Seminar: Advances in Cellulose-based materials in food packaging

Applications of Micro and Nanocellulose

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VTT – beyond the obvious

VTT is one of the leading research, development and innovation organisations in Europe. We help our customers and society to grow and renew through applied research. The business sector and the entire society get the best benefit from VTT when we solve challenges that require world-class know-how together and translate them into business opportunities.

Our vision
A brighter future is created through science-based innovations.

Our mission
Customers and society grow and renew through applied research.

Strategy
Impact through scientific and technological excellence.

Established in
1942

261 M€
(VTT Group 2023)

2,213
Total personnel
(VTT Group 2023)

Owned by

Ministry of Economic Affairs and Employment

32%
Doctorates and Licentiates
(VTT Group 2023)

43%
of the net turnover from abroad

OUR PURPOSE

We bring together people, business, science and technology,

TO SOLVE THE WORLD'S BIGGEST CHALLENGES,

creating sustainable growth, jobs and wellbeing.

Cellulose-based barriers for packaging applications

Key enabling technologies for creating barrier from cellulose

Fibrillated cellulose

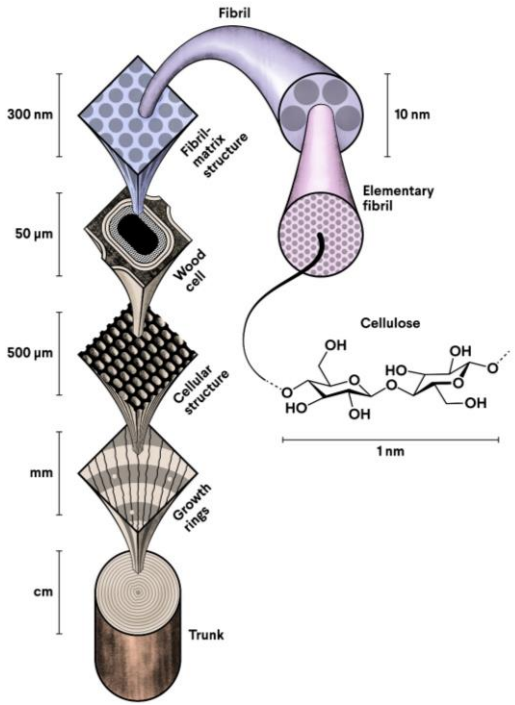
Thermoplastic Cellulose

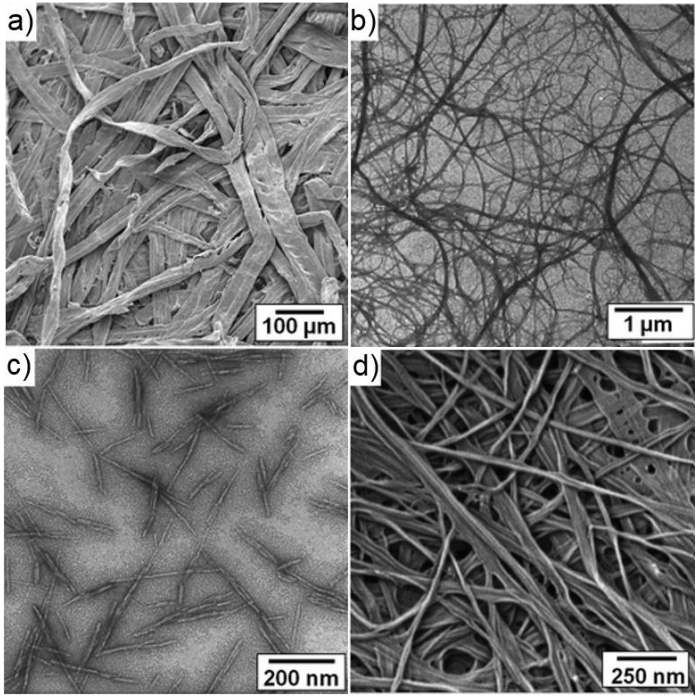
Dissolving/ Regenerating

Films/coatings from cellulose

Introduction to micro and nanocellulose

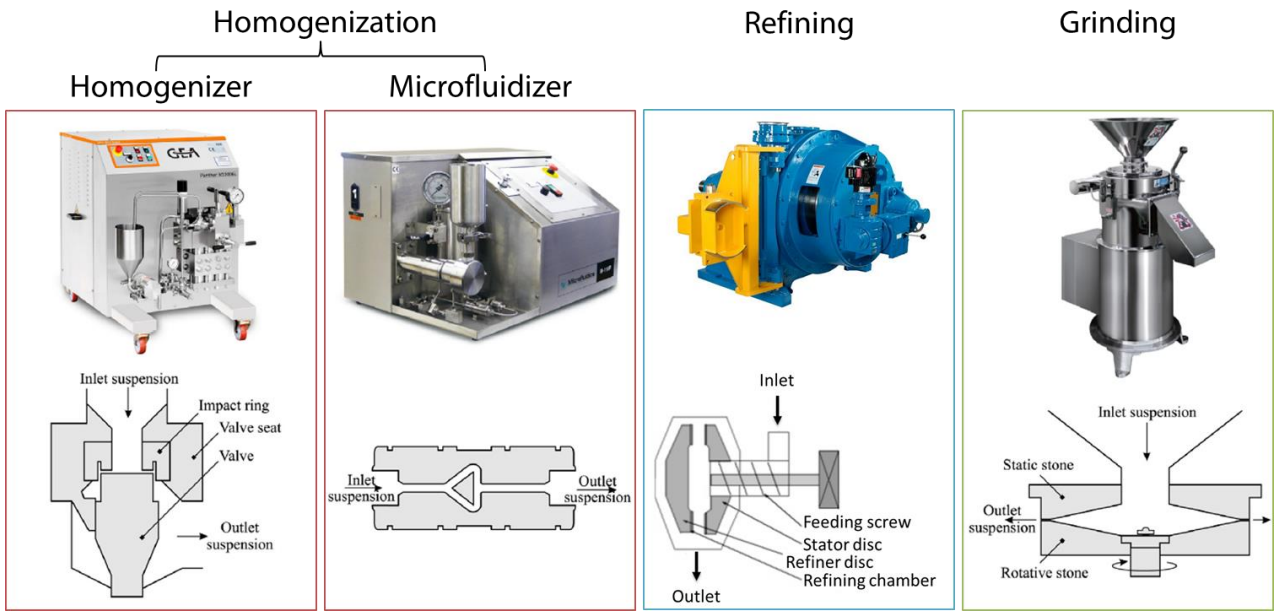
Nanocellulose: Plant based nanomaterial





- Nanocellulose refers to numerous kinds of cellulosic materials which have at least one dimension on the nano-scale
- Classified into three broad categories
  1. Cellulose nanocrystals (CNCs), aka nanocrystalline cellulose (NCC), or cellulose nanowhiskers (CNWs)
  2. Cellulose nanofibers (CNFs), aka nanofibrillated cellulose (NFC), or microfibrillated cellulose (MFC)
  3. Bacterial nanocellulose (BNC), or simply bacterial cellulose (BC)
- Different approaches are used to extract these nanoparticles from cellulose sources, resulting in particles with varied morphology & functionality

Some mechanical treatment methods for MFC/NFC production

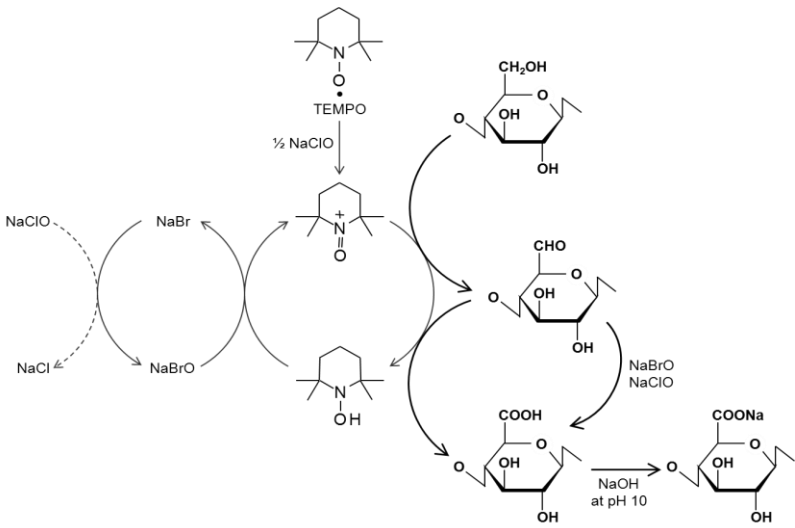


Kumar, V. 2018. *Roll-to-roll processing of nanocellulose into coatings. PhD thesis,* Åbo Akademi, Finland.
Nechyporchuk, et al. 2016. *Industrial Crops and Products* 93, 2-25.

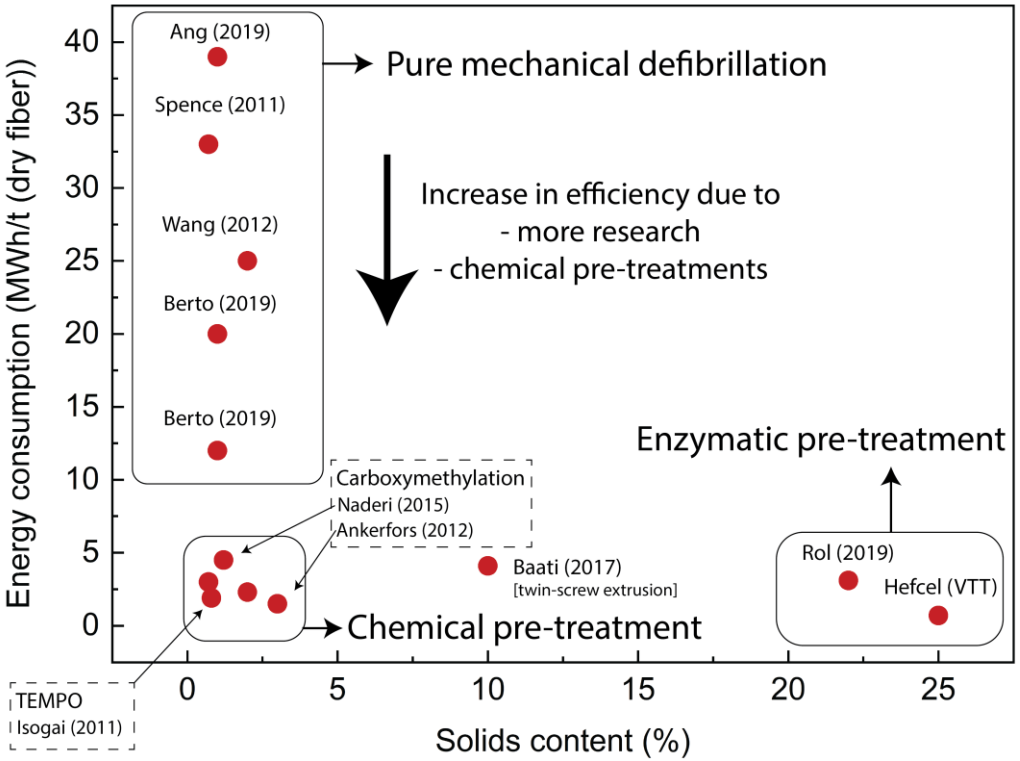
Pre-treatments for energy saving

- Pure mechanical treatments for MFC/NFC production are known to be energy intensive
- Chemical or biological pre-treatments are employed to reduce energy consumption during mechanical defibrillation
- These pre-treatments have the potential to significantly decrease energy requirements
- Chemical pre-treatments typically introduce charged surface groups onto cellulose fibers, which induces swelling and fiber repulsion, thereby facilitating easier delamination of fibrils during mechanical treatments
- Typical chemical pre-treatments
  - Carboxylation (such as TEMPO-mediated or periodate-chlorite oxidation),
  - carboxymethylation,
  - sulfonation,
  - quaternization.
- Biological pre-treatments use enzymatic hydrolysis to delaminate cellulose fibers to enhance the efficiency of the defibrillation process.

TEMPO oxidation



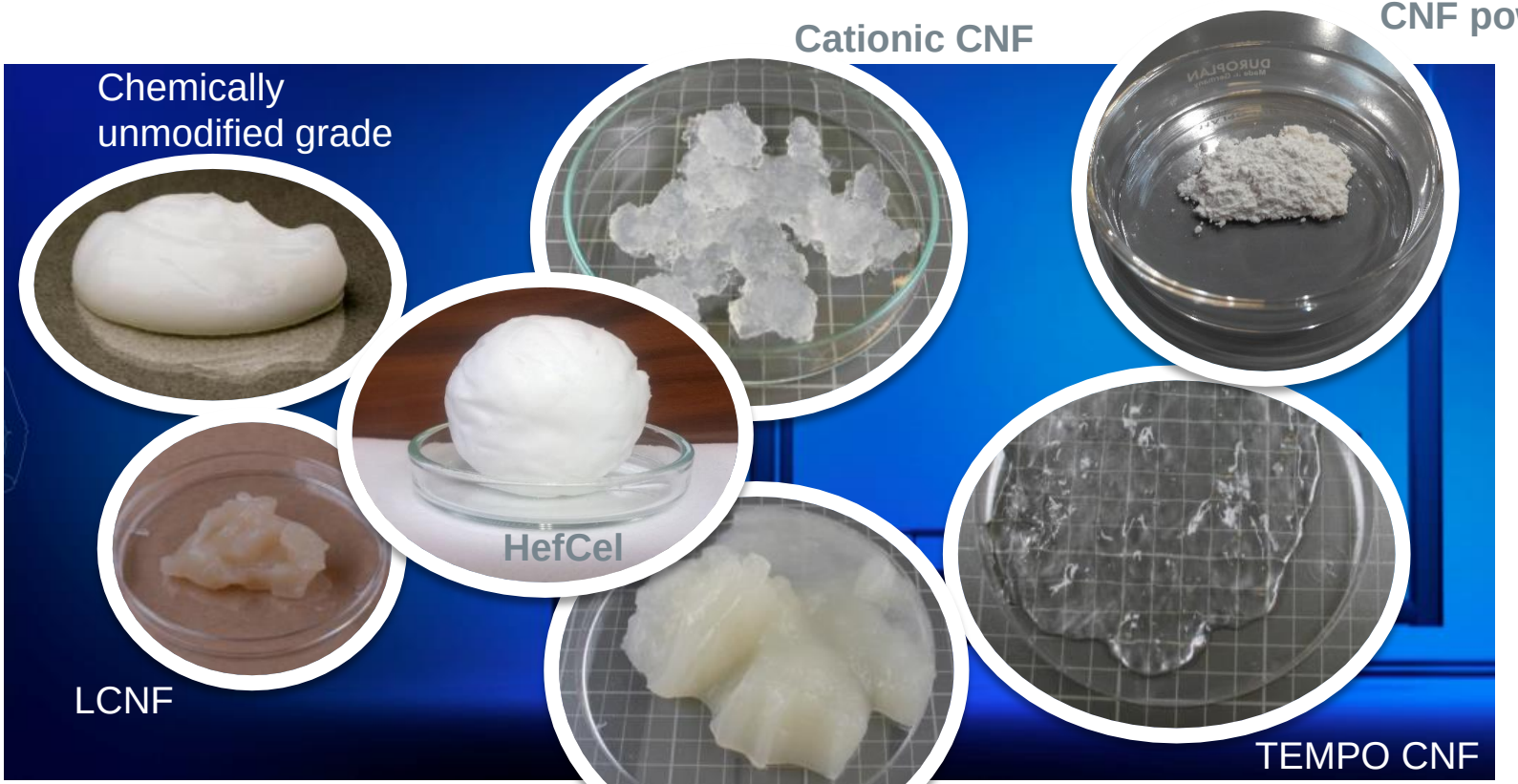
Energy consumption and solids content



- Most nanocellulose (cellulose nanofiber – CNF) grades are limited to low solids content of < 3%
  - Major challenge deterring industrial adaptation of CNF-based coatings
- Example: Drying energy need to coat 10 g/m^2 CNF layer:
  - 832 kJ/m2 for 3% suspension
  - 145 kJ/m2 for 15% suspension (85% reduction!)
- Enzymatic pre-treatment allows CNF to be produced at >20% solids content and has low energy consumption (both during production and coating)
- Complex rheology is a challenge during reel-to-reel (R2R) coating!

Spence (2011) -10.1007/s10570-011-9533-z; Wang (2012) - 10.1007/s10570-012-9765-6; Naderi (2015) - 10.1007/s10570-015-0577-3; Rol (2017) - 10.1021/acssuschemeng.9b01913; Baati (2017) - 10.1021/acssuschemeng.6b02673; Berto (2019) - 10.1016/j.ijbiomac.2019.01.169; Ang (2019) - 10.1007/s10570-019-02400-5; Ankerfors 2012 - ISSN 1654-1081; Isogai (2011) - 10.1007/s10570-010-9484-9

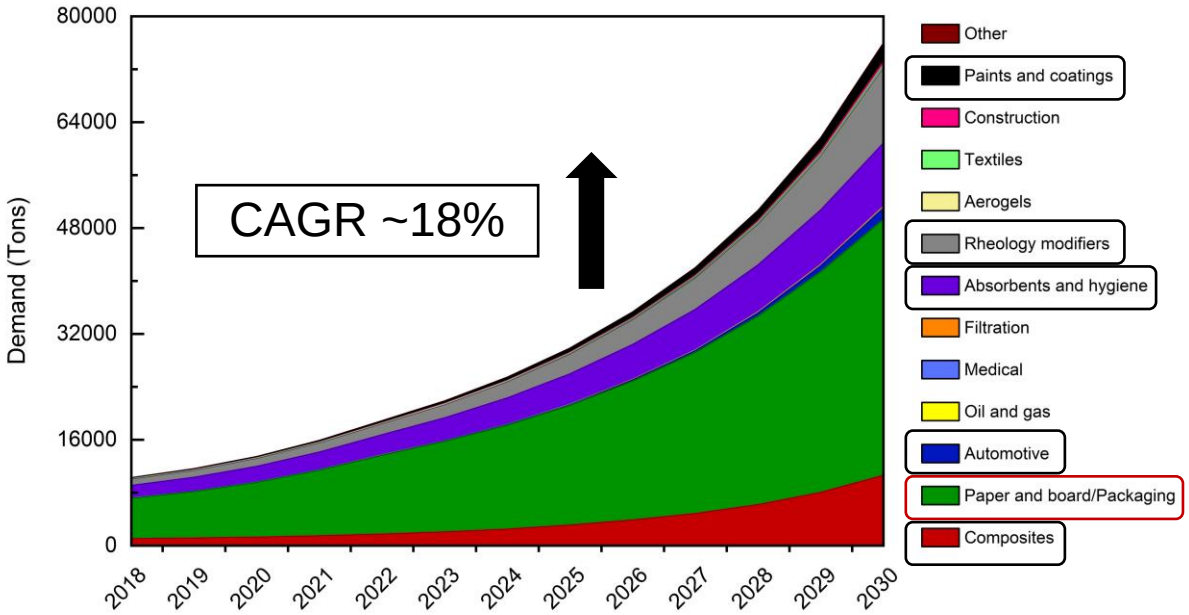
Examples of nanocellulose grades



Extensive knowledge on fibrillated cellulose at VTT

The next decade with nanocellulose

Nanocellulose to play a key role in our transition to a clean and sustainable future!



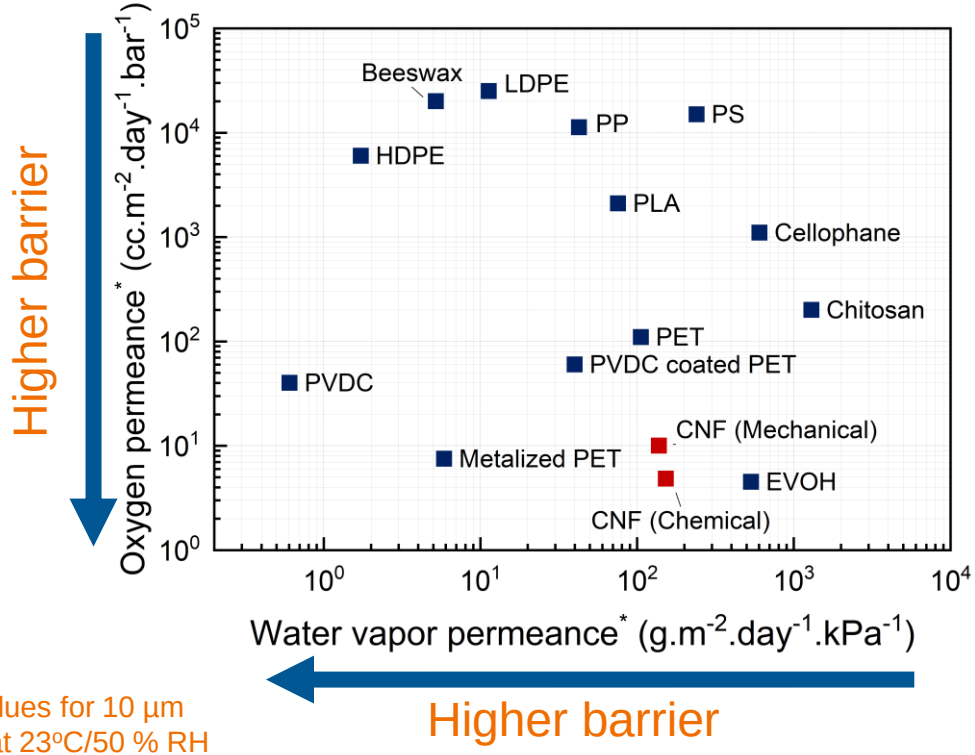
Future Markets Inc. – The global market for nanocellulose to 2030 (2019)

- Most researched bio-material in recent times
- Abundant, renewable, bio-compatible, biodegradable, and excellent functionalization potential
- Dominated by applications in Paper and board/Packaging
- Several pilot-scale facilities already online to produce nanocellulose

Koppolu R. & Toivakka M. (2022). *Advances in Pulp and Paper Research, Cambridge 2022*, *Trans. of the XVIIth Fund. Res. Symp. Cambridge, 2022*, pp 217 – 245

Nanocellulose films and coatings and their barrier function

Why nanocellulose in barrier packaging?



*All values for 10 µm films at 23°C/50 % RH

- Dense film forming through hydrogen bonding
- Excellent barrier against oxygen, mineral oils, and grease
- Fully biodegradable/compostable
- Repulpable

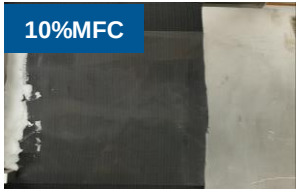
- Some challenges need to be addressed in order to be commercialized

Lindström T. & Österberg G., *Nord Pulp Paper Res J*, 34-4, (2020)
An D.S. et al., *J Food Process Eng.*, 41, (2018)

Challenges for nanocellulose films and coatings

Challenges
(deterring industrial adaptation of nanocellulose films and coatings)

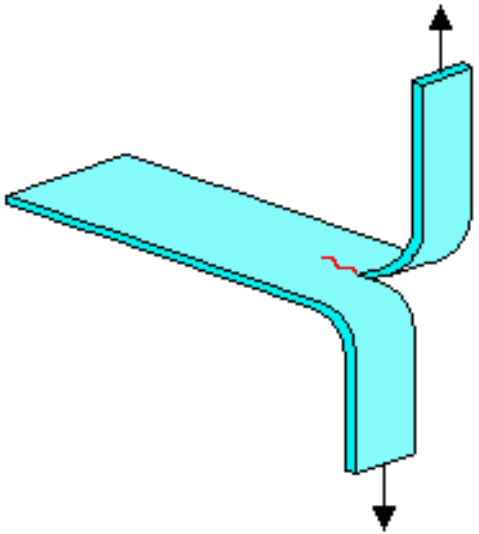
- Poor moisture barrier
- Yield stress
  - Scales according to power-law with solids content (power index ~2.5)
  - Cavitation during pumping; increased resistance to flow; non-yielding regions in coating head; inability to reorganize into a tightly packed structure
- Viscosity
  - Also scales according to power-law with solids content
  - Most coating applicators cannot handle such high viscosity suspensions
  - Challenging to remove entrapped air
- Thixotropy
  - High gel strength (storage modulus – G') and rapid recovery upon removal of shear stress → less time to reorganize and form tightly packed microstructure → coating defects
- High water amount in the suspensions (≥98%) → drying is costly
- Shrinkage challenges during drying



Koppolu R. & Toivakka M. (2022). *Advances in Pulp and Paper Research, Cambridge 2022*, *Trans. of the XVIIth Fund. Res. Symp. Cambridge, 2022*, pp 217 – 245

Film production challenges

- Mixing of additives at high consistency
- Film roll-up on the rewinder at high speed
  - Low tear strength leads to web breaks



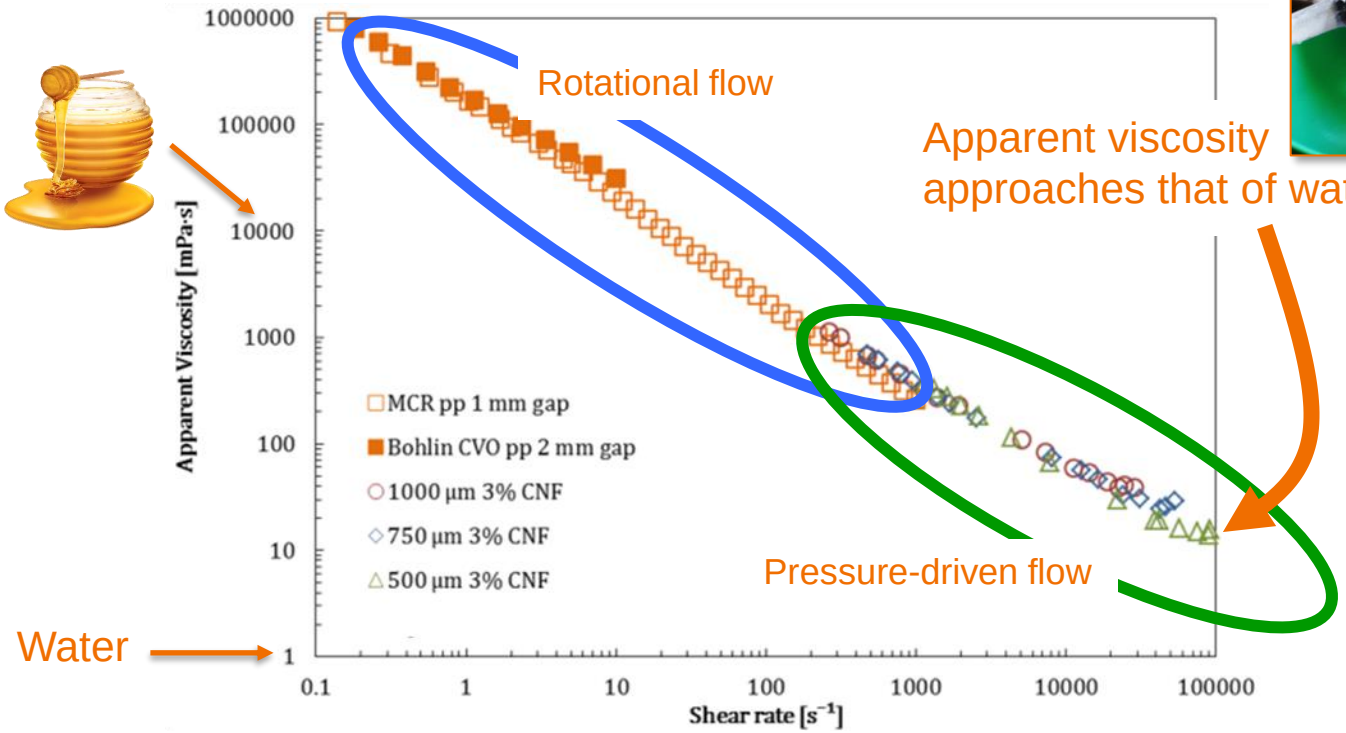
Film performance challenges

- Poor tear resistance
- Film gets highly brittle at low humidity
- Plasticizer (sorbitol & glycerol) migration issues

Production upscaling of nanocellulose films and coatings

Flow behaviour of nanocellulose suspension

Shearthinning continues to high shear rates



High-shear flow

3wt.% CNF

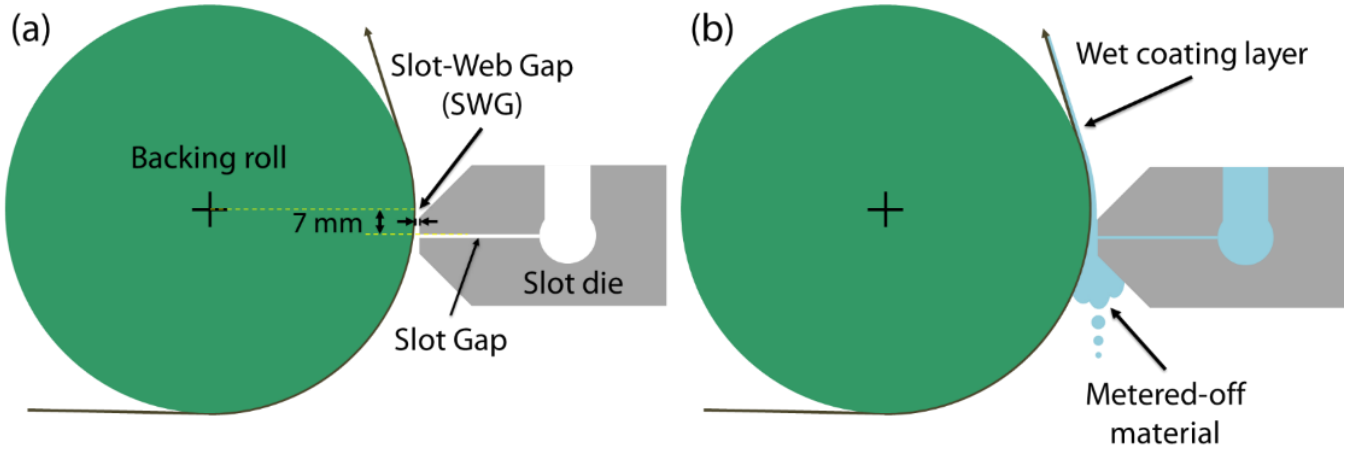
Increasing pressure drop (and shear rate)

3wt.% CNC

Continuous process for coating

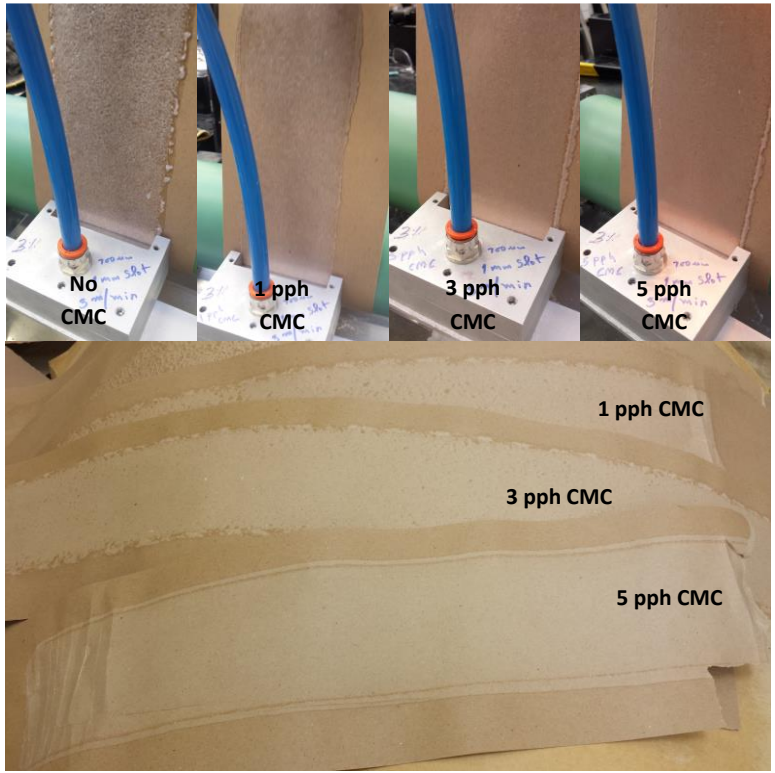
This highly viscous material tends to flow like water if forced into a narrow gap!

How about we use the fluidized state of the material to form a continuous film?



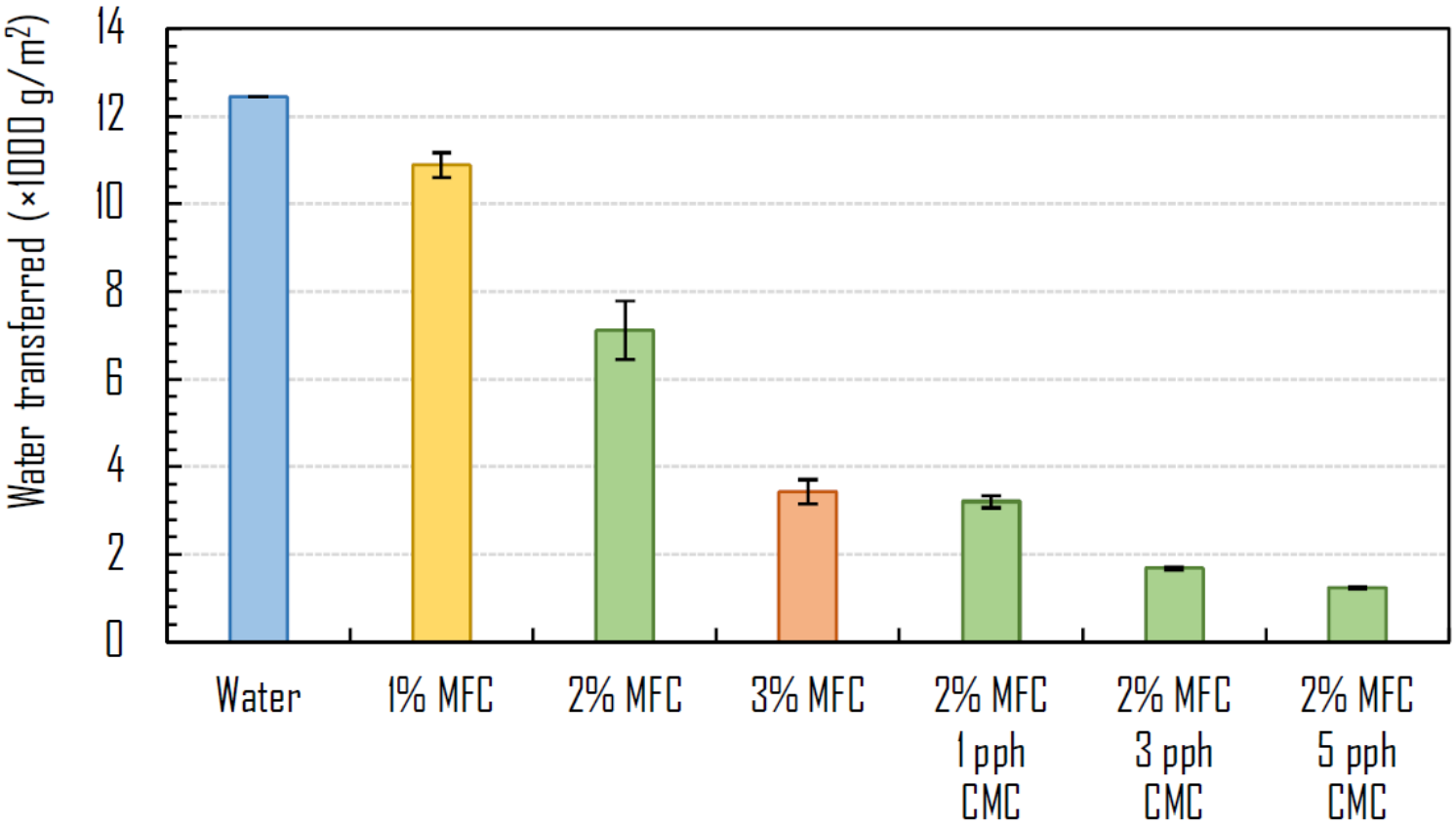
Coating quaility optimization

Addition of 5 wt% CMC

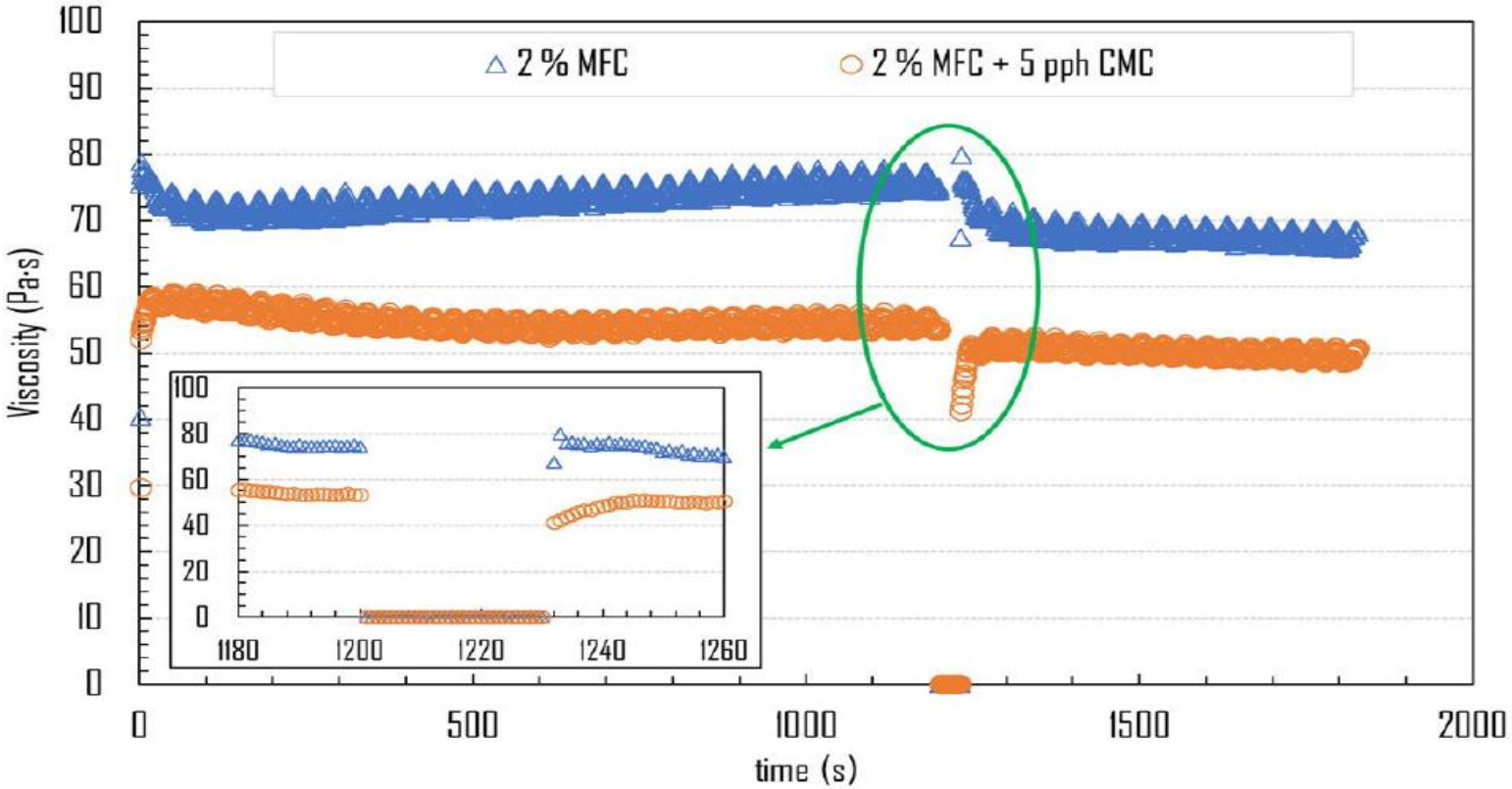


- Plasticizer: 5 wt% CMC (FINNFIX 4000G)
- Coating uniformity improves
- Helps with processing in three ways:
  - Improves water retention
  - Reduces low shear viscosity
  - Delays structure recovery

Impact of CMC on dewatering (ÅAGWR)

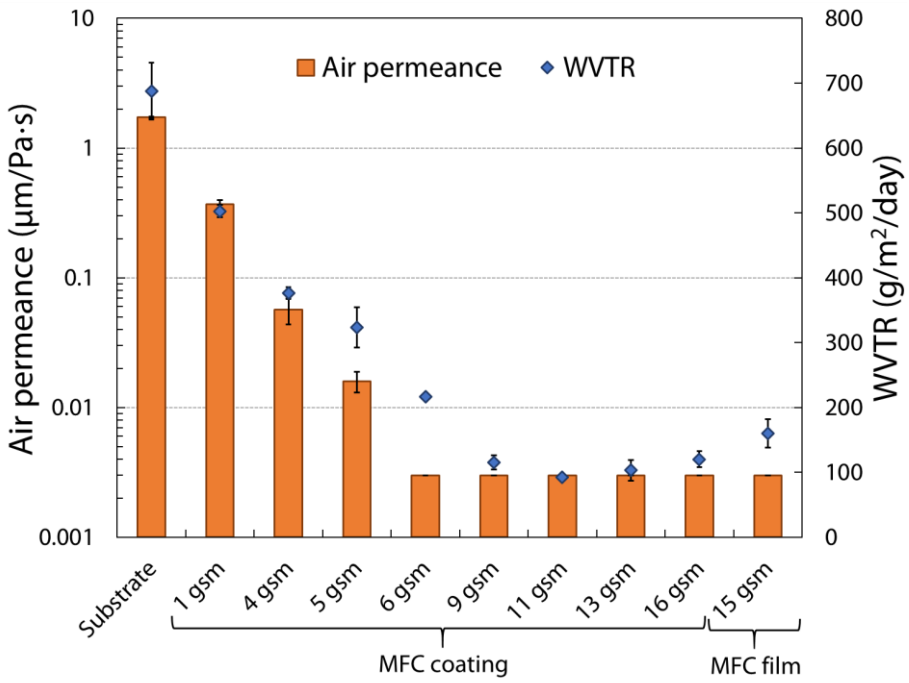


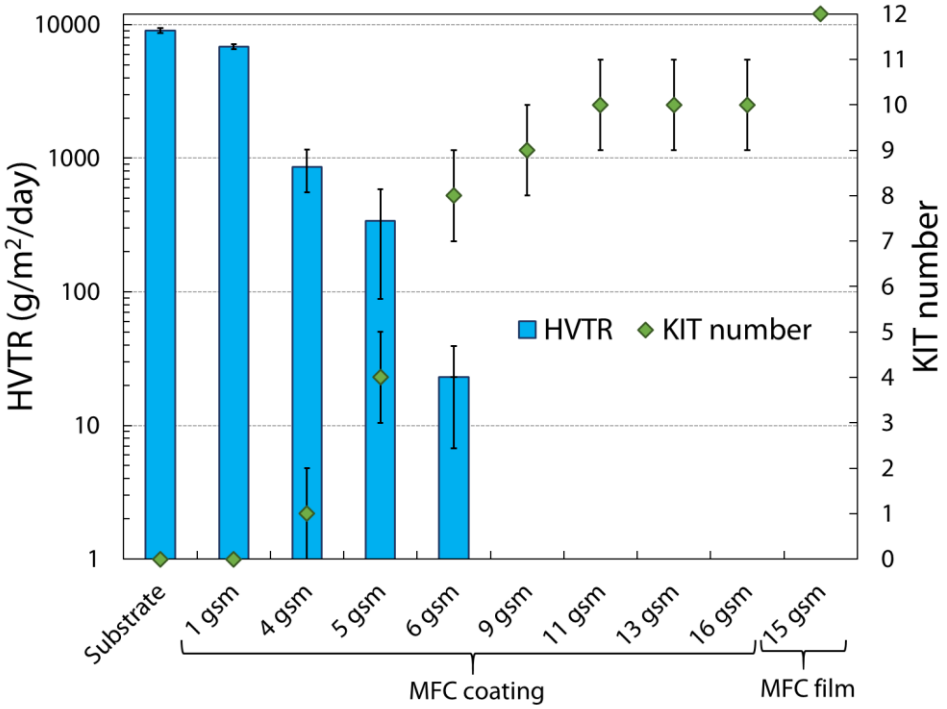
Impact of CMC on thixotropic behavior of MFC



Barrier Performance of MFC films/coatings

Air Permeance, WVTR, HVTR, grease resistance

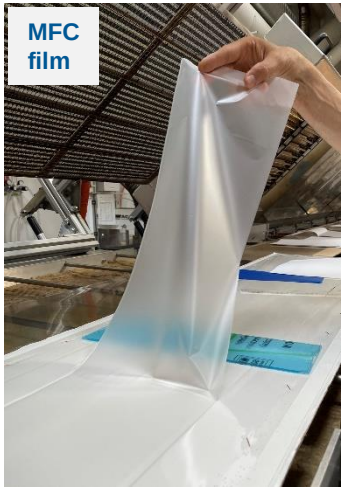




50% RH & 23°C

Examples of nanocellulose films and coatings in packaging applications

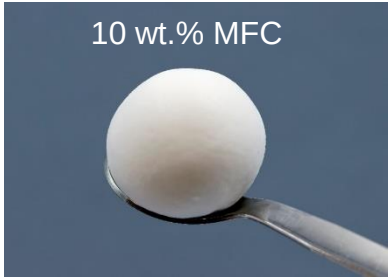
Nanocellulose film making on pilot scale



- ✓ Cellulose fiber based
- ✓ Excellent strength and barrier properties
- ✓ Transparent/translucent appearance
- ✓ 100% Recyclable (in paper stream)
- ✓ 100% biodegradable (soil and marine)
- ✓ Non-toxic and non-accumulative

- Nanocellulose coated evenly on plastic film
- Controlled spreading and adhesion
- No shrinkage (adhered to plastic while drying)
- Smooth base surface replicated to the film
- Tunable thickness

Scalable production of fibrillated cellulose films



HiCMF Tech.

Packaging film

- ✓ Oxygen barrier
- ✓ Oil and grease barrier
- ✓ Strong, foldable, creasable

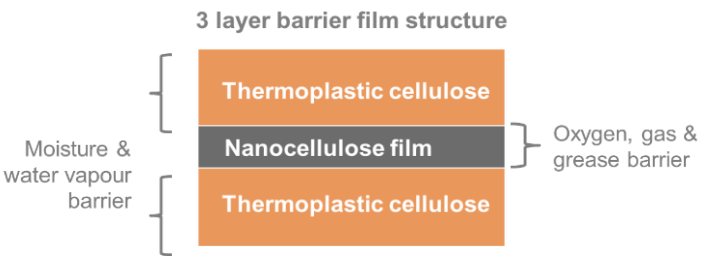
HiCMF Tech.

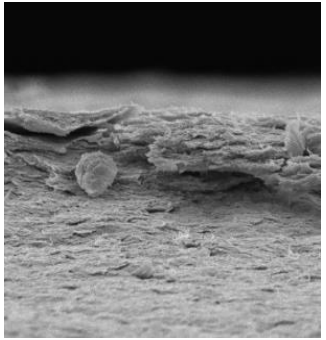
- ➢ Rapid low-cost film production
- ➢ Consumes 90% less water and energy
- ➢ Plug-in to existing industrial infra

HiCNF: High-consistency Cellulose Microfibrils Film

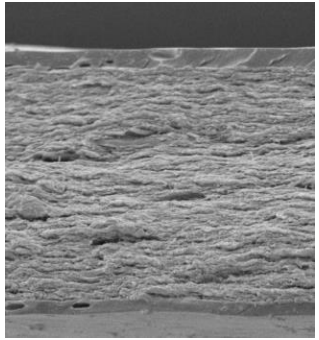
Patent pending: WO2020201627

Multilayer film structure from cellulose

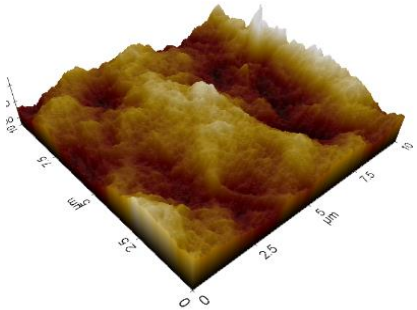


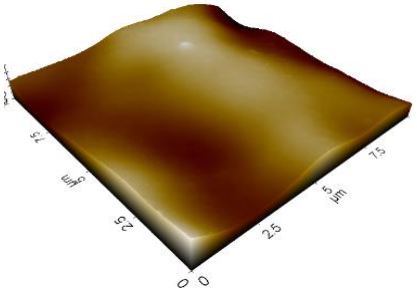


CNF



CNF+ThermoCell





Willberg-Keyriläinen *et al.* Carbohydrate Polymers (2017), 170, 160-165

Novel material solutions: Prototypes

Stand-up pouch

Bio-PE/CNF/PLA/Paper

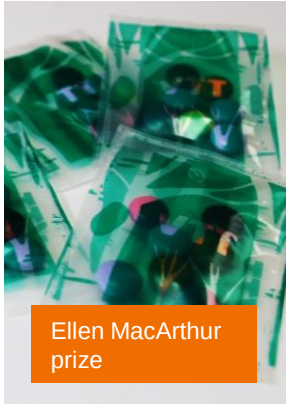
Bag-in-box

Bio-HDPE/CNF/(BioLDPE)

MAP

Bio-HDPE/PGA/(BioLDPE)

Multilayered films



Full cellulose
TPC/MFC/TPC

Packaging, coating and covers

Full cellulose
TPC coated board
+ TPC/MFC/TPC

PE - PolyEthylene can be replaced with ThermoCell

Fully bio-based packaging for chocolate and cookies

Structure	BioPBSA film Fibril. Cellulose coating BioPBSA film Paper	
Barrier performance	OTR ($cc/m^2/day$)	WVTR ($g/m^2/day$)
	1.06 ± 0.25	63.5 ± 0.8

https://www.packageheroes.fi/en/

Thank You

beyond
the obvious

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