Overview Functional Cellulose

Marie Bäckström
RISE

Summary

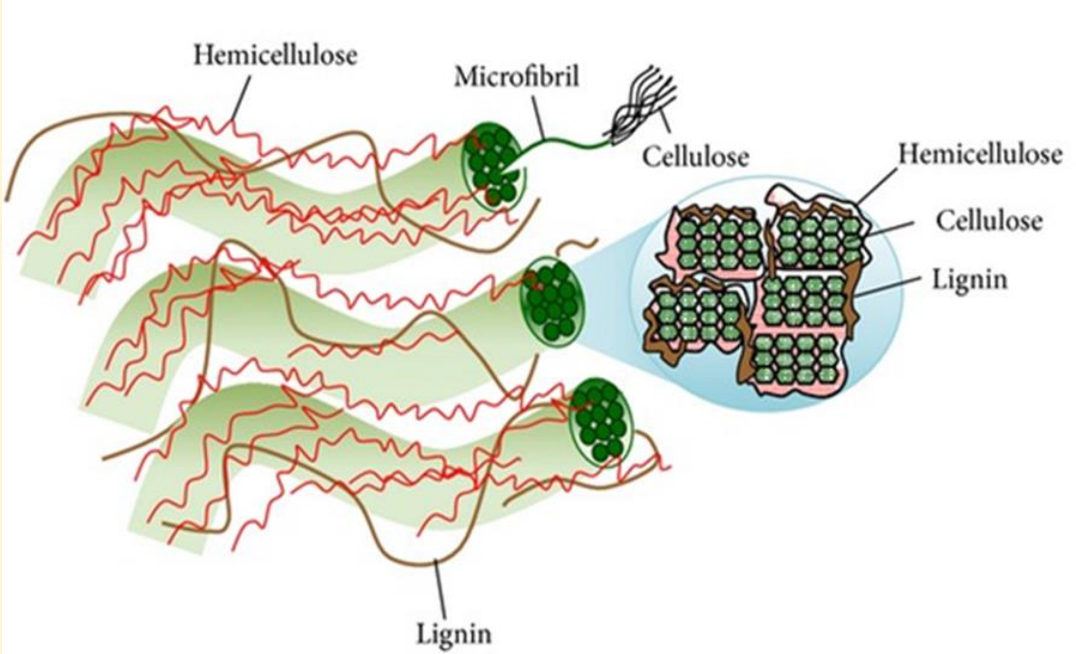
The amount of cellulose is vast, but not always easy accessible. The infrastructure to retrieve cellulose from forest is well developed in most part of the world, while the infrastructure to retrieve cellulose from agricultures crops (except for bagasse) or other resources is usually not well developed. Viable efficient process alternatives to extract cellulose are therefore needed. Obstacles that need to be considered are uneven material flows and silica as NPE (non process elements).

Further industrial process improvement in the manufacturing of CNF and CNC is needed. In production of CNF, enzymatic/refining system is probably the most economical lay-out. Industrial process improvement is required in the CNC production where too much acid and too many process step are obstacles in the currently used process designs.

Many techniques to functionalize cellulose have been identified, particularly in small (laboratory) scale. Upscaling together with techno-economical evaluation and LCA is therefore needed. In some cases several types of cellulose materials (RC, CD, fiber, CNC, CNF) can be considered for the same application.

Suggestion: Identify 2-4 different scenarios and then evaluate the whole value chain (cellulose in plant to functional cellulose in a product) in order to select or concentrate the work on the most beneficial one.

Cellulose



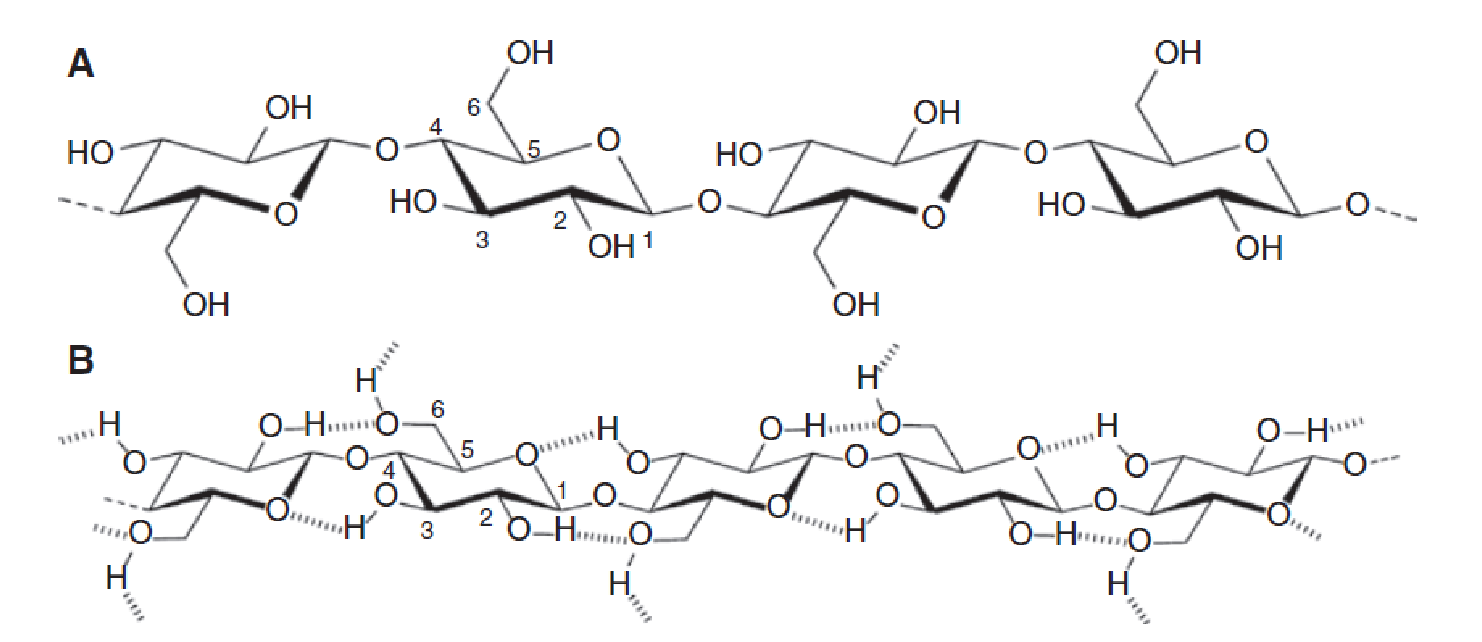
Resources of cellulose

Functionalization

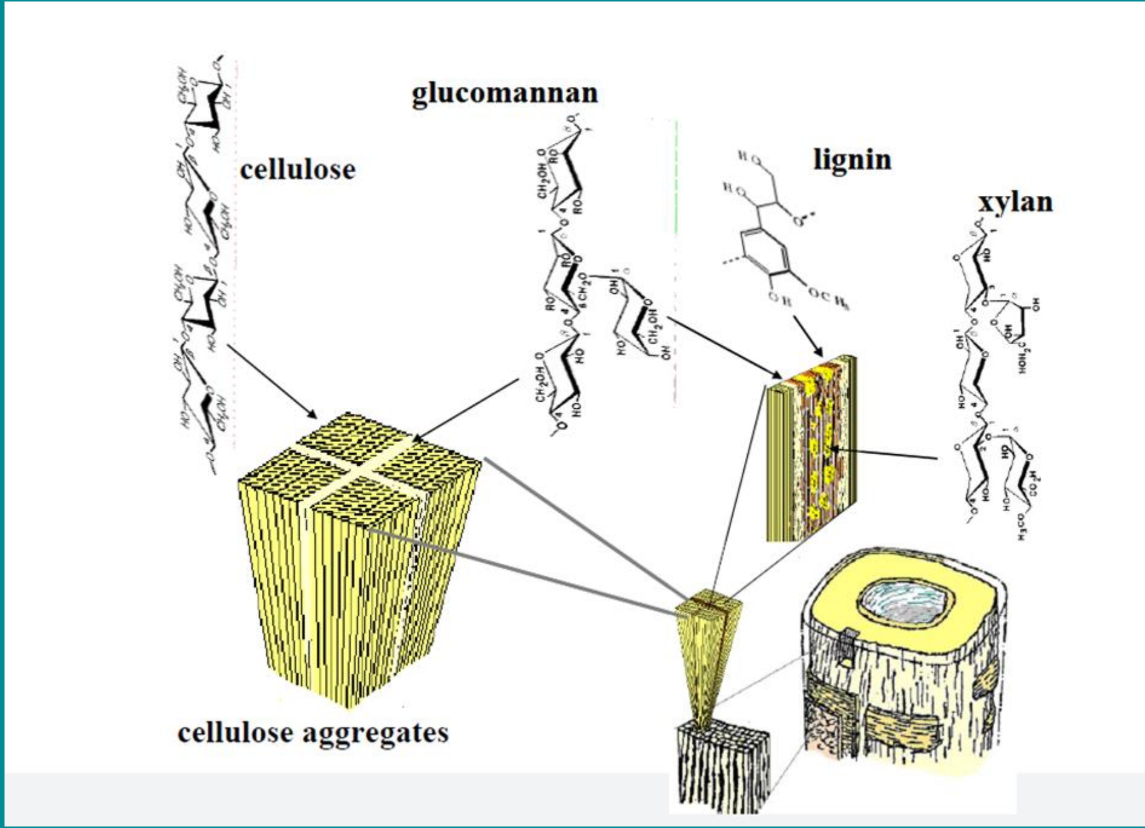
Applications

Cellulose

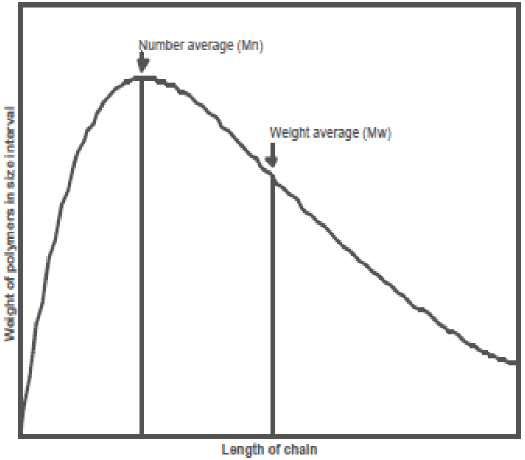
D-glucopyranose sugar units liked in a β- configuration

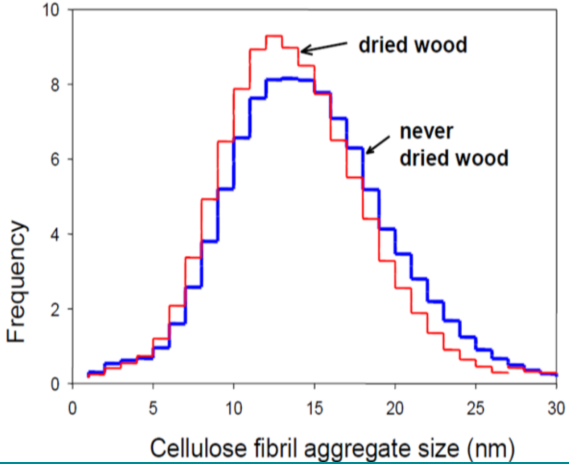


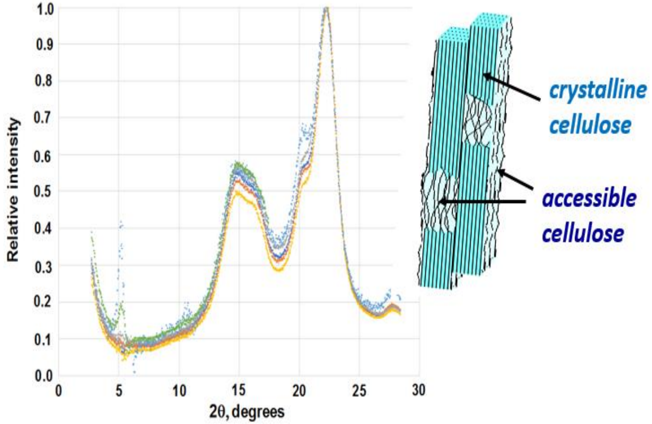
Cellulose – complex structure in biomaterials



Cellulose Characteristics







Degree of polymerization

Fibrill aggregate size

Crystallinity

Characteristics different raw materials

Source	DP
Cotton	15300
Hardwood (Aspen)	10300
Softwood (Jack Pine)	7900
Bleached Sulphite	1250
Kraft Pulp	975
Rayon	355

Characteristics different raw materials

Fiber dried direct heat	Crystallinity, %	Crystallite orientation, °
Ramie	74	7
Mesta	65	11
Jute (Tossa)	60	10
Roselle	35	10

Chemical composition different raw waste materials

Source	**Holo-cellulose,%**	**Cellulose, %**	**Lignin, %**	**Ash, %**	**Pectin, %**
Rape Straw	73.0	**40.8**	19.0	4.5	6.3
Wheat Straw	79.1	**40.8**	22.4	5.6	0.5
Corn Straw	70.9	**38.8**	20.0	5.8	1.4
Rye Straw	78.1	**45.1**	21.65	4.9	0.8
Carrot Leaves	52.9	**31.6**	18.5	15.2	1.9
Sunflower Straw	71.8	**40.4**	19.4	7.3	4.7
Bean Straw	59.5	**40.2**	18.1	10.6	11.0

Studies on Isolation of Cellulose Fibres
from Waste Plant Biomass, Kopania,, Wietecha,
Ciechańska; FIBRES & TEXTILES in Eastern Europe
2012; 20, 6B (96): 167-172.

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Chemical composition different raw materials

Source	Hemicelluloses, %	Cellulose, %	Lignin, %
Sugar cane bagasse	25	**42**	20
Sweet sorghum	27	**45**	21
Hardwood	24-40	**40-55**	18-25
Softwood	25-35	**45-50**	25-35
Corn cobs	35	**45**	15
Corn stover	26	**38**	19
Rice straw	24	**32**	18
Grasses	25-50	**25-40**	10-30
Wheat straw	26-32	**29-35**	16-21
Bagasse	16	**55**	23

Advances in the valorization of lignocellulosic materials by Biotechnology, Hafiz, Iqbal, Keshavarz, Bioresources 2013

Chemical composition different raw materials

Source	Cellulose, %
Bagasse	35-45
Bamboo	40-55
Cotton	90-99
Flax	70-75
Hemp	75-80
Jute	60-65
Kapok	70-75
Ramie	70-75
Straw	40-50
Wood	40-50

Resources of Celluloses

Every year 1000 billions tonne of cellulose are produced, equivalent to 3000 tonne per second

Resources of celluloses (incl. in this study)

Forest

Agriculture/ agriculture waste

Vegetables, fruit/ wastes

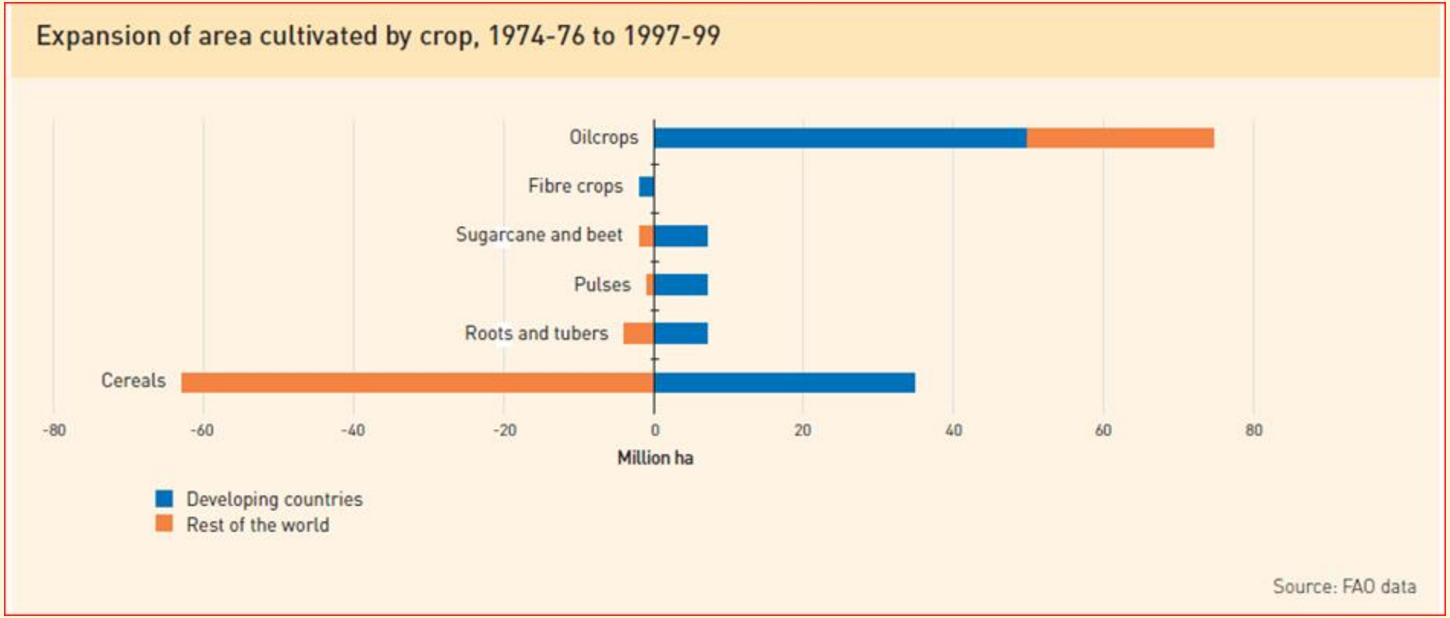
Bacteria
Fungi
Algae
Animals (tunicates)

Forestry area as a percentage of country area land

During the 1990s, the area of tropical forests shrank by a net 12.3 million ha each year, but non-tropical areas actually added 2.9 million ha a year to their forests.

http://www.fao.org/docrep/004/Y3557E/y3557e08.htm

Area changes cultivated by crop



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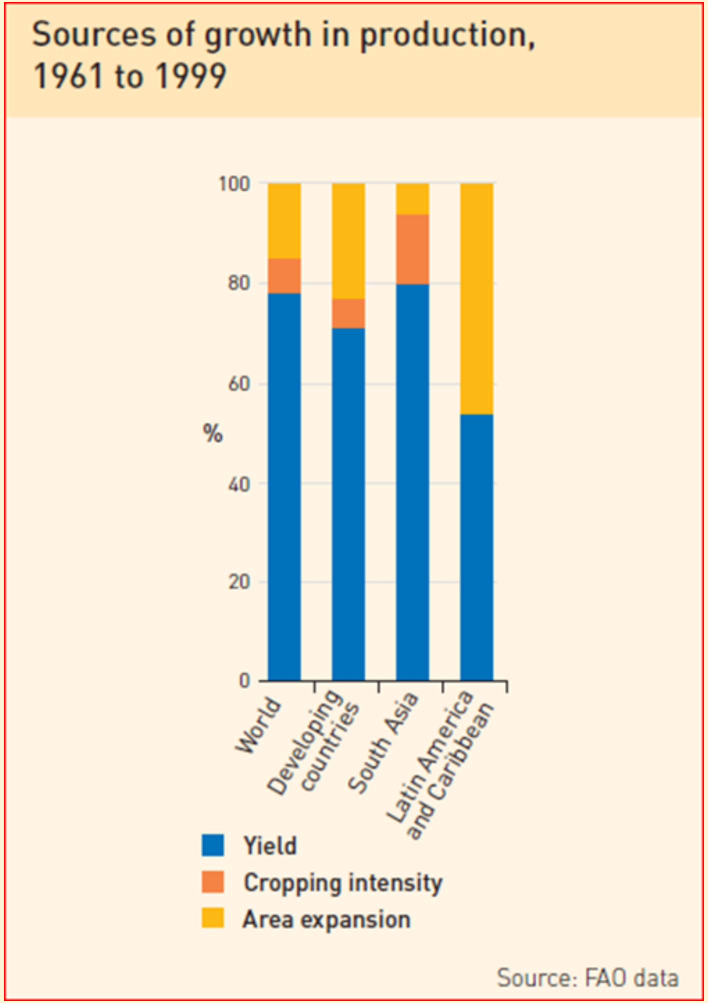
Growth in production

Yield
Cropping intensity
Area expansion



http://www.fao.org/docrep/004/Y3557E/y3557e08.htm

Netherlands

Areal	1996	2016
Agriculture total, ha	2 360 382	2 236 317
Woodland and nature, ha	478 396	498 956

CBS, Statistics

Netherlands' agriculture crops

- wheat
- green maize,
- potatoes
- sugar beet

Arable crops	2000 Gross yield, total 1 000 kg	2017 Gross yield, total 1 000 kg
Total wheat	1,142,695	1,054,151
Winter wheat	1,032,342	996,379
Spring wheat	110,354	57,772
Winter barley	20,876	79,843
Spring barley	266,967	124,473
Rye	29,033	4,385
Oats	13,315	6,728
Triticale	36,009	6,395
Grain maize	343,505	116,711
Green maize	8,154,177	9,955,458
Corn Cob Mix	133,274	47,956
Red kidney beans	3,153	4,648
Rape	2,907	7,894
Fibre flax	26,860	10,224
Linseed	4,000	1,496
Chicory for inulin	184,431	152,640
Hemp	4,651	9,539
Total potatoes	8,126,799	7,391,881
Total ware potatoes	4,465,429	3,950,307
Ware potatoes on clay soil	3,165,512	
Ware potatoes on sandy or peat soil	1,299,914	
Total seed potatoes	1,495,767	1,547,843
Seed potatoes on clay soil	1,268,852	
Seed potatoes on sandy or peat soil	226,914	
Starch potatoes	2,165,606	1,893,758
Sugar beet	6,727,494	7,959,266
Seed onions	821,022	1,453,789
Seed onions (excl. loss)	788,483	1,322,482

Source: CBS

CBS, Statistics

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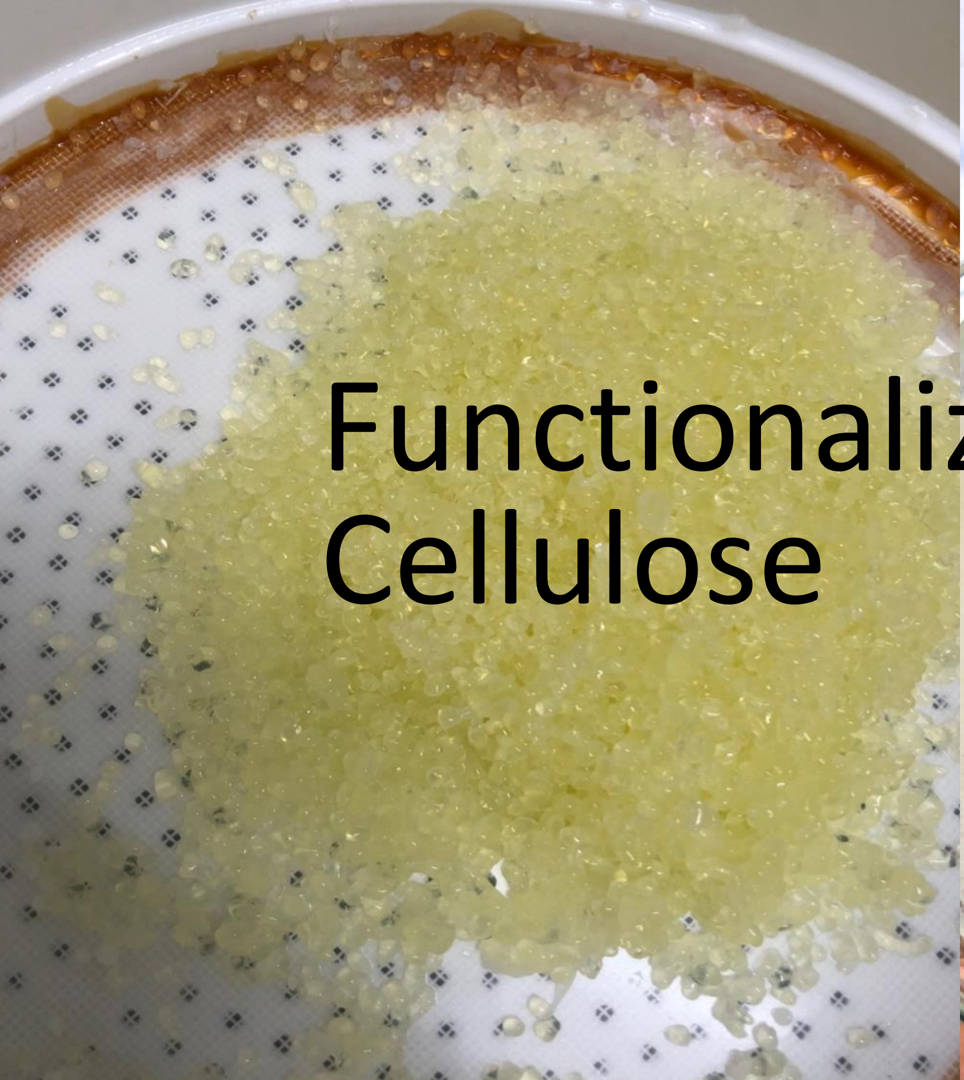
Source: CBS

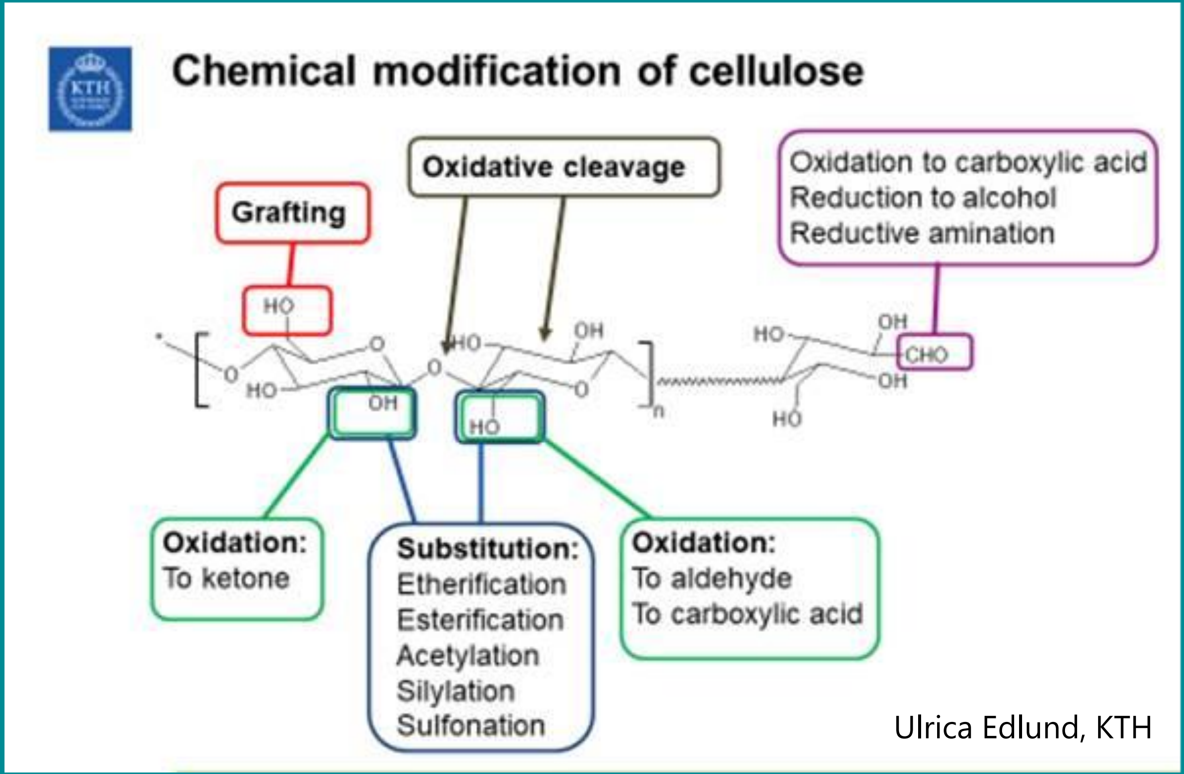
Cellulose content of the waste material:

- wheat 30-40%
- green maize, 30-40%
- potato tuber cells, 40%
- sugar beet pulp, 30-35%

Functionalization of Cellulose



Reactive sites on the cellulose chain



Ulrica Edlund, KTH

Functionalization

- Chemically
  - esterification
  - etherification
  - oxidation
  - dehydration
- Bio-catalytic
  - enzymes
- Physico-mechanically
  - physical changes

Functionalization

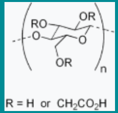
- Polymer adsorption
  - Multilayering

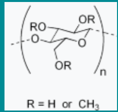
- Grafting
  -initiated by free radicals
  - initiated by ionic polymerization
  - grafting by condensation and ring-opening

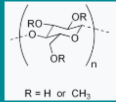
Cellulose Derivate - esterification

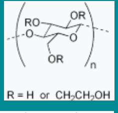
Cellulose ester	DP	DS Acetyl	DS propyl/butyl
Triacetat	150-60	2.8-3.0	-
Diacetat	100-200	2.5	-
Acetat/propionate	150-200	0.3	2.3
Acetat/butyrate	100-150	2.1-0.5	0.6-2.3

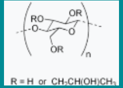
Cellulose Derivate – etherification

- Carboxymethyl cellulose (CMC) 

- Methyl cellulose (MC) 

- Ethyl cellulose (EC) 

- Hydroxyethyl cellulose (HEC) 

- Hydroxypropyl cellulose (HPC) 

  and mixed ethers (hydroxyethylmethylcellulose, HPMC).

Bio-catalytic functionalization

Reactive sites targeted by the enzymes is the hydroxyl groups of cellulose.

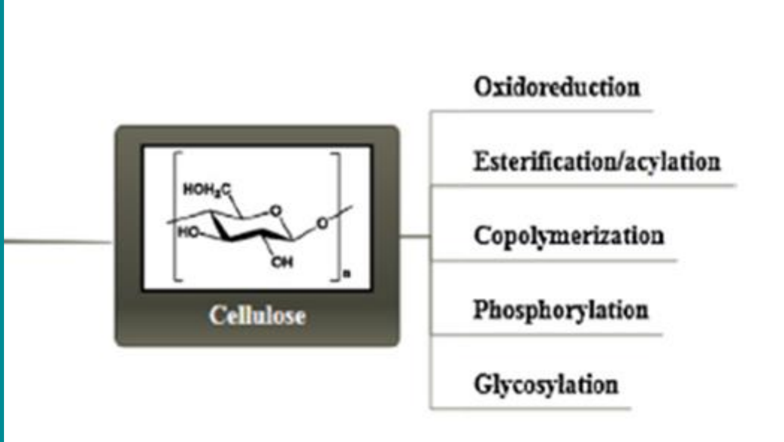
- Oxidation reaction catalyzed
  - by laccas
  - Grafting of phenolic compounds onto cellulose by laccas

- Estherification/acylation
  - Enzymatic acylering with hydrolases

- Co-polymerization
  - Coupling of cellulose with polyesters catalyzed by lipases
  - Coupling of cellulose with amylose catalyzed by phosphorylases

- Phosphorylation reactions catalyzed by hexokinases

- Glycosylation reactions catalyzed by glycosidases



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Bio-catalytic functionalization - oxidation

Examples of biocatalytic reactions with functionality and applications that can be used with cellulose

- Oxidation reaction catalyzed by laccas[1] . Higher content of aldehyde and carboxyl groups increase the water retention capacity, tensile strength (mechanical properties) of cellulose in fibers.
- Grafting phenolic compound by laccas gives derivates with enhanced hydrophobicity, improved antioxidant and antimicrobial activities. Mainly for the paper and food packaging industries.

1. S. Xu, Z. Song, X. Qian, J. Shen, Introducing carboxyl and aldehyde groups tosoftwood-derived cellulosic fibers by laccase/TEMPO-catalyzed oxidation,Cellulose 20 (2013) 2371–2378.

Bio-catalytic functionalization – acylation/estherfication

- Acylation/esterification reactions catalyzed by hydrolases to increase the hydrophobicity. Used to design surfactants and rheology modifiers.
- Regioselective reactions with cellulose, control of moisture absorption properties of fibres.
- Enzymatic acylation of HEC (hydroxyethyl cellulose) derivates particularly relevant for a range of application (pharmaceuticals, cosmetics, food, oil drilling, paper, panit, constructions, adhesives).

Bio-catalytic functionalization – co-polymerization

- Copolymerizations reactions:
  - coupling of cellulose with polyesters catalyzed by lipases creating a hydrophobic-hydrophilic polymer used for compatibilizers for polymer blends, water repellent material, oil absorbents and biodegradable detergents

  - coupling of cellulose with amylos catalyzed by phoshorylases can create copolymers able to form films and strong gel [2,3]

2. Y. Omagari, S. Matsuda, Y. Kaneko, J. Kadokawa, Chemoenzymatic synthesisof amylose-grafted cellulose, Macromol. Biosci. 9 (2009) 450–455
3. . J. Kadokawa, Synthesis of amylose-grafted polysaccharide materials byphosphorylase-catalyzed enzymatic polymerization, in: P.B. Smith, R.A.Gross (Eds.), Biobased Monomers, Polymers, and Materials, AmericanChemical Society, Washington, DC, 2012, pp. 237–255.

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Bio-catalytic functionalization – phosphorylation

- Phosphorylation reactions catalyzed by hexokinases. Transfer a phosphate to cellulose. Applications is enhance the capacity to get colored and increased flame resistance. Application in biosorbent for heavy metal removal[4]
- but also in medical application as calcium ions binders to promote bone generation [5]

4. T. Tzanov, M. Stamenova, A. Cavaco-Paulo, Phosphorylation of cottoncellulose with baker's yeast hexokinase, Macromol. Rapid Commun. 23(2002) 962–964.
5. P.L. Granja, L. Pouységu, M. Pétraud, B. De Jéso, C. Baquey, M.A. Barbosa, I.Cellulose phosphates as biomaterials, Synthesis and characterization ofhighly phosphorylated cellulose gels, J. Appl. Polym. Sci. 82 (2001)3341–3353.

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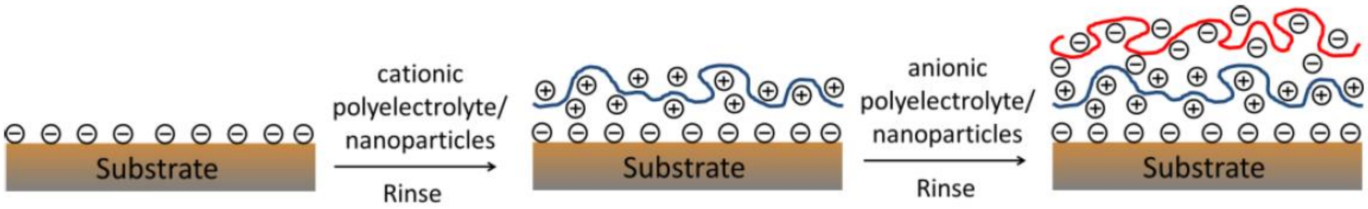
Bio-catalytic functionalization – glycosylation

- Glycosylation reactions catalyzed by glycosidases to improve HEC performance. Galactosylated HEC improved performance as thickening agent, rheology modifier and protective colloids.[6,7]

6. T. Tzanov, M. Stamenova, A. Cavaco-Paulo, Phosphorylation of cottoncellulose with baker's yeast hexokinase, Macromol. Rapid Commun. 23(2002) 962–964.
7. P.L. Granja, L. Pouységu, M. Pétraud, B. De Jéso, C. Baquey, M.A. Barbosa, I.Cellulose phosphates as biomaterials, Synthesis and characterization ofhighly phosphorylated cellulose gels, J. Appl. Polym. Sci. 82 (2001)3341–3353.

Polymer adsorption

- Multi-layering
- Xylan adsorption onto fibres.



Ghanadpour, KTH

Physico-mechanically

- Grinding
- Homogenizer

Cellulose Nanofibrills (CNF)

Fibril particles 20-40 nm wide and 200-400 nm long

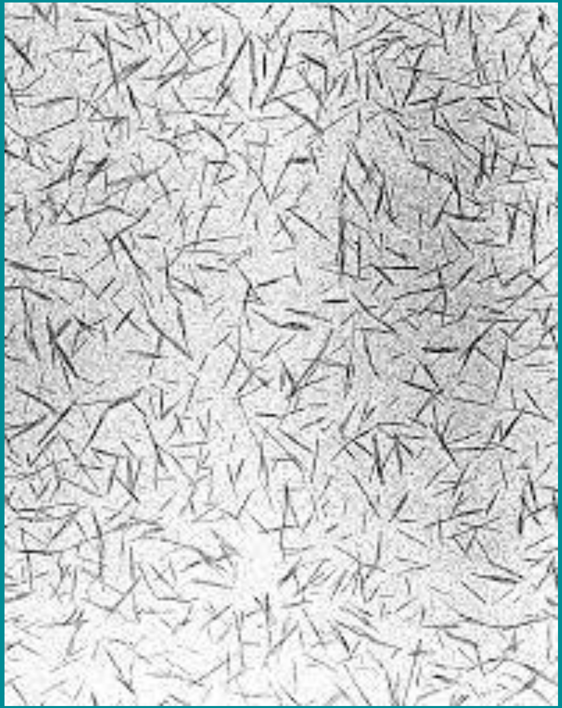
Crystallinity commonly between 50%-80%

Seldom 100% cellulose

Cellulose Nanofibrills (CNF)

- Purification stages in some cases.
- Tempo-oxidation
- Combined mechanical and enzymatic treatment
- Carboxymethylation

Cellulose nanocrystals (CNC)

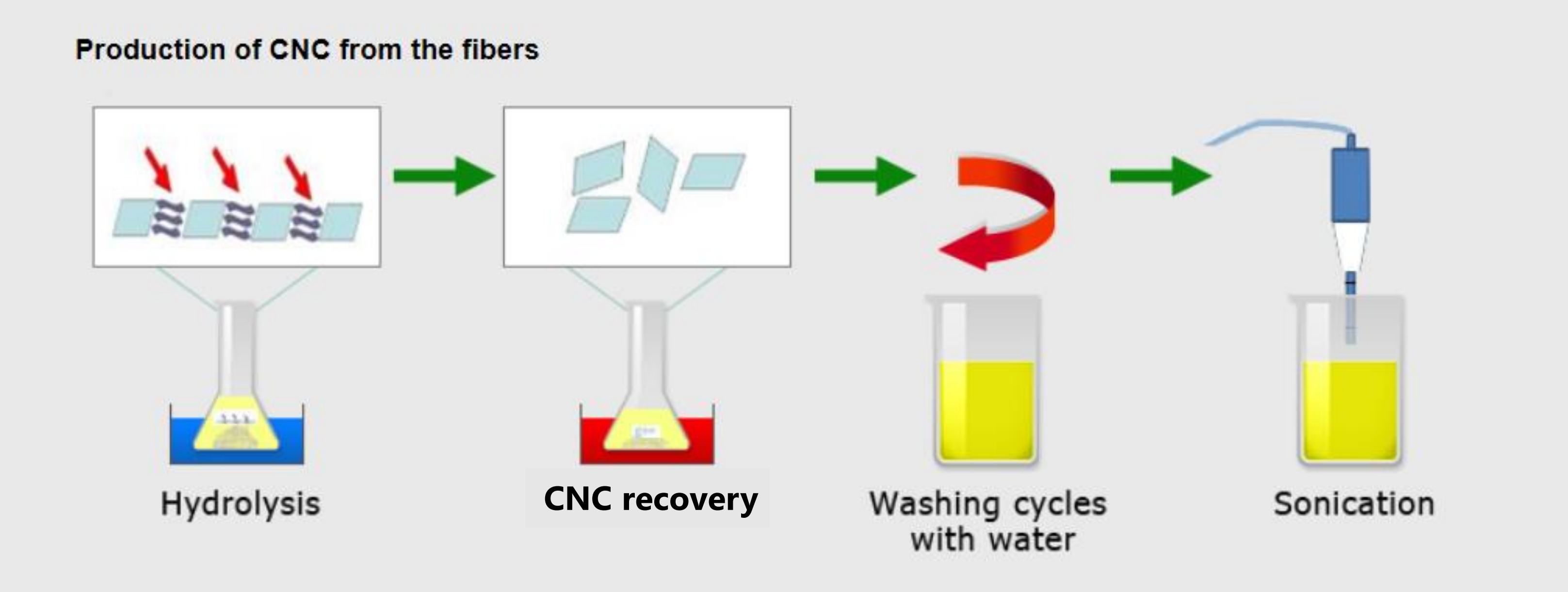


Purification stage and then acid hydrolysis to remove amorphous parts

Rod-like particles 3-20 nm wide and 50-200 nm long

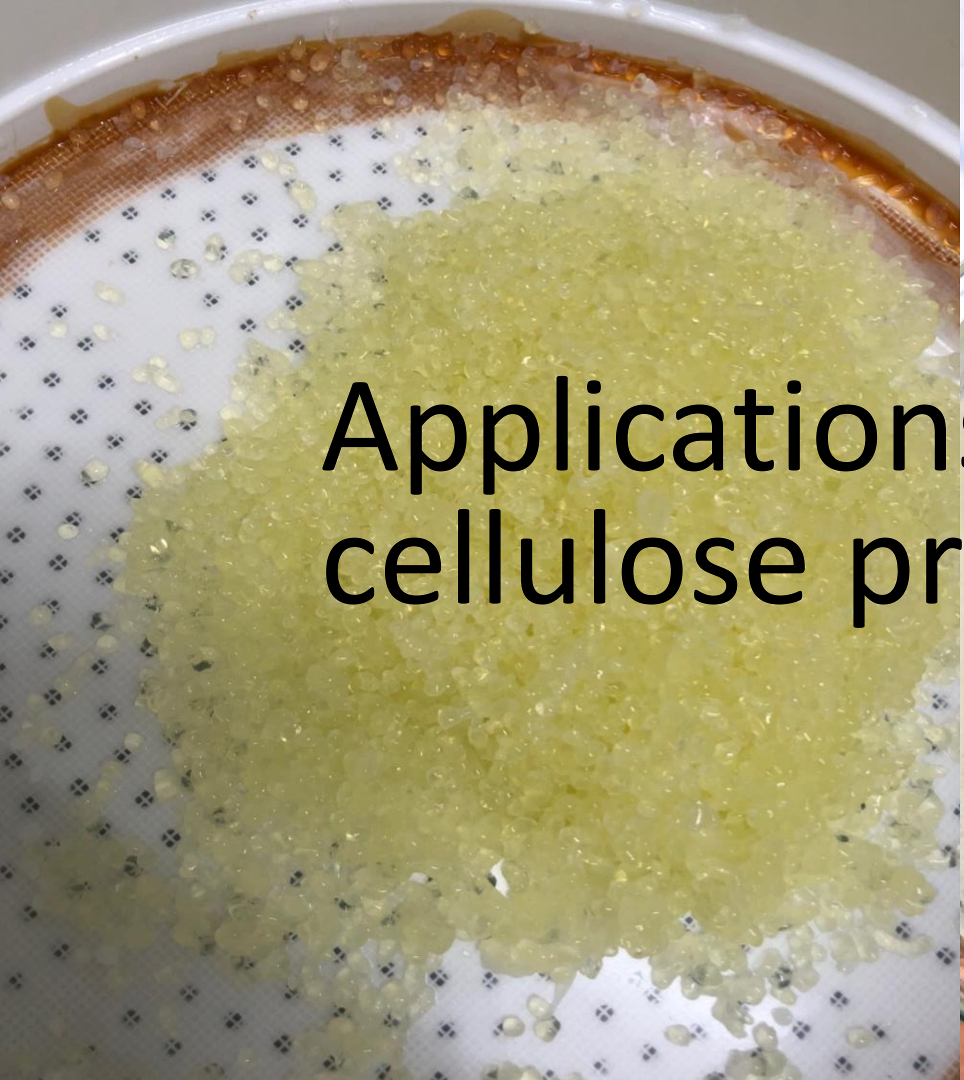
Crystallinity commonly between 62%-90%.

CNC production



http://www.melodea.eu/Default.asp?sType=0&PageId=104256

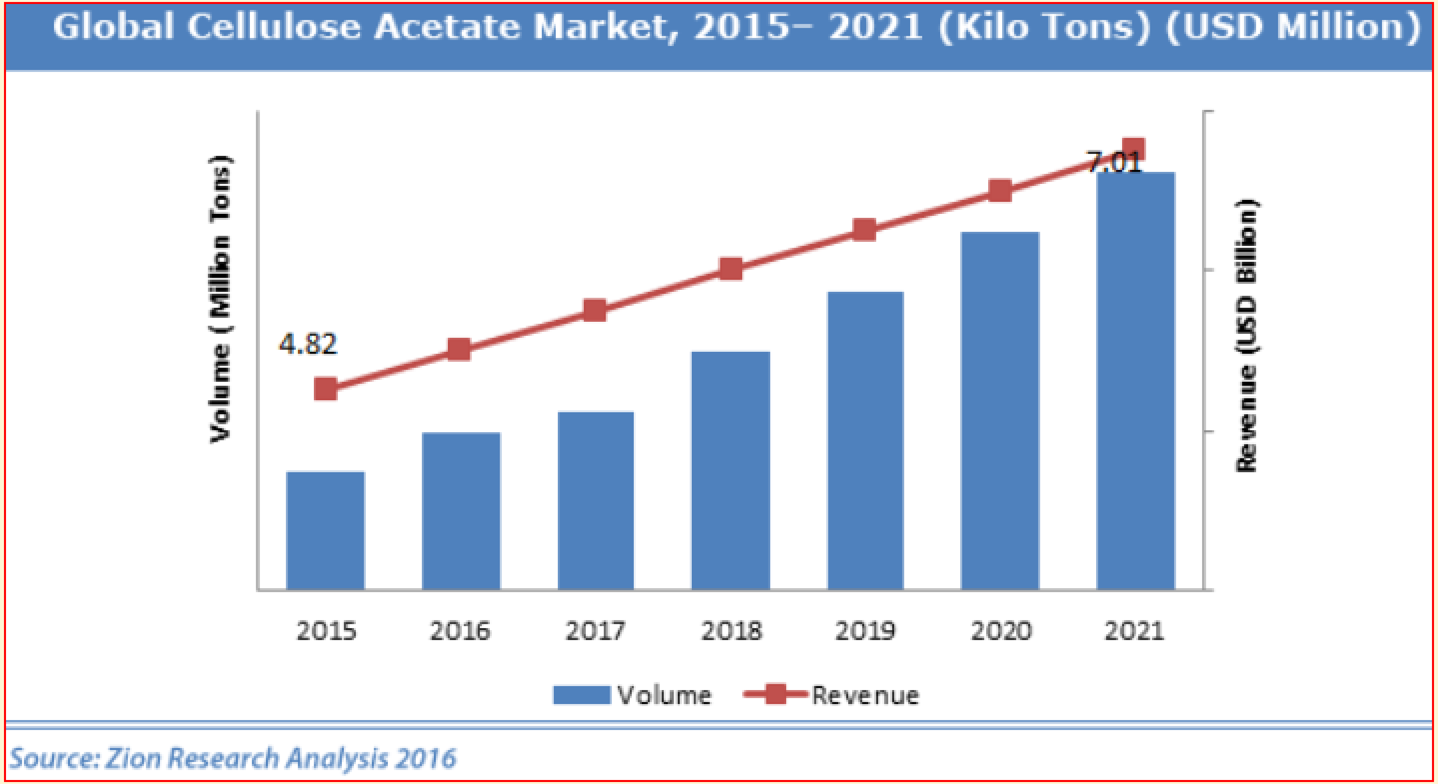
Applications of upgraded cellulose products



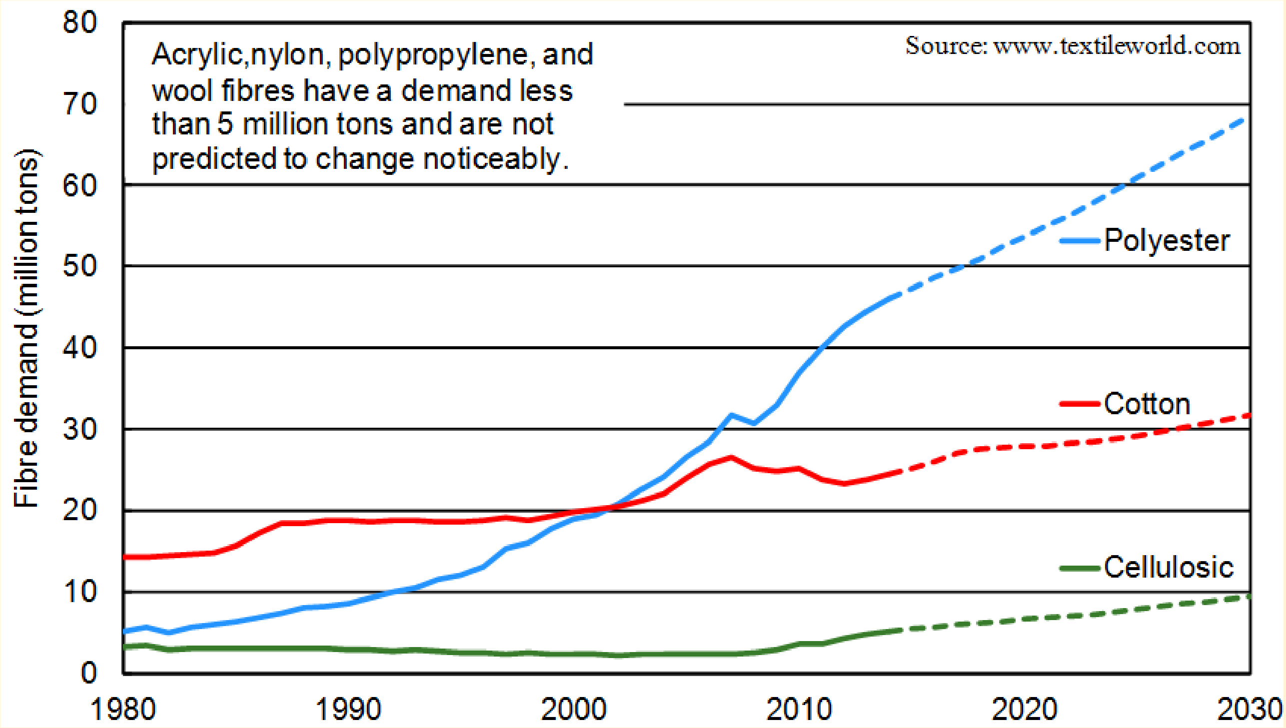
Applications

- Traditional cellulose derivates are still well positioned on the market.
- A renewed interest for finding replacement for cotton is seen.
- Numerous market studies of CNF and CNC. Yet only a few products have reached the customer.
- New emerging ideas on application for functionalized cellulose are in the air.

Global acetate market



Market forecast for textiles



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Applications and potential volume market study CNF (thousands ton)

Application	Market size	Nanocellulose potential
Paper and Board	400 000	20 000
Textile	50 000	1 000
Paint and coatings*	40 000	800
Carbon Black	12 000	300
Films and Barriers	9 670	193
Composites	9 000	180
Oil and gas	17 500	175
Nonwoven	7 000	140
Water treatment	4 650	93

* Data on slide is from
Cellulose Nanomaterials: The Road to Commercialization: Opportunities and Recommendations for Researchers, Producers, and End Users. Presented by: Jack Miller, Principal Consultant, Market-Intell LLC, Nov13, 2017

The data on paint originate from a report by Freedonia world paints and coatings projected global demand to reach 45.6 million tonnes by 2015. The idea was to get a ballpark estimate for the potential for nanocellulose, not a precise estimate of the paint market.

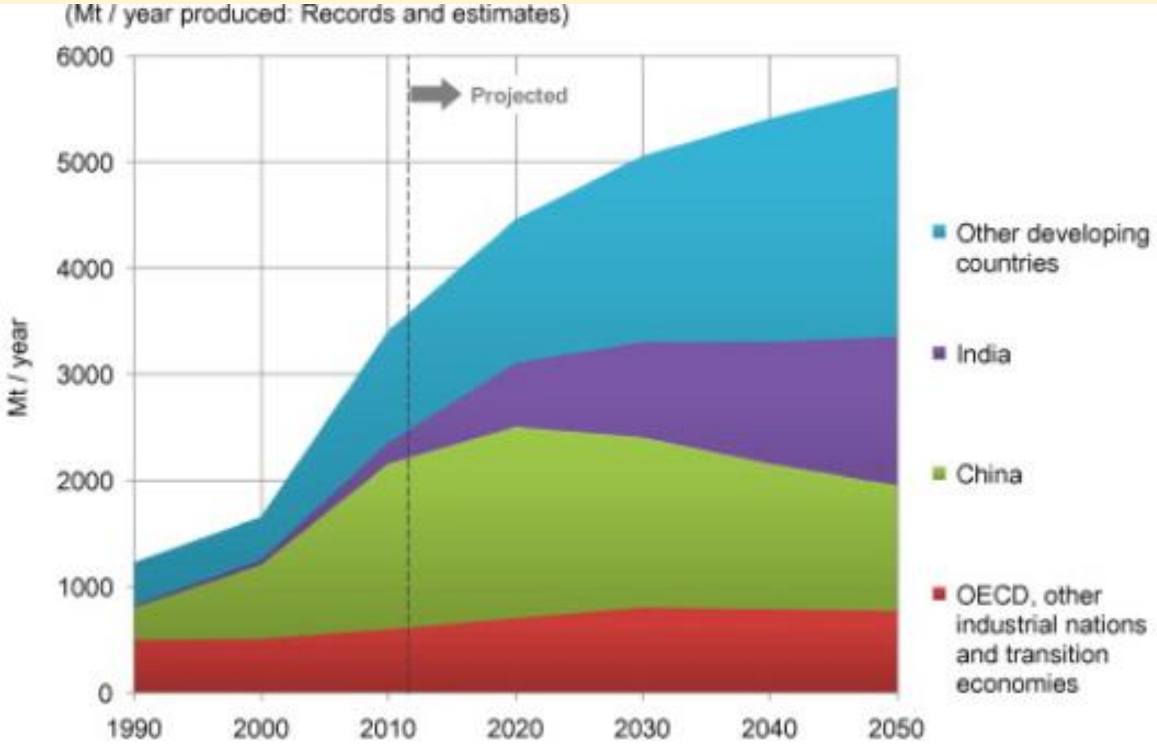
Source: *Nanocellulose: Technology, Applications and Markets*, RISI 2014; updated Market-Intell, May, 2017

Applications CNF

High-Volume Applications	Low-Volume Applications	Novel and Emerging Application
Hygiene and adsorbent products		
Cement	Wallboard facing	Sensors-medical, environmental and industrial
Automotive body and interior	Insulation	Reinforcement fiber-construction
Packaging coating	Aerospace structure and interior	Water filtration
Packing filler	Aerogels for the oil and gas industry	Air filtration
Replacement-plastic packaging	Paint	Viscosity modifier
Plastic film replacement		Cosmetics
Textiles for clothing		Organic LED
		3-D printing

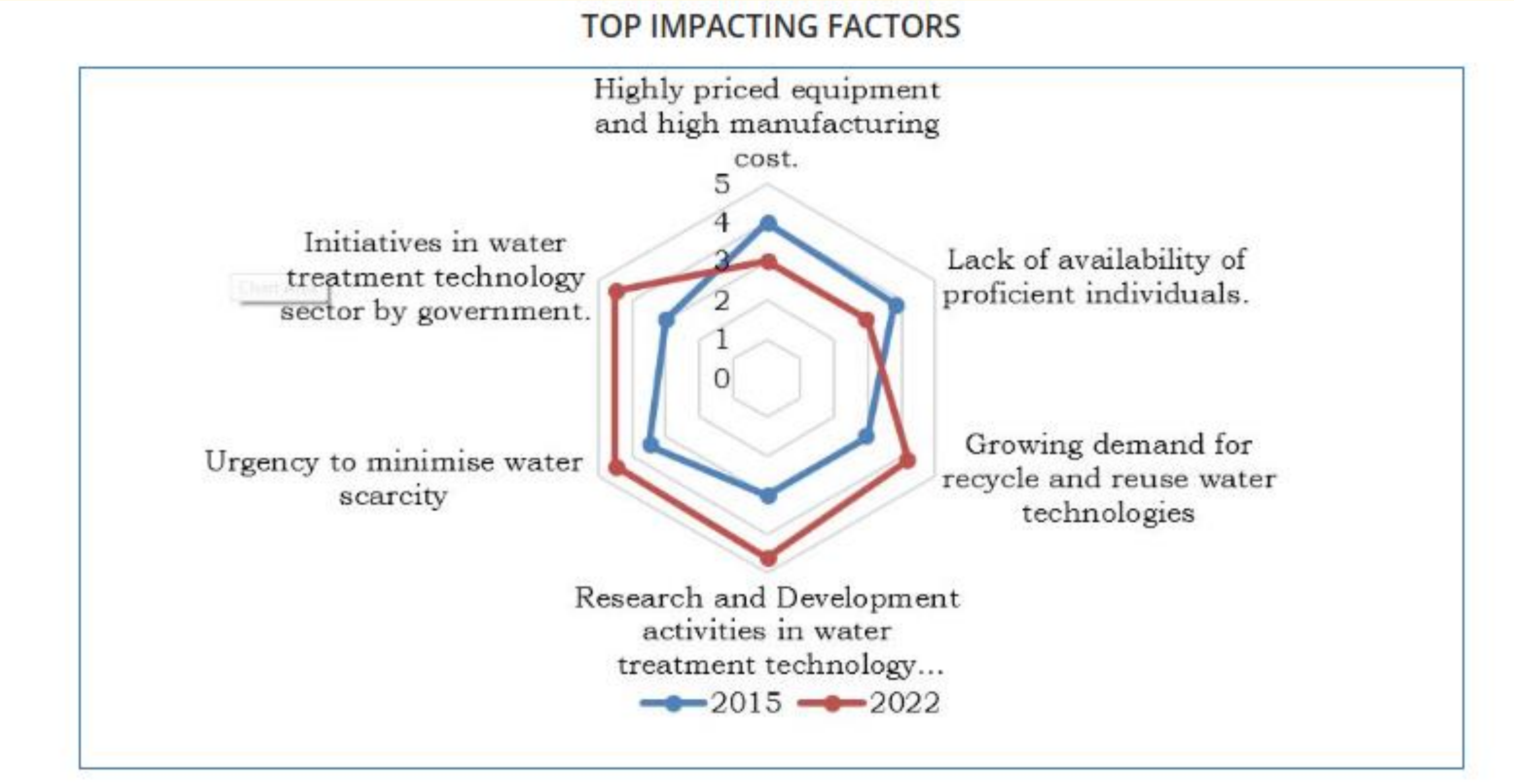
Source: *Nanocellulose: Technology, Applications and Markets*, RISI 2014; updated Market-Intell, May, 2017

Market forecast for cement



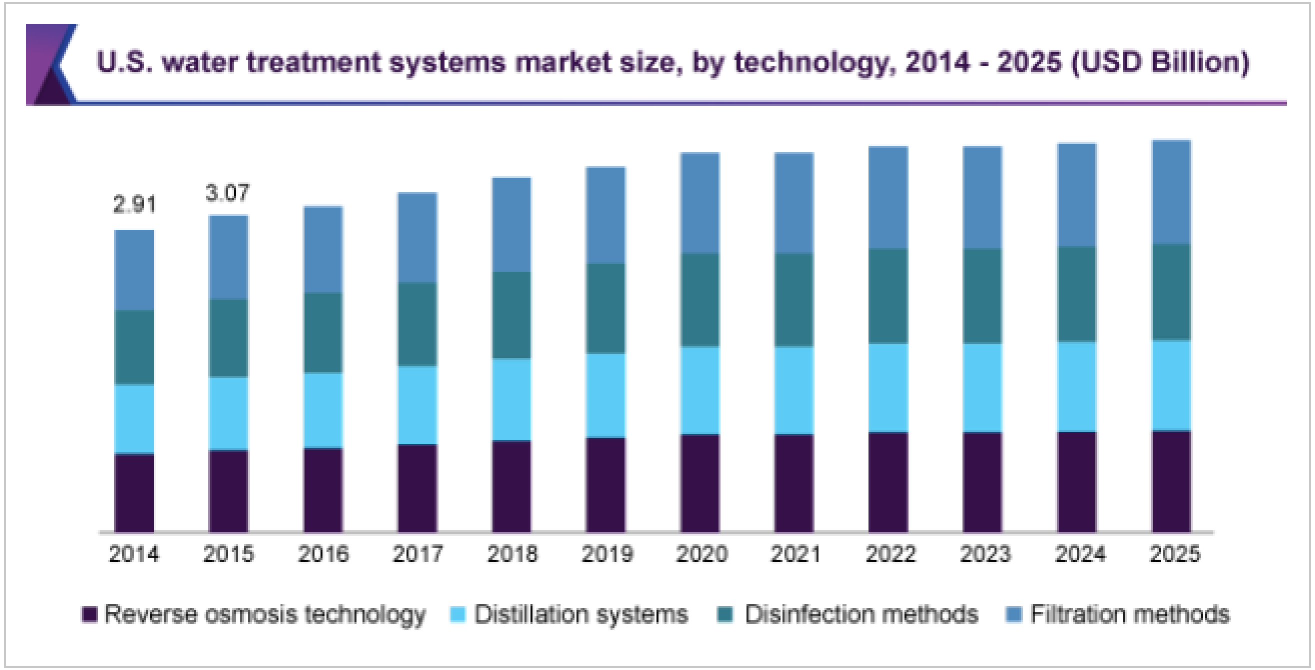
https://www.sciencedirect.com/science/article/pii/S2212609013000071

Market forecast for water treatment



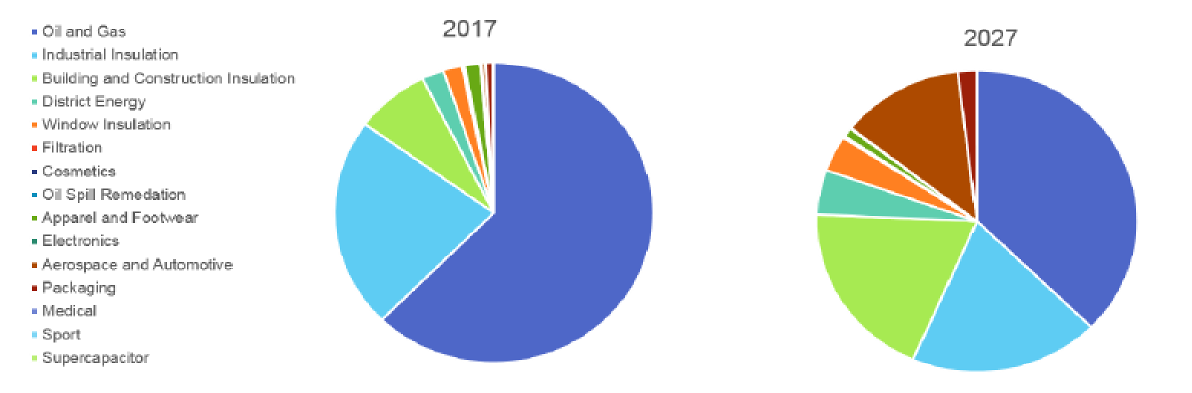
https://www.alliedmarketresearch.com/water-treatment-technology-market

Market forecast for water treatment



https://www.grandviewresearch.com/industry-analysis/water-treatment-systems-market

Market forecast for aerogels



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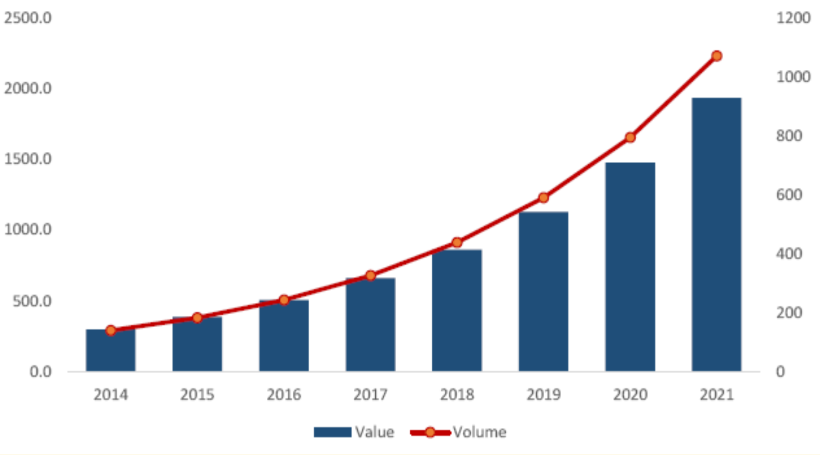
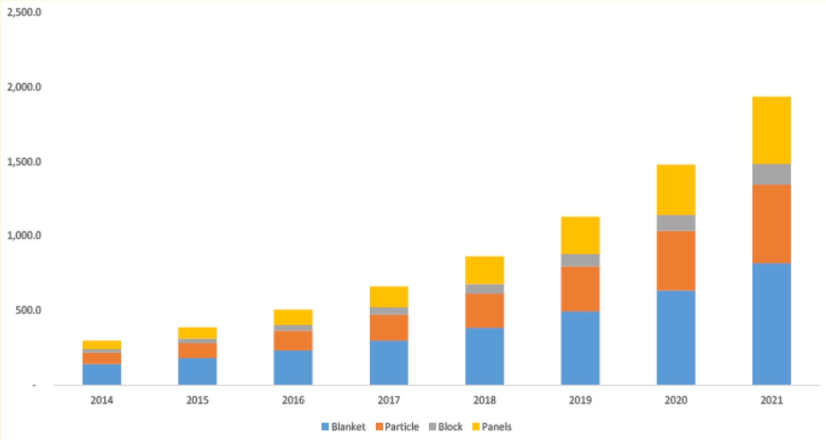
Sq. ft.



IDTechEx; www.IDTechEx.com. Infinium Global Research Analysis.

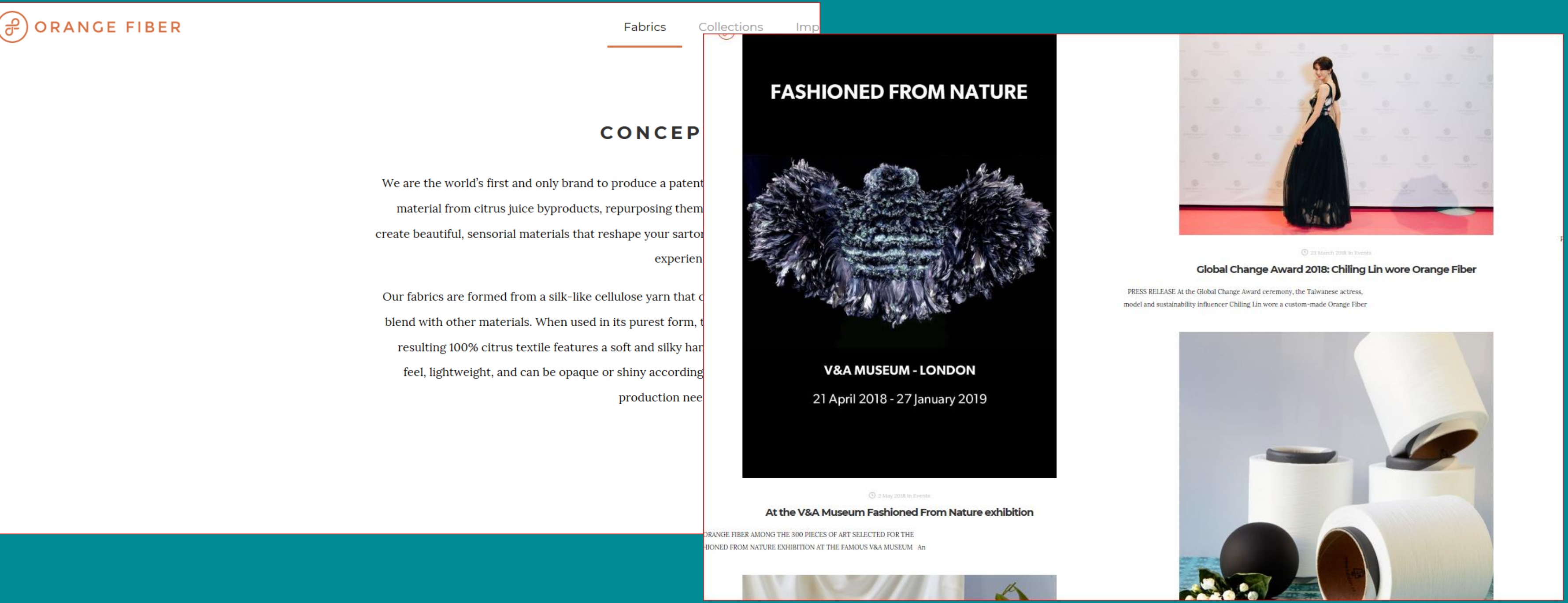
US$



Particles CAGR (2016-2021): 32%

Some commercial examples

Textile from orange peel cellulose



Melodea, company in Israel with Swedish connections

Cellulose Nano Crystals (CNC) is a primary building block of the cell wall of all living plants. CNC has high mechanical strength modulus of 150 GPa and tensile strength of 10 GPA in line with supreme synthetic material. CNC plays a major role in the structure of the cell wall giving plants their extraordinary strength exemplified by the gigantic dimensions of some forest tress such as Sequoia. This role can be adapted into man-made products utilizing CNC as a nano building block for the enhancement of existing materials and for the production of novel eco-friendly materials.

What is CNC good for?

Foams for composites and insulation panels

CNC films for coatings and optical properties

Gas barrier aluminum replacement in food packaging

Displays

Reinforcing of paper and paperboard

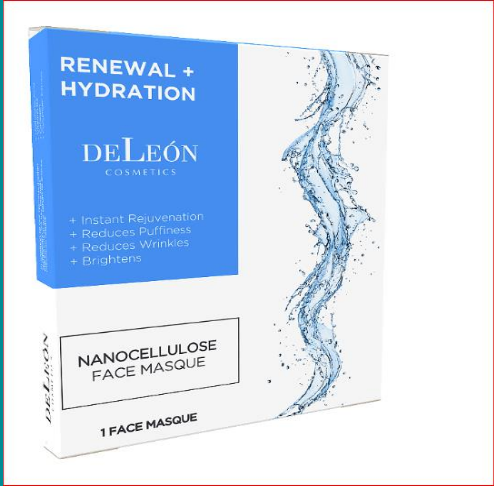
Reinforcing of acrylic polymers

Additive to plastics (biobased and synthetic)

Additive to coating and barriers materials

Commercial applications of nanocellulose

- Nippon Paper Crecia Co. Ltd "first commercial products made of functional cellulose nanofiber" TEMPO CNF in deodorant sheets for Hada Care Acty" **Adult diapers** 2015
- Nippon Paper Crecia Co. Ltd **water-absorbing** "Poise Sara Sara Kyusui Lener" April 2016
- DeLeón Cosmetics, U.S, commercial cosmetics product with Innovatech nanocellulose for nanohydration. Products include Eye Masque, Face Masque and Neck Masque
- Innovatech: DeLeón cosmetic and nanocellulose sheet
- Mitsubishi Pencil Co and DKS ballpoint pen ink with Rheocrysta
- Consortium of 100 companies: Nipon Paper Industries; Oji Holdings Copr. Toyota Auto Body Co, Mitsubishi Motors Corp. Mitsui Chemicals Inc.



FiberLean – process for CNF
Paper and packaging oriented

FiberLean Technologies

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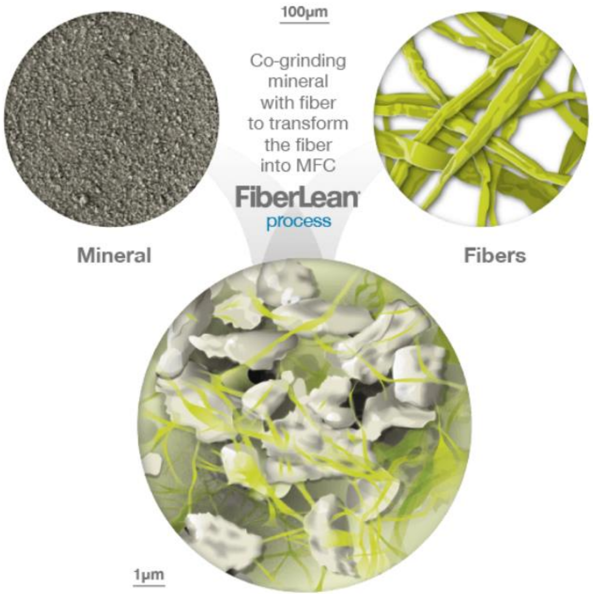


Our process is robust, reliable and scalable

The product coming out of the FiberLean® Technologies proprietary process is a MFC-mineral composite. The mineral plays an essential role in the transfer of mechanical energy, transforming regular pulp into MFC. This also allows the use of robust and reliable industrial equipment.

A wide range of pulp species can be fed into the process and no pretreatment is required. A number of different minerals, such as Calcium Carbonate, Kaolin, Graphite, Talc and many others can be used.

FiberLean® Technologies MFC plants are available in different capacities ranging from one thousand to over ten thousand tons of FiberLean® MFC per year. The capacity and flexibility of the plants has made use of FiberLean® MFC in full-scale papermaking a reality.

RI. SE

When to use regenerated cellulose, cellulose derivates, CNF, CNC or cellulosic fibers?

How to know??

The function of cellulose

- Cellulose as a carrier
- Cellulose as grafting media
- Cellulose as a strength contributor
- Cellulose as a barrier (film)
- Cellulose as a dispergent agent /viscosity regulator
- Cellulose as a moisture regulator
- Cellulose as a material with high surface area
- Cellulose as a network material
- Cellulose as a NON-toxic material

Application	RC, CD	CNF	CNC	Fiber
Composites	(x)	x	x	x
Transport (automotive/aerospace)	x	x	x	x
Moulded composites in construction		x	x	x
Cement		x	x	(x)
Film&barrier	x	x	x	
Membran	x	x	x	x
Dispergering agents	x	x	x	
Cosmetic, disperging and hydrating	x	x	x	
Oil and gas		x	x	

RI.
SE

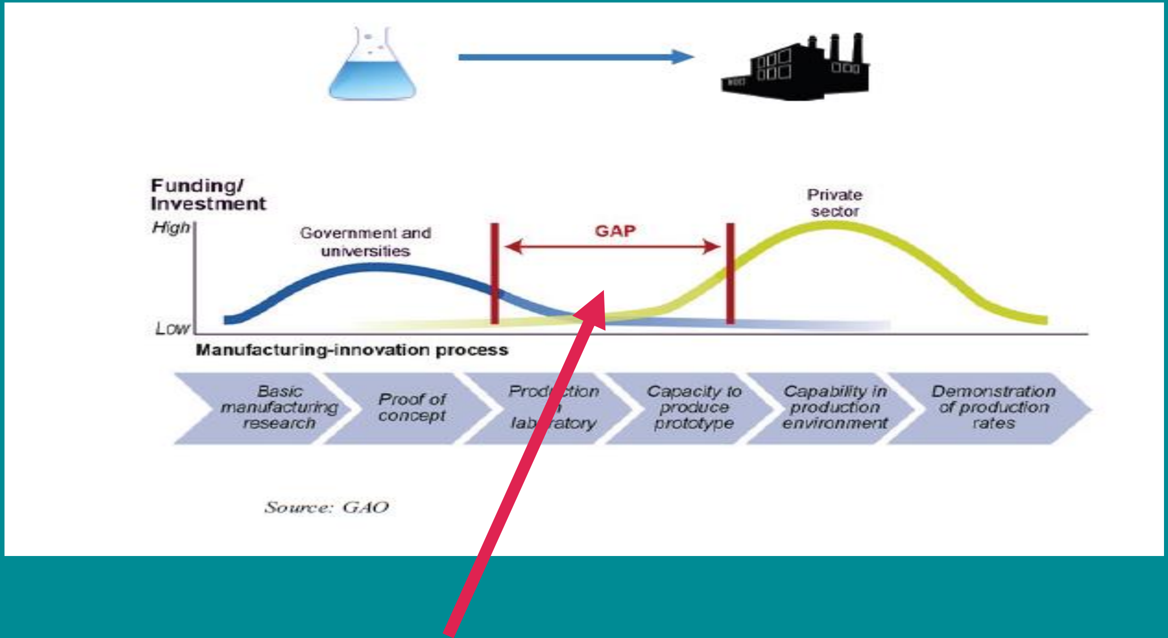
Application	RC, CD	CNF	CNC	Fiber
Electronics		x	x	x
Batteries		x	x	
Fire resistant material		x	x	(x)
Medical applications	x	x	x	
Antibacterial	x	x	x	x
Hygiene	x	x	x	x

Applications

- Cellulose functionalization can be performed in many different ways.
- Why cellulose?
  - reactive sites, the cellulose chain is linear and is controllable

Cellulose as a starting material is an attractive material for functionalization and as a carrier for substances

Challenges for commercialization



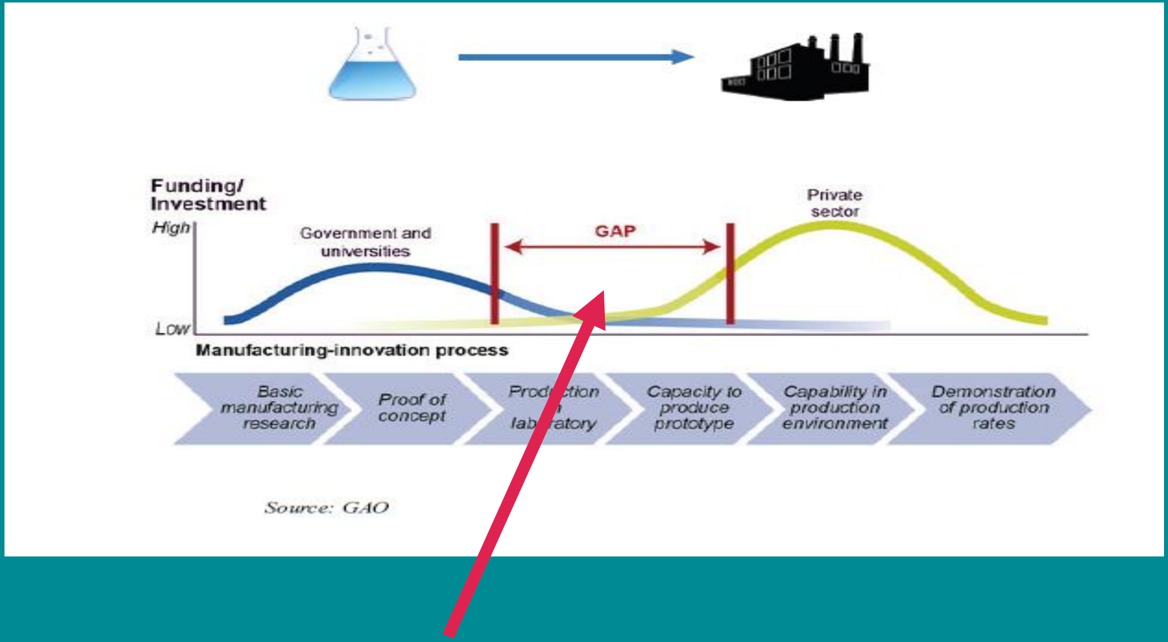
Cellulose production (from agricultures residues)

Challenges for cellulose manufacturing

- The infrastructure to retrieve cellulose from forest is well developed in most part of the world. Cellulose from agricultures crops or other resources are usually not well developed. Exception exists for bagasse.

- Viable efficient process to extract cellulose.
  - uneven material flow
  - silica as a NPE
  - techno-economical evaluated needed

Challenges for commercialization

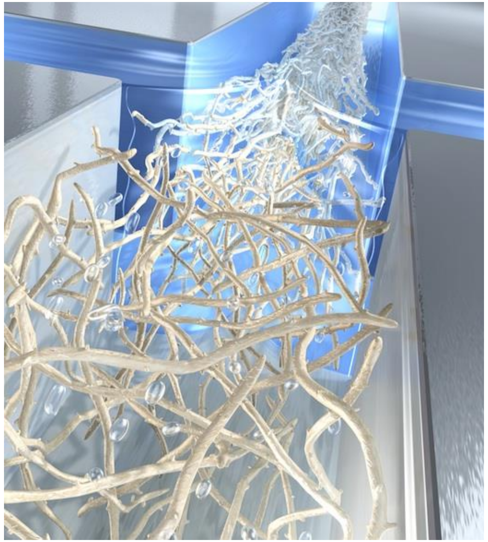


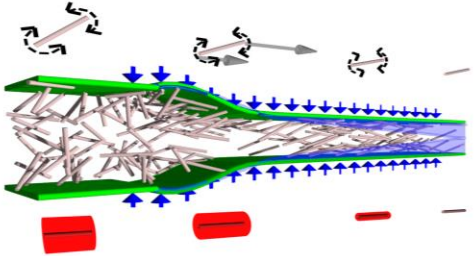
Cellulose functionalized product

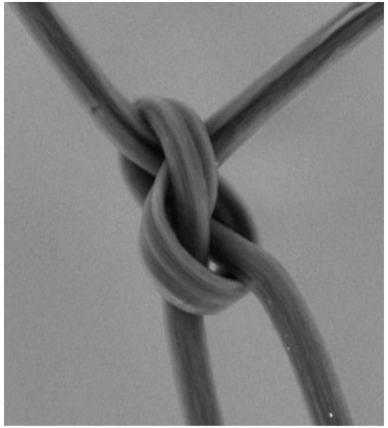
Challenges cellulose functionalization

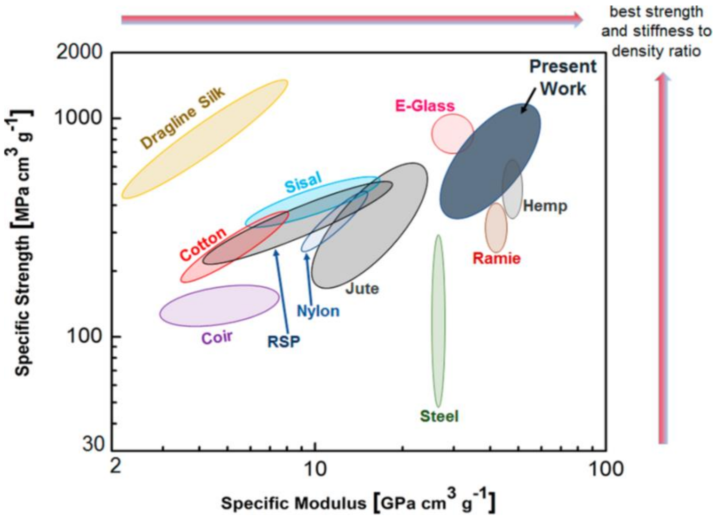
- Upscaling
- Cost! Techno-economic evaluation is needed. In some cases different "type" of cellulose can be considered for the same application
- Producing CNF, enzymatic/refining system probably most economical. Most often it is functionalized in order to be able to fibrillated it in a efficient way.
- Nanocrystalline cellulose (CNC). Too much acid and too many process step in the current used technologies.
- Many ideas on functionalization of cellulose in small scale.

Nanocellulose Spinning









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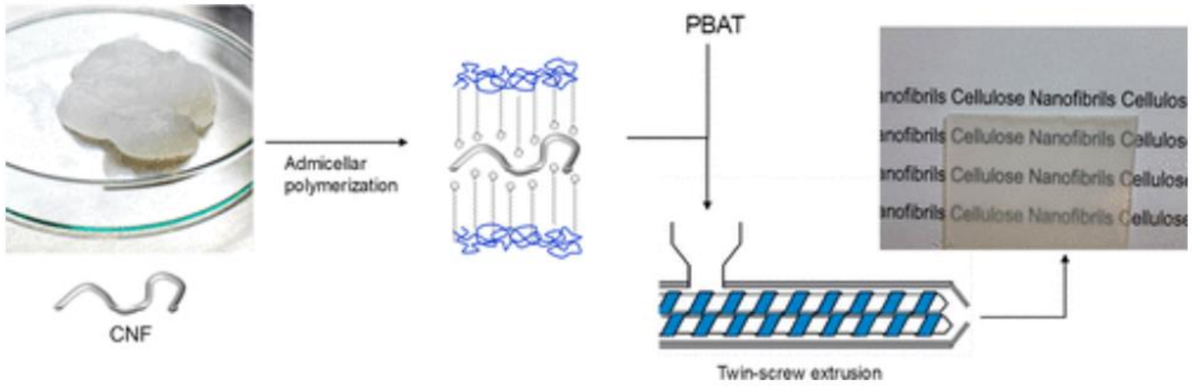
Karl Håkansson, RISE

Strategy for producing hydrophobic CNF in water and under mild conditions



Ulrica Edlund, KTH

Formable holocellulose product

11 December 2018, 11:21

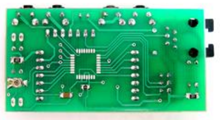
Teenage engineering and RISE Research Institutes of Sweden have built a speaker cabinet of holocellulose – a newly researched material with some unique properties. It is wood as we know it – but in pure white. Most importantly, it is easy to recycle to become something completely different like apparel, transparent film or even a moisturiser.

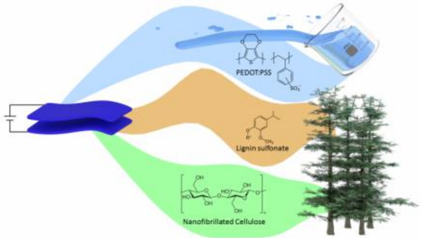
Aerogels from regenerated cellulose

Designed cellulose hybrid aerogels from regenerated cellulose for different applications

- Moisture sorption
- Slow-release properties
- Additives in cosmetics

Electronic production paradigms

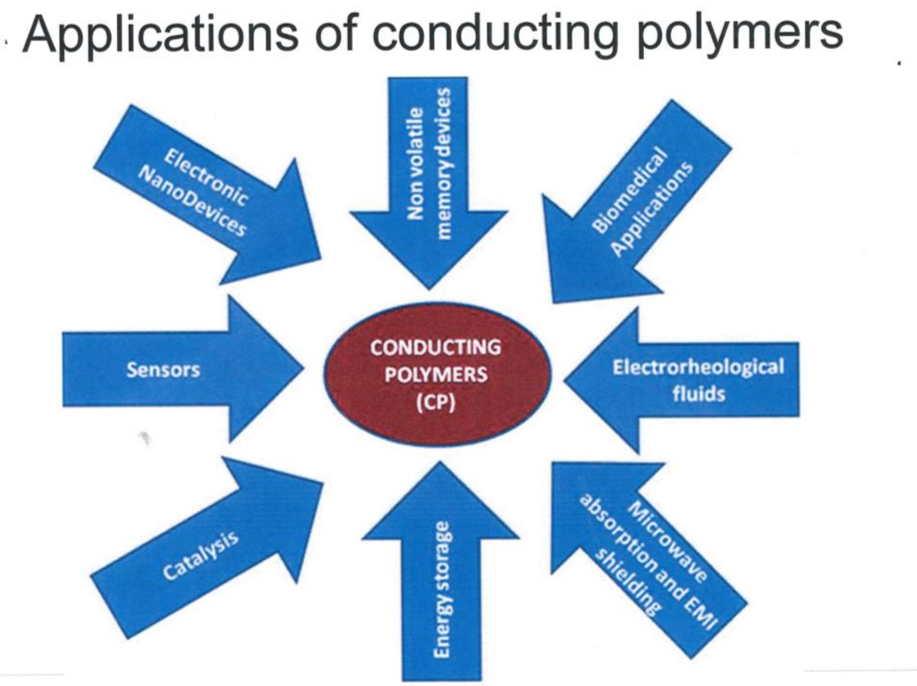




	Silicon electronics	Printed electronics	Biobased electronics
Investment	GSEK	MSEK	MSEK-GSEK
Processing	Generic batch	Addressable print	Generic tonnes
Size	*Nano to milli*	*Large 2D*	*Large 3D*
Component speed	Fast	Slow	Slow
Capacitance	Low	Medium	High
Eco requirements	Low	Medium	High
Form factor	2D - Rigid	2D - Flexible	3D - Stretchable
Material cost	Low	Medium	High
Fabrication cost	High	Low	Low

Pia Wågberg, RISE

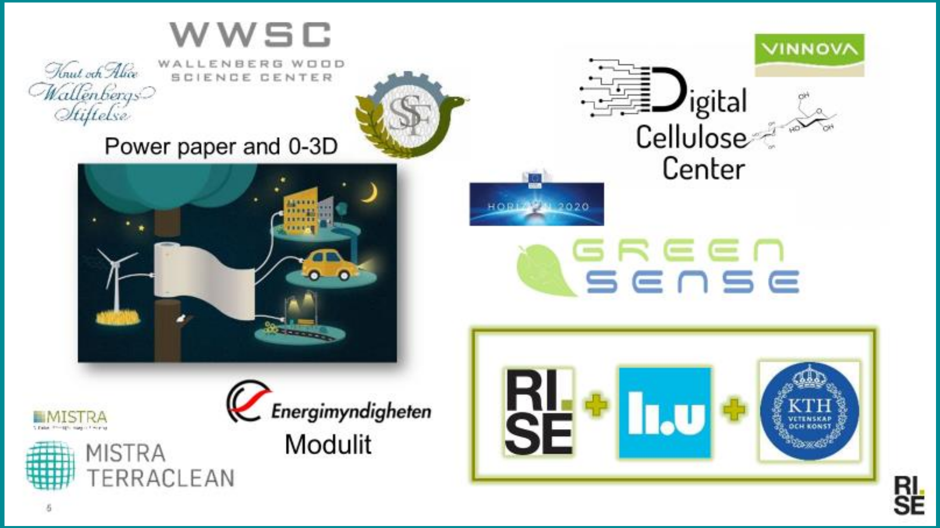
Integrated biobased electronics



Das and Prusty in Polymer-Plastic Techn. and Engng. (2012) 51(14) 1487

Biobased electronics

- Several initiatives worldwide on biobased electronics. RISE are heavily involved in Digital Cellulose Center



Biobased electronics

Table 2 Cellulose-based electrolytes for LIBs as reported in the literature

Reference	Cellulose form	Treatment/modification before introduction into the matrix[a]	Polymeric matrix
Section I Cellulose used as a reinforcement of polymeric matrices			
Nair et al. (2009, 2011)	Sheet	None	Photocured acrylic matrices
Wang et al. (2010)	Fibers	Grafting with acrylic acid	PVA
Azizi Samir et al. (2006), Azizi Samir et al. (2004a, b, c, d, 2005a, b)	NCC	None	PEO or crosslinked PEO
Schroers et al. (2004)	NCC	None	Ethyleneoxide-epichlorohydrin copolymers
Alloin et al. (2010)	MFC	None	PEO
Chiappone (2011)	MFC	None	Photocured acrylic matrices

Reference	Cellulose derivative	Treatment/modification
Section II Cellulose derivatives used as SPEs or GPEs		
Chelmecki et al. (2007)	Hydroxypropylcellulose	Grafting with PEO
Lee et al. (2010)	Cellulose triacetate	Plasticization with ionic liquids
Machado et al. (2005)	Ethylcellulose	Plasticization with glycerol
Paracha et al. (2012)	Ethylcellulose	Grafting with methylmethacrylate
Ramesh et al. (2012a, b)	Cellulose acetate	Plasticization with ionic liquid or eutectic solvents
Ko et al. (2010)	Cellulose phthalate	None
Sato et al. (2005)	Cyanoethylated cellulose	None
Ren et al. (2009)	Cyanoethylated cellulose	Blended with PVDF
Yue et al. (2003), Yue and Cowie (2002)	Cellulose esters	Esterification with PEO monocarboxylic acid
Le Nest et al. (1992), Regiani et al. (2001)	Hydroxyethylcellulose	Grafted with oligoetherisocyanate

[a] The presence of functionalities onto the NCC or MFC due to the preparation procedure (e.g. hydrolysis) is not regarded here as a modification

Cellulose and cellulose derivatives for the elaboration of separators, electrolytes and electrodes in Li-ion batteries, se table below and for references in Cellulose-based Li-ion batteries: a review (Jabbour et al 2013: Cellulose (2013) 20:1523–1545)

RI. SE

Biobased electronics

https://www.billerudkorsnas.com/media/press-releases/2018/swedish-research-breaks-new-ground--closer-to-a-commercial-paper-battery

BILLERUDKORSNÄS

HOME > PRESS & NEWS > PRESS RELEASES > SWEDISH RESEARCH BREAKS NEW GROUND – CLOSER T

PRESS RELEASE · 12 JUL 2018, 11:00 CET

Swedish research breaks new ground – closer to a commercial paper battery

BillerudKorsnäs and Uppsala University are making paper batteries a reality, paving the way for energy storage in packaging materials.

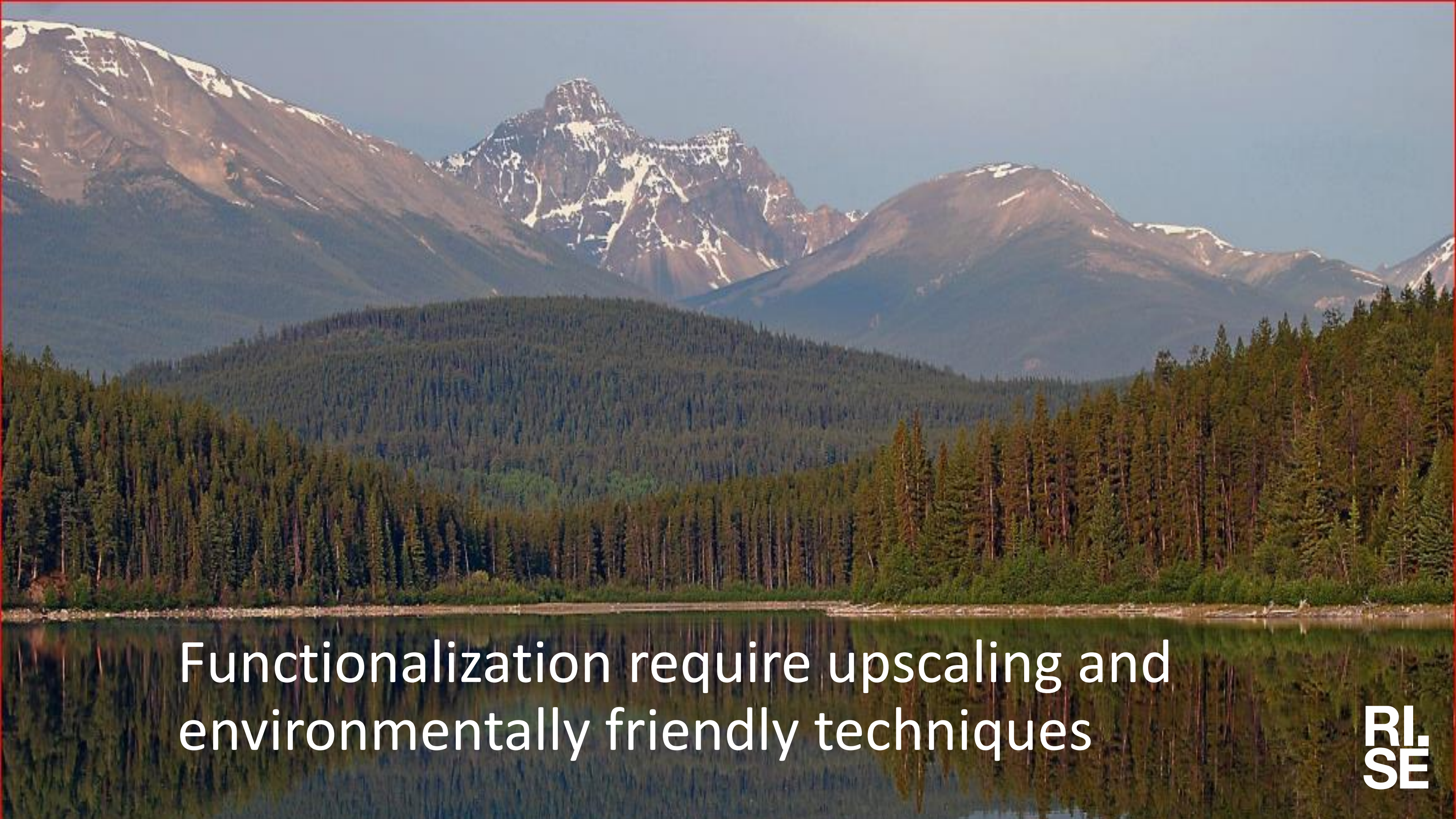
BillerudKorsnäs and researchers at Uppsala University have together taken an important step towards the future's paper batteries. Together they have taken basic research based on pure cellulose from algae and developed it to work with the same type of fibre that BillerudKorsnäs usually uses to

Concluding remarks

- Environmental and economical process for retrieving the celluloses
  - upscaling
  - techno-economical assessments
- Process improvement to manufacture CNF and CNC.
- Usage of CNF and CNC promising in products to improve environmental performance.
- Functionalizing cellulose material.
  - upscaling
  - techno-economical assessments

Emerging areas

- Paper&Packaging (in situ productions)
- Flexible electronics
- Textiles (substitute cotton with cellulose)
- Aerogels (hydrophilic and hydrophobic)
- Biobased composites



Functionalization require upscaling and environmentally friendly techniques


Questions ?

Acknowledgement:
RISE team:
- Lennart Salmén
- Anna Carlmark
- Karl Håkansson
- Pia Wågberg

Tom Lindström, KTH
Ulrica Edlund, KTH

Contact information:

Marie Bäckström, marie.backstrom@ri.se
Pia Wågberg, pia.wagberg@ri.se (biobased electronic)
Prof. Ulrica Edlund, edlund@polymer.kth.se (polymerizations reaction)
Anna Carlmark, anna.carlmark@ri.se (nanocellulose)

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N. Karaki et al. / Enzyme and Microbial Technology 90 (2016) 1–18

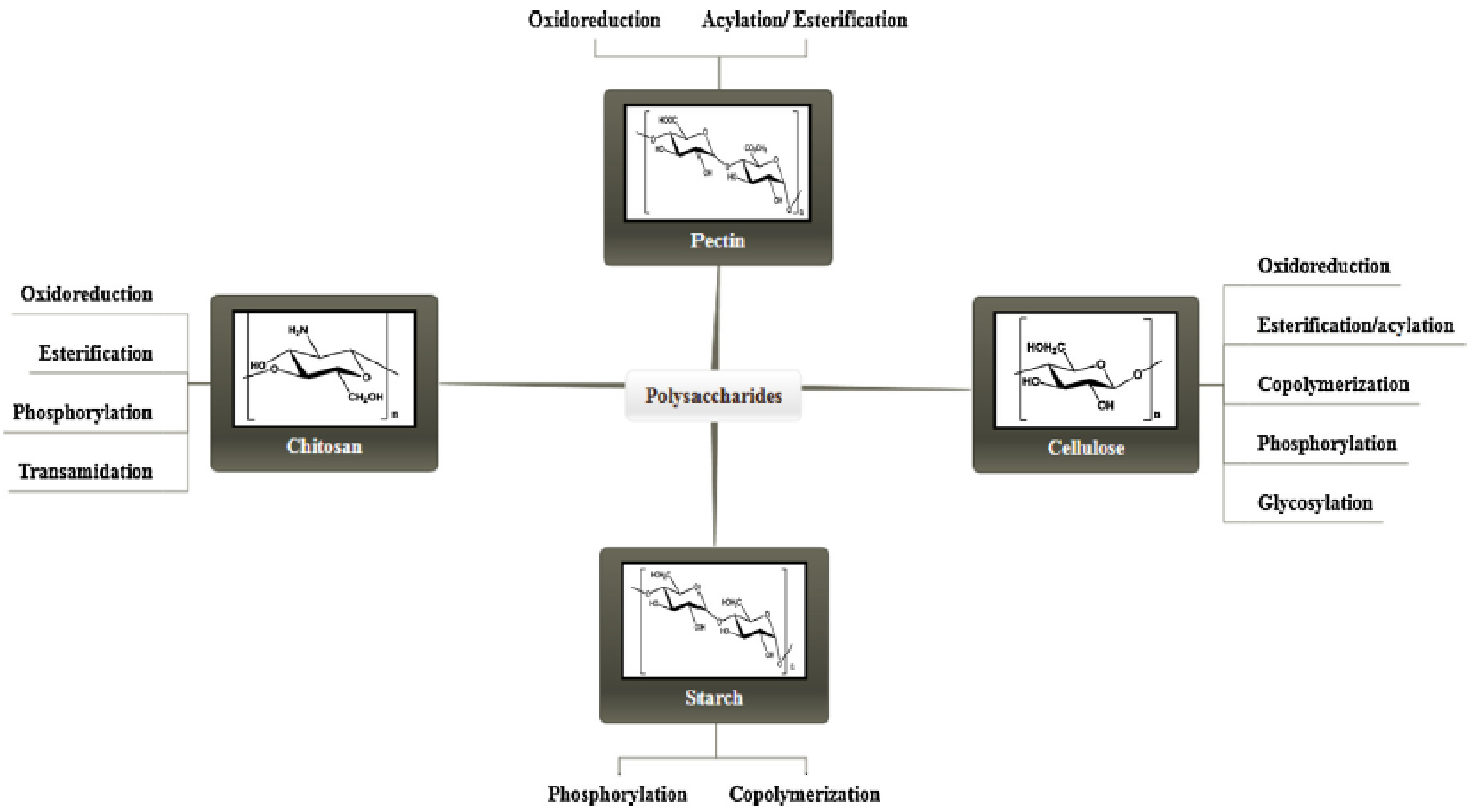
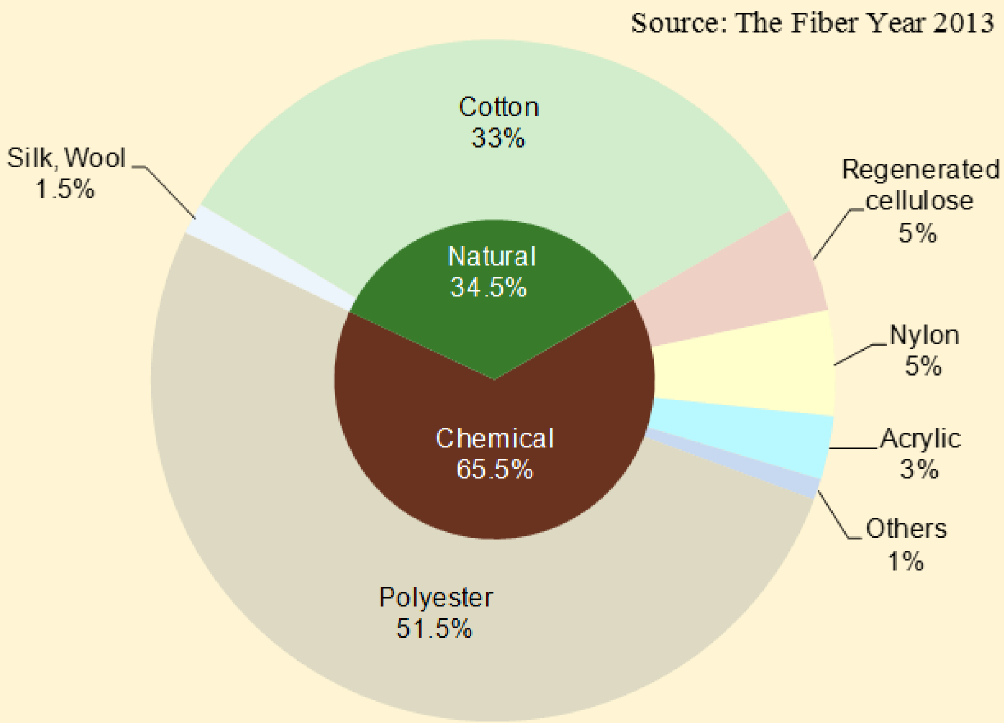


Fig. 1. Summary of the different enzymatic modifications applied to chitosan, cellulose, pectin and starch, mentioned in the review.

Global market share divided per fibre type



Roselle

Sweet sorghum

Corn cub

Netherlands’ vegetables

TA BORT BILD

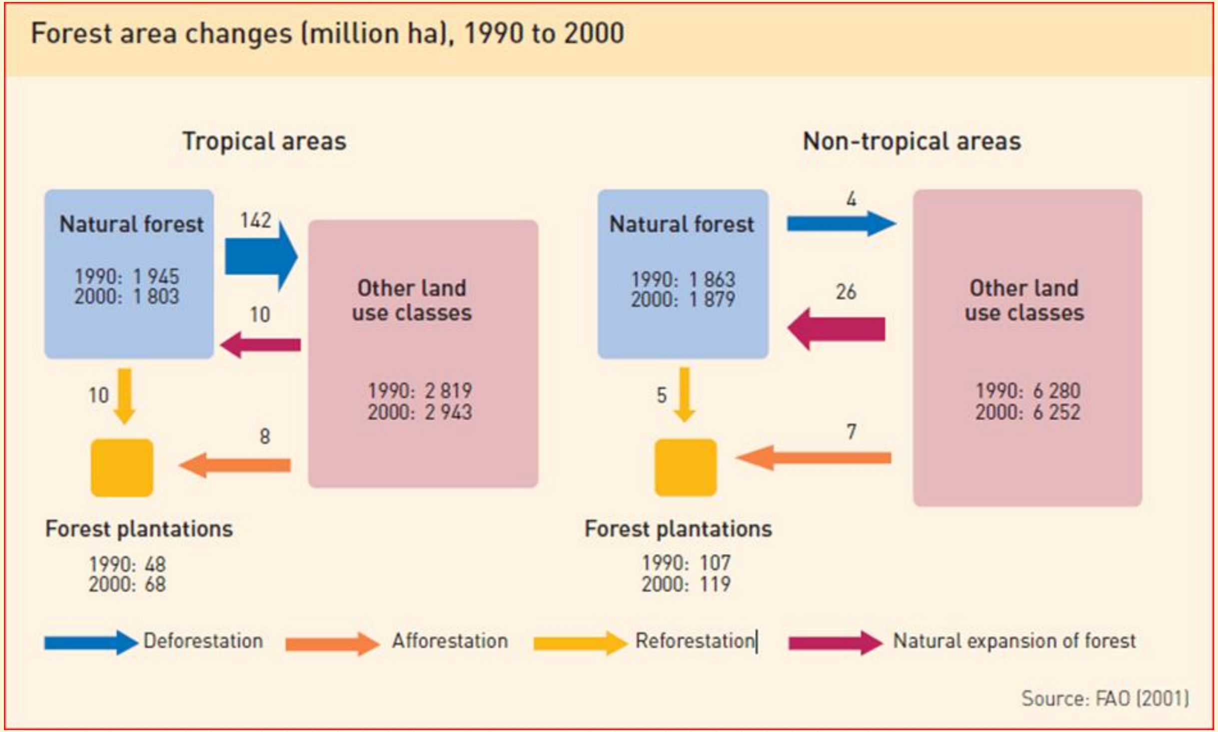
Vegetables	Gross yield 1998 (mln kg)	Gross yield 2016 (mln kg)
Total vegetables	3,339.0	5,002.1
Mushrooms	246.0	300.0
Total strawberries	35.9	61.2
Total leaf and stem vegetables	327.5	336.8
Total tuberous and root vegetables	1,004.0	2,198.9
Total kind of cabbage	334.5	307.8
Total legumes	106.1	52.1
Total fruit eaten as vegetables	1,253.0	1,711.0
Other vegetables	32.0	60.0

Source: CBS

CBS, Statistics

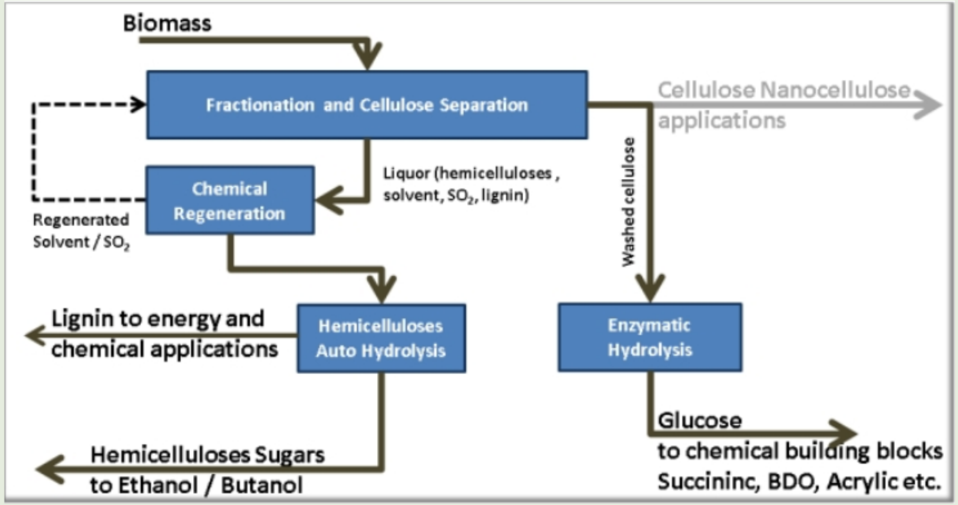
RI. SE

Forestry area changes



AVAP – commercial process

In a parallel second step the cellulose fraction is converted to products. The cellulose that is generated from **AVAP®** has very low content of lignin and hemicelluloses. It is an ideal feedstock for the production of pure cellulose, nanocellulose or cellulosic glucose.



The high purity fiber leads to very low cost enzyme dosages to convert the **AVAP®** cellulose to a clean glucose stream in preparation for downstream conversion to chemicals using biological organisms or chemical catalysis. Lignin is recovered for use in lignin derived products or becomes boiler fuel to produce the energy to run the process.