Cellulose nanomaterials, processing methods and applications

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Outline

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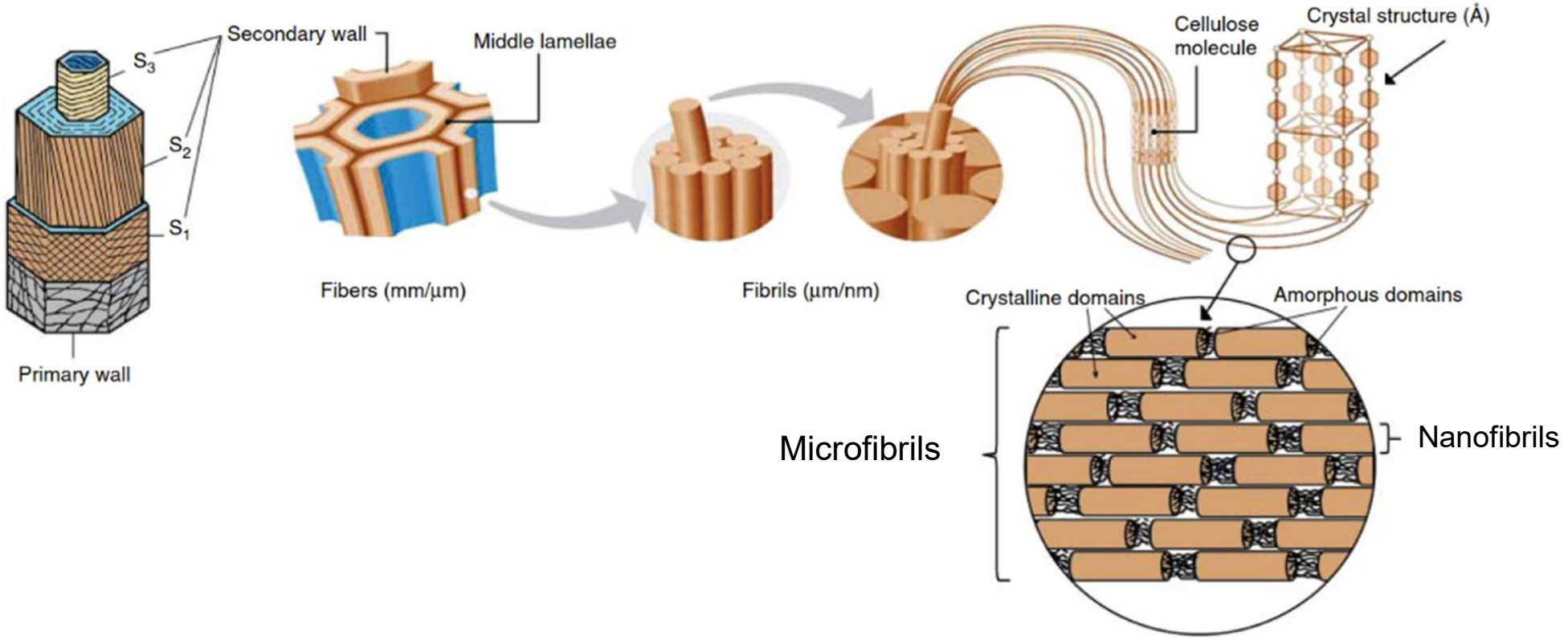
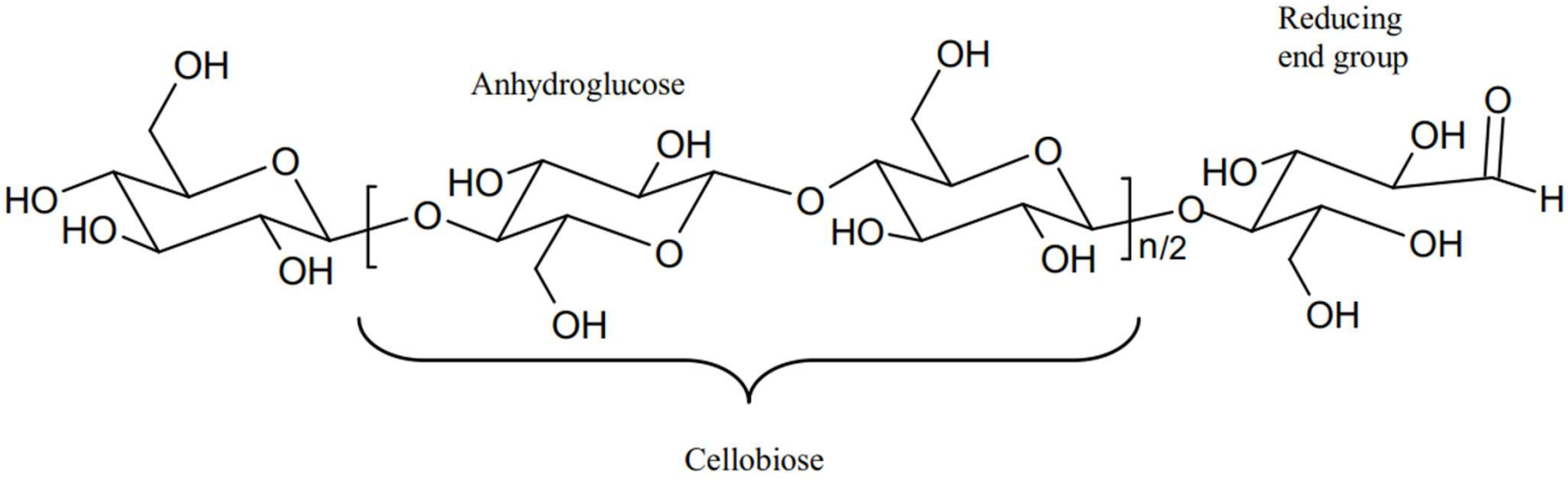
- **What are cellulose and cellulose nanomaterials?**
  - Terminology: NFC, MFC, BC, CNC
  - Advantages and properties
- **Mechanical processing and its history**
  - Various pretreatment methods
  - Economic barrier of the current nanocellulose extraction
  - Producers and their production capacity
- **Expectations and prospects**
  - Market forecast
  - Next supermaterial? Potential technical applications
  - TUT approach
- **Work shop demos**

What is cellulose?



Kargarzadeh, H., Handbook of Nanocellulose and cellulose nanocomposites, 2017

What is cellulose?



Terminology

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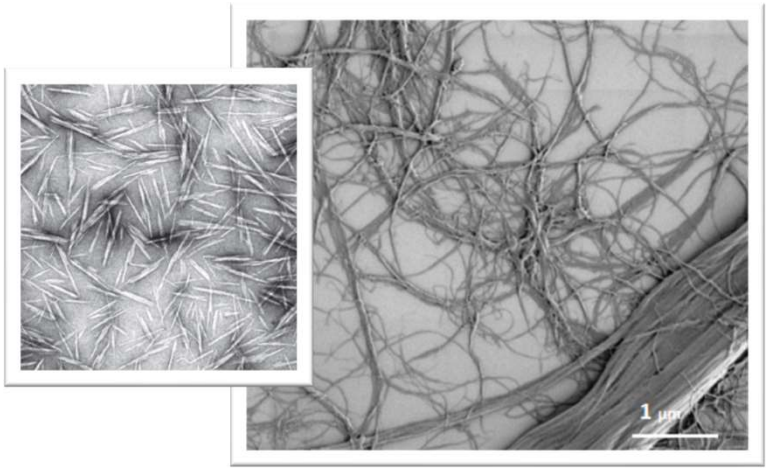
- **Nanofibrillar cellulose, cellulose nanofibrils (NFC, CNF)**
  - Long threads of individualized cellulose microfibrils
- **Microfibrillar cellulose, (MFC)**

	Length	Diameter
CNC	50–500 nm	3–20 nm
CNF	0.5–2 µm	3–100 nm
MFC	0.5–10's µm	10–100 nm



- **Cellulose nanocrystals, CNC**
  - Rigid rods of crystalline cellulose
- **Bacterial cellulose, BC**
  - A species of bacteria (acetobacteria xylinum) is able to produce pure cellulose microfibrils from sugars

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What nanocellulose and cellulose nanomaterials are?

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ADVANTAGES

abundant, bio-based, renewable, sustainable, and non-toxic

- **Mechanical**
  - ➢ High aspect ratio
- **Chemical**
  - ➢ Connections to itself and other materials
- **Physical**
  - ➢ Piezoelectric properties
- **Rheology**

Specifications

- Form: slurry, gel, powder
- Percent solids or percent moisture
- Particle size distribution
- Crystallinity
- Specific gravity
- Specific surface area
- Density
- pH
- Charge
- Additives

Mechanical processing methods

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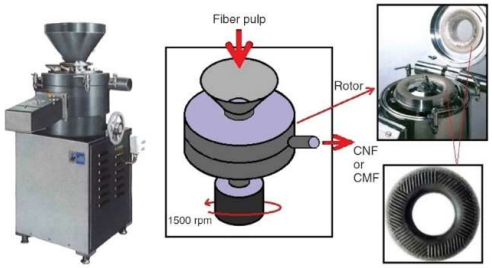
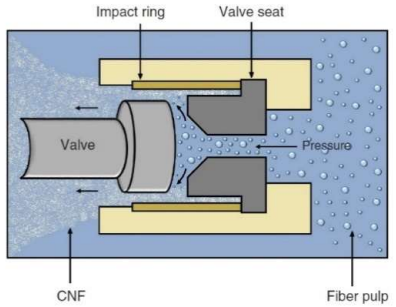
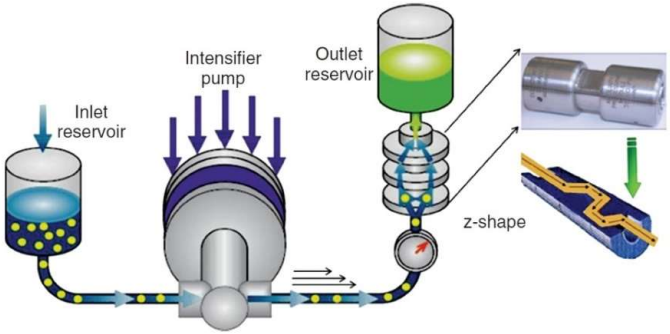
- High-Pressure homogenization
- Microfluidization
- High-intensity ultrasonication
- Grinding, microgrinding
- Cryocrushing
- Ball milling
- Steam explosion
- Dual water jet aqueous counter collision system







Kargarzadeh, H., Handbook of Nanocellulose and cellulose nanocomposites, 2017
Dufresne, A., Nanocellulose: From nature to high performance tailored materials, 2017
Phanthong, P., Nanocellulose: Extraction and application, 2018

Various pretreatment methods

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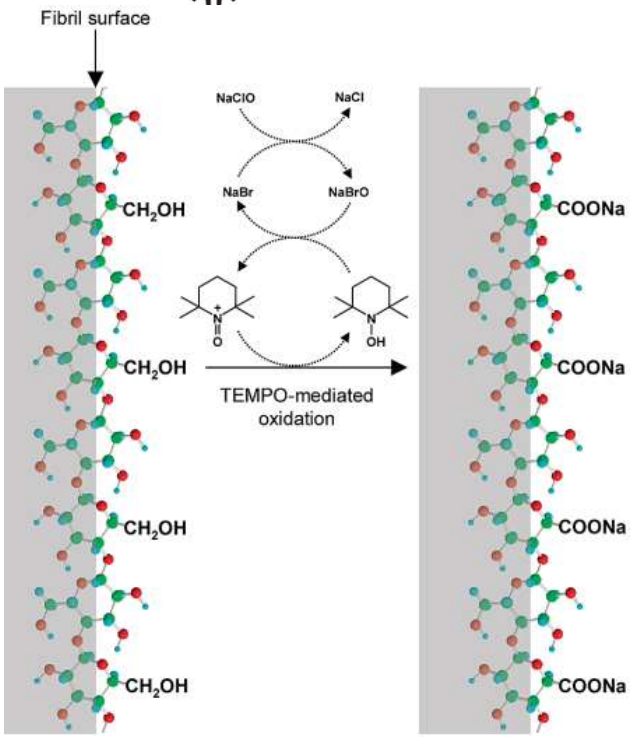
More efficient operation, reduced energy comsumption and improved quality.

- TEMPO-mediated oxidation
  - Cellulose hydroxyl groups to carboxyl groups
  - TEMPO catalyst is toxic and difficul to recycle
- Periodate oxidation
- Enzymatic



Energy consumption vary from 5580 kJ/kg to 78 800 kJ/kg
Meaning roughly 1500 kWh/ton to 20 000 kWh/ton

Okita et al. Biomacromolecules 2010, 11, 1696

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Expectations and prospects: Market forecast

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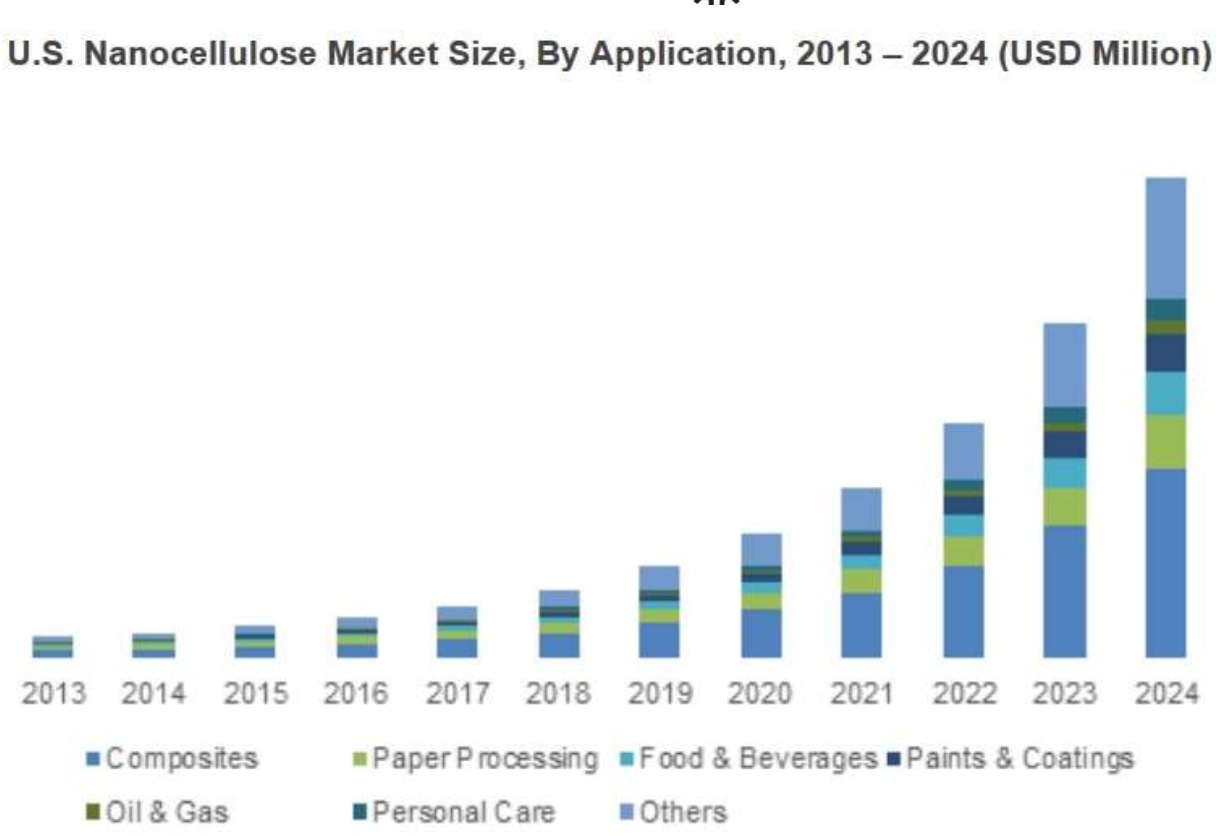
Nanocellulose market:
USD 1 billion by 2024

Nanofibrillated cellulose segment is said to gain the highest share of over USD 540 million by 2024

Key players: Nippon Paper Group Inc., Borregard ASA, Sappi Ltd., Innventia AB, Asahi Kasei Corporation, J. Rettenmaire & Sohne GmBH (JRS), Kruger Inc., Fp innovations, CelluForce Inc., CelluComp Ltd., Melodea Ltd., Daicel FineChem Ltd., Stora Enso and American Process Inc.



https://www.gminsights.com/industry-analysis/nanocellulose-market

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Producers and their production capacity

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Producer	Process	Capacity	
Nippon Paper, Japan	TEMPO, carboxylated	560	
Turners Falls Paper, U.S.	Mechanical	520	*
University of Maine, U.S.	Mechanical	260	*
American Process, U.S.	SO_2 fractionation	130	*
CelluComp, U.K.	Chemical pre-treatment	100	
Chuetsu Pulp and Paper, Japan	Aqueous counter-collision	100	
Oji Paper, Japan	Phosphate esterification	40	
Sugino Machine, Japan	Mechanical	26	*
Seiko PMC, Japan	Modified hydrophobic	24	
SAPPI, Netherlands	Chemical	5	*
VTT, Finland	Chemical, enzymatic	5	*
Tianjin Haojia Cellulose Co., Ltd., China	TEMPO, carboxylated	3	*
DKS Co. Ltd., Japan	TEMPO	1	
U.S. Forest Products Laboratory, United States	TEMPO, mechanical	<1	**
Daio Paper, Japan	N/A	Pilot	
ICAR-CIRCOT, India	Chemical, microbial	Pilot	
InoFib, France	Chemical pre-treatment	Pilot	
Luleå University of Technology, Sweden	Mechanical	Pilot	
Nanovin, Iran	N/A	Pilot	
U. of Kyoto (RISH), Japan	Modified hydrophobic	Pilot	
UPM, Finland	N/A	Pilot	

Capacity 2017
(metric tons/year, dry basis)

Next supermaterial? Potential technical applications

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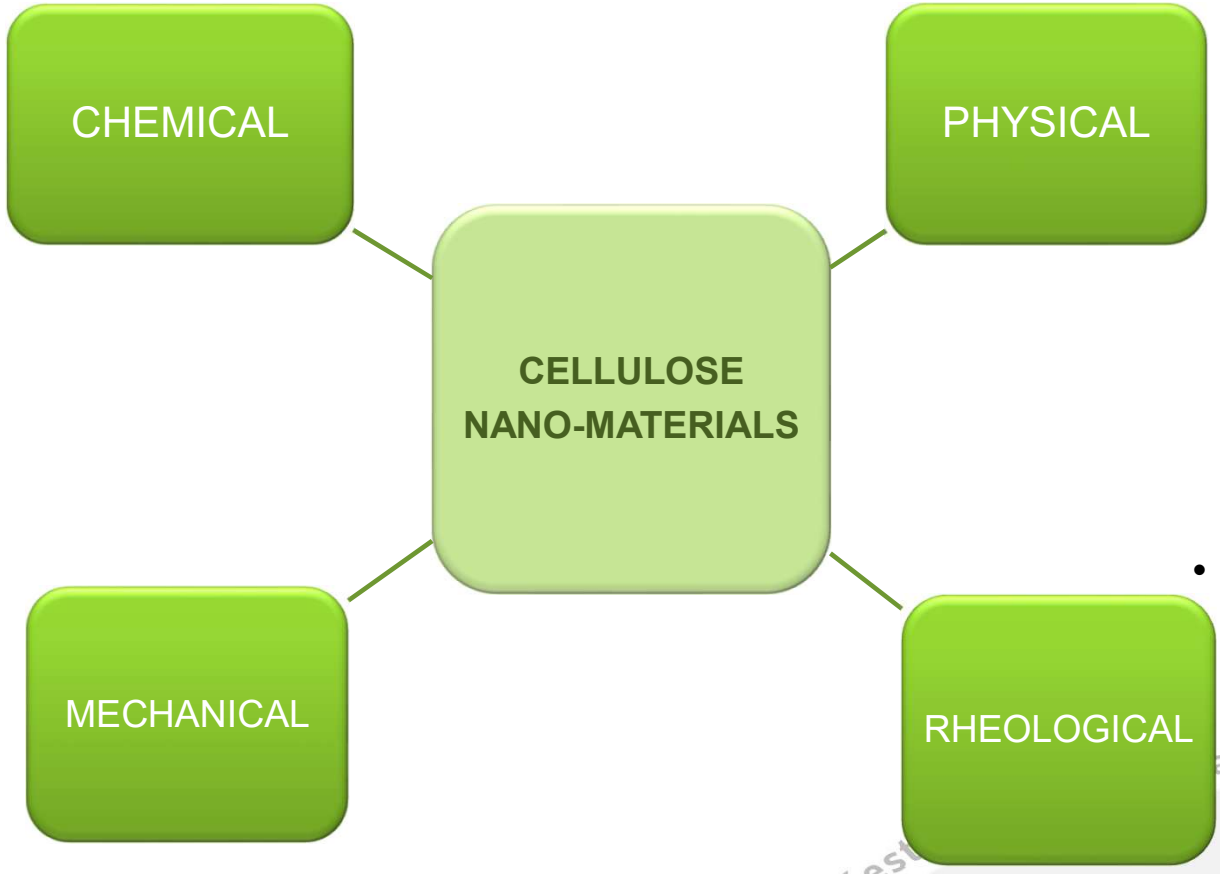
- Self-assembly
- Barrier properties
- Functionality
  - Conductivity
  - Heating



- Piezoelectric properties
  - Sensors

- Light weight materials with high strength
  - Composites
  - Films
  - Hybrids
  - Insulation

- Thixotropic modifier
  - Stabilizer

Economic barrier of the current nanocellulose extraction

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- High energy consumption
  - Fibrillation process, dewatering
- Multi-step processes
- High cost of the chemicals
- Maintenance of equipment operated in acidic environments
- Difficult acid wastewater treatment

TUT approach to overcome economic barriers

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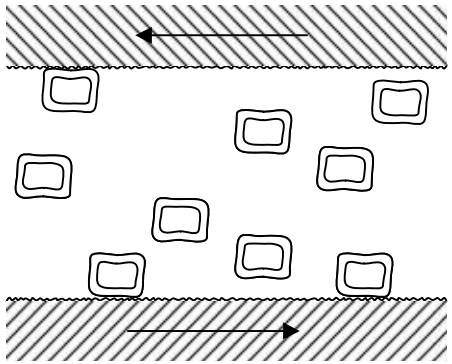
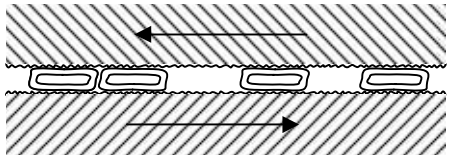
- Energy efficient microfibrillation
- Rising new methods for
  - Dewatering
  - Surface modification
  - Chemical treatments with green chemicals
- TUT investment for new machinery





Workshop demos

- Material samples
- Film samples
- Conductivity demo
- Heating element “Salmiakki”

Photos: Eeva Suorlahti
Design: Anastasia Ivanova

Thank You! Kiitos!

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