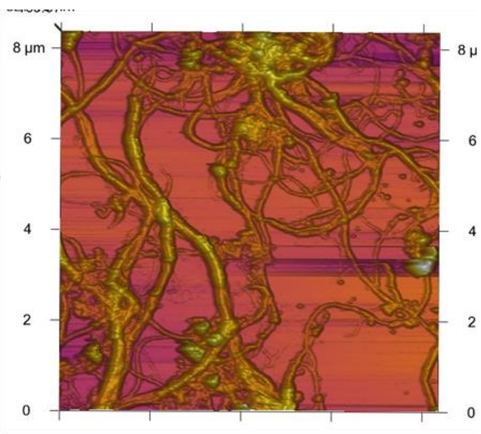
The conversion of waste paper to cellulose nanofibers and to high value products.



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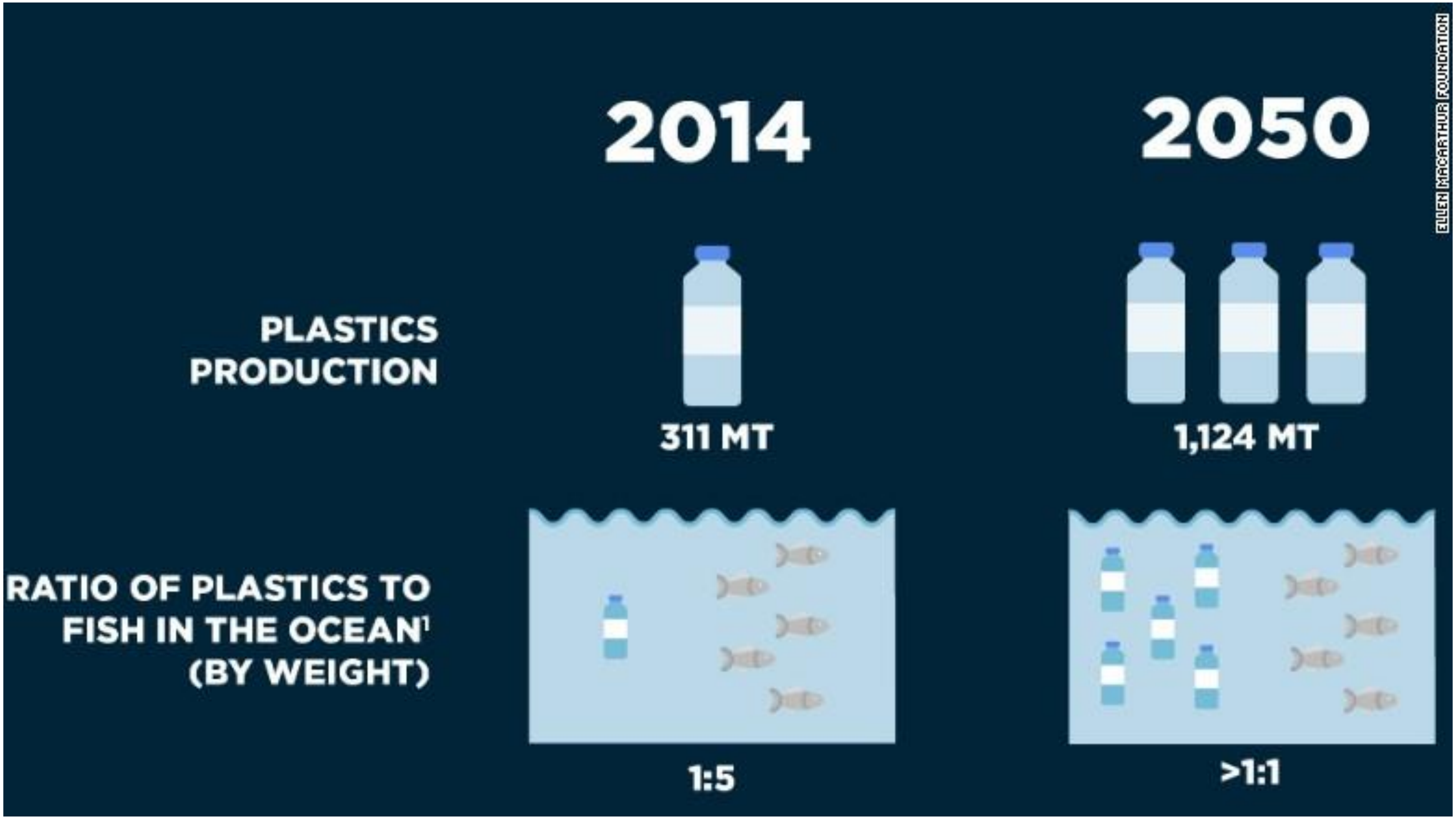
Paper or Plastic?

- In the US, 250 million tons of waste. 87 million tons recycled. 29 million tons combusted. Balance goes to landfills. (https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/index.html)
- Plastic is easy to recycle, but the re-use is usually for some lower value material, such as construction material.
- Plastic, if littered or dropped in ocean, persists a long time. 8 million tons of plastic end up in the ocean every year (http://www.plasticoceans.org).
- Paper enjoys high recycling rate. Recycled paper can be used for the same or higher value application several times.
- Paper, if littered, decays and causes little harm.

Plastic accumulates because it does not decay



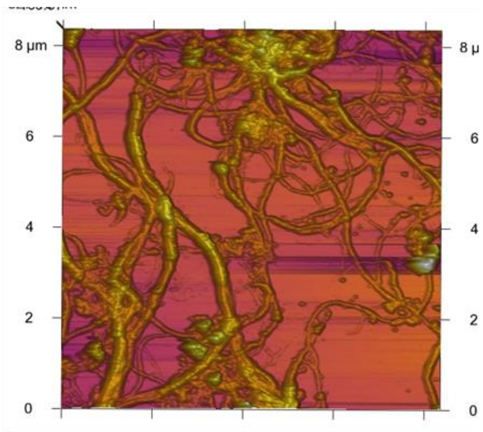
Other packaging

- Glass - little value in recycling (in fact, a cost). High energy costs to produce and high energy costs to recycle.
- Metal – good value but high energy costs to re-use.
- Aluminum – only cans are recovered. Foil and similar uses end up in ash streams or landfills. Aluminum has a high energy input to produce as well as it generates toxic waste streams.

- We should struggle to move to cellulose only packaging materials!!

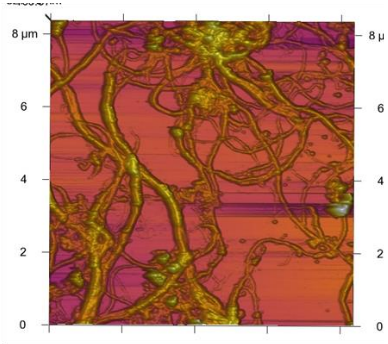
New material – cellulose nanomaterials

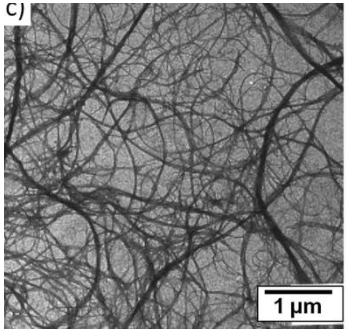
- Fine scale fibers that can be produced from waste paper.
- When dried, we get plastic like properties.
- Possible to generate high value products from these fibers.



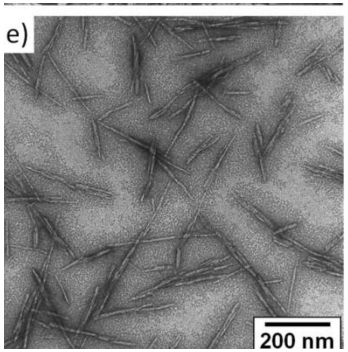
Key forms of cellulose nanomaterials

- **Mechanically produced**. Cellulose nanofibers (CNF), microfibrillated cellulose (MFC)

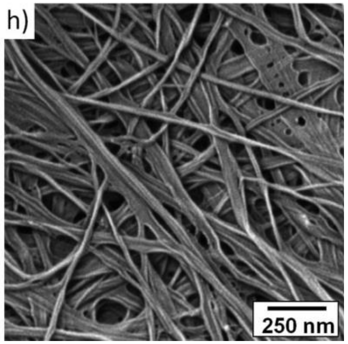




- **Chemically produced**. Cellulose nanocrystals. (CNC)



- **Bacterial cellulose**. (BC)



Cellulose nanomaterials

- Sustainable, renewable, recyclable, bio-compatable and compostable.

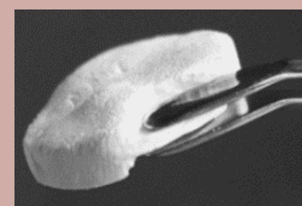
Tissue Engineering

- Scaffolds
- Bandages
- Ligament
- Blood Vessels
- Drug Delivery


Deng et al.

Foams

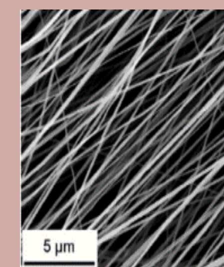
- Acoustic
- Structural
- Thermal
- Absorption
- products



Paakko et al., Soft Matter, 2008

Fibers and Films

- Reinforcement
- Textiles
- Woven
- Films

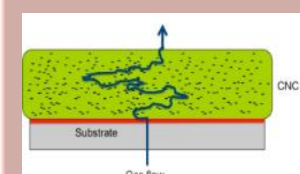


Dong et al., 2012

Rheology Modifier

- Paints
- Cosmetics
- Food
- Adhesives

Specialty Packaging

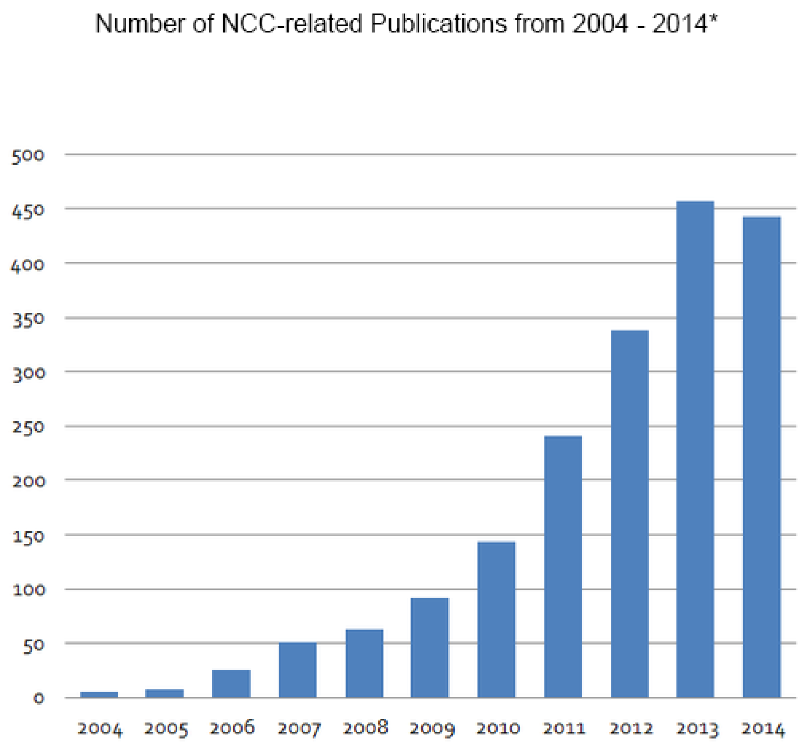


Herrera et al.

Vartiainen et al.

Moon, R. J., Martini, A., Nairn, J., Simonsen, J., & Youngblood, J. (2011). Cellulose nanomaterials review: structure, properties and nanocomposites. *Chemical Society Reviews*, *40*(7), 3941-3994.

Cellulose Nanomaterials Related Publications



*Obtained using the *Web of Knowledge* using the keywords "nanocrystalline cellulose", "cellulose nanocrystals", "nanocellulose", "cellulose nanofibers", and "microfibrillated cellulose".

Source: Lux Research, Inc.
www.luxresearchinc.com

Potential US Market for Cellulose Nanomaterials

6 million tons/yr

Application	Annual Volume, in ‘000 tonne/yr.
Packaging	1657
Plastics	1624
Paper	985
Hygiene and Absorbent	700
Textiles	550
Automotive	428
Cement	21

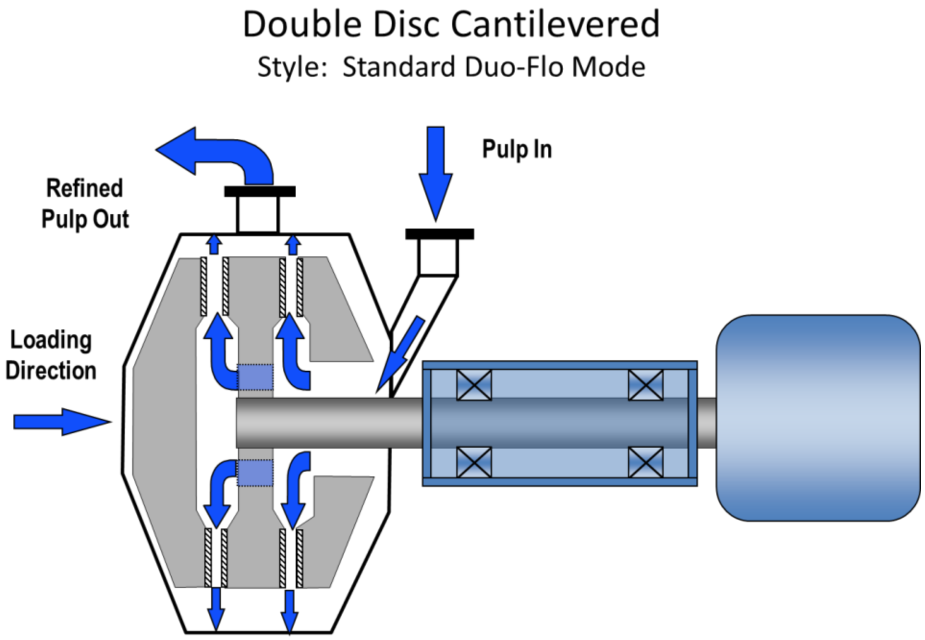
Ref: Shatkin, J., et. al. Tappi Nano Conference Vancouver, BC 2014.

Cellulose Nanomaterial Samples supplied by the University of Maine April 2013 – May 2016

- Samples provided to
  - 218 private companies
  - 199 academic institutions
  - 46 research centers
  - In 39 different countries
- CNF – 7,025 lbs.
- CNC – 568 lbs.
- Tempo – CNF – 2.3 lbs.

University of Maine Production

- Mechanical methods. Ultra-fine friction grinder and pilot scale refiners.



Operate until “fines” content in fiber diameter sizer is over 90%

UMaine CNF Pilot Facility

- Capability
  - Refiner CNF
    - Pre-treatment
  - Mass Colloider Grinder
- Capacity
  - 1 ton/day
  - Slurry form (3% solids)

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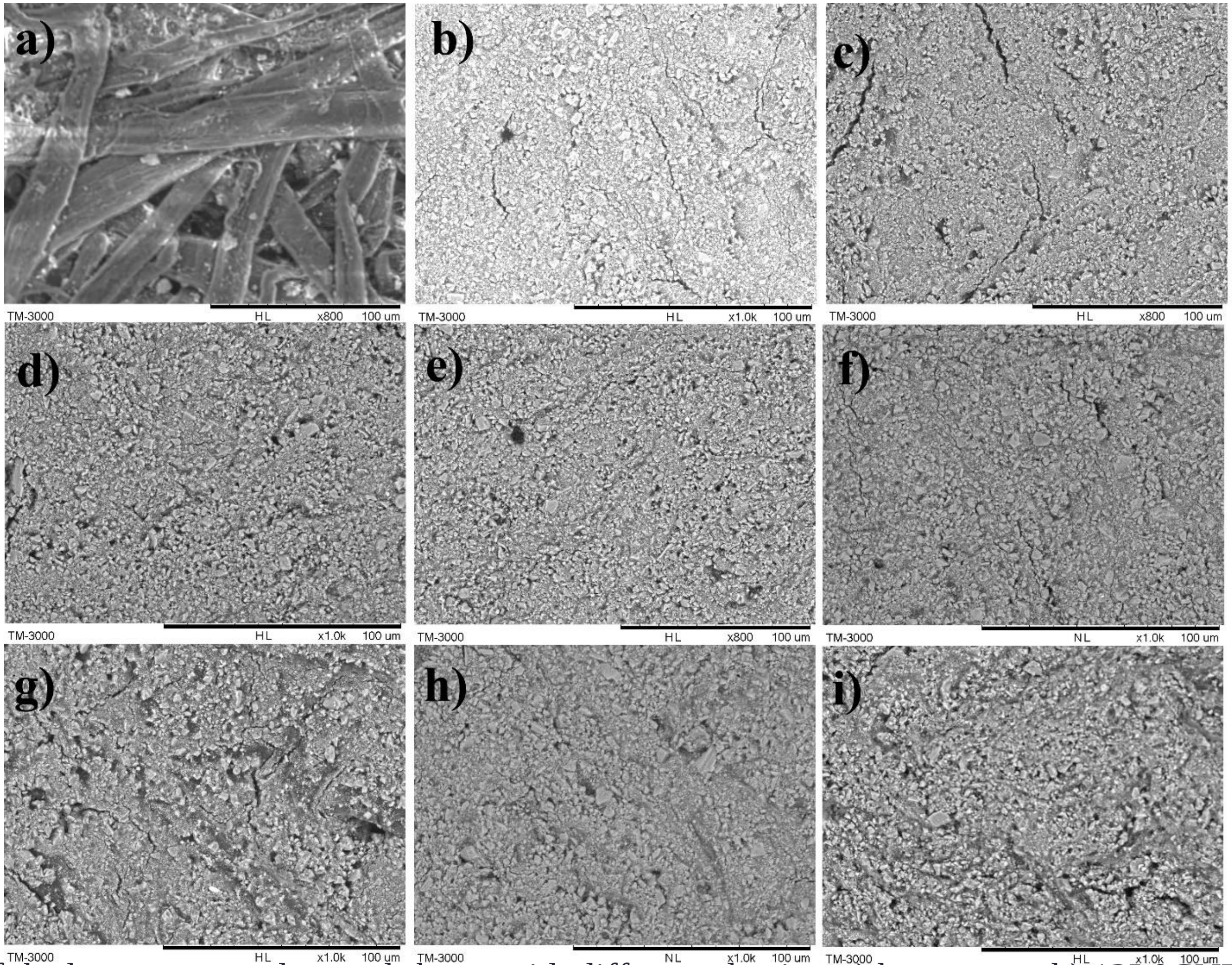
Process Development Center

Challenges

- How can we use?
- Where are the best applications for this new material?
- What process modifications do we need to make to utilize?
- What are issues about recycling?

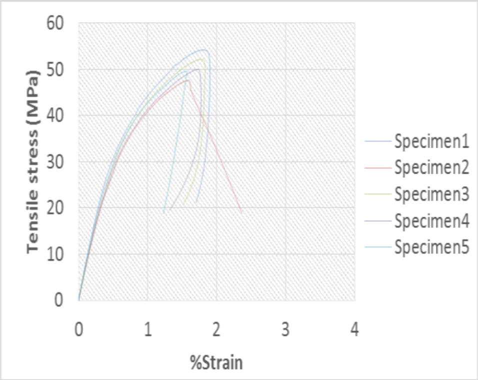
CNF in paperboard coatings – replaces polymer based binders.



SEM images of the base paper and coated sheets with different slurries: a) base paper, b) 12L0CNF, c) 11L1CNF, d) 12L1CNF, e) 10L2CNF, f) 12L2CNF, g) 9L3CNF, h) 12L3CNF, and i) 6L6CNF.

Cellubound

- Motivation: CNF has binding capabilities. Can we use it to make high density laminates of paper?
- Our approach: Use CNF in slurry form to bind sheets of paper into a laminate
- Result: stiff board like structures.

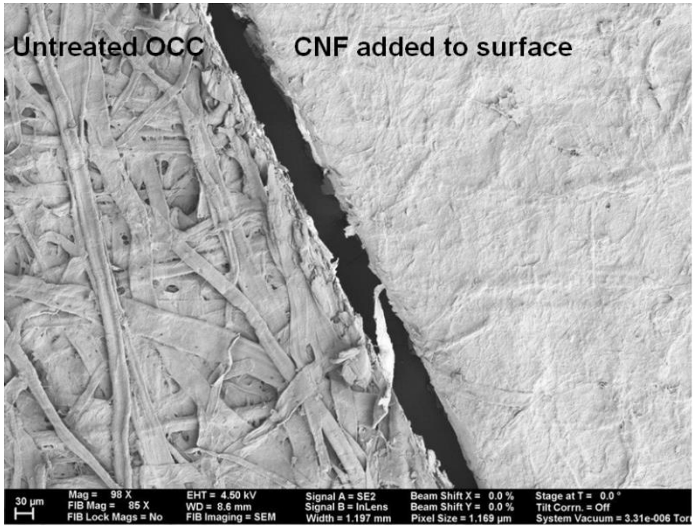


CNF: green adhesive for particleboard

- Motivation: Fully replace urea-formaldehyde resin by CNF as a green adhesive Low formaldehyde products.
- Our approach: Make particleboard panels using CNF as the resin
- Our solution: Develop a sequential pressing technique to reduce initial moisture content to successfully manufacture panels
- Result: Particle boards with low formaldehyde emissions.

Example application - future goal

- Replace the aluminum coated polypropylene chip bag with paper coated with cellulose nanofibers (CNF).



Potential contact with food.

Large volumes.

CNF provide the oxygen barrier that polymers are not able to obtain.

Product here could be recycled in the paper stream and would decompose if littered on the land or ocean

Motivation to use recovered paper

- Mechanical methods can be used to generate material with no pollution issues. Can be done in a metropolitan area.
- Produce products close to consumer base.
- Minimize transportation costs. Increases value of recycled paper.

Summary

- Cellulose nanomaterials have great potential.
- Low value – high volume applications in packaging seem logical. Imparts oxygen and grease barrier layer to paper. Can be recycled with paper stream.
- High value –low volume applications. Medical devices, drug delivery, bone healing.
- Medium value – medium volumes - thickeners, adhesives in construction materials, binders in paint, etc.

Thank you for your attention

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