Cellulose nanofibrils (CNF) – a big hype or on the edge of a breakthrough

Webinar May 27th, 2015
Pia Qvintus & Heli Kangas
VTT Technical Research Centre of Finland Ltd
Introduction

PRESENTERS

Pia Qvintus
Head of Research Area
Fibres and biobased materials

Heli Kangas
Senior Scientist
High performance fibre products
VTT – Technology for business

VTT Technical Research Centre of Finland Ltd is the leading research and technology company in the Nordic countries. We provide expertise for our domestic and international customers and partners, and for both private and public sectors.

- Turnover 277 M€ (2014 VTT Group), personnel 2,600 (1.1.2015 VTT Group)
- Unique research and testing infrastructure
- Wide national and international cooperation network

Today: cellulose micro- and nanofibrils

Chain or rod-like structure
All dimensions in nanoscale

Nanocrystals
Image area 1x1 μm

Nanofibres
Image area 2x2 μm

Nanofibrillated
Image area 2x2 μm

Microfibrillated
Image area 2x2 μm

Charge/Chemistry

Colloidal dispersion
Polyelectrolyte-like
Decreasing surface charge

Wood-fibre like

Size/Dimensions/Branching

Bacterial cellulose

Ribbon-like structure
Overall dimensions in macroscale, fine structure in nanoscale

Branched structure
Overall dimensions in macroscale, fine structure in nanoscale


Market outlook
# Potential in key application markets

<table>
<thead>
<tr>
<th>Market</th>
<th>Market size (k ton)</th>
<th>Loading, %</th>
<th>Market penetration, %</th>
<th>Demand (k ton)</th>
<th>Estimated CAGR, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and paperboard</td>
<td>400,000</td>
<td>5</td>
<td>5-10</td>
<td>1000-2000</td>
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<tr>
<td>Excipients</td>
<td>4,600-550,000</td>
<td>2-10</td>
<td>2,5-6</td>
<td>2-3300</td>
<td>4-5</td>
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<td>Packaging composites</td>
<td>16,000</td>
<td>5</td>
<td>5-10</td>
<td>40-80</td>
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<td>High barrier packaging films</td>
<td>1,600</td>
<td>50</td>
<td>3-10</td>
<td>24-80</td>
<td>5</td>
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<td>Paints and coatings</td>
<td>40-44,000</td>
<td>2</td>
<td>3-6</td>
<td>26-53</td>
<td>4</td>
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<tr>
<td>Manufactured textiles</td>
<td>50-56,000</td>
<td>2</td>
<td>2-5</td>
<td>20-56</td>
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<tr>
<td>Natural textiles</td>
<td>35,000</td>
<td>2</td>
<td>2-5</td>
<td>14-35</td>
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<tr>
<td>Oil&amp;Gas</td>
<td>17,500</td>
<td>1</td>
<td>5</td>
<td>9</td>
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<tr>
<td>Natural fiber composites</td>
<td>5,500</td>
<td>2</td>
<td>3-7</td>
<td>3-8</td>
<td>10-12</td>
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<tr>
<td>Non-wovens</td>
<td>7,000</td>
<td>2</td>
<td>5</td>
<td>7</td>
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<tr>
<td>Adhesives</td>
<td>4,000</td>
<td>2</td>
<td>5</td>
<td>4</td>
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<tr>
<td>Cement</td>
<td>15-16,000</td>
<td>0,5-1</td>
<td>2-5</td>
<td>1,5-8</td>
<td>7-8</td>
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<tr>
<td>Functional and barrier coatings (in paper and board)</td>
<td>2,000</td>
<td>2</td>
<td>3-6</td>
<td>1-2</td>
<td>4-5</td>
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### Stage of commercialisation

<table>
<thead>
<tr>
<th>Applications</th>
<th>Research (Basic concept + Tech concept)</th>
<th>Applied research &amp; development (Proof of concept→Lab tested→Field tested)</th>
<th>Demonstration (Basic prototype→Field prototype)</th>
<th>Commercial (Fully tested→in operation)</th>
</tr>
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<tbody>
<tr>
<td><strong>High Volume Applications</strong></td>
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<tr>
<td>Cement additives</td>
<td></td>
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<tr>
<td>Anti-static coatings</td>
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<td>Transparent barrier films in food packaging</td>
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<td>Polymer composites</td>
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<td>Printing paper</td>
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<td>Pharmaceutical (filler)</td>
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<td>Paper composites</td>
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<td>Self-cleaning coatings</td>
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<tr>
<td>Filtration</td>
<td></td>
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<td><strong>Low Volume Applications</strong></td>
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<td>Insulation</td>
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<td>Medical implants</td>
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<td><strong>Novel Applications</strong></td>
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<tr>
<td>Flexible circuits, printable electronics, conductive substrates</td>
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<tr>
<td>Drug delivery</td>
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Nippon Paper
Asahi Kasei
Verso Paper
Oji Holdings

Paper and board
Healthcare
Non-Wovens
Composites

Several commercial products based on CNF already on the market
CNF – Production status

- American Process Inc. (USA)
- University of Maine (USA)
- Kruger (CAN)

- Stora Enso (FI)
- UPM (FI)
- Inventia (SWE)
- Borregaard (NO)
- BillerudKorsnäs (SWE)
- Norske Skog (NO)

- CNF – Production status
  - Commercial
  - Pre-commercial
  - Pilot
  - Under planning/construction

- Imerys
  - CelluComp

- Rettenmaier (GE)
  - CTP/FCBA (FR)
  - AkzoNobel (NL)
  - Munksjö (FRA)
  - BASF (GE)
  - Sappi (NL)

- Asahi Kasei
  - Chuetsu Pulp & Paper
  - Daicel
  - Daiichi Kogyo
  - Daio Paper
  - Nippon Paper
  - Oji Holdings
  - Sugino Machine
  - Seiko PMC

- Suzano (BRA)
Production estimates


Significant increase in production expected

Source: RISI, NANOCELLULOSE: Technology, Applications and Markets 2014

Table 1
Nanocellulose Forecast to 2025

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2020</th>
<th>2025</th>
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<tbody>
<tr>
<td>CNF</td>
<td>10</td>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td>CNC</td>
<td>&lt; 1</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>BNC</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
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Source: Market-Intell
Innovation landscapes
Innovation landscape services
- Foresee the trends and technologies with VTT

Clarify your business opportunities

Identify your competitors

Find customers and partners

Find technology trends

Commercialise your patents and research results

Market forerunner and opinion influencer
From science to technology
Extensive knowledge in cellulose nanomaterials

Over 2000 samples produced and analysed.

Over 40 different partners & customers

More than 40 different raw materials used

Project portfolio ~53M€ since 2008

Over 2000 samples produced and analysed.

Over 40 different partners & customers

More than 40 different raw materials used

Project portfolio ~53M€ since 2008
International co-operation

"Our laboratory is actively advancing collaborative researches with VTT in terms of fundamentals and applications of nanocelluloses, and we are obtaining synergistic effects and significant results in nanocellulose science.

It is also valuable for us to establish nanocellulose-related human networks between Finland and Japan, enabling student and researcher exchange”
Scale-up of CNF manufacturing

High-consistency enzymatic fibrillation (HefCel)

CNF in paper & board

CNF films

Rheology of CNF suspensions

CNF as rheology modifier

CNF yarns

Performance vs. cost

Production method selected based on the application requirement

- Grinding
- High-pressure homogenization
- Refiner
- Extrusion
- Ball milling
- Enzymatic

Fibrillation potential

Coarse

Fine

Low

High

Production cost
Cellulose nanofibril development
Pre-commercial production launched in 2011

UPM HAS STARTED PRE-COMMERCIAL PRODUCTION OF FIBRIL CELLULOSE

(UPM, Helsinki, 15 November 2011) UPM has started pre-commercial production of fibril cellulose using new technology for converting wood into nanofibrillar cellulose. UPM says the new technology will enable the production of high quality cellulosic materials suitable for a wide range of applications. The first phase of the project has demonstrated the feasibility of the process, and the next phase will focus on scale-up and commercialisation.

UPM initiated the turnkey project development process in 2008. Pre-commercial production began at a site in Otaniemi, Espoo, Finland. UPM is now able to provide different types of fibril cellulose for extensive customer testing. UPM's objective is to create a commercial-scale process for producing fibril cellulose.

The production process used by UPM for fibril cellulose was developed in cooperation with VTT. The fibres in the fibril cellulose are obtained from the wood furnish and selected for their quality. The fibril cellulose is produced in a process that involves mechanical and chemical treatments. The fibril cellulose is then washed and dried to produce the final product.

Fibril cellulose can be used in a wide range of applications. UPM's fibril cellulose provides new opportunities for various industries, including the pulp and paper, the chemical, and the pharmaceutical industries. Fibril cellulose can be used in applications such as coatings, adhesives, and composite materials.

When water is added to fibril cellulose, a gel-like structure is formed. This means that fibril cellulose can be used in applications where a high degree of flexibility and strength are required.

UPM's fibril cellulose has been used in several applications, including the production of composite materials for the automotive industry. The use of fibril cellulose in composite materials has led to significant improvements in the strength and flexibility of the materials.

UPM's fibril cellulose has also been used in the production of paper and board products. The fibril cellulose is used as a reinforcement material to improve the strength and stiffness of the paper and board products.

UPM is currently working on improving the production process and scaling up the production of fibril cellulose. The company plans to continue improving the process and expanding the use of fibril cellulose in various applications.

WEBINAR TOPIC LINE:
INTRO MARKET OUTLOOK Application Status INNOVATION LANDSCAPES Case study SCIENCE TO TECHNOLOGY Case studies FAST TO MARKETS CONCLUSIONS
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- High-consistency enzymatic fibrillation (HefCel)
- CNF in paper & board
- CNF films
- Rheology of CNF suspensions
- CNF as rheology modifier
- CNF yarns


CNF in paper & board
High-consistency enzymatic fibrillation (HefCel)
CNF films
Rheology of CNF suspensions
CNF as rheology modifier
CNF yarns
Towards lower energy consumption and reduced costs

Enzyme assisted, high consistency (20-40%), low energy production of fibrillated cellulose

VTT’s HefCel concept
VTT’s HefCel concept

VTT’s HefCel concept

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WEBINAR TOPIC LINE:
High consistency enzymatic fibrillation

- Extremely low energy consumption (energy cost ~1€/ton)
- Commercially available cellulase enzyme
  - Inactivation by boiling or steam
- The fibrillation degree can be tuned by treatment time and enzyme concentration
- Potential to produce high value sugars as a by-product
- VTT will launch a project on upscaling during 2016

Test the performance in your application

3 h
5 h
9 h
WEBINAR TOPIC LINE:

INTRO
MARKET OUTLOOK
Application
Status
INNOVATION LANDSCAPES
Case study
SCIENCE TO TECHNOLOGY
Case studies
FAST TO MARKETS
CONCLUSIONS

Scale-up of CNF manufacturing

High-consistency enzymatic fibrillation (HefCel)

CNF in paper & board

CNF films

Rheology of CNF suspensions

CNF as rheology modifier

CNF yarns


2008

Scale-up of CNF manufacturing

2010

CNF in paper & board

2012

CNF films

2014

Rheology of CNF suspensions

2015

High-consistency enzymatic fibrillation (HefCel)

CNF as rheology modifier

CNF yarns
Lightweighting with CNFs

1-2% CNF added to paper - Trial at VTT’s pilot research environment

- Reduction of wire section dewatering but dry solids 1-3%-unit **higher** after the press section
- Potential to measure retention and distribution of CNFs

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**Increased strength without compromising dewatering**

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I. Kajanto and M. Kosonen, UPM - 2012 TAPPI International Conference on Nanotechnology for Renewable Materials
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CNF yarns
CNF multilayer films

- CNF acts as an oxygen barrier
- Heat-sealibility and moisture barrier by using bio-Polyethylene (PE) as the outer layers

Minimum C14 content >95% "biobased content"

Improved moisture sensitivity with multilayer films
Water stable membranes through chemical modification

Typically films made from cellulose nanofibrils are highly unstable in water

Water stability greatly improved with simple chemical modification (PVA)
Manufacturing of CNF films in semi-pilot scale

Potential application areas
- **Packaging:** High oxygen barrier
- **Sensors:** Moisture uptake ability
- **Membranes:** Hydrophilic films
- **Printed Electronics:** Smooth and dense films

Patented technology WO2013/060934

Potential application areas:
- **Packaging:** High oxygen barrier
- **Sensors:** Moisture uptake ability
- **Membranes:** Hydrophilic films
- **Printed Electronics:** Smooth and dense films
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Scale-up of CNF manufacturing

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CNF films

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CNF as rheology modifier

CNF yarns

2008-2010:
- CNF films

2010-2012:
- Rheology of CNF suspensions
- CNF in paper & board

2012-2014:
- Scale-up of CNF manufacturing
- CNF as rheology modifier

2014-2015:
- High-consistency enzymatic fibrillation (HefCel)
- CNF yarns
Flow behaviour of CNF depends on the grade and concentration


VTT, unpublished results
CNF as rheology and stability modifier

Formulations for emulsions, dispersions, gels and foams

Rheology development and testing

Wide process performance range
Excellent pH, temperature and salt stability.

Nutritional value, Biocompatibility

Application related tailored solutions

Pilot-scale flow behavior testing and process verification

Food & Pharma
Cosmetics
Oil & gas
Paint & Cement Industry

CNF as rheology and stability modifier

Rheology
development
and testing

Formulations for
emulsions, dispersions, gels
and foams

Nutritional value, Biocompatibility

Application related tailored solutions

Wide process performance range
Excellent pH, temperature and salt stability.

Paint & Cement Industry

Oil & gas

Food & Pharma

Cosmetics
CNF filaments & yarns

- Prepared by extrusion process
  - No dissolution and regeneration
- Very good mechanical properties

Enabled by profound knowledge on systems rheology
Fast to markets through co-operation
Status and future outlook

- We believe that CNF is on the verge of a breakthrough
  - However, some applications far, far away (hype)

- First commercial products are already on the market

- Availability will not soon anymore limit commercialization

- Higher value applications are emerging

- Scientific excellence can help to overcome bottlenecks
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INTRO
MARKET OUTLOOK
APPLICATION
INNOVATION LANDSCAPES
CASE STUDIES
SCIENCE TO TECHNOLOGY
FAST TO MARKETS
CONCLUSIONS

INDUSTRY

VTT

Business env.
Application
Piloting
Implementation

Raw material
Market

Functionalisation
Material properties
Small-scale feasibility

Rheology
Films
Enzyme technology

Barriers

Market awareness
Innovation landscape

Raw materials

Scientific excellence

2015
Partnering for success

- Cellulose micro- and nanofibrils have **a huge potential** in several applications
  - packaging, oil&gas, paints, cement, composites, pharma, cosmetics etc.
- The major challenge is their **cost competitiveness**
  - In each sector there are a lot of alternatives available
- **Key to success** is a seamless co-operation requiring
  - a good understanding of market needs, business&innovation landscapes, raw materials AND
  - scientific excellence combined with fast piloting
- **VTT** partners with innovative companies to help in **commercialization** of CNFs
  - Value chain approach: from raw materials to applications
Key learnings

- There are quite a few CNFs on the markets already and new applications are expected to emerge even faster.
- High consistency enzymatic fibrillation could be a breakthrough for certain applications.
- CNFs have a great potential as strength additives, in multilayer films & membranes and as rheology modifiers.
- Application driven approach: Combine the right raw material with the most suitable production technology.
MEET US

- International workshop on biorefinery of lignocellulosic materials (June 9-12, Cordoba, Spain)
- Tappi Nanotechnology Conference (June 22-25, Atlanta, USA)
- PTS Coating Symposium (September 16-17, Munich, Germany)
- Nordic Wood Biorefinery Conference (October 20-22, Helsinki)
- Tokyo Paper 2015 (October 29- November 1, Tokyo, Japan)
Further questions

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Find out more about VTT’s activities related to fibre-based value chains at ForestTech industrial platform  
www.vtt.fi/foresttech
TECHNOLOGY FOR BUSINESS