



Biorefinery Cellulose Nanomaterials

Worlds collide



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Worlds collide



- Biorefineries and pulp mills

By Credit: NASA; ESA; Z. Levay and R. van der Marel, STScI; T. Hallas, and A. Mellinger - http://www.nasa.gov/mission_pages/hubble/science/milky-way-collide.html, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=19992539>

Worlds collide



- Biorefineries and pulp mills
- MCC and CNC/CNF/MFC

By Credit: NASA; ESA; Z. Levay and R. van der Marel, STScI; T. Hallas, and A. Mellinger - http://www.nasa.gov/mission_pages/hubble/science/milky-way-collide.html, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=19992539>

Biorefinery cellulose nanomaterials

- Low cost feedstock vs pulp
- Feedstock contains lignin
- Co-products can include lignin, C5 and C6 sugars, ethanol
- Cellulose nanomaterials can include lignin and can be blends or hybrids of MCC/CNC/CNF/MFC

What is a cellulose nanomaterial?

Material composed predominantly of cellulose, with any external dimension in the nanoscale, or a material having internal structure or surface structure in the nanoscale, with the internal structure or surface structure composed predominantly of cellulose.

Source: <https://www.iso.org/obp/ui/en/#iso:std:iso:ts:20477:ed-2:v1:en> (2023)

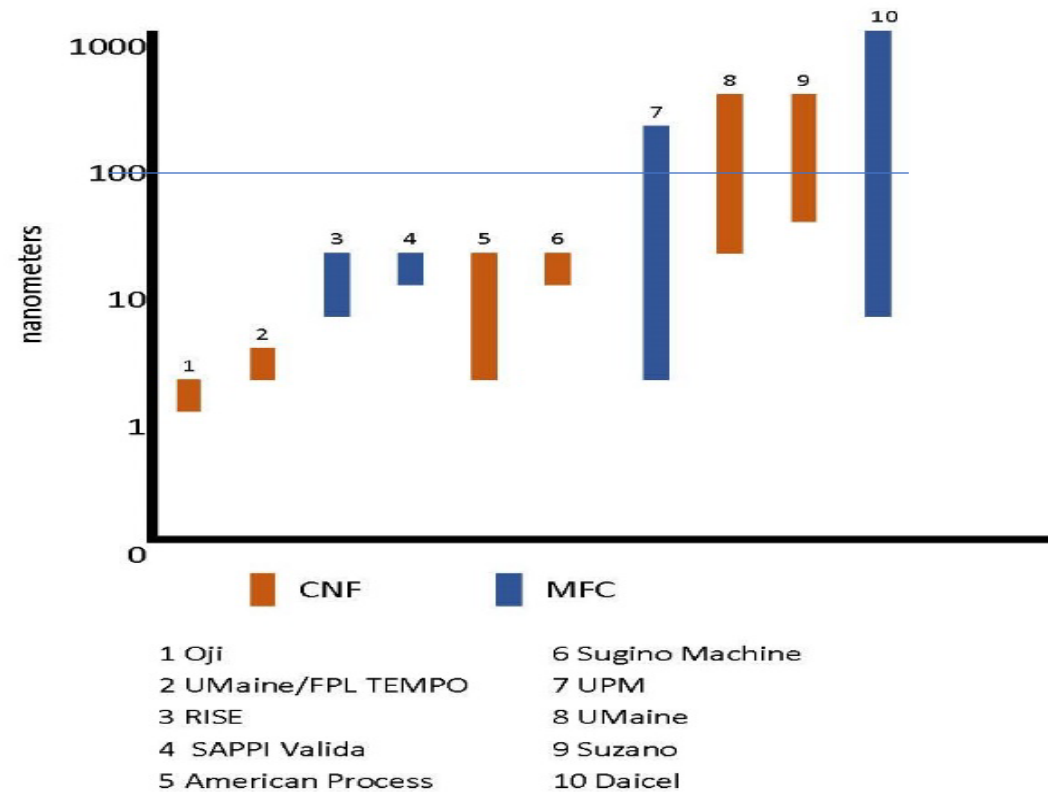
Types of “nano” “cellulose”

It used to be simple:

- Cellulose nanocrystals (CNC): Sulfuric acid hydrolysis “dissolves” the amorphous regions leaving CNC.
- Cellulose nanofibrils (CNF): entangled fibrils with high aspect ratio formed by mechanical process, sometimes with enzymatic or chemical pretreatment.
- Microfibrillated cellulose (MFC): like CNF, but micro-scale rather than nano-scale

CNF or MFC??

(particle diameter in nanometers)



Source: J. Miller, *Nanocellulose Producers, Products, and Applications: A Guide for End Users*, TAPPI, 2017

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But now, biorefineries are producing a variety of materials such as hybrid CNC/CNF, lignin containing CNC or CNF, and MCC which is agglomerated CNC or CNF.

What is a cellulose nanofibril?

Cellulose nanofiber composed of at least one [elementary fibril](#) that can contain branches, a significant fraction of which are in the nanoscale.

The dimensions are typically 3 nm to 100 nm in cross-section and typically up to 100 μm in length.

CNF can form entanglements between particles or network-like structure when the distance between CNF fibres is sufficiently close.

Cellulose nanofibrils from plant sources, produced by mechanical processes, can be accompanied by [hemicellulose](#), and in some cases lignin.

Source: <https://www.iso.org/obp/ui/en/#iso:std:iso:ts:20477:ed-2:v1:en> (2023)

What is a cellulose nanocrystal?

Nanocrystal composed predominantly of cellulose containing predominantly crystalline and paracrystalline regions, with at least one elementary fibril, not exhibiting longitudinal splits.

The aspect ratio of cellulose nanocrystals is usually smaller than 50 but usually greater than 5, where aspect ratio refers to the ratio of the longest to the shortest dimensions.

Cellulose nanocrystals do not exhibit interparticle entanglement or network-like structures.

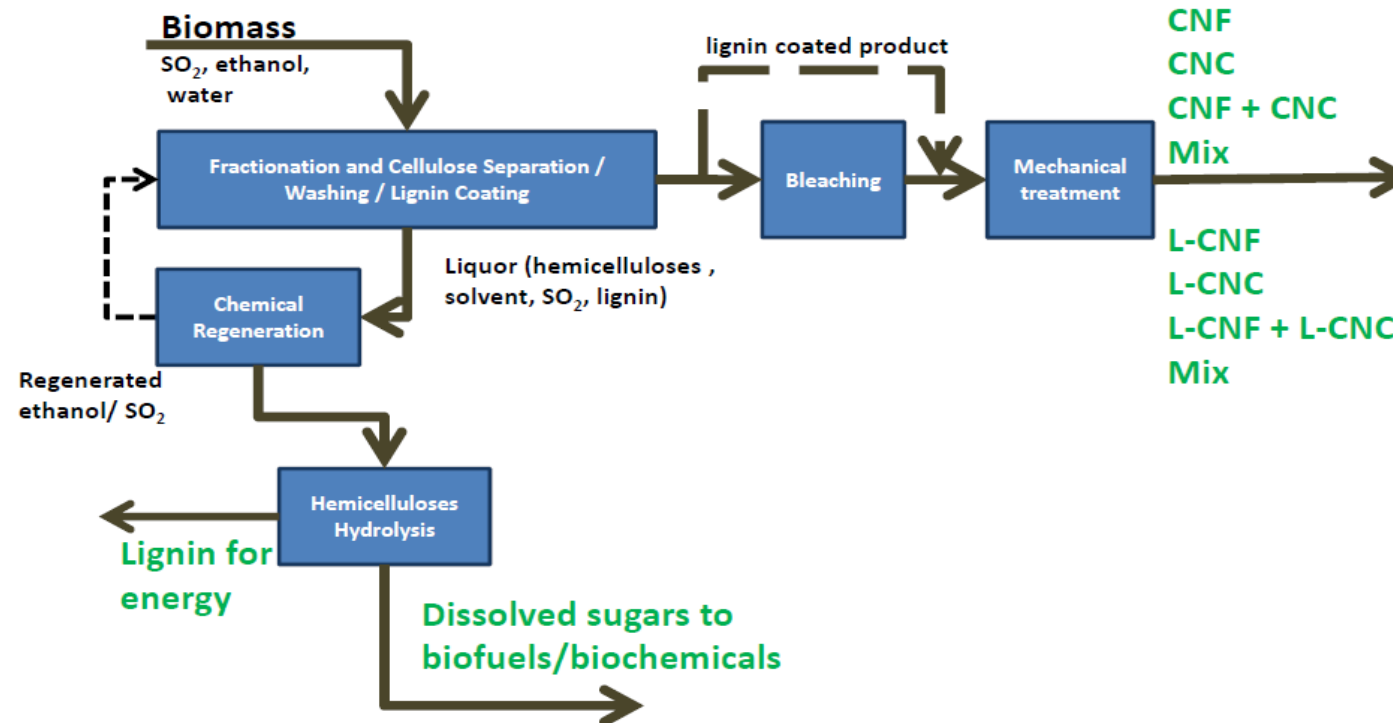
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Biorefineries

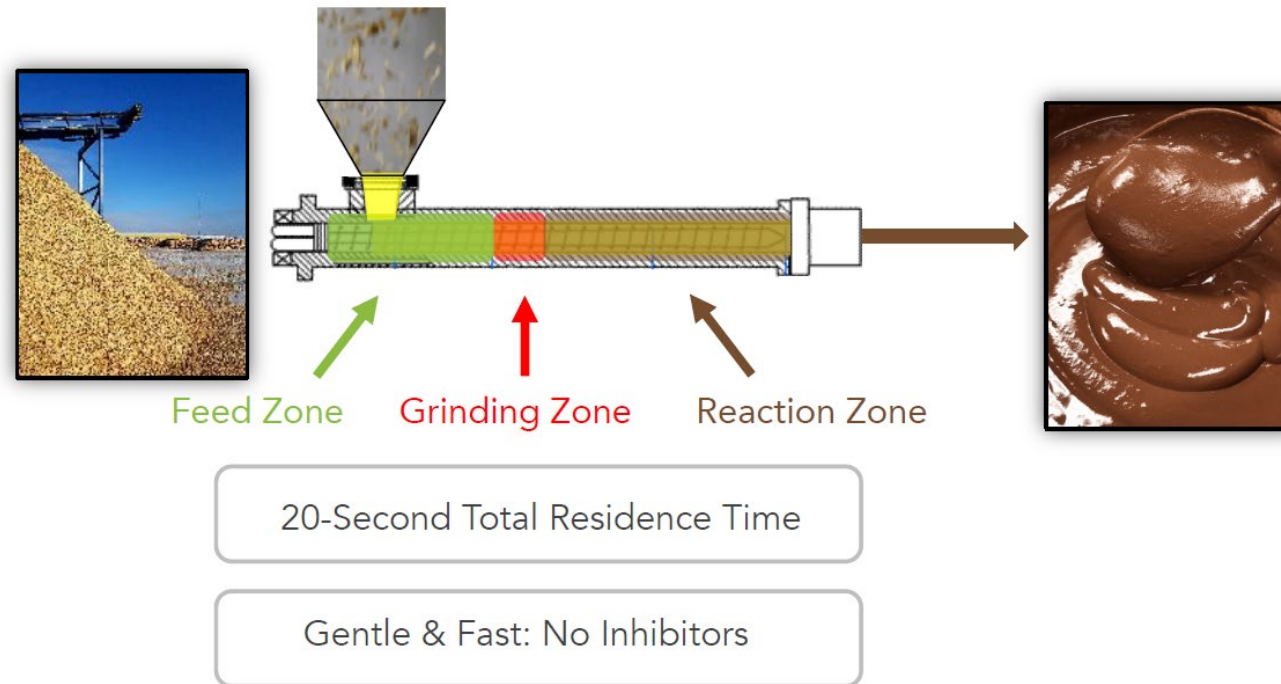
- AVAP Process – GranBio
- Sweetwoods Project – Fibenol
- Borregaard
- CELLiCON
- CelluComp
- Genera
- Melodea
- Nordic Bioproducts Group
- Re-Fresh Global

AVAP Process



Source: J. Miller, *Nanocellulose Producers, Products, and Applications: A Guide for End Users*, TAPPI, 2017 (originally K. Nelson, presentation at TAPPI Nano, Vancouver, 2014)

Sunburst Reactive Extrusion



4

Source: J. Miller, *Lignin 2021: a Pivotal Year*; Sweetwater Energy

Fibenol

- MCC from hardwood
- Sunburst reactive extrusion - fractionation
- MetGen enzymatic hydrolysis to separate the fractions
- Lignin, cellulosic wood sugars

Source: J. Miller, *Lignin 2021: a Pivotal Year*

Borregaard

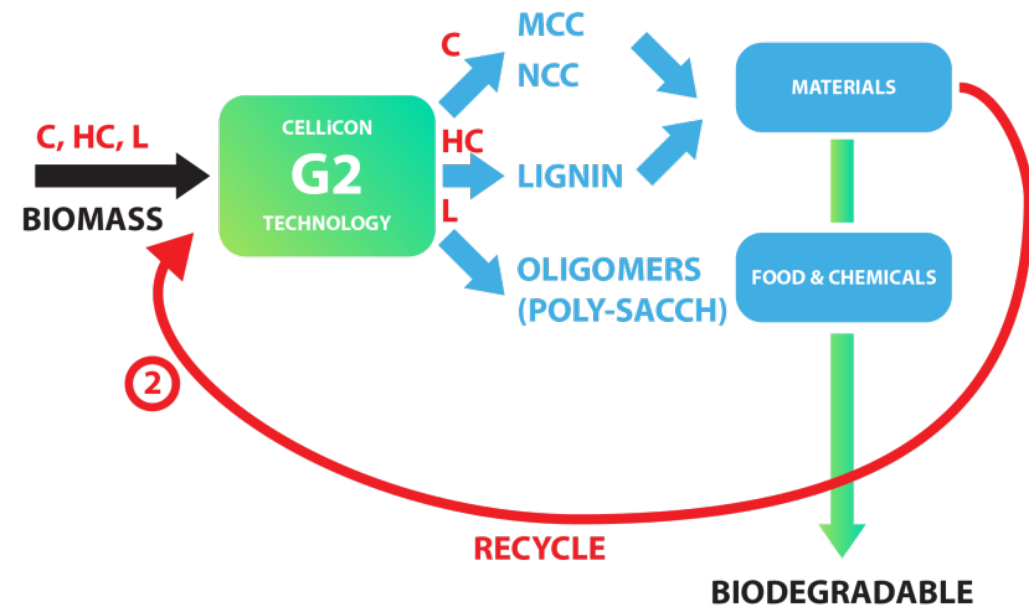
- Exilva® microfibrillated cellulose from Norway spruce
- Entangled, fibrillated cellulose fibres with the ability to interact both physically and chemically through hydrogen bonding
- Fibrils retain crystallinity features
- Barrier coatings, rheology modifiers, etc.



Source <https://www.borregaard.com/product-areas/cellulose-fibrils/>

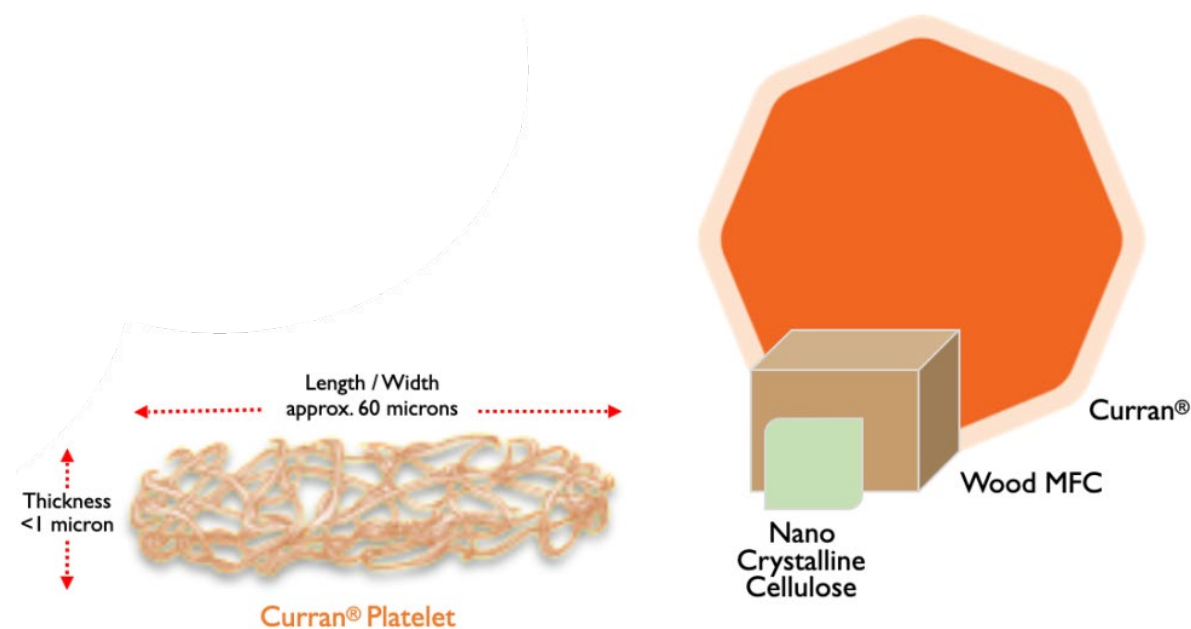
CELLiCON

- Netherlands-based; part owned by Sulzer
- G2 technology fractionates biomass and textile waste into lignin, MCC and NCC
- Proprietary technology based on simple molten salt hydrates
- Low cost, low energy process uses no enzymes



CelluComp

- Curran® Microfibrillated Cellulose from sugar beet pulp
- Relatively flat, microscopic fibre bundles which are actually portions of cell walls
- Paste or granules
- Barrier coatings



Source: <https://www.cellucomp.com/>

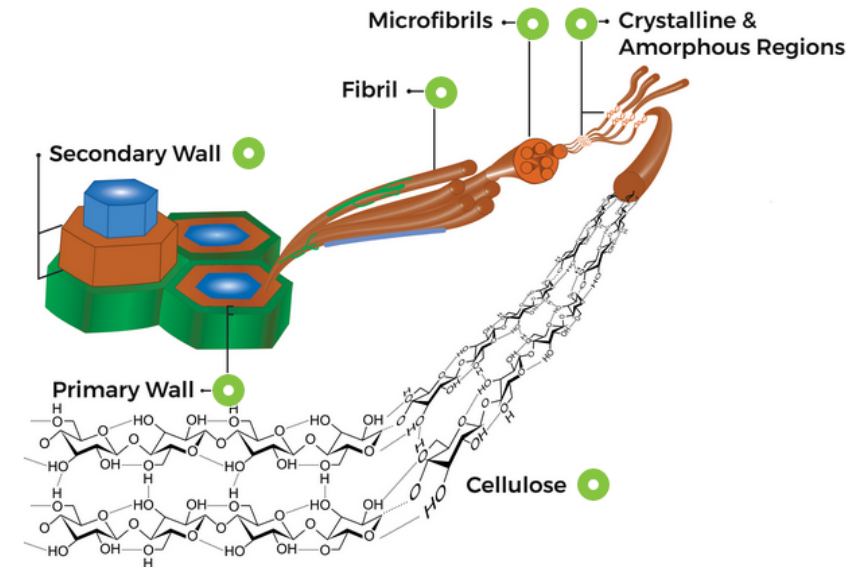
Genera



- Vonore, TN Fiber Products Mill
- Vonore, TN Biomass Innovation Park
- Ag-based compostable molded fiber products with MFC
- Market pulp
- Lignin co-product

Melodea

- CNC from wood pulp and paper production side streams
- MelOx™, a plant-sourced barrier coating that protects packaged products from oxygen transmission
- VBcoat™ & Melodea VBseal™ which protects packaged goods from water vapor and oil & grease transmission.



Nordic Bioproducts Group (NBG)



- Microcrystalline cellulose (MCC) from kraft pulp with AaltoCell™
 - Novel hydrolysis process
 - 10,000 t/a
 - Pharma, supplements, food ingredients, cosmetics and biocomposites
- Pilot scale production of carboxylated cellulose nanomaterials from MCC
- Partner with CMPC Ventures to produce textile fibers with Norratex process

Re-Fresh Global



- Biotech company with a patented process that converts textile waste into cellulose nanomaterials called **Re-Nano™**
- Patented microfibrillated cellulose that enhances the strength, stability, and flexibility of numerous natural products

Conclusions

- Different source materials; different processes
- Different economics
 - Low cost feedstock vs pulp
 - Different outputs: lignin, C5 and C6 sugars, biochemicals, ethanol
- Different products: MCC - definitions are evolving
- Cellulose nanomaterials can include lignin and can be blends or hybrids of MCC/CNC/CNF/MFC
- Different characteristics: particle size, crystallinity, surface chemistry, charge, purity, thermal stability, rheological behavior, optical

References

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Thank you

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