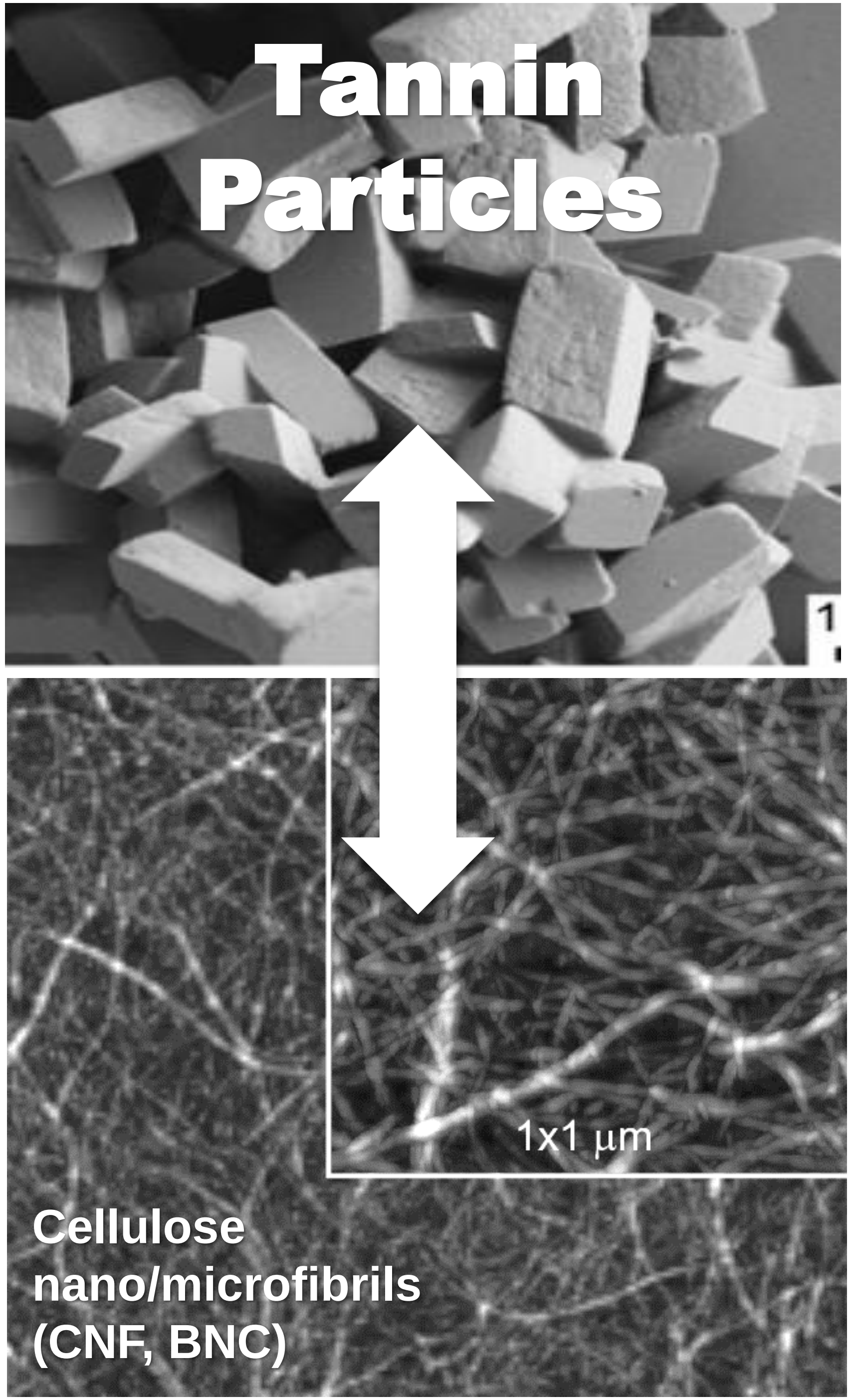
Nature 590, 47–56 (2021). DOI: 10.1038/s41586-020-03167-7




Cellulose
1x1 μm
Cellulose nano/microfibrils (CNF, BNC)
Cellulose nanocrystals (CNC)
Lignin Particles
Tannin Particles
1 μm
Chitin
Chitin nanofibrils (ChNF)
Chitin nanocrystals (ChNC)


Cellulose
Lignin Particles
Chitin
1x1 μm
2
3
Cellulose nano/microfibrils (CNF, BNC)
1
Chitin nanofibrils (ChNF)
Cellulose nanocrystals (CNC)
Tannin Particles
1 μm
Chitin nanocrystals (ChNC)

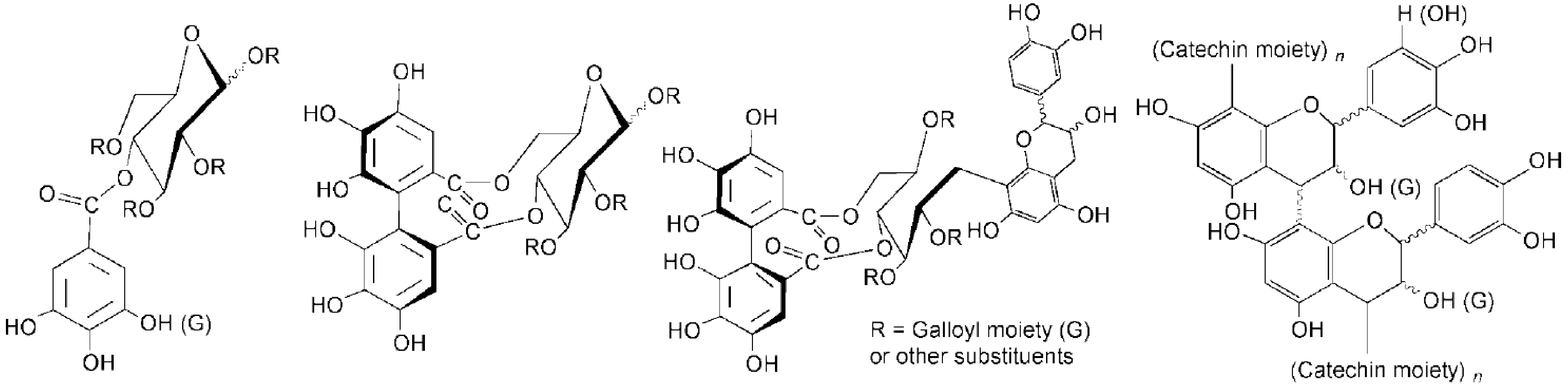

Tannins


Tannin Particles
1x1 µm
Cellulose nano/microfibrils (CNF, BNC)

Tannins

Hydrolyzable tannins

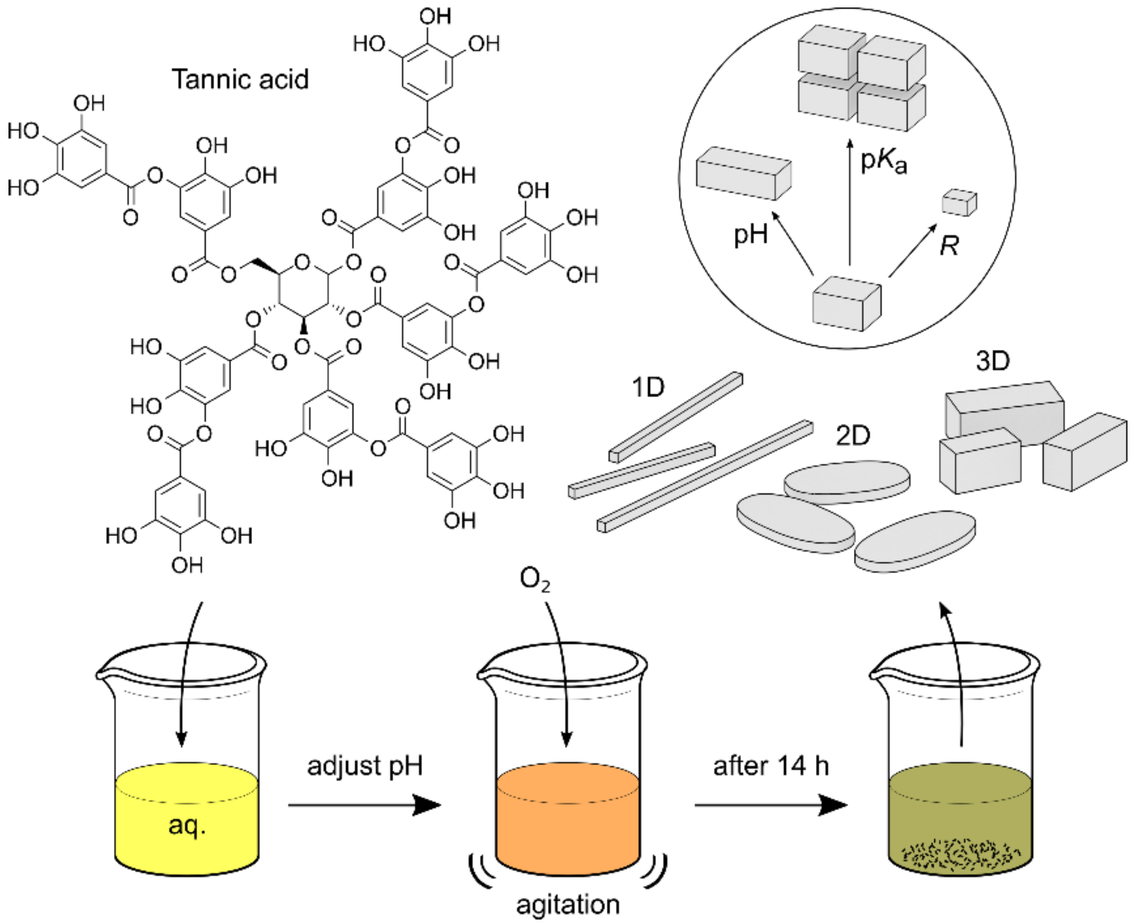
Gallotannins | Ellagitannins | Complex Tannins | Condensed Tannins

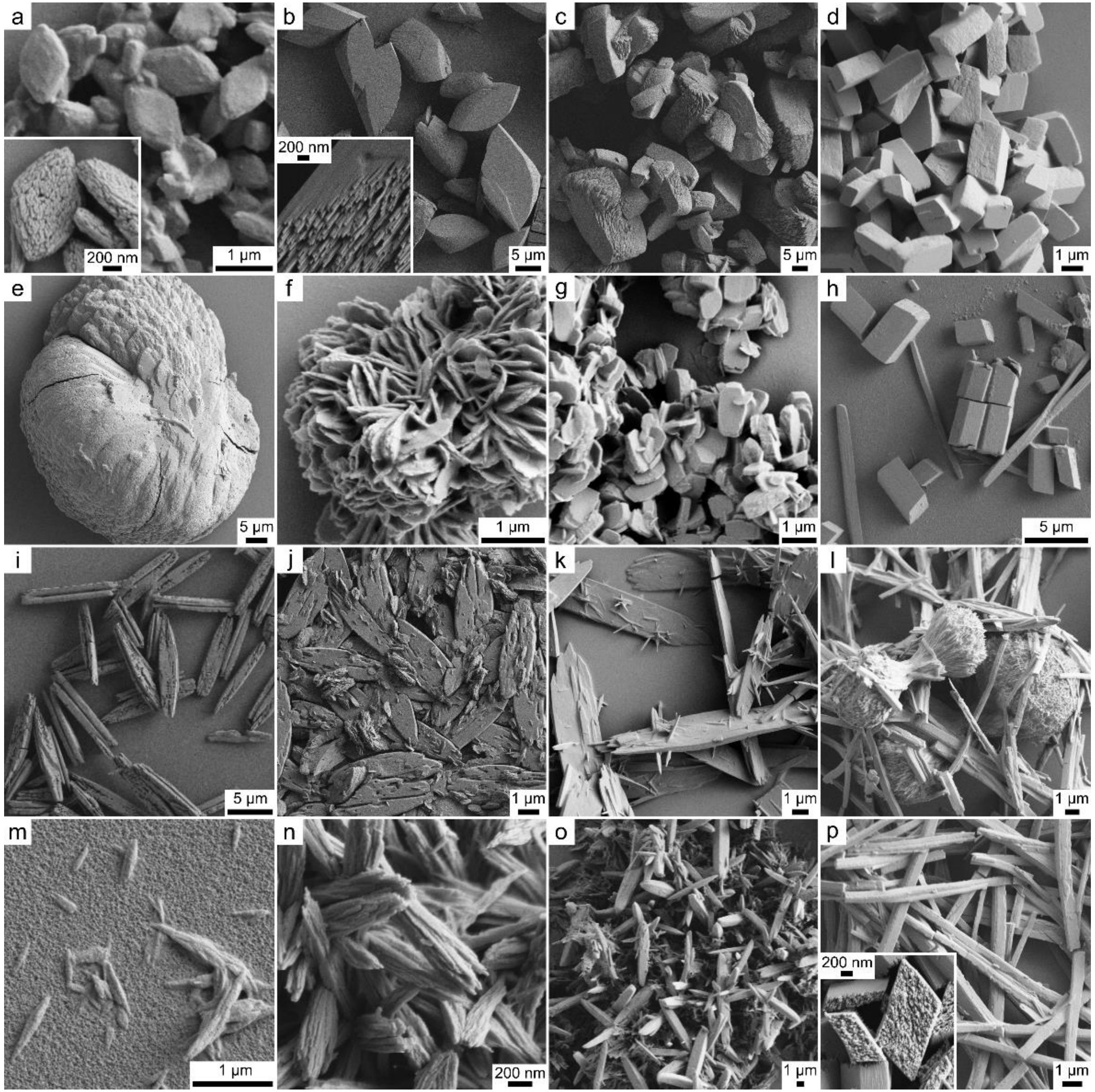


Anti-inflammatory Antimicrobial Antimutagenic Anticarcinogenic Antioxidative

Nat Prod Rep, 2001, **18**, 641–649.

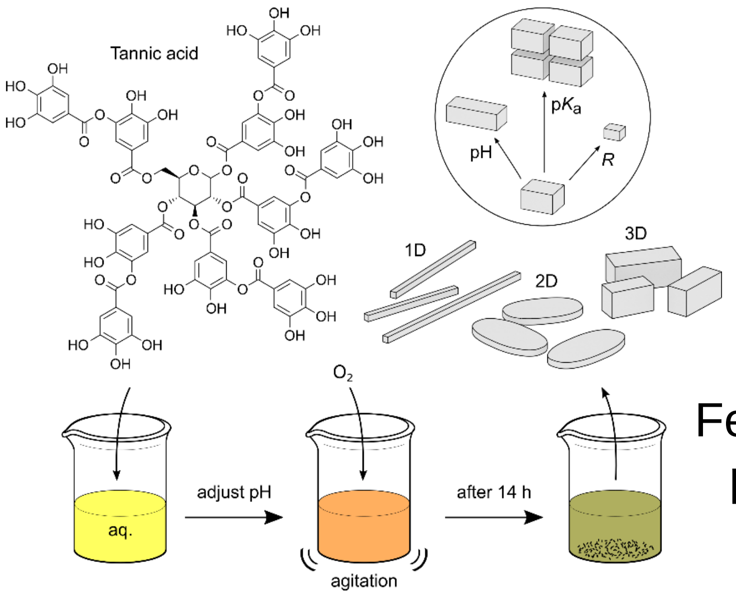
Self-assembly of tannic acid





Kämäräinen et al. Morphology-controlled synthesis of colloidal polyphenol particles from aqueous solutions of tannic acid, **ACS Sustainable Chemistry & Engineering**, DOI: 10.1021/acssuschemeng.9b02378

Typical renewable nanoparticles: Difficult to direct their assembly into macroscale materials

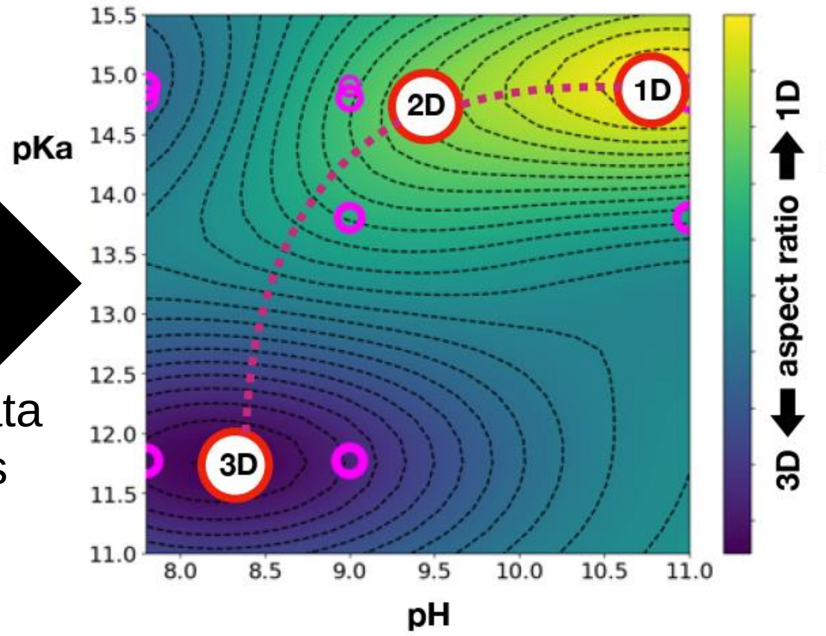


Growth conditions and shapes (1, 2, or 3D)

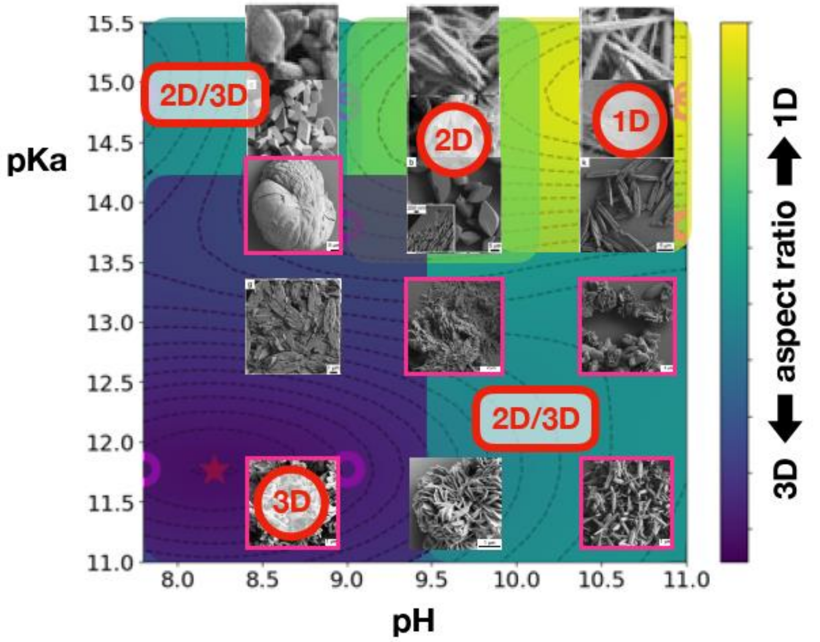
Few data points

Machine learning to predict assembly

(Bayesian Optimization for Structure Search, BOSS*)



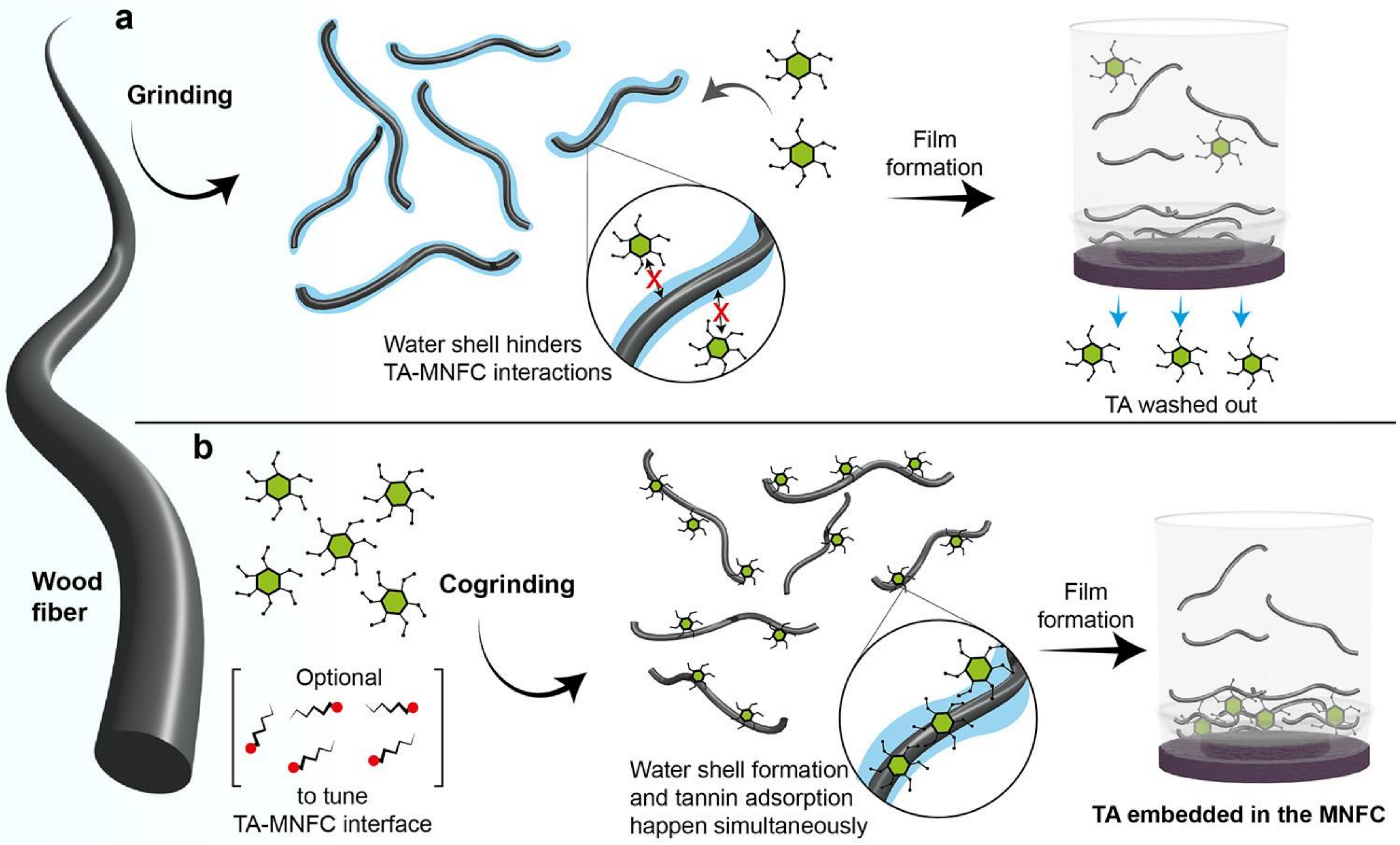
BOSS: visualize the dependence of nanoparticle shape on the growth conditions

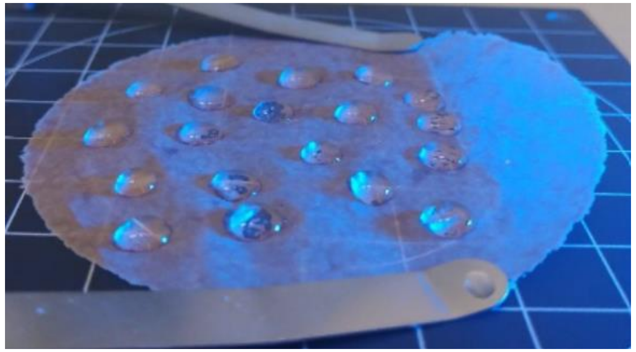


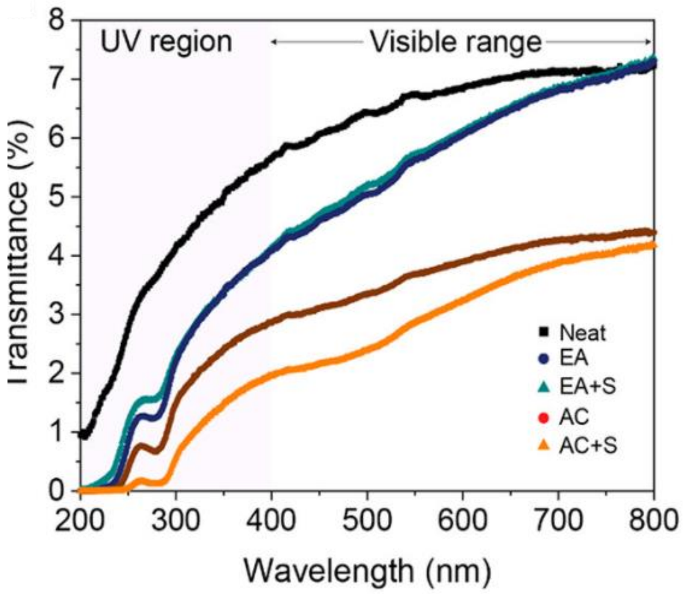
The experimentally determined shapes correlate with visual map

(*) Todorović, Gutmann, Corander Rinke, NPJ Comp. Mat. 5, 35 (2019)

Tannins: Fiber microfluidization into nanocellulose

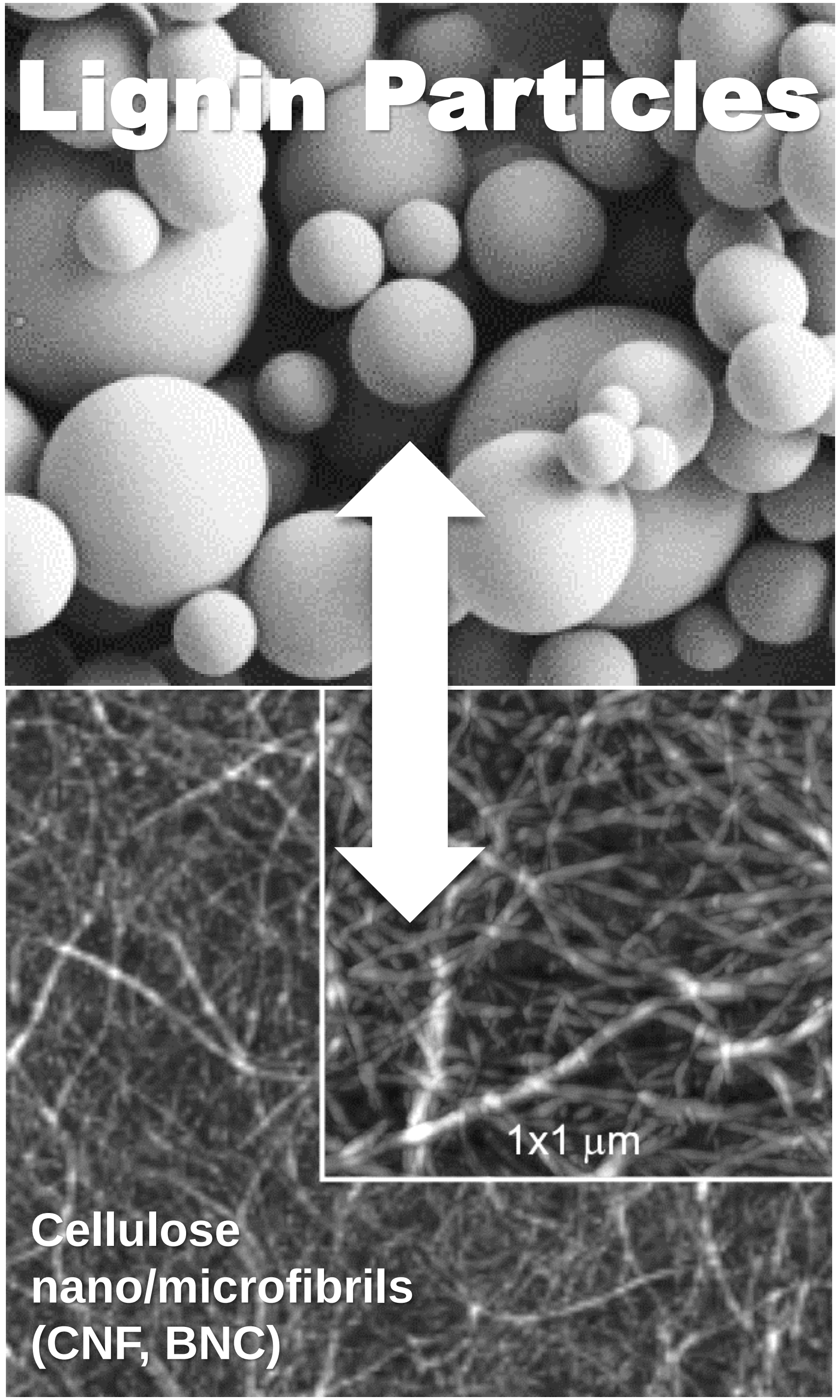






Missio, Mattos et al **Cogrinding Wood Fibers and Tannins: Surfactant Effects on the Interactions and Properties of Functional Films for Sustainable Packaging Materials,** *Biomacromolecules* 21, 5, 1865 (2020)


Lignin


Lignin Particles
1x1 μm
Cellulose
nano/microfibrils
(CNF, BNC)

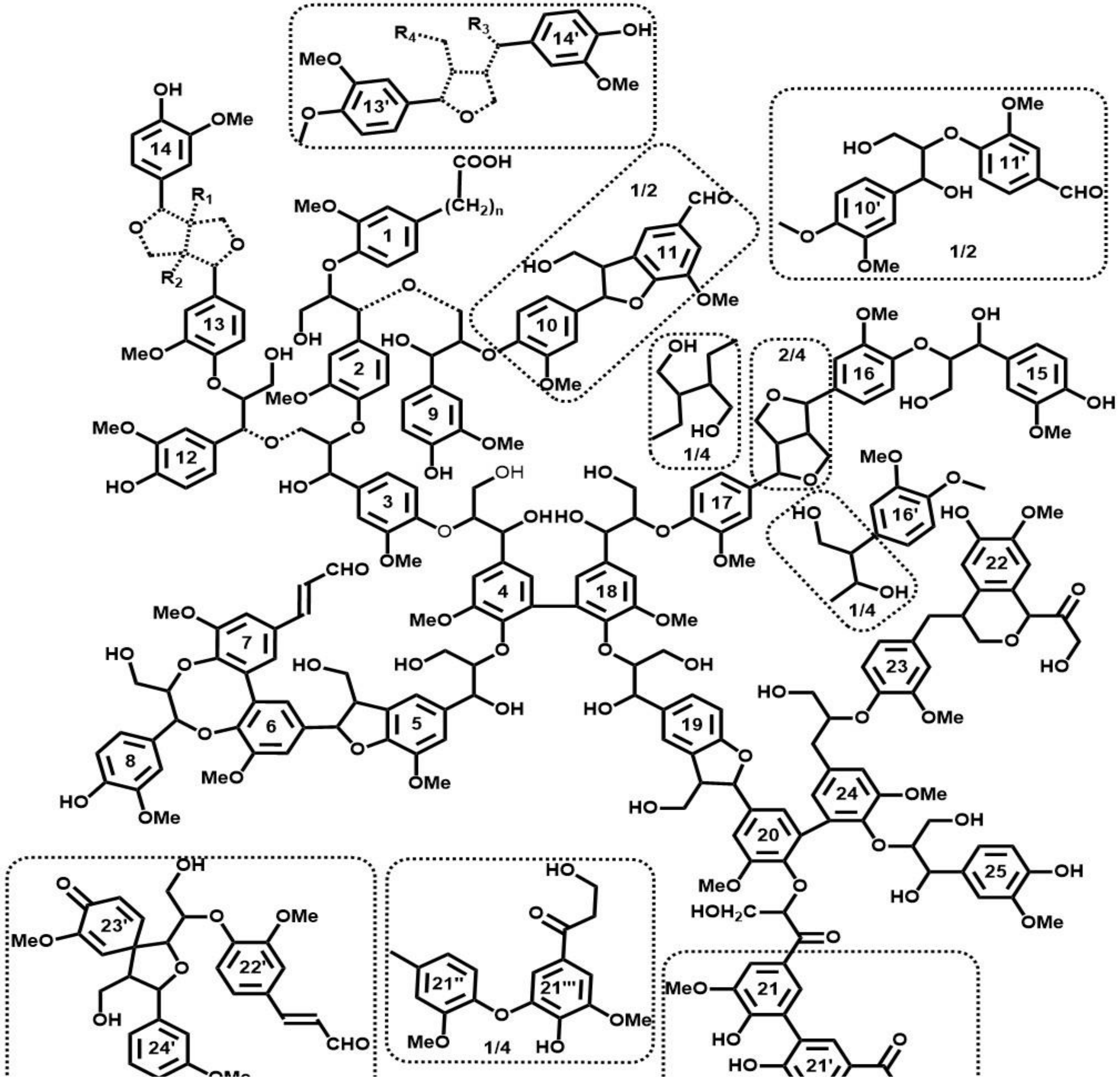
Lignin Nanoparticles (LP)

Kämäräinen et al., corrugation & colloidal interactions, JCIS 794 (2020)

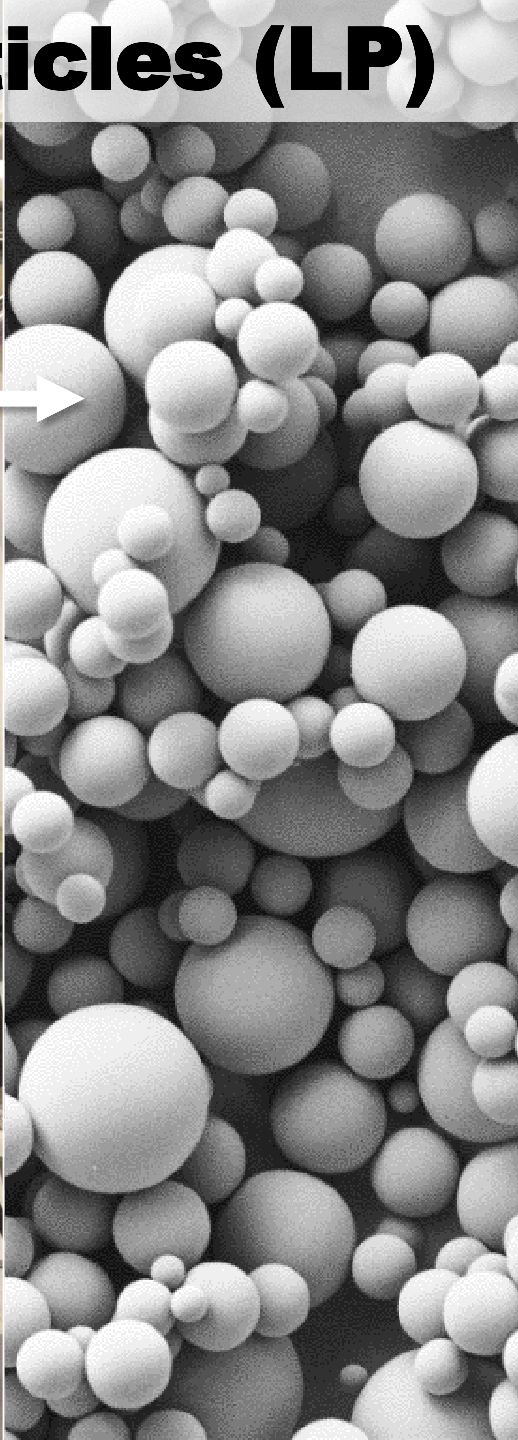
Balakshin et al, Lignin: Linear, Branched? **Green Chem**, 22, 3985 (2020)

Wang et al., Electroactive materials, **ACS Sustainable Chem & Eng**, 8549 (2020).

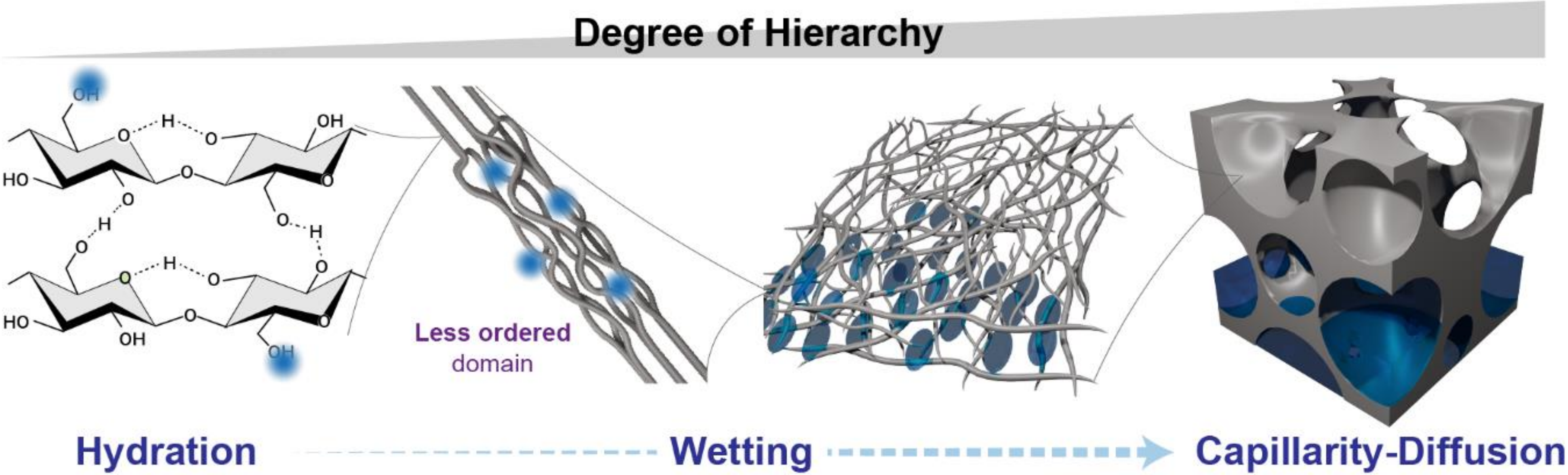
Lourençon et al., Biorefinery particles, **ACS Sustainable Chem & Eng**, 1230 (2020).



Balakshin, Green Chemistry (2020). DOI: [10.1039/D0GC00926A](10.1039/D0GC00926A)

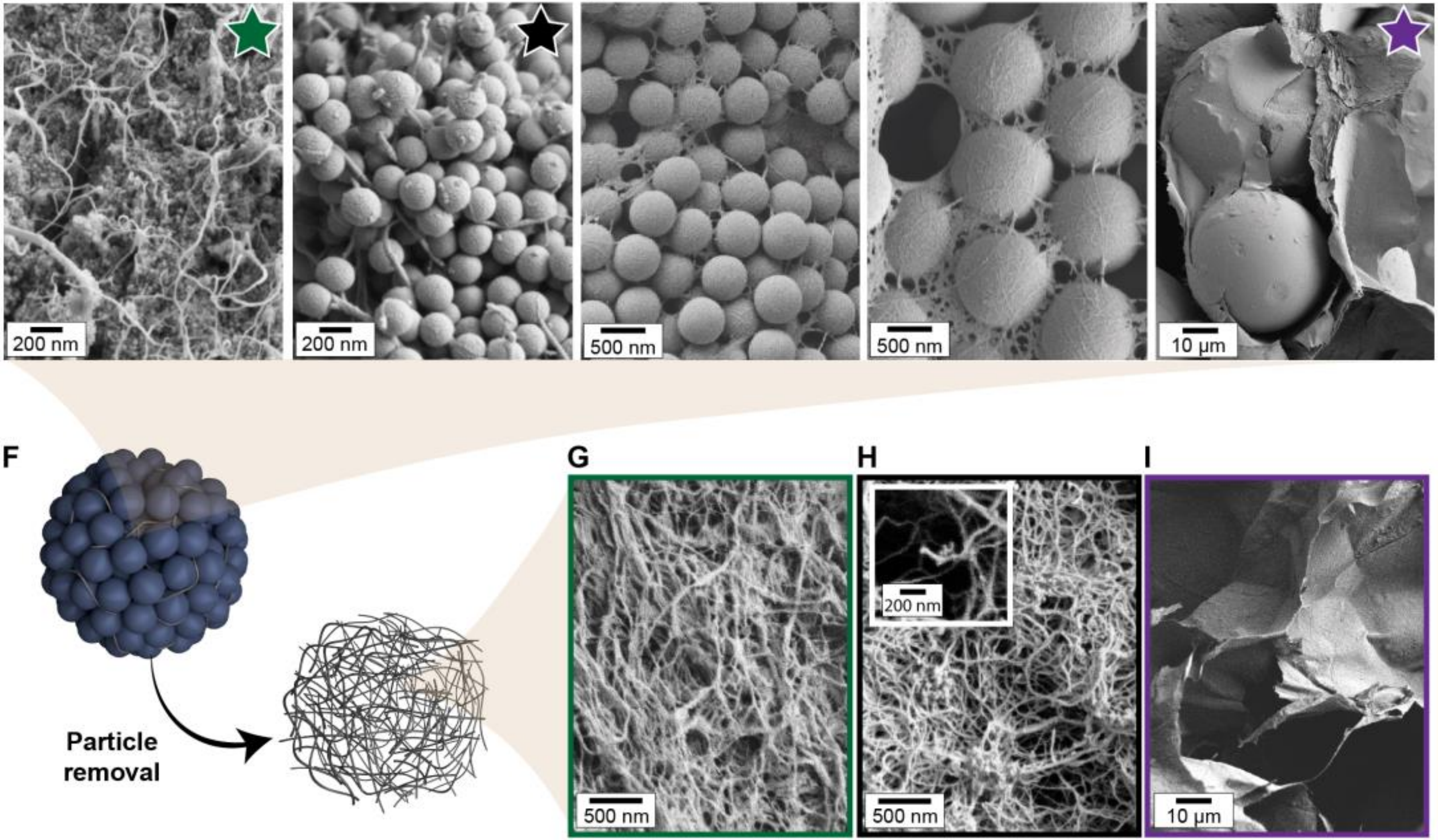


Water-nanocellulose interactions: A challenge but also an opportunity

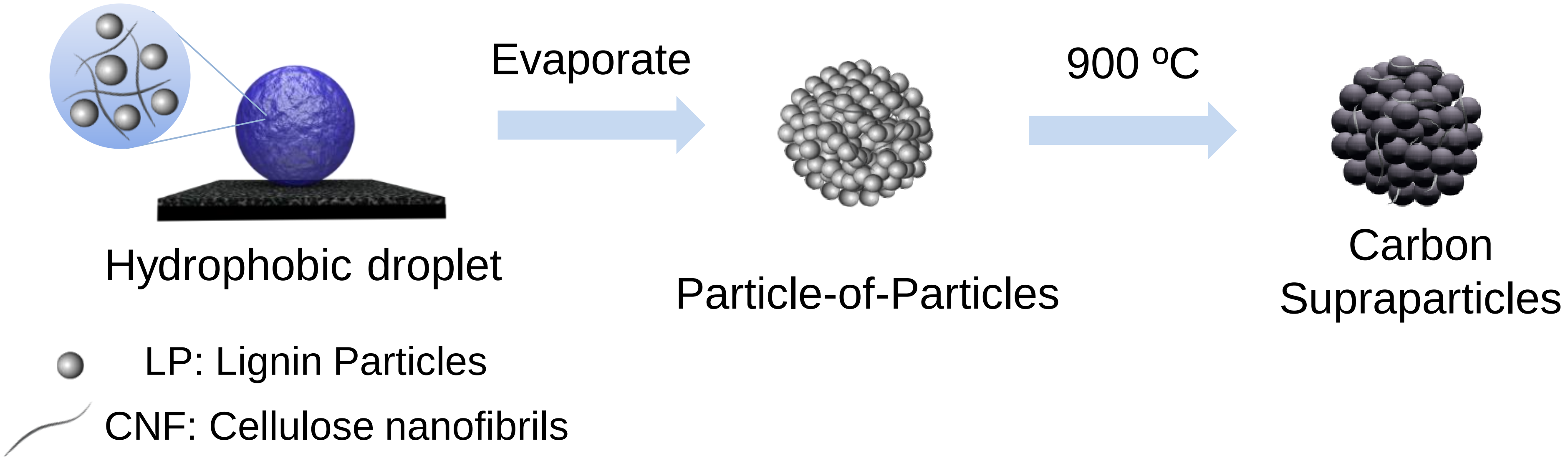


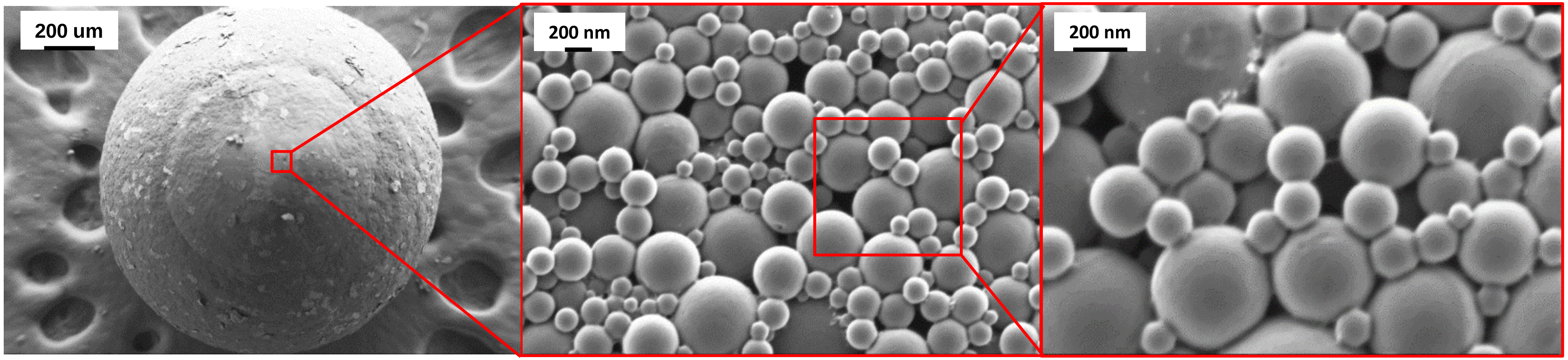
Ajdary et al., Plant Nanomaterials and Inspiration from Nature: Water Interactions and Hierarchically-Structured Hydrogels, **Advanced Materials**, 2001085 (2020).

Nanocellulose: universal binder (upon drying)



Lignin-based supraparticle for CO_2 adsorption



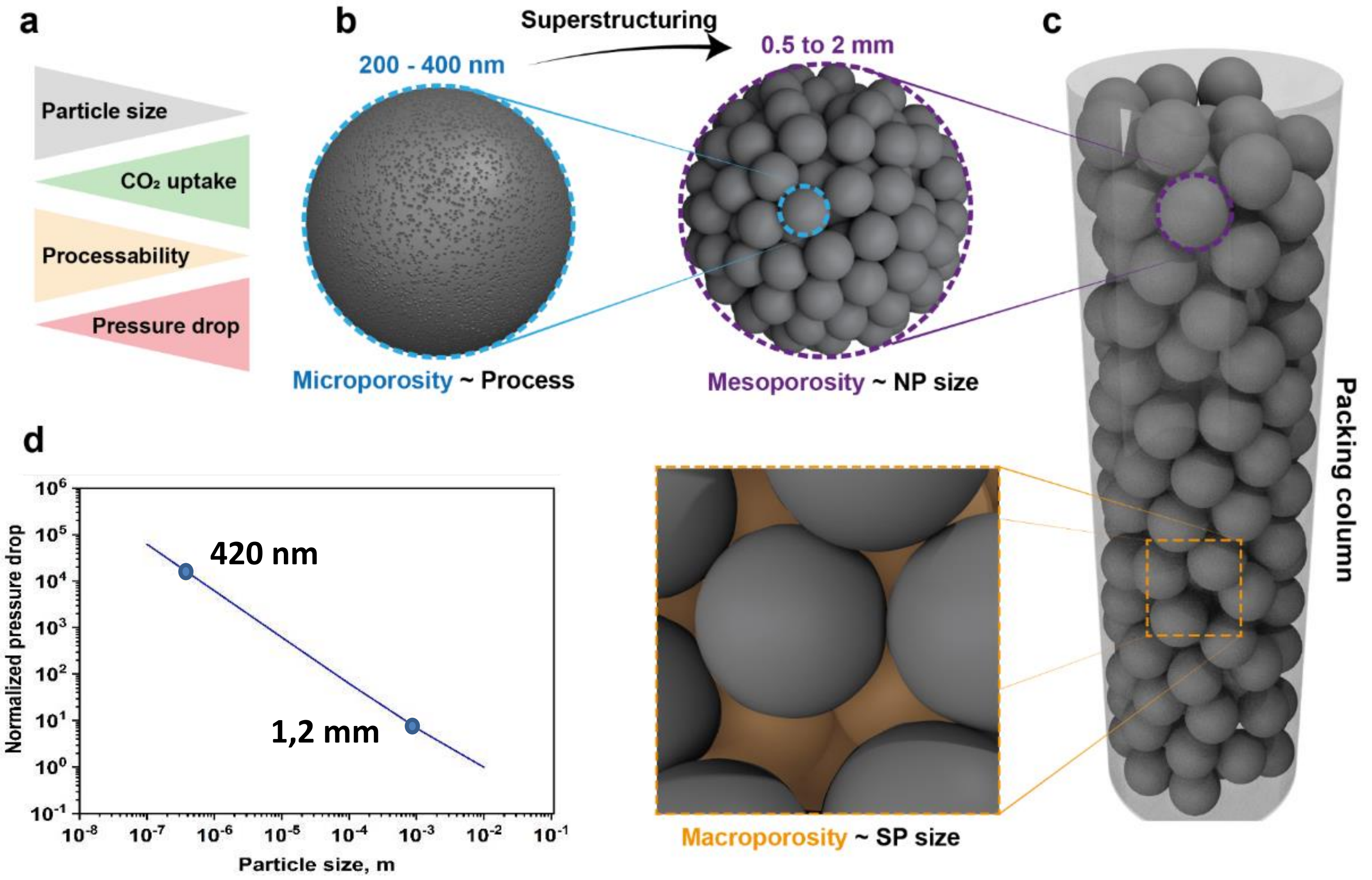


Macroscopic carbon

Carbon Nanosphere

Mattos, B.D., et al. Small, 2018

Reduced pressure drop by super-structuring lignin-derived carbon micro spheres

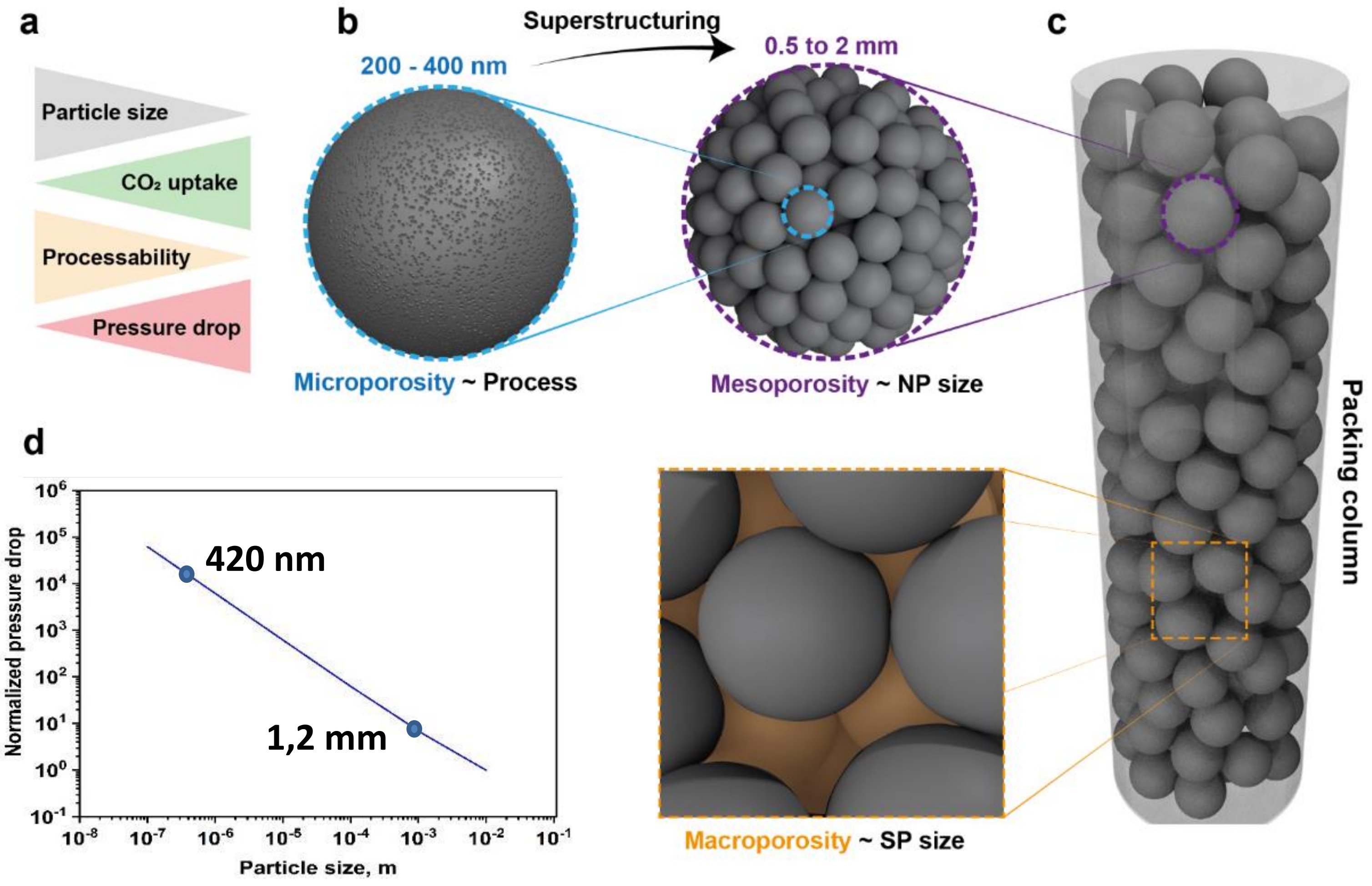


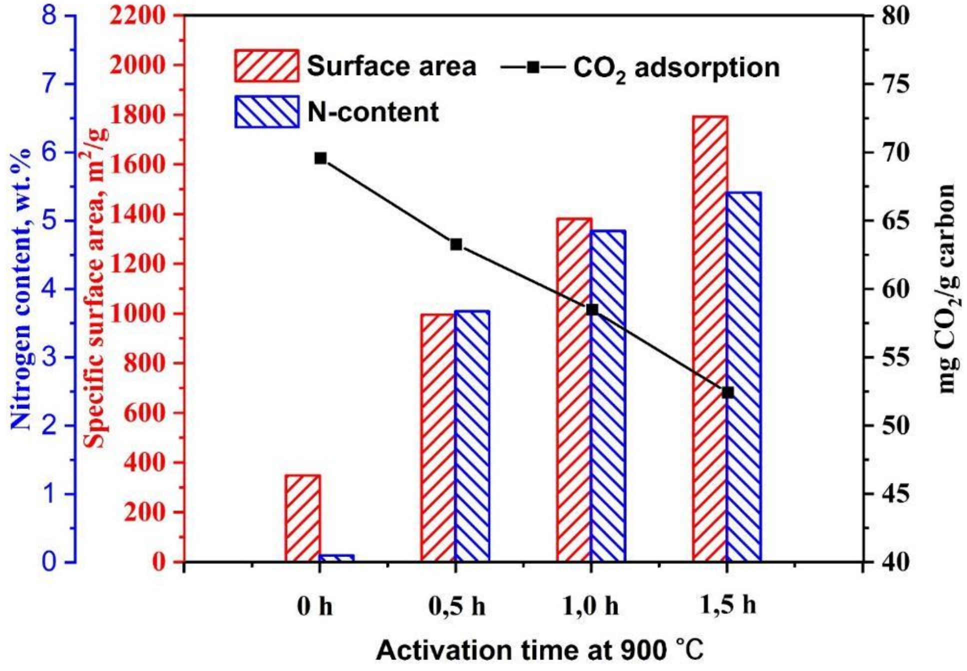
Ergun equation

$$\Delta p = \frac{150\mu\, L}{D_p^2}\,\frac{(1-\epsilon)^2}{\epsilon^3}v_s + \frac{1.75\, L\, \rho}{D_p}\,\frac{(1-\epsilon)}{\epsilon^3}v_s|v_s|.$$

Supraparticles lower the pressure drop by 4 orders of magnitude

CO_2 Adsorption performance

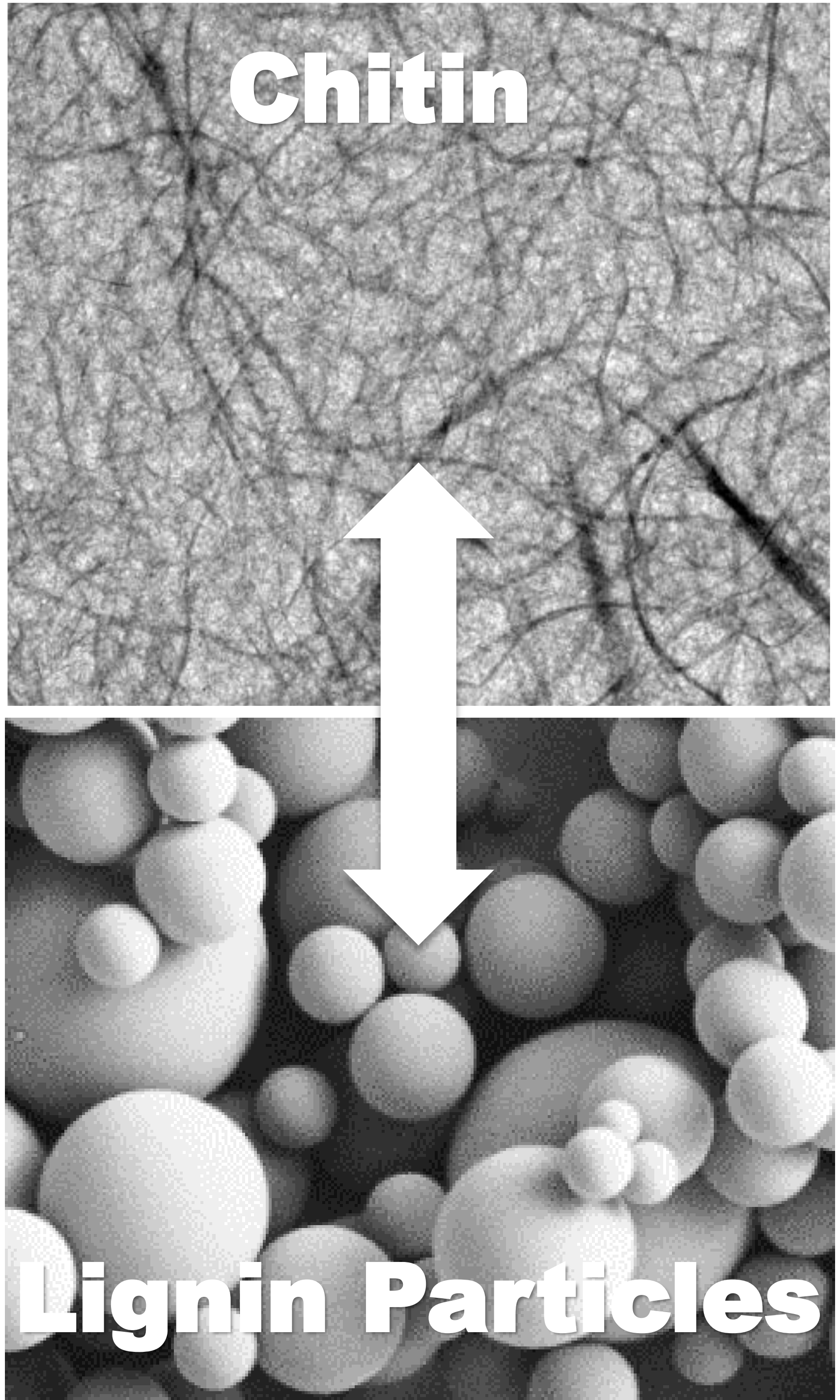




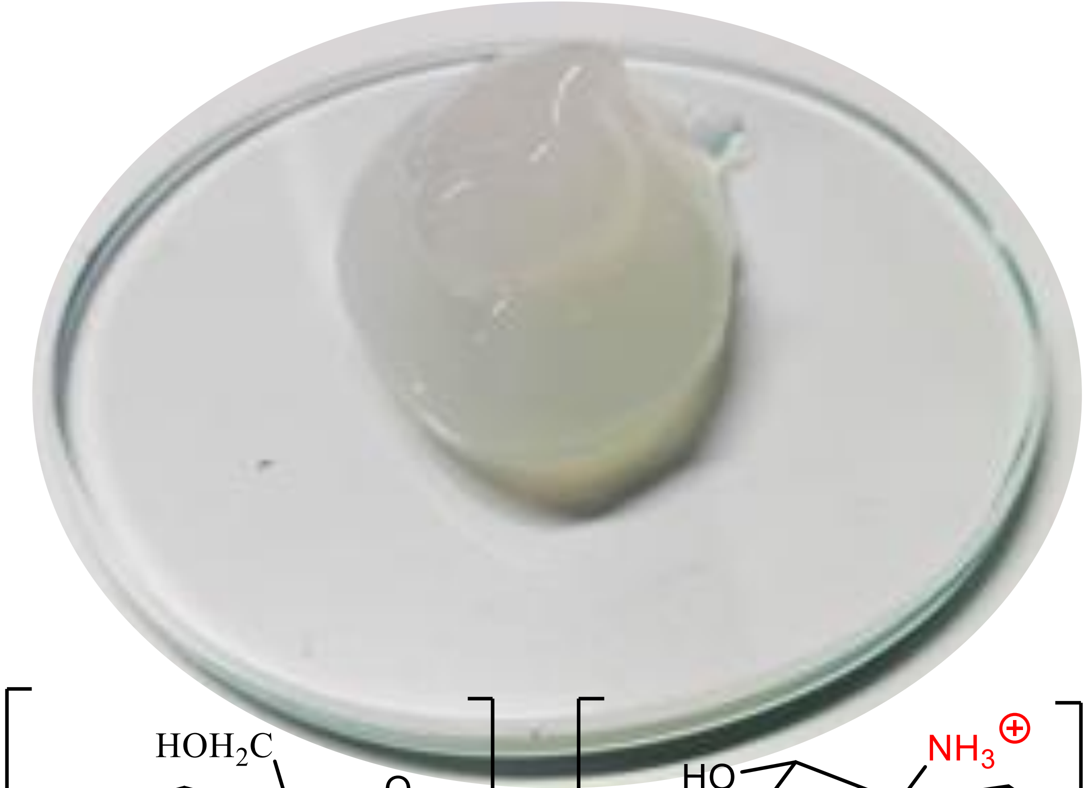
75 mg CO_2/g carbon

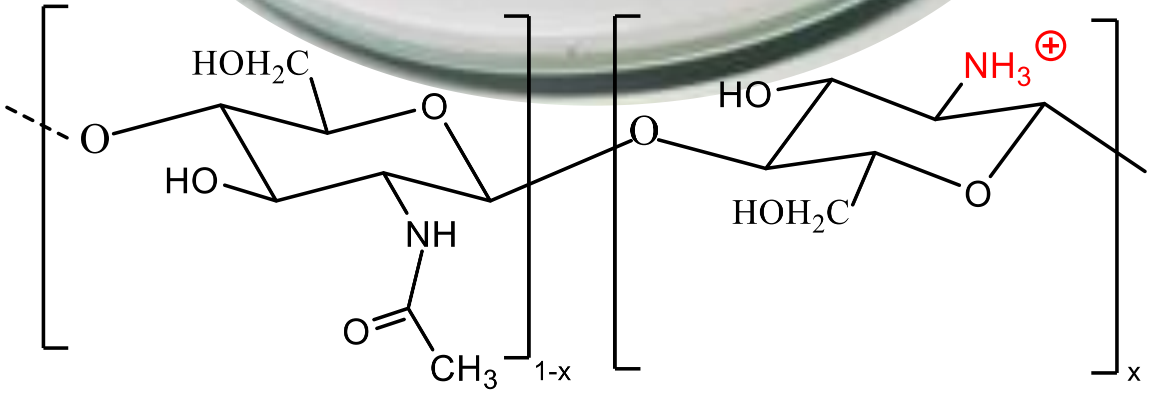
Zhao, ACS Nano (2021)


Chitin


Chitin
Lignin Particles

Deacetylated chitin nanofibrils (ChNF)

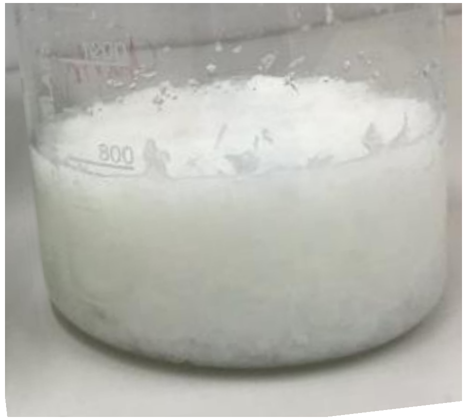




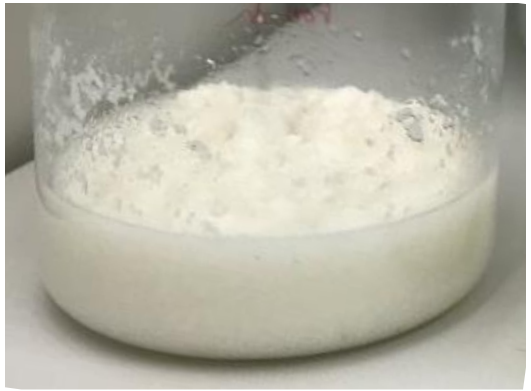
X= Deacetylation degree

Nanochitin: other sources

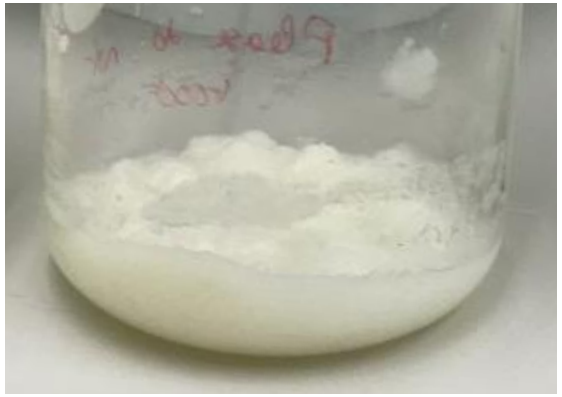
Chitin from shrimp



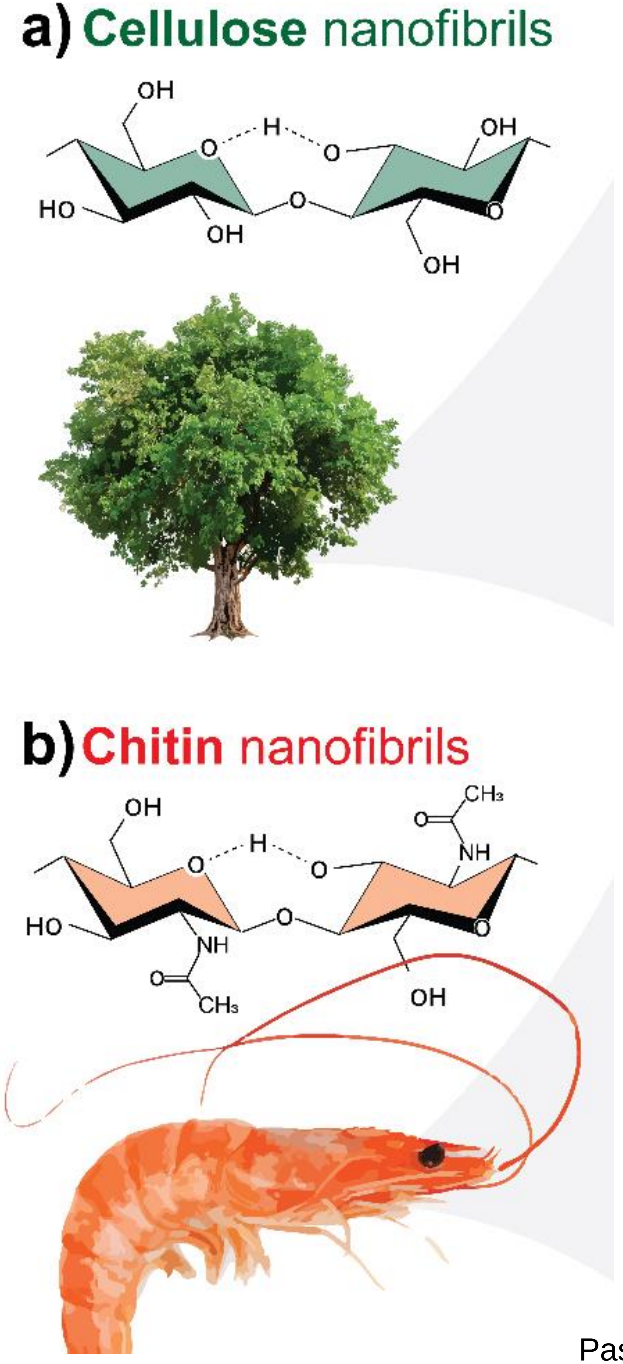
Chitin from fly

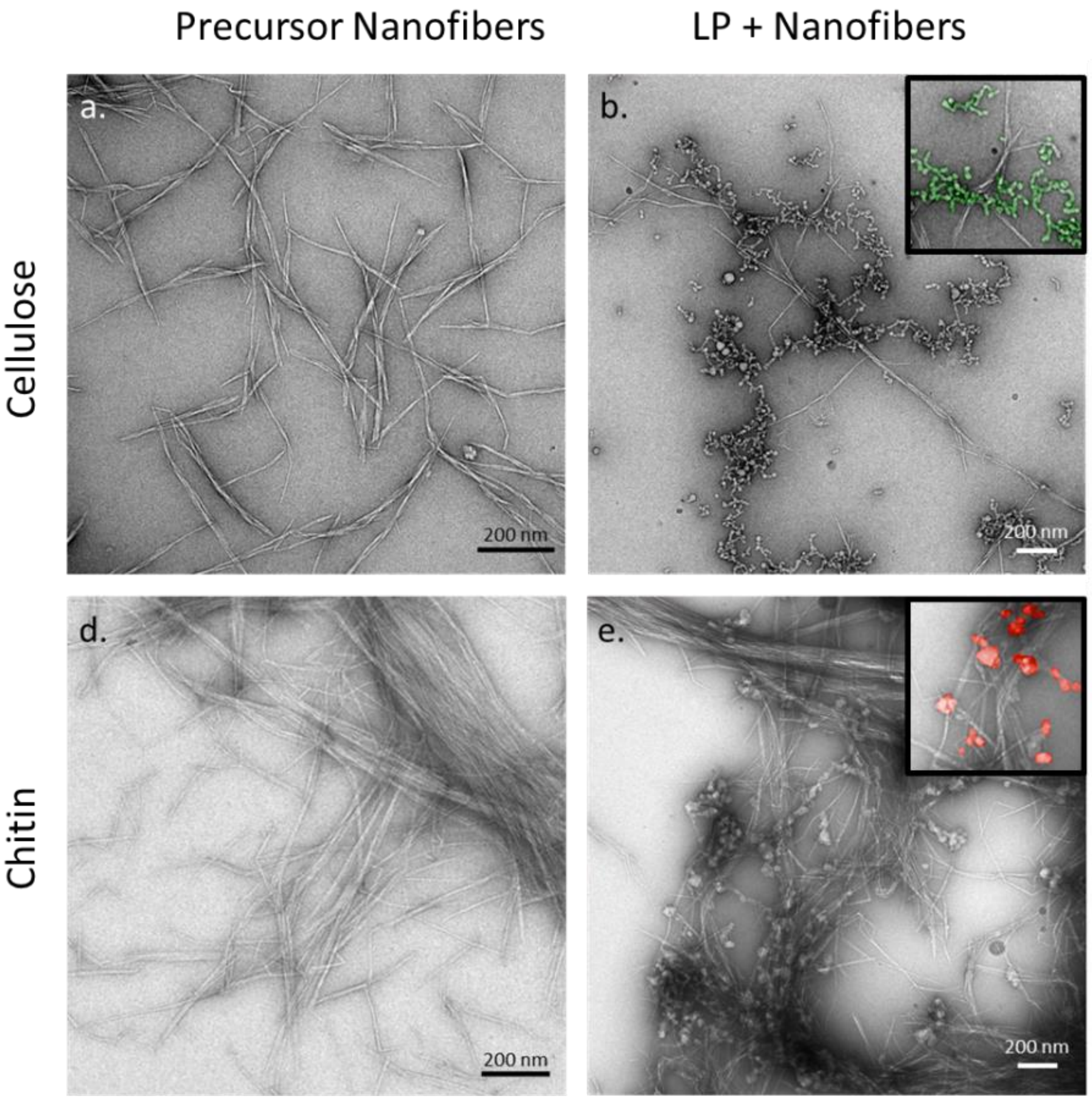


Mealworm (raw exuvium)



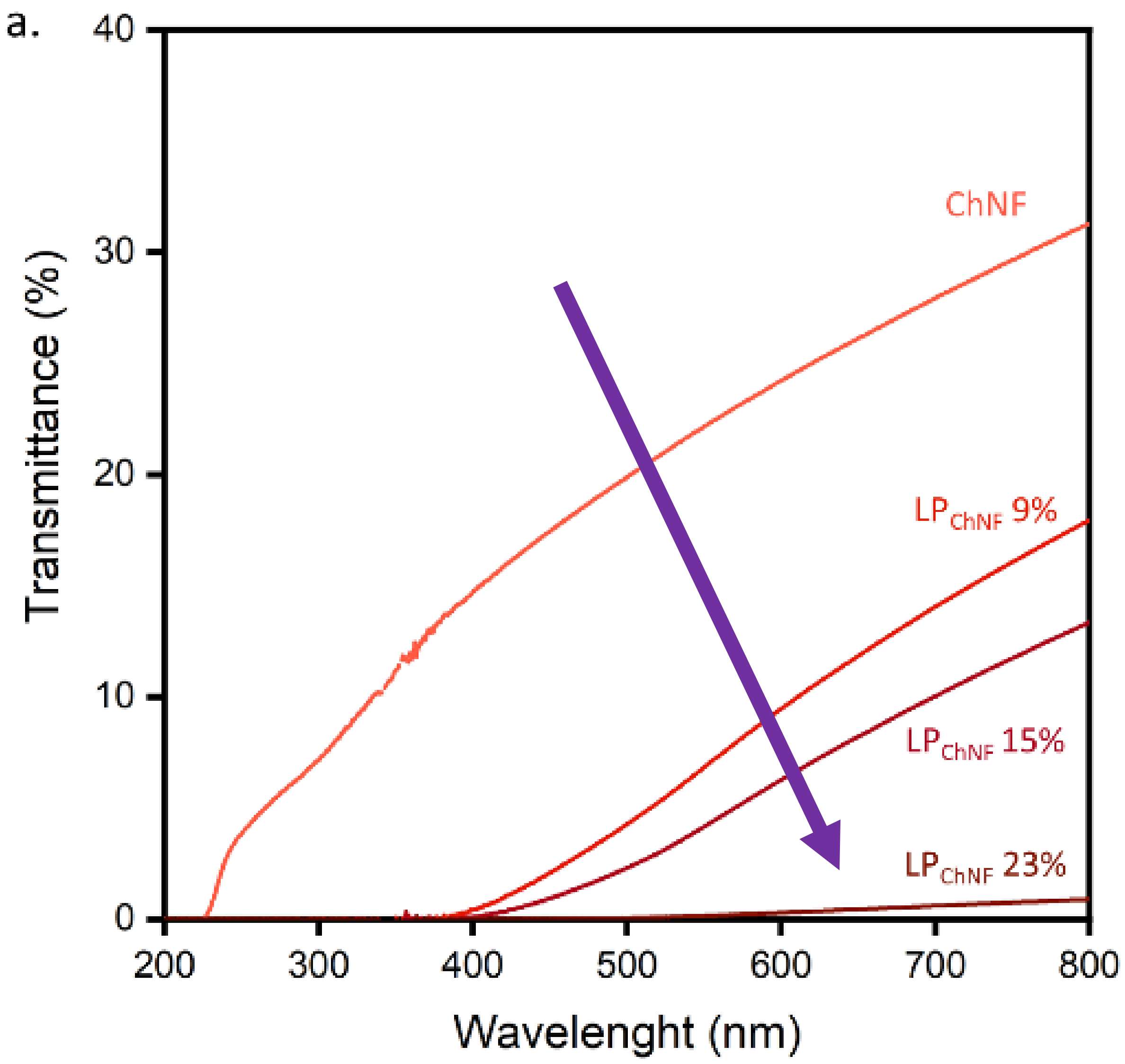
Wet method for LP synthesis



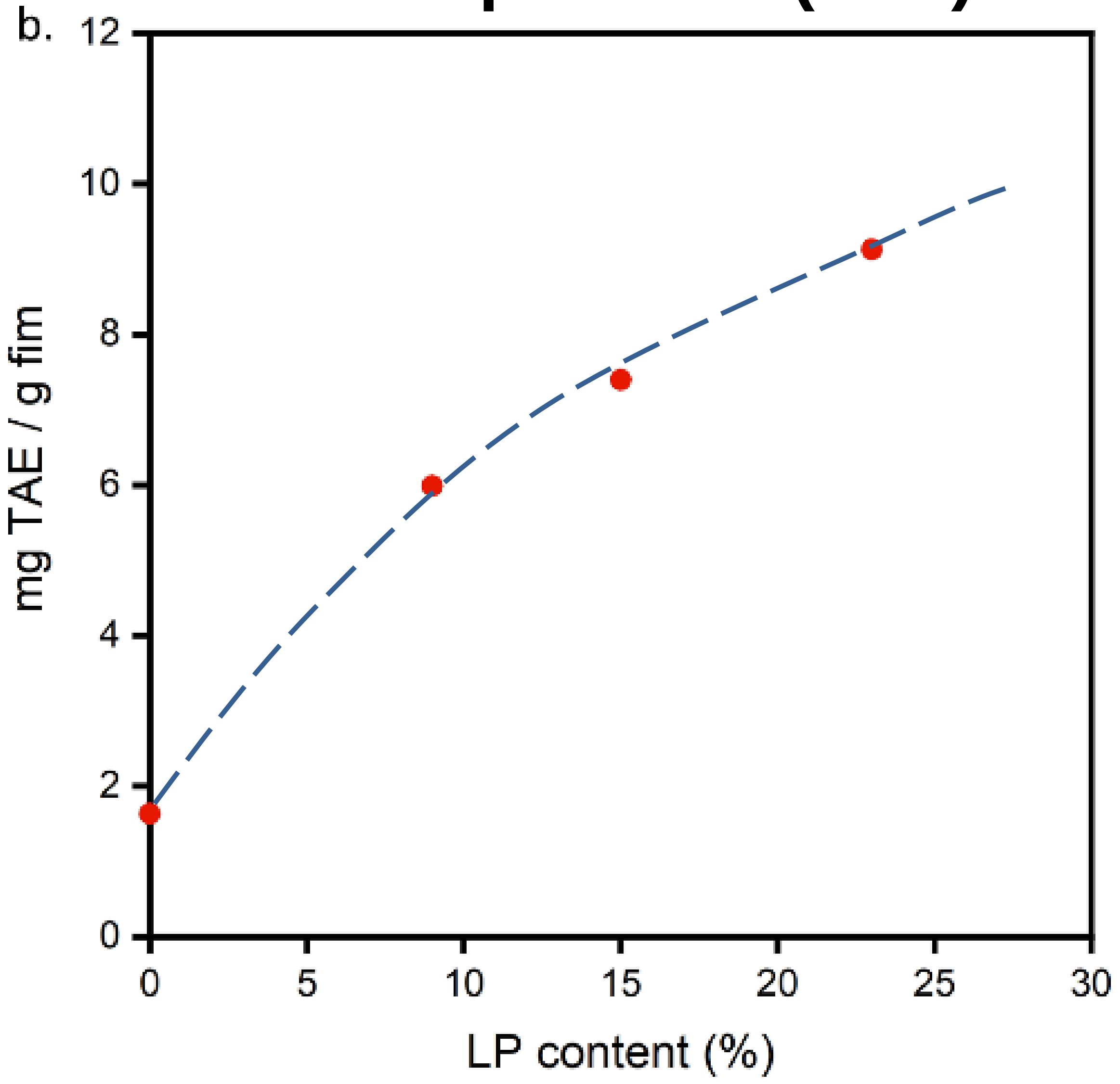


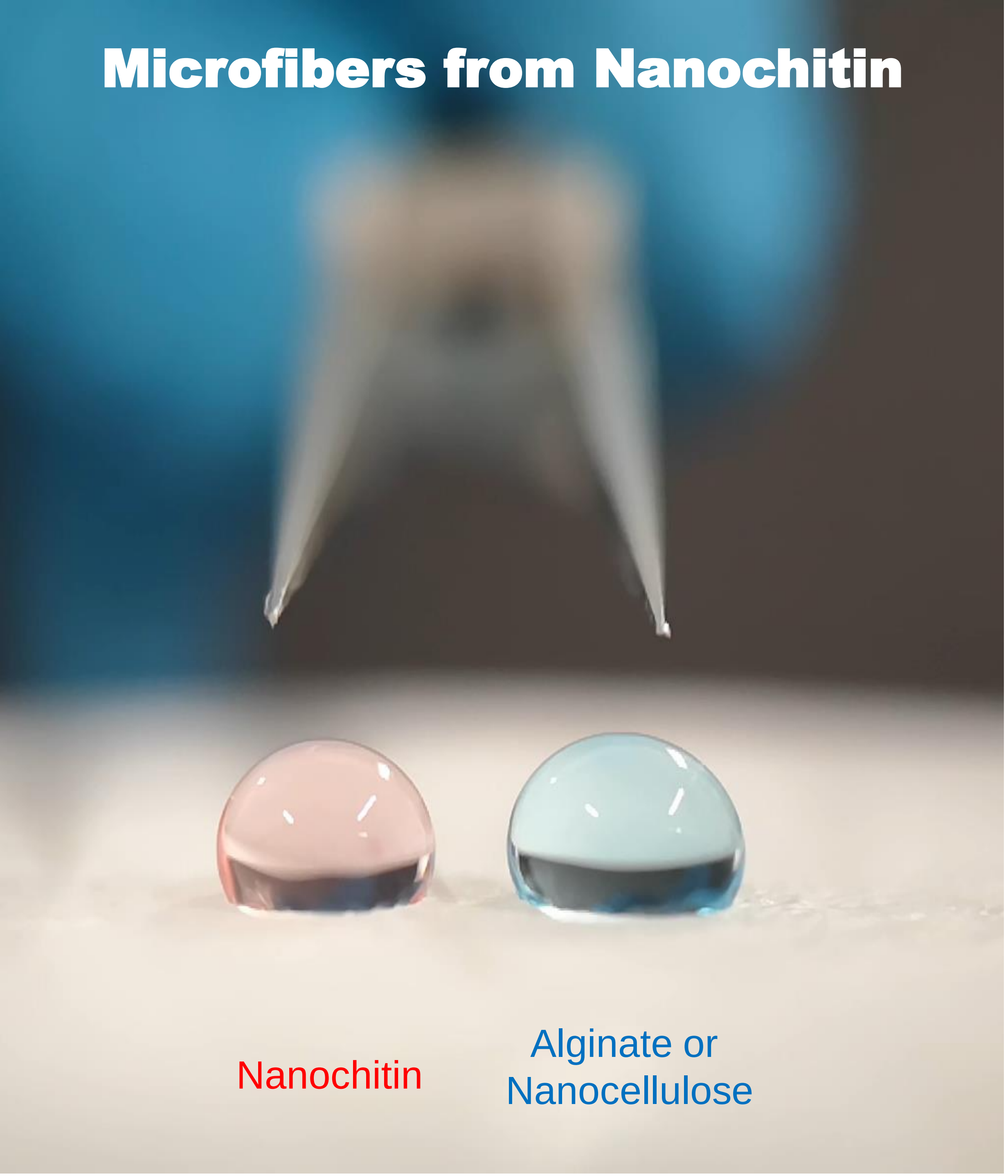
Pasquier, Mattos, Belgacem, Bras, Rojas, Lignin nanoparticle nucleation and growth on cellulose and chitin nanofibers, **Biomacromolecules**, 22, 880–889 (2021). DOI: 10.1021/acs.biomac.0c01596

UV-Visible transmittance of the films

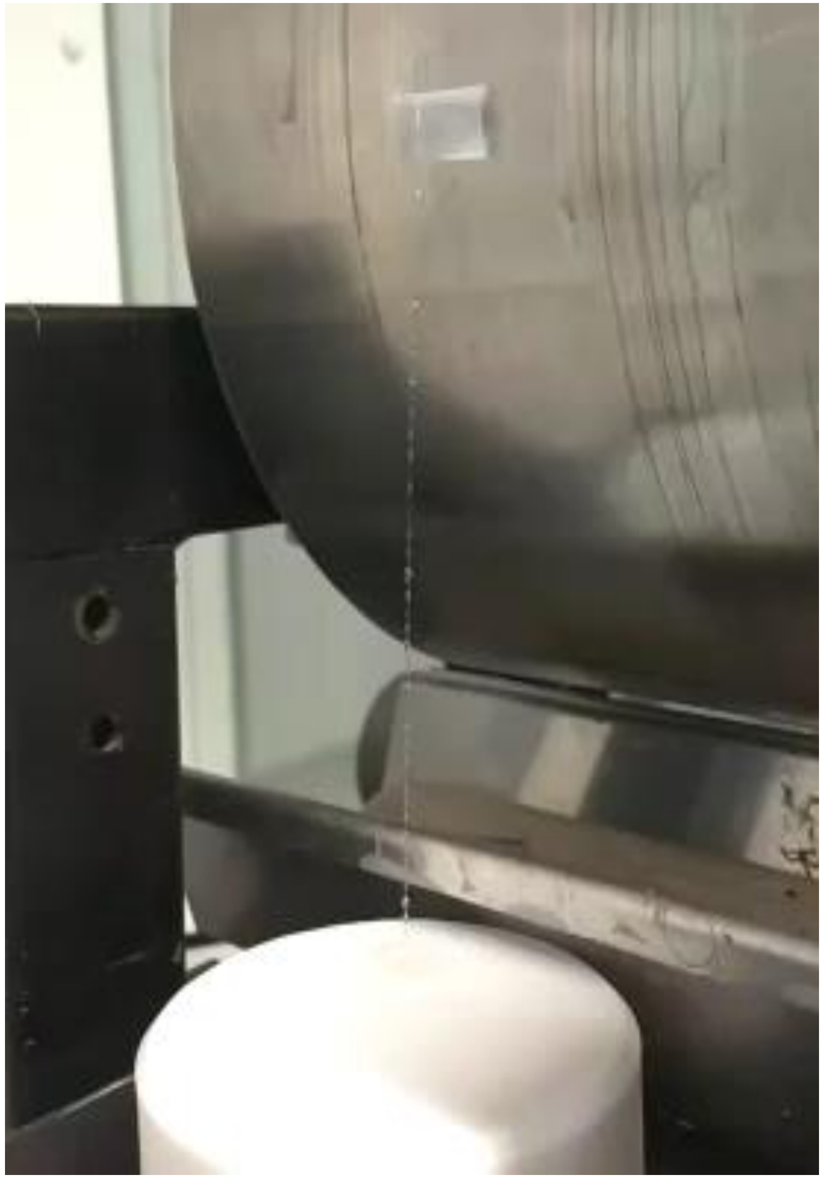


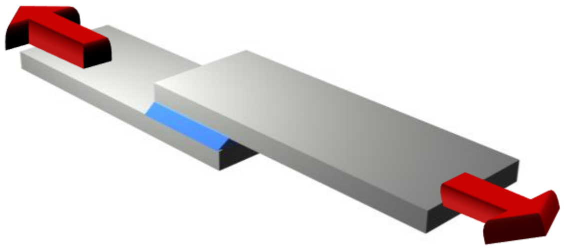
Antioxidant activity of films measured by the tannic acid equivalent (TAE)



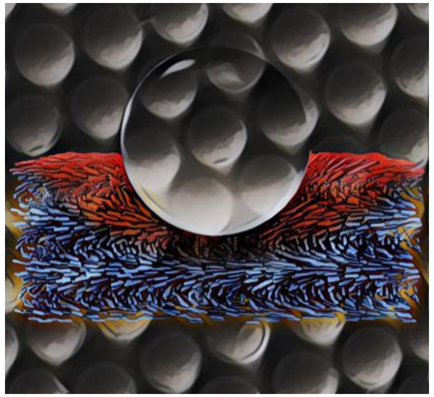


Dry spinning via interfacial complexation



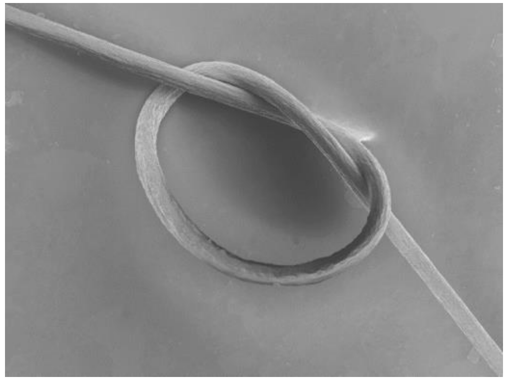


Anisotropic adhesives, **Advanced Materials**, 1906886 (2020).

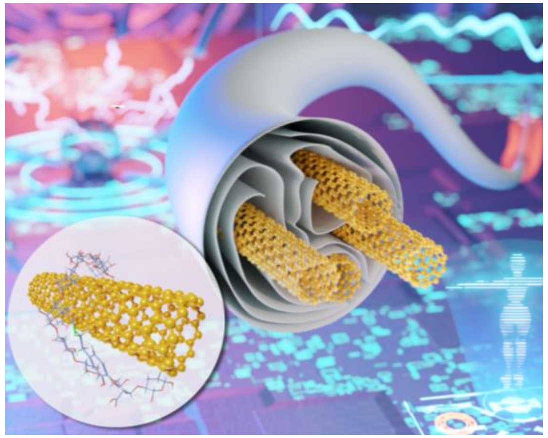


Retroreflector & Microlens Array, **Advanced Optical Materials**, 2002258 (2021); Tunable Optical Films, **JCIS** (2021).

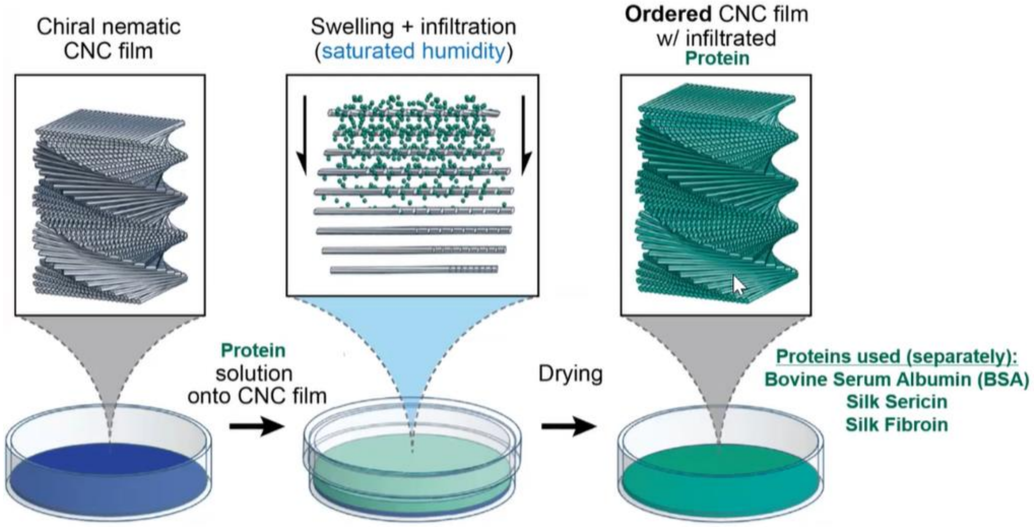
Dye-sensitized solar cells, **Cellulose** 26, 6151 (2019); **ACS Sustainable Chemistry & Engineering**, 7, 10257 (2019).



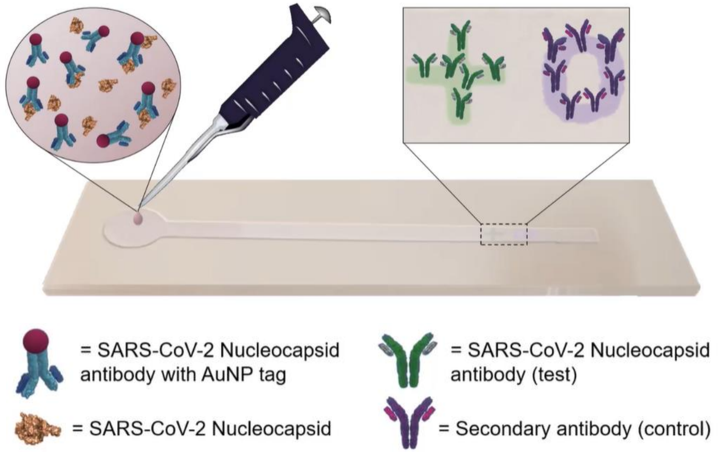
Microfibers by interfacial complexation, **ACS Sustainable Chemistry & Engineering**, 8, 1137-1145 (2020).



Multifunctional wearables, **Chem Eng J**, 128981 (2021).



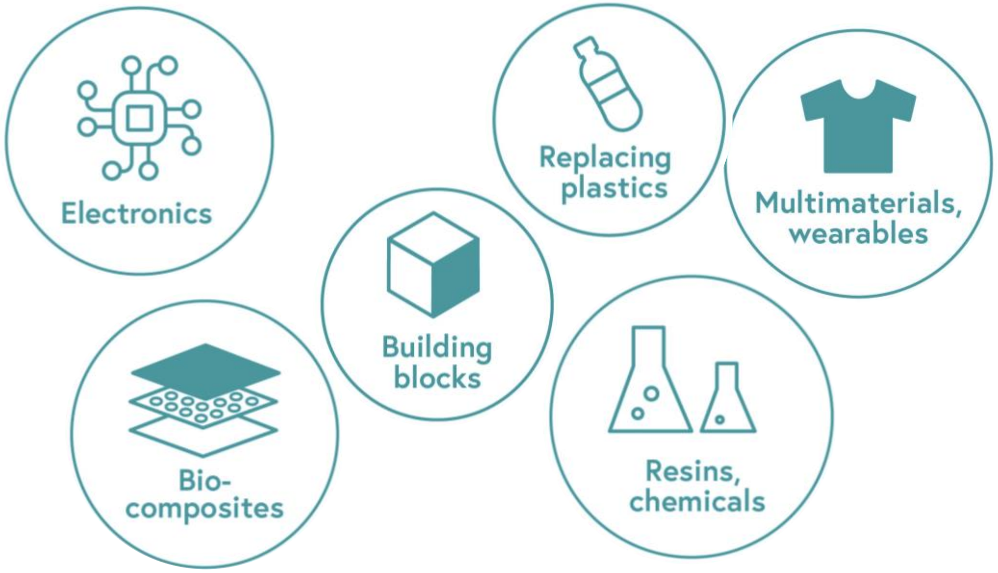
Cholesteric Films via protein infiltration **Biomacromolecules** (2021).



Electrochromic devices, **ACS Applied Polymer Materials,** (2021). Next-Generation Immunoassays, **Small**, 16, 2004702 (2020).

Climate resilience and Environmental Stewardship

- **Plant biomass**: Safe, Local, Regenerative, renewable, Sustainable, Recyclable, (Bio)degradable (controllably), Positive environmental impacts
- **New solutions to current and future material**: integration of biotechnology, understanding the supramolecular interactions between biobased building blocks.



Harnessing the natural properties of **lignocellulose** to create **new sustainable materials**

UBC
BioProducts Institute
NSERC CRSNG
erc
Aalto University
FinnCERES Lignocellulose Materials Cluster for Our Future
ACADEMY OF FINLAND
BUSINESS FINLAND