



2019 International Conference on Nanotechnology for Renewable Materials

Chiba, Japan · 3 — 7 June 2019

Held in conjunction with the Nanocellulose Forum (NCF)

Overview of Canada

PRESENTED BY:

Emily D. Cranston

Associate Professor

President's Excellence Chair in Forest Bioproducts

University of British Columbia



Overview of Canada



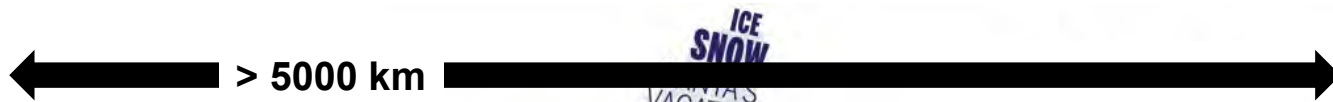
THE UNIVERSITY OF BRITISH COLUMBIA

Emily D. Cranston

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President's Excellence Chair in Forest Bio-Products

Wood Science and Chemical & Biological Engineering



- **Nice**
- **Modest**
- **Apologetic (Sorry!)**
- **Open-minded**
- **Inclusive**
- **Diverse**
- **Spread-out**
- **Eh?**

<https://www.macleans.ca/society/mapped-out-canada-our-home-and-cliche-land/>

https://en.wikipedia.org/wiki/Canadian_identity#Outsider_perceptions



Cellulose Nanomaterials: The *Canadian* Experience

HIGH STRENGTH
NANO BUILDING BLOCK



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x1000 MICRONS

***“Being Canadian means you
appreciate everything you have”***

– EVELYN HARFORD, Ottawa Citizen, July 2, 2016

Canada's Forests - \$25B GDP

Canada has over
347 million hectares
of forest land
(less than 0.5% are
harvested each year)

Canada's forests
cover more than 9
times the area of
Japan; most of it is
not commercially
managed.

35%

of Canada is
forestland,
>90% publicly
owned

9%

of the world's
forests (24% of
the boreal)

300

communities reliant
on forests
(210,000 jobs)

7%

of exports are
forest products
(2nd worldwide)

29%
Softwood lumber



23%
Wood pulp



6%
Printing
and
writing
paper



6%
Newsprint



7%
Structural
wood panels



29%
Other
(includes over
400 categories
of products)

Content: A.-H. Mathey, Natural Resources Canada
National Forest Inventory; State of Forest Report

Our Resources – Global Approach

- Natural resources & forests
- Forest & agricultural industry
- Government “buy in” - circular economy

***Do more with less (out of necessity) →
collaborative and cooperative culture
of networking to move forward***

- Sense of community
- High quality science, engineering
and universities



Big Country = Different Nanocelluloses

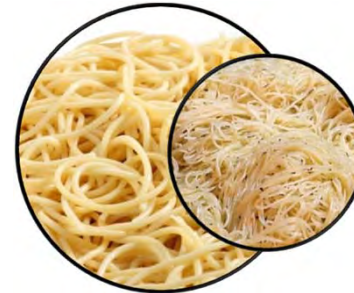
- Cellulose nanocrystals (CNC)

- 4 production methods (acid, catalysed ox, peroxide, APS)
- Short rods (3-20 nm x 100-200 nm), highly crystalline
- Different surface chemistries



- Cellulose micro/nanofibrils (CMF/CNF)

- Mechanical (optional: chemical + enzyme pre-treatment)
- Crystalline + amorphous, cross-sections 5-15 nm vs >100 nm
- Various degrees of fibrillation & surface chemistry

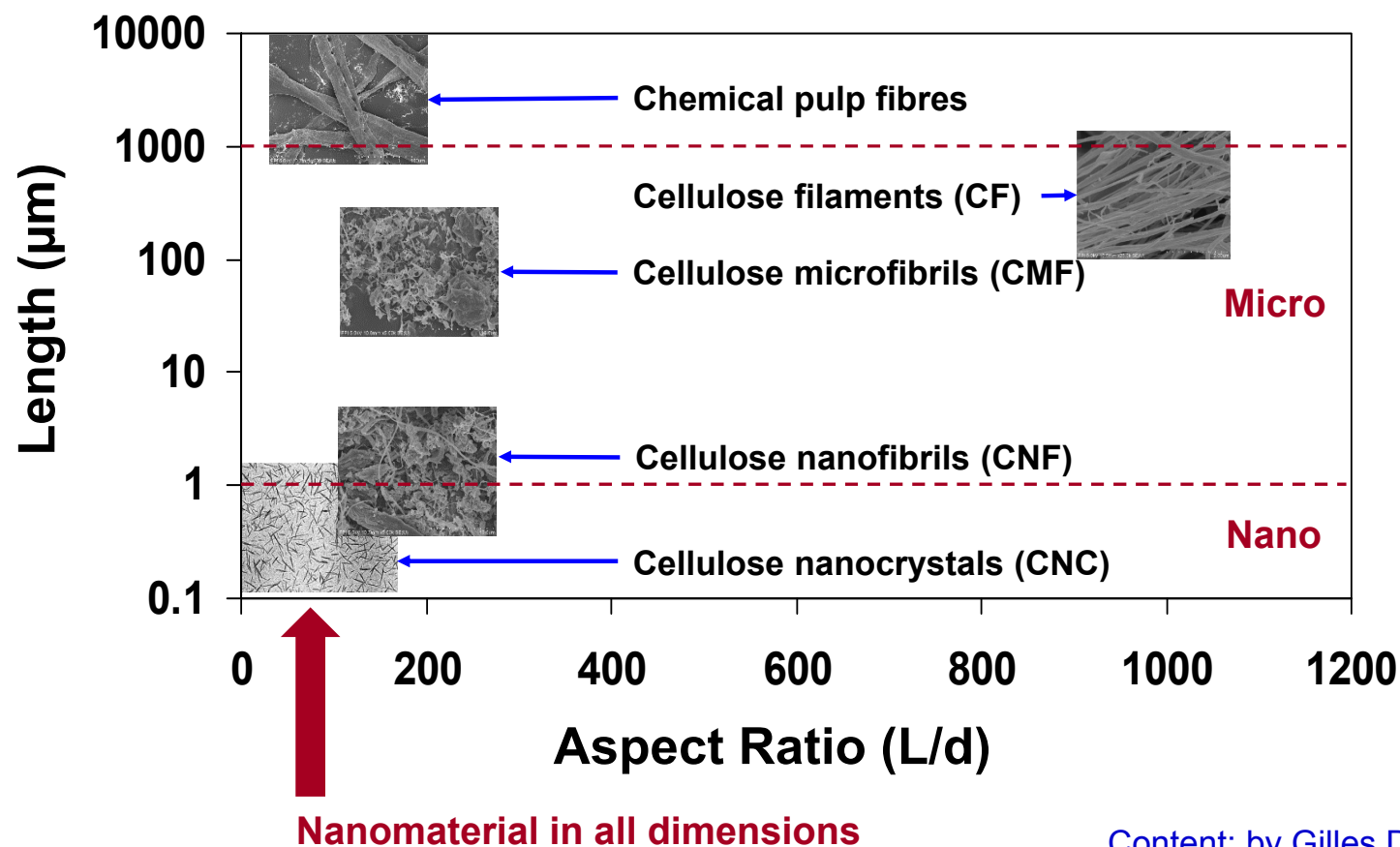


- Cellulose filaments (CF)

- Peeling fibers (mechanically), no chemical/enzyme treatment
- 80 to 300 nm wide and 100 to 2,000 µm long



Nanocellulose Material Size



Content: by Gilles Dorris, FPInnovations

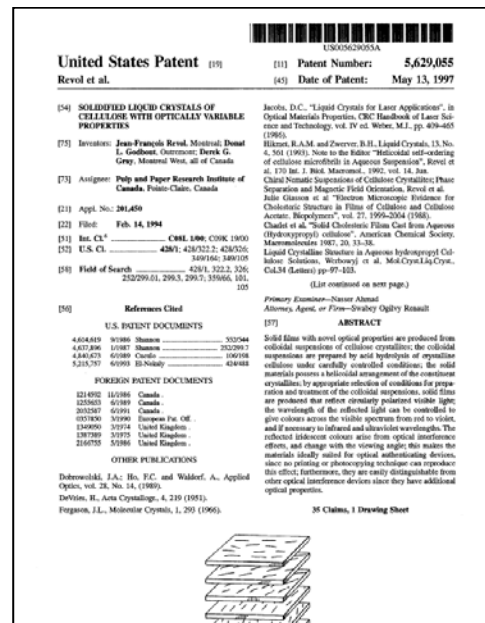
The Canadian Journey (<1993)

- 1947: Nickerson and Habrle – CNC
- 1949: Rånby – CNC
- 1959: Marchessault (a Canadian at American Viscose Corp.) – CNC (but focused on MCC)
- 1983: Turbak (at ITT Rayonier) – MFC
- 1987: Gray (at McGill) – gives up on MFC after visit to STFI Sweden
- 1992: Gray (at McGill) with Marchessault, Revol, Giasson, Bradford publish 1st report of sulfated CNCs forming chiral nematic phases



The Canadian Journey (1993-1998)

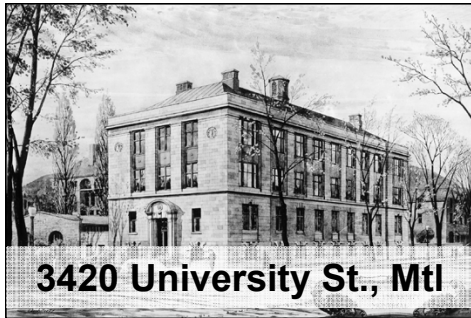
- Hydrolysis conditions
- Imaging TEM and AFM (with Cermav)
- Magnetic field effects
- Key parameters controlling optics
- Solid iridescent CNC films – patent



Mega tons of nano cellulose?!

Content: Derek Gray, McGill

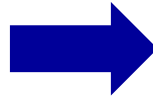
The Canadian Journey (2000s)



Paprican laboratories at McGill University (Pulp & Paper Centre)



2000s



Former Paprican, Pointe-Claire



Scale up led by VP Research Dave McDonald & Richard Berry (circa 2004) in Vancouver and Pointe-Claire, supported by Natural Resources Canada Transformative Technologies program (2007)



Domtar's Fine Paper Mill



Supported by Provincial and Federal government



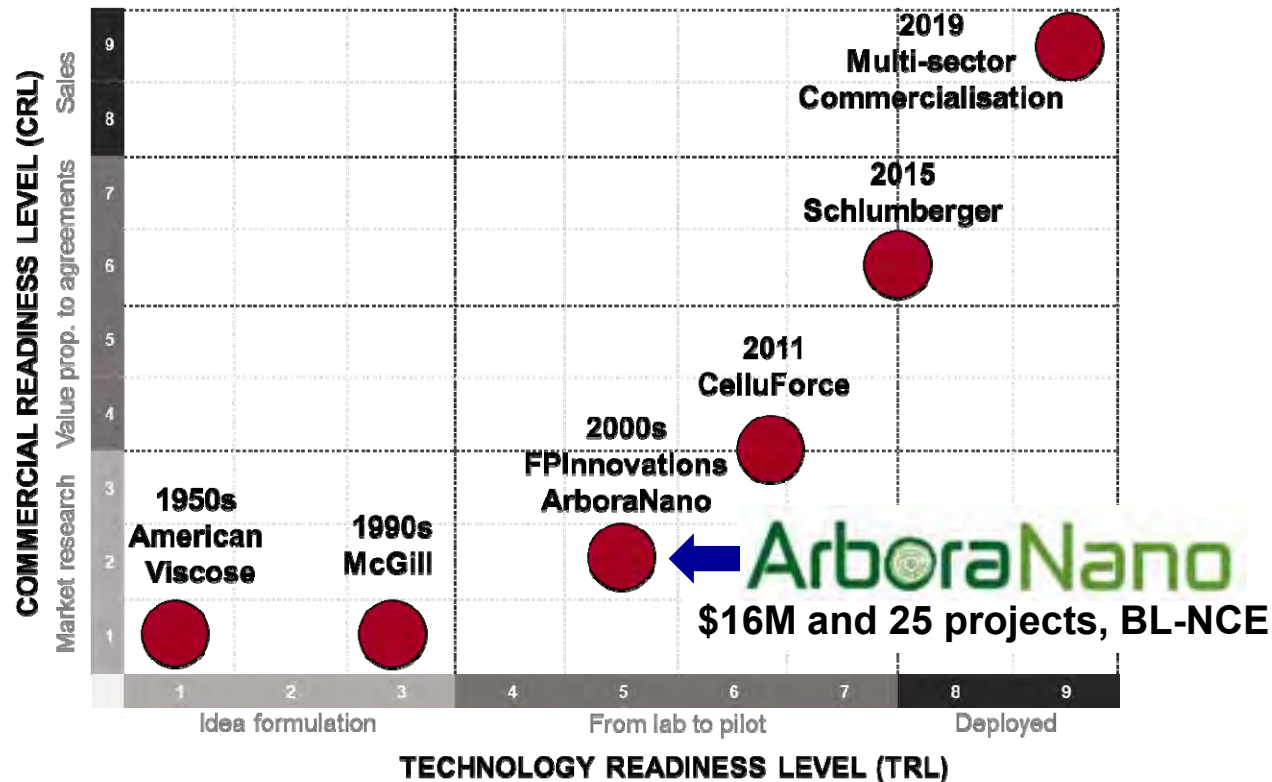
Windsor, QC (Jan. 2012)



First commercial CNC plant: 1 tonne/day

Content: Derek Gray, McGill & Scott Rennecker, UBC

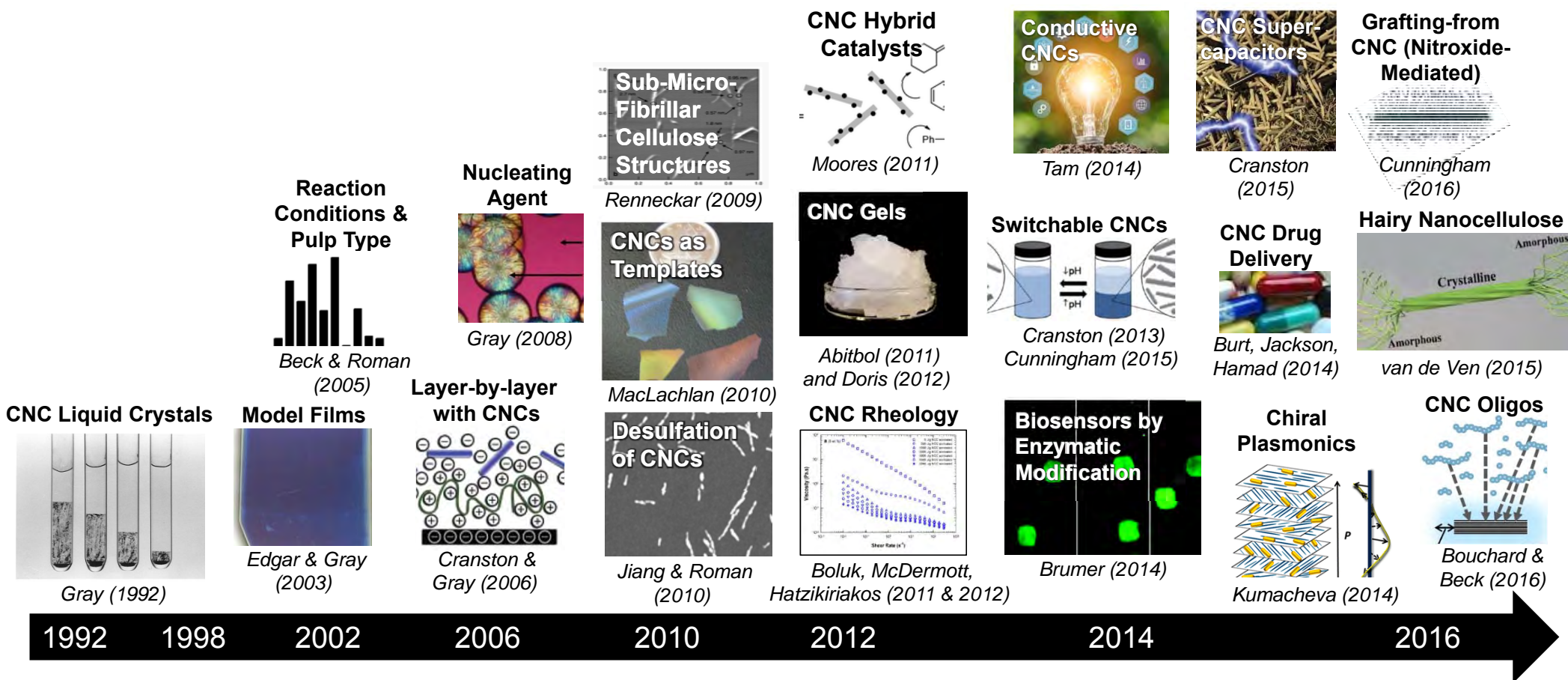
The Canadian Journey (Commercialization)



- **2010:** Ecotoxicological and mammalian toxicity testing – Brian O'Connor (FPIinnovations)
- **2012:** Canadian Domestic substance listing as first safe nanomaterial
- **Ongoing** Canadian Food Inspection Agency approval efforts

Content: Richard Berry, CelluForce, Jimmy Jong, FPIinnovations

Key Canadian Scientific Advances



Government Supported Programs

- **Natural Resources Canada**

- CleanTech Platforms
- Standards development/regulation
- Investments in Forest Industry Transformation (IFIT) \$100M fund

Forest Bioeconomy is seen as a **growing opportunity**

- **Natural Sciences and Engineering Research Council of Canada (NSERC)**

- Collaborate R&D Grants
- Strategic Networks
- CREATE Training Networks

- **National Centres of Excellence (Networks)**

- *ArboraNano*

- GreenCentre Canada, GreenSTEM, MITACS, Alberta Innovates, PrimaQuébec, OCE, FQRNT

- Pulp & Paper Ind., Sustainable Forest Management



Content: A.-H. Mathey, Natural Resources Canada and Scott Rennekar, UBC

National Programs Initiatives



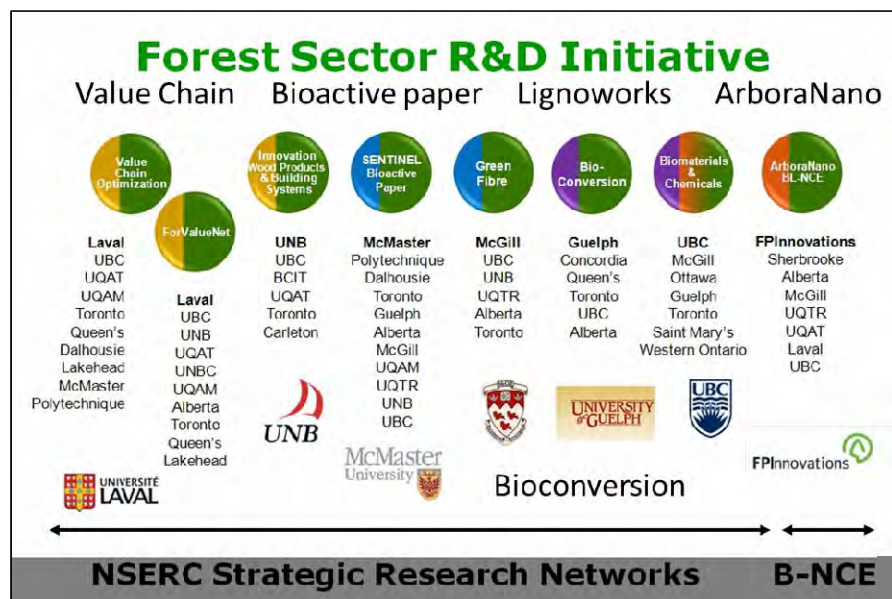
Forest Innovation by Research and Education (2011-2016)

Lead: Prof. Theo van de Ven (McGill)

\$34M Federal Investment

8 Networks, 100 Professors

(Largest forest bio-economy research network in the world)

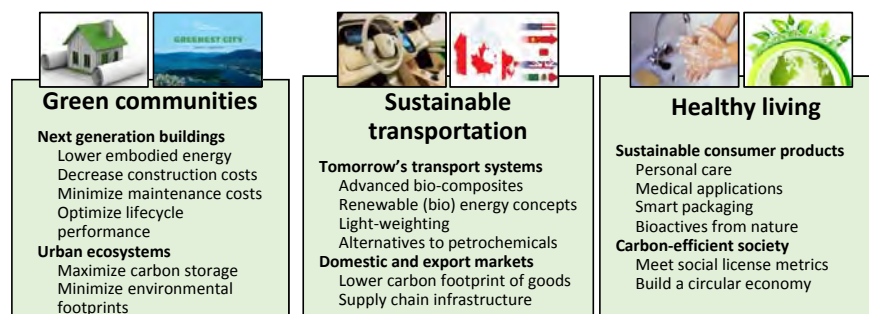


Bio-Innovative Renewables Network

2017 (~\$15M)

Lead: UBC + Prof. Mark MacLachlan (UBC) & Prof. Warren Mabee (Queens)

22 universities	7 provincial/fed. departments/agencies
126 academic researchers	23 Canadian manufacturers
6 not-for-profit research groups	7 international downstream companies
4 industrial research consortia	6 international research partners



FPIInnovations



- **World's largest not-for-profit forest research organization**

- \$76M innovation activities
- 430 employees
- 175 member companies
- 95 years of history
- 30 universities (research network)
- ISO laboratories + pilot facilities

- **Major innovation programs**

- Forest Operations
- Wood Products – Advanced Building Systems
- Pulp, Paper, Packaging & Consumer Products
- Bioproducts

- ***Public-private partnerships (PPP) around nanocellulose, lignin and bio-sourced chemicals development in Canada***

2012 - World's First CNC Plant, CelluForce (1 tonne/day)

- JV FPIInnovations and Domtar (R&D \$21M, plant \$45M)
- New shareholders: Schlumberger, Fibria, and Investissement Que.
- 1st commercial application 2013



Windsor, QC - 2012

2014 - World's First Cellulose Filaments Plant

- Strategic alliance between FPIInnovations and Kruger (R&D \$25M, plant \$43M)
- 10 tonne/day
- Pre-commercial stage



Trois-Rivières, QC - 2014

2014 - Canada's First Lignin Separation plant

- Licensing to West Fraser (>\$10M)
- 30 tonne/day
- Pre-commercial stage



Hinton, AB - 2014

Content: Jimmy Jong, Wadood Hamad, John Schmidt, FPI

Global & National Accolades

- **2012 NSERC Synergy Award for Innovation** to **Derek Gray** with McGill University, FPInnovations, ArboraNano, and CelluForce Inc.

The Marcus Wallenberg Prize

- **2013 Wallenberg Prize** to **Derek Gray**, McGill
- **TAPPI Nano Technical Award and FiberLean Prize** to **Richard Berry**, CelluForce (**2014**) and **Wadood Hamad**, FPInnovations (**2018**)
- **2019 NSERC Brockhouse Canada Prize** to **Michael Cunningham**, Queens University
- **2018 John S. Bates Memorial Gold Medal** to **Richard Berry**, CelluForce
- **2019 John S. Bates Memorial Gold Medal** to **Theo van de Ven**, McGill



Joining the Wave



Researchers



Industrial Producers

*Multiple suppliers
is important for
market growth!*



1 kg/day CNC
5 kg/day CNF



500 kg/day CNC (2021)



200 kg/day CNF



10 kg/day CNC



1.5 kg/day CNC
150 kg/day CF



30 kg/day CNC



10 tonne/day CF



10 kg/day CNC
50 kg/day CNF

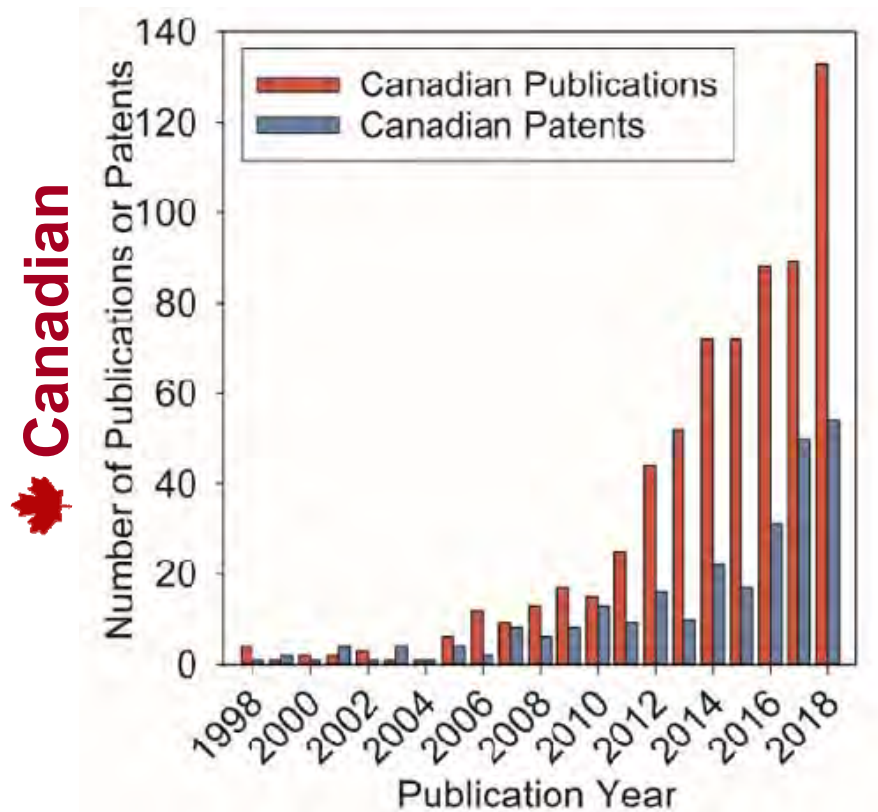


1 tonne/day CNC

Global Collaborators & End Users



Sense of Momentum – Productivity



Almost all industrial processes and applications for polymers were first developed for cellulose based materials...

so it is not unexpected that cellulose would play a significant role in the application of nanotechnology to materials science.

- Prof. Derek Gray, McGill

FPIInnovations holds the largest number of (granted) patents in CNC applications worldwide

Keywords: Cellulose nanocrystal, Cellulose nanowhisker, Nanocrystalline cellulose, Cellulose nanofiber, Nanofibrillated cellulose, Cellulose fibrils, Microfibrillated cellulose, Cellulose filament (Compared with ~ 400 papers in 2018 globally)

Plot generated by Stephanie Kedzior, U. Calgary

Challenges (are Opportunities)

Challenges
are global

Which
nanocellulose
for which
application?

Canada is
“feedstock
agnostic”

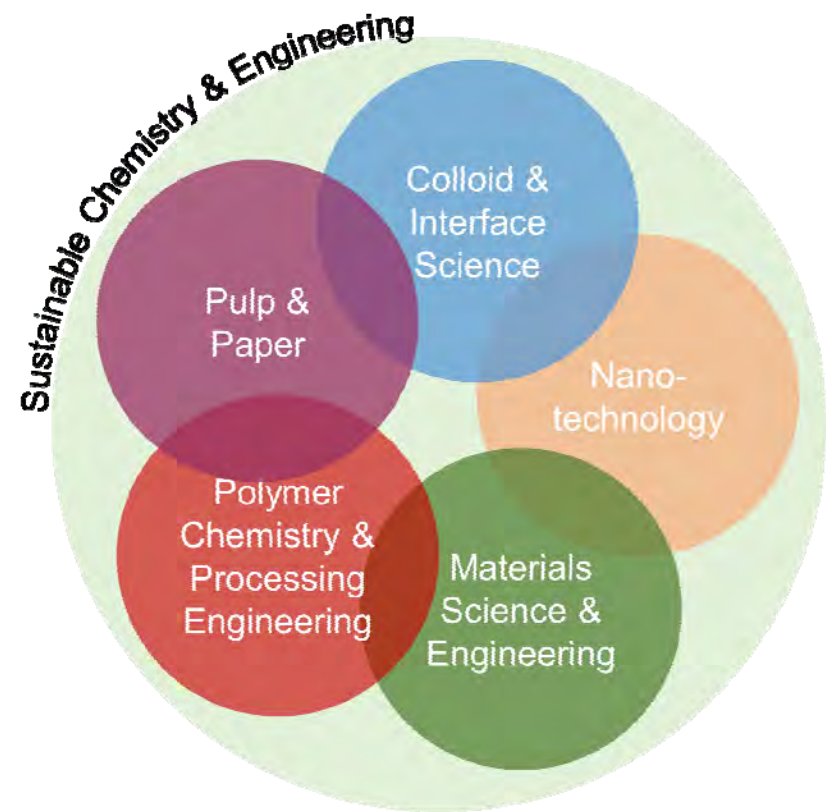
Share
results in
open
literature

- Today we understand the challenges better
- Objective, open-minded, collaborative
- Benefit from conferences, meetings, workshops, consortium/networks

**In 2015 FPInnovations launched (\$1.7M)
“Nanocellulose Challenges Program”**

- *Compatibilization*
- *Strength reinforcement potential*
- *Thermal stability*
- *Dispersion in aqueous media*
- *Dispersion in non-polar matrices*
- *Characterization*

Scientific Research





Boluk, Yaman

Civil & Environmental
Engineering

- Nanofiber Chair in Forest Products



UNIVERSITY OF
ALBERTA

*CNC and CNF in polymer composites, cement and concrete, air filtration, smart coatings, 3D printing, water treatment (**characterization and processing**)*



Brumer, Harry

Michael Smith Laboratories
Chemistry

- 2017 UBC Killam Prize



*Development of **chemo-enzymatic methods** for polysaccharide and fiber modification and cellulose-based biosensors and biomedical devices*



POLYTECHNIQUE
MONTREAL

TECHNOLOGICAL
UNIVERSITY



Carreau, Pierre; Tavares, Jason;

Heuzey, Marie-Claude

Chemical Engineering

CNC dispersion:
*dictated by surface
properties, improved by soni-
cation, quantified by rheology*



Champagne, Pascal

Cunningham, Mike

Chemical Eng.
Civil Engineering



Queen's
UNIVERSITY

- 2019 NSERC Brockhouse Canada Prize

***Surface modification** of CNCs using polymer grafting to impart desired properties and responsive behaviour*



Cranston, Emily

Wood Science and
Chemical & Biological Engineering



*Sustainable nano-biocomposites and hybrid materials: **Interfacial engineering** of CNCs in gels, emulsions, foams, latexes, and films*



Dubé, Marc

Chemical & Biological Engineering

- 2017 George S. Glinski
Research Award



uOttawa

*Green polymer reaction engineering – development of **adhesives with CNCs**, lignin, starch and renewable monomers*



Boluk, Yaman

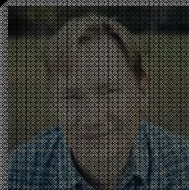
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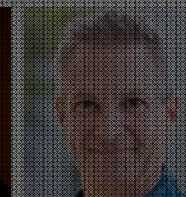
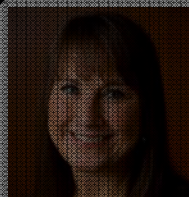
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**Carreau, Pierre; Tavares, Jason;
Heuzey, Marie-Claude**

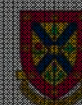
CNC dispersion:
*dictated by surface
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Cunningham, Mike

Chemical Eng.
Civil Engineering



Queens
UNIVERSITY

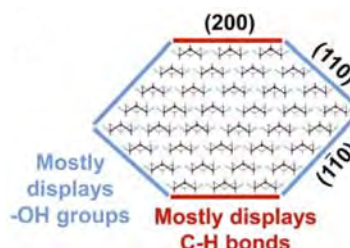
- 2019 NSERC Brockhouse Canada Prize

Surface modification of CNCs using polymer grafting

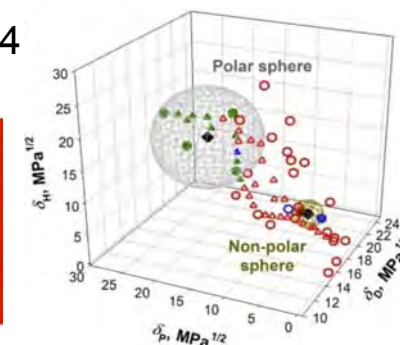
Cohesion Parameters for CNCs to Describe Amphiphilicity

Bruel, Tavares, Carreau, Heuzey. *Carbohydrate Polymers* **2019**, 205, 184

- CNC affinity is mapped through sedimentation tests
- CNCs display an amphiphilic behavior: 2 sets of Hansen solubility parameters
- Insight on CNC dispersibility in polymer matrices



toluene





Boluk, Yaman

Civil & Environmental Engineering

- Nanofiber Chair in Forest Products



UNIVERSITY OF ALBERTA

*CNC and CNF in polymer composites, cement and concrete, air filtration, smart coatings, 3D printing, water treatment (**characterization and processing**)*



Brumer, Harry

Michael Smith Laboratories Chemistry

- 2017 UBC Killam Prize



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POLYTECHNIQUE MONTREAL

TECHNOLOGICAL UNIVERSITY



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Heuzey, Marie-Claude

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***CNC dispersion:** dictated by surface properties, improved by sonication, quantified by rheology*



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Cunningham, Mike

Chemical Eng. Civil Engineering



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Cranston, Emily

Wood Science and Chemical & Biological Engineering



*Sustainable nano-biocomposites and hybrid materials: **Interfacial engineering** of CNCs in gels, emulsions, foams, latexes, and films*



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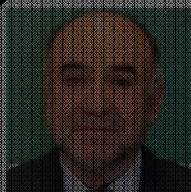
Chemical & Biological Engineering

- 2017 George S. Glinski Research Award



uOttawa

*Green polymer reaction engineering – development of **adhesives with CNCs**, lignin, starch and renewable monomers*

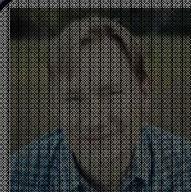


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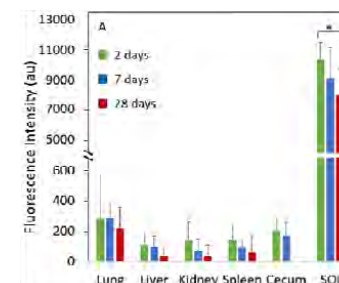
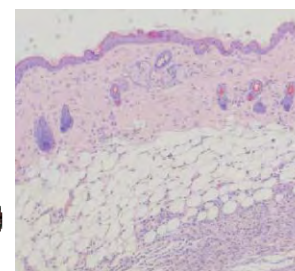
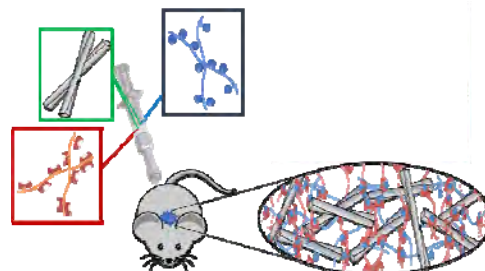


*Development of **chemo-enzymatic methods** for polysaccharide and fiber modification and cellulose-*

Biodistribution and Tissue Response of CNCs *in vivo*

De France...Moran-Mirabal, Lawlor, Cranston, Hoare. *ACS Biomater Sci Eng* **2019**, 5, 2235

- CNCs increase cell adhesion, decrease protein adhesion, no inflammation
- No significant bioaccumulation in any common clearance organs after 30 days



Cranston, Emily
Wood Science and
Chemical & Biological Engineering



*Sustainable nano-biocomposites and hybrid materials: **Interfacial engineering** of CNCs in gels, emulsions, foams, latexes, and films*



Dubé, Marc
Chemical & Biological Engineering
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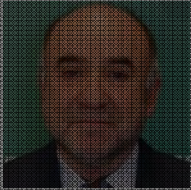
Chemical & Biological Engineering

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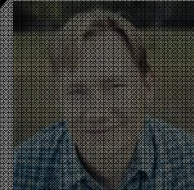
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ALBERTA

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Brumer, Harry

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Chemistry

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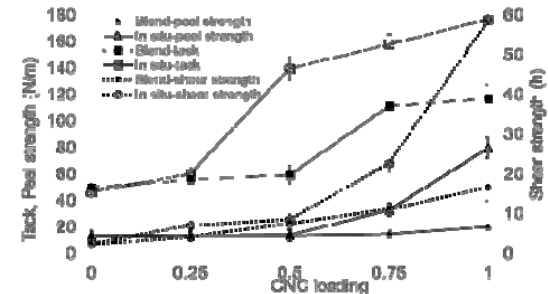
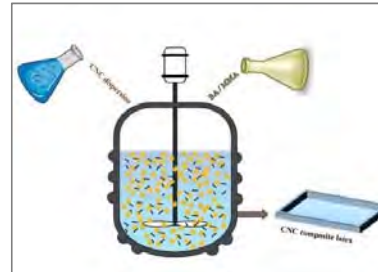


*Development of **chemo-enzymatic methods** for polysaccharide and fiber modification and cellulose-*

Latex-Based Pressure Sensitive Adhesives with CNCs

Dastjerdi, Ouzas, Niinivaara, Cranston, Dubé. *Macro Reac Eng* **2017**, 11, 1700013; *Int. J. Adhesion & Adhesives* **2018**, 81, 36.

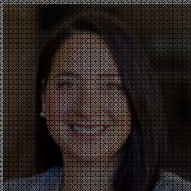
- *CNCs in scalable emulsion polymerization (batch and semi-batch) of BA/MMA, IBA, VAc, AA*
- *All PSA performance metrics improve with CNCs (in situ better than blends)*



Tack 4x ↑

Shear 20x ↑

Peel 6x ↑

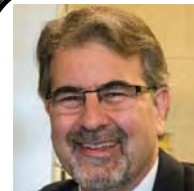


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Chemical & Biological Engineering

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uOttawa

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Gray, Derek

Chemistry

- 2012 NSERC Synergy Award
- 2013 Marcus Wallenberg Prize



*Characterization of **liquid crystalline suspensions** of CNCs, and of iridescent chiral nematic films cast from the suspensions*



Jiang, Feng

Wood Science

- Canada Research Chair in Sustainable Functional Biomaterials



*Isolation and chemical modification of nanocellulose for advanced structure (1D to 3D) and **energy, biomedical and environment** applications*



Johnston, Linda

Metrology Research Centre
National Research Centre
Adjunct Professor, uOttawa



*Cellulose nanomaterials **characterization** method development, metrology, commercial reference materials and Standards*



MacLachlan, Mark

Chemistry

- 2014 Steacie Prize
- 2016 Royal Society of Chemistry



*Supramolecular organic and inorganic materials for electronics, photonics, catalysis, and other applications; **templating mesoporous materials** from CNCs*



Moores, Audrey

Friscic, Tomislav (Steacie Fellow)
Chemistry



- CNC as supports for nanoparticle growth and **catalysis**
- **Mechanochemistry** to chemically modify lignocellulosics



Moran-Mirabal, Jose

Chemistry/Chemical Biology

- Canada Research Chair in Micro- and Nanostructured Materials



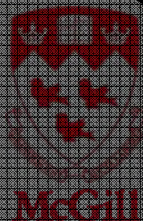
***Modular functionalization** of CNCs and fluorescence labeling for super-resolution microscopy of cellulose*



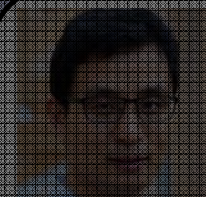
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Chemistry

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Characterization of *liquid crystalline suspensions* of CNCs, and of *iridescent chiral nematic films* cast



Jiang, Feng

Wood Science


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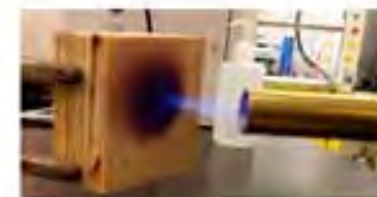
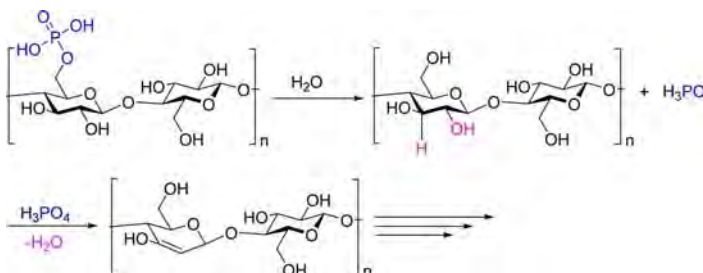


Isolation and chemical modification of nanocellulose for advanced structure (1D to 3D) and energy,

Flame-Retardant CNCs by Mechanochemical Phosphorylation

Fiss, Hatherly, Stein, Frišćić, Moores. *ACS Sustainable Chem Eng* **2019**, 7, 7951

- *Dry mechanochemistry instead of corrosive concentrated phosphoric acid*
- P₂O₅, Urea, 30 Hz, 90 min** 
- *Phosphate loadings of up to 3300 mmol/kg*



Viable flame-retardant coating material

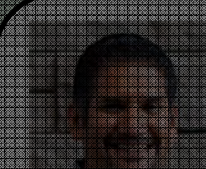


Moores, Audrey

Friscic, Tomislav (Steacie Fellow)
Chemistry



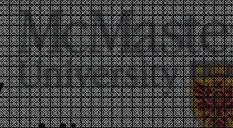
- *CNC as supports for nanoparticle growth and **catalysis***
- ***Mechanochemistry*** to chemically modify lignocellulosics



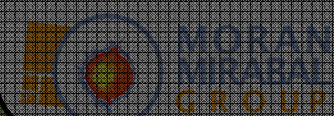
Moran-Mirabal, Jose

Chemistry/Chemical Biology

- Canada Research Chair in Micro- and Nanostructured Materials



Modular functionalization of CNCs and fluorescence labeling for super-resolution microscopy of cellulose





Gray, Derek

Chemistry

- 2012 NSERC Synergy Award
- 2013 Marcus Wallenberg Prize



*Characterization of **liquid crystalline suspensions** of CNCs, and of iridescent chiral nematic films cast from the suspensions*



Jiang, Feng

Wood Science

- Canada Research Chair in Sustainable Functional Biomaterials



*Isolation and chemical modification of nanocellulose for advanced structure (1D to 3D) and **energy, biomedical and environment** applications*



Johnston, Linda

Metrology Research Centre
National Research Centre
Adjunct Professor, uOttawa



*Cellulose nanomaterials **characterization** method development, metrology, commercial reference materials and Standards*



MacLachlan, Mark

Chemistry

- 2014 Steacie Prize
- 2016 Royal Society of Chemistry



*Supramolecular organic and inorganic materials for electronics, photonics, catalysis, and other applications; **templating mesoporous materials** from CNCs*



Moores, Audrey

Friscic, Tomislav (Steacie Fellow)
Chemistry



- CNC as supports for nanoparticle growth and **catalysis**
- **Mechanochemistry** to chemically modify lignocellulosics



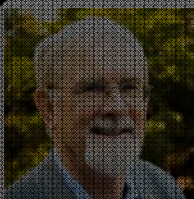
Moran-Mirabal, Jose

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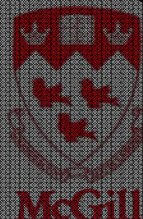
***Modular functionalization** of CNCs and fluorescence labeling for super-resolution microscopy of cellulose*



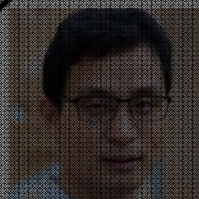
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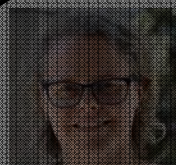
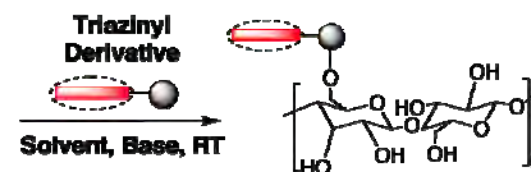
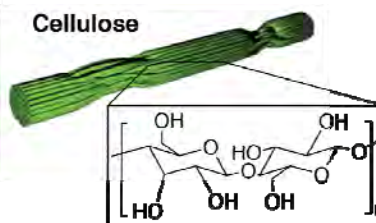


Isolation and chemical modification of nanocellulose for advanced structure (1D to 3D) and **energy**,

Modular “Click” Surface Functionalization of Cellulose

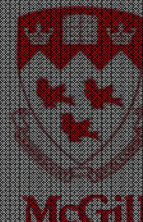
Fatona, Berry, Brook, and Moran-Mirabal. *Chemistry of Materials* **2018**, 30, 2424

- **Triazinyl chemistry** = Linker = = Functionality
- For tunable interfacial properties, hydrophobicity, fluorescence labeling and super-resolution microscopy of nanocellulose (H_2O or organic media)

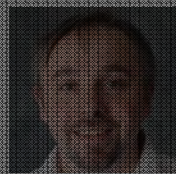


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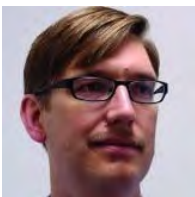
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Modular functionalization of CNCs and fluorescence labeling for super-resolution microscopy of cellulose



Rennekar, Scott

Wood Science

- Canada Research Chair in Advanced Renewable Materials



*Molecular structure and reactions of wood to **transform trees and recycled fiber** into novel materials that will serve as a platform for the bioeconomy*



Tam, Michael K. C.

Chemical Engineering

- Associate Editor, ACS Sustainable Chemistry & Engineering



*Sustainable nanomaterials for **advanced applications** – water, energy, bio, food, agriculture, coatings*

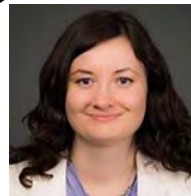


Trajano, Heather & Martinez, Mark

Chemical & Biological Engineering



*Evaluate methods for producing highly **fibrillated fibers** using enzymes and mechanical refining (+ microscopy)*



Trifkovic, Milana

Chemical & Petroleum Engineering



*Nanocellulose-stabilized **emulsions** and templated porous materials for enhanced oil recovery and energy applications*



Van de Ven, Theo

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*Transforming cellulose into useful products; one of these products is a novel form of nanocellulose, called **hairy nanocellulose***



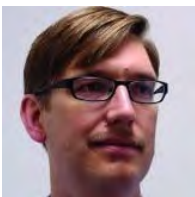
Winnick, Mitchell

Chemistry



*Understanding how the physico-chemical properties of polymer-grafted **CNC nanomedicines** affect interaction with tumours (model systems)*





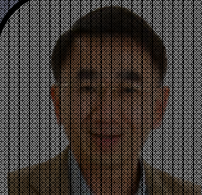
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UNIVERSITY OF
WATERLOO

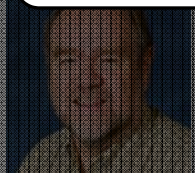
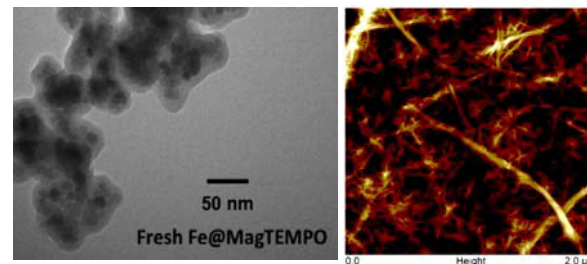


*Sustainable nanomaterials for **advanced applications** – water, energy, bio, food, agriculture, coatings*

Synthesis of CNF using Magnetically Separable TEMPO Nanocatalyst

Patankar and Renneckar. *Green Chemistry* **2017**, 19, 4792

- Solid catalyst to synthesize nanofibrillated cellulose in water
- Process is cost effective through catalyst recovery and eliminates catalyst release into wastewater streams

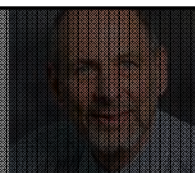
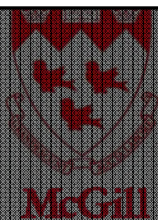


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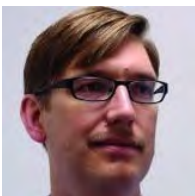


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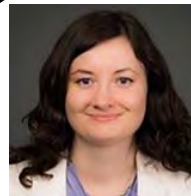


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Trifkovic, Milana

Chemical & Petroleum Engineering



UNIVERSITY OF
CALGARY



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WATERLOO

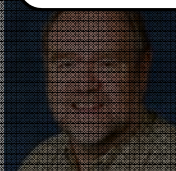
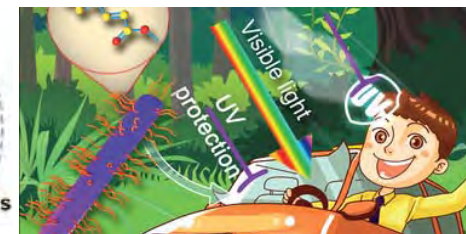
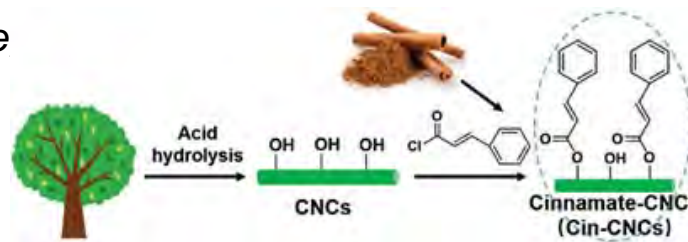


Sustainable nanomaterials for advanced applications – water, energy, bio, food, agriculture, coatings

Cinnamate-Functionalized CNCs as UV-Shielding Nanofillers

Zhang, Zhang, Grishkewich, Berry, Tam. *Adv Sustainable Syst*, **2019**, 1800156

- Cinnamate-CNC dispersion is waterborne alcohol-free, nonwhitening, waterproof, photo-stable, and possesses a high SPF
- Next generation cosmetic products and transparent protective coatings

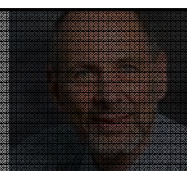
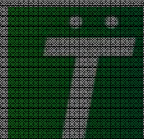


van de Ven, Theo

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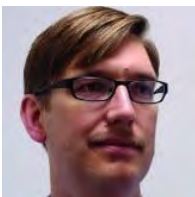


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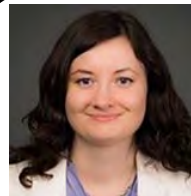


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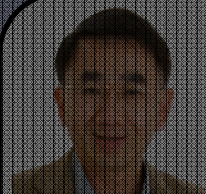
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Molecular structure and reactions of wood to transform trees and recycled fiber into novel materials that will



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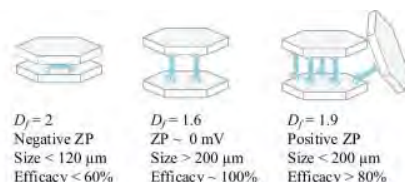
Sustainable nanomaterials for advanced applications – water, energy,

Microalgae and Clay Flocculation with Hairy Nanocelluloses

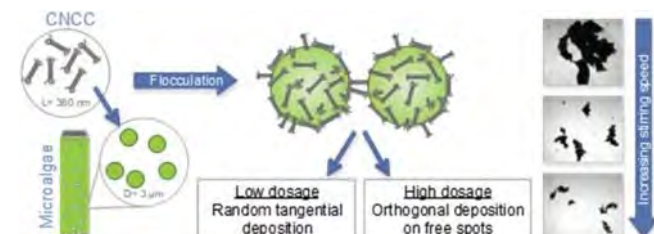
Lopez-Exposito, Campano, van de Ven, Blanco. *Colloids and Surface B* **2019**, 178, 329

Campano, Lopez-Exposito...van de Ven. *Journal of Colloids and Interface Science* **2019**, 545,153

- Hairy nanocellulose has high colloidal stability (sterics) → functions in wider range of conditions



Hairy cationic CNCs effectively flocculate clay & microalgae (effect of isoelectric point investigated)

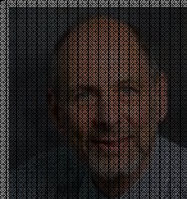


Van de Ven, Theo

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- Past chair of FIBRE network

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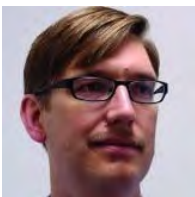


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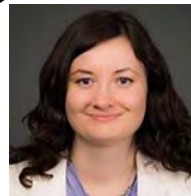


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Academic Collaborators Outside Canada



Standards Development

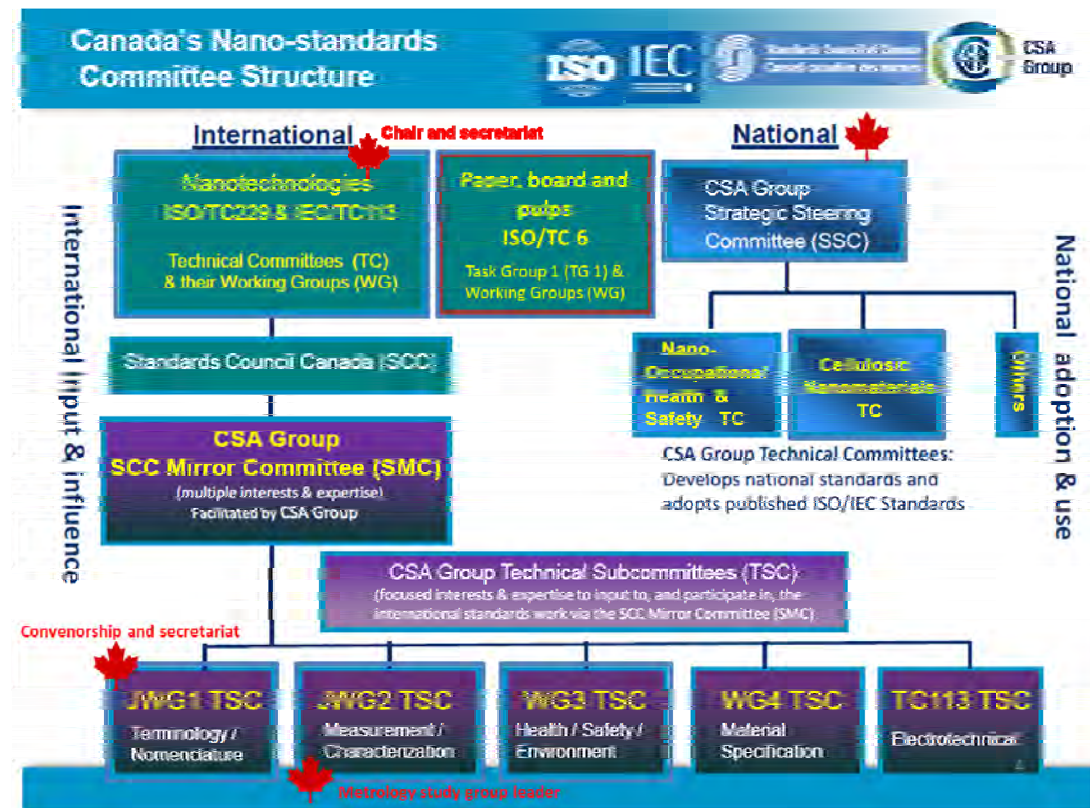
- **Impact:** Facilitating commercial development of CNC and enhanced competitiveness of Canadian forestry sector

- **Funding:** Industry, FPI +



- **Currently planning new CNM standards** - Talk to **Colleen Walker** to get involved and share ideas!

(Stephanie Beck, Linda Johnston, Bryan Haydon, Lyne Cormier, Maurice Douek, Joanne Zwinkels, Bernadette Quémerais, Greg Smallwood & others)



Content: Stephanie Beck, FPI and Linda Johnston, NRC

Standards Development

- **Canadian Standards Association (CSA)**

1. *CSA Z5100-17, Cellulosic nanomaterials: Test Methods for Characterization*
2. *CSA Z5200-17, Cellulose nanomaterials – Blank detail specifications*
3. In progress: *CSA Z5300, Cellulose filaments (CF) – Handsheet preparation for physical tests*

- **Canada-led ISO/TC 229**

1. *ISO/TR 19716:2017, Nanotechnologies – Characterization of CNCs*
2. *ISO TS 23151, Nanotechnologies – Particle size distribution for cellulose nanocrystals (ballot closed)*
3. *PWI 23361, Nanotechnologies – Crystallinity of cellulose nanomaterials by powder X-ray diffraction (Ruland-Rietveld analysis)*

- **Canada-input ISO/TC 229**

1. *ISO/TS 20477:2017, Nanotechnologies – Standard terms and their definition for cellulose nanomaterial*
2. *ISO/DTS 21346, Nanotechnologies – Characterization of individualized cellulose nanofibril samples*

Nanoscience can only evolve into **nanotechnology** once the measurement problems and metrology are under control

Economic
impacts



Workplace
safety,
environment
& health



Content: Stephanie Beck, FPI and Linda Johnston, NRC

Standards Development

- **Canada-led ISO/TC 6**

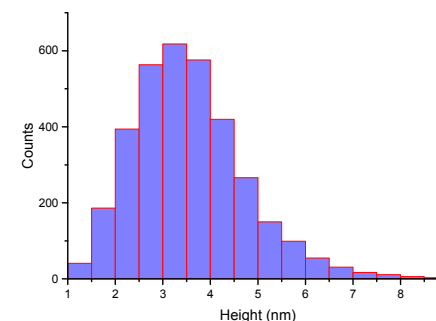
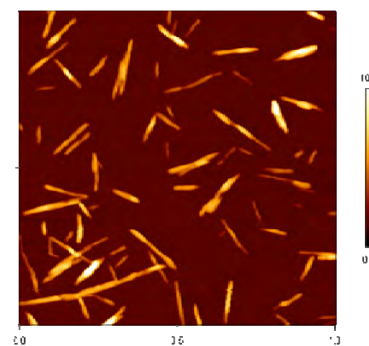
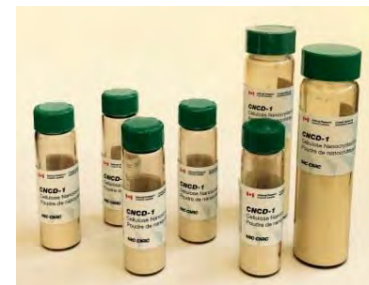
1. ISO TG 1 Cellulosic Nanomaterials
 - Review existing standard test methods to evaluate whether they need to be revised to include CNMs or identify additional
2. *ISO 21400, Pulps – Determination of cellulose nanocrystal sulfur and sulfate half-ester content* published December 2018
3. Extending Ash content/Acid-soluble metals content Standards
4. Optical properties of CNC powder method development (WG3)

- **Canada-input ISO/TC 6**

1. WD 638, *Dry matter content – Oven-drying method*
 - 638-1 Materials in solid form
 - 638-2 Liquid suspensions and gels

- **CNC certified reference material (NRC)**

- Characterized for surface groups, particle size, crystallinity, charge, thermal stability
- Interlaboratory comparison studies of sulfur content, size...



Content: Stephanie Beck, FPI and Linda Johnston, NRC

Scale-Up & Producer Updates



NORAM Group

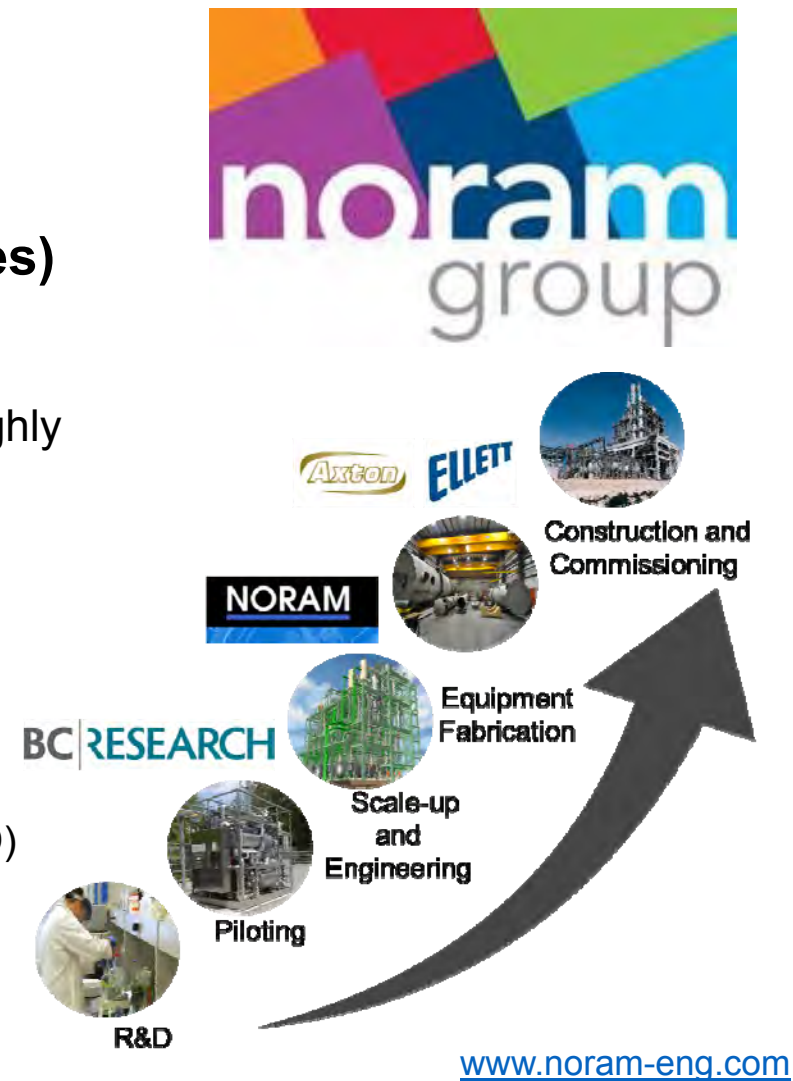
>10 years in nanocellulose (+ variety of industries)

- Initial CNC pilot by FPIInnovations and design/costing by NORAM in 2008
- Joint engineering (NORAM) and piloting (FPI) effort roughly halved capital costs

• Design & scale-up (~7000X) by NORAM

- Supplied acid reconcentration unit
- Successful CelluForce plant startup 2012

- Independently developed and patented CNC process improvements (reduce acid, \$, water & waste/BOD)
- Working with several partners to develop new & improved CNC and CNF processes



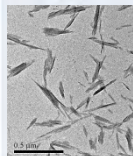
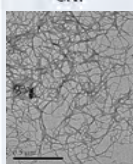
www.noram-eng.com



Cellulose Lab



- **Product: Sulfated-CNC and CNF**
 - TEMPO, cationic, surface modified
- **Process:** Sulfuric acid hydrolysis (CNC) and supermasscolloider (CNF)
- **Feedstock:** Dissolving/commercial pulp, cotton, sisal, tunicate, etc.
- **Capacity – projected 2021:**
10 kg/day CNC and 50 kg/day CNF
- **Applications:**
 - Packaging/pulp & paper
 - Healthcare
 - Oil & gas
 - Components in energy production

Product category	Production Process	Feedstock	Available nanomaterials	Production capacity (kg/day)	Key property
CNC	Acid hydrolysis, , with/without modification	dissolving pulp, cotton, sisal, tunicate, etc.	Unmodified CNC	10	Provide the most diversified nanocellulose products with a variety of surface modified nanocellulose to meet customer needs
			TEMPO-CNC	2	
			Carboxymethylated-CNC	2	
			Cationic-CNC	2	
			Hydrophobic-CNC	1	
			Lignin-coated-CNC	1	
			Powder CNC (Freeze-dried)	1	
CNF	Mechanical refining (supermass colloid, high pressure homogenizer), with/without modification	dissolving pulp, bleached commercial pulp, cotton, sisal, etc.	Unmodified CNF	50	
			TEMPO-CNF	5	
			Carboxymethylated-CNF	5	
			Cationic-CNF	5	
			Hydrophobic-CNF	2	
			Lignin-coated-CNF	2	
			Powder CNF	5	



www.celluloselab.com



CelluForce Inc.

- **Product: Sulfated-CNC** (CelluForce NCC®)
 - Shipped as dried powder or liquid
 - Modified CNC also available
- **Process:** Sulfuric acid hydrolysis
- **Feedstock:** Bleached softwood kraft pulp
- **Capacity: 1 tonne/day**
(world's largest since 2012)
- **Feb. 2019: CelluForce restarts production of CNCs at its newly modernized facility**
- **Applications:**
 - Rubbers/elastomers
 - Oil & gas
 - Adhesives
 - Paints, coatings
 - Electronics
 - P&P processing
 - Composites



www.celluforce.com

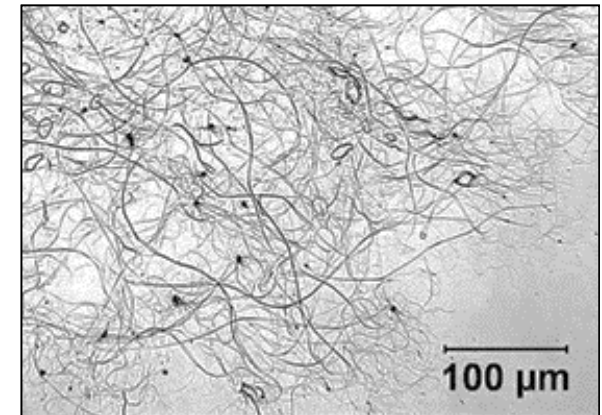


Kruger

Kruger Biomaterials Inc.



- **Product: Cellulose filaments (CF)** (FiloCell®)
 - Dry film, Dry fluff, wet (30%), dispersed (<10%)
- **Process:** Mechanical, with no chemicals, no enzyme
- **Feedstock:** Bleached or unbleached pulp
- **Capacity: 10 tonne/day**
- **Applications:**
 - Pulp & paper products
 - Composites (thermoplastics/sets)
 - Concretes and mortars
 - Paints and adhesives



<https://biomaterials.kruger.com>



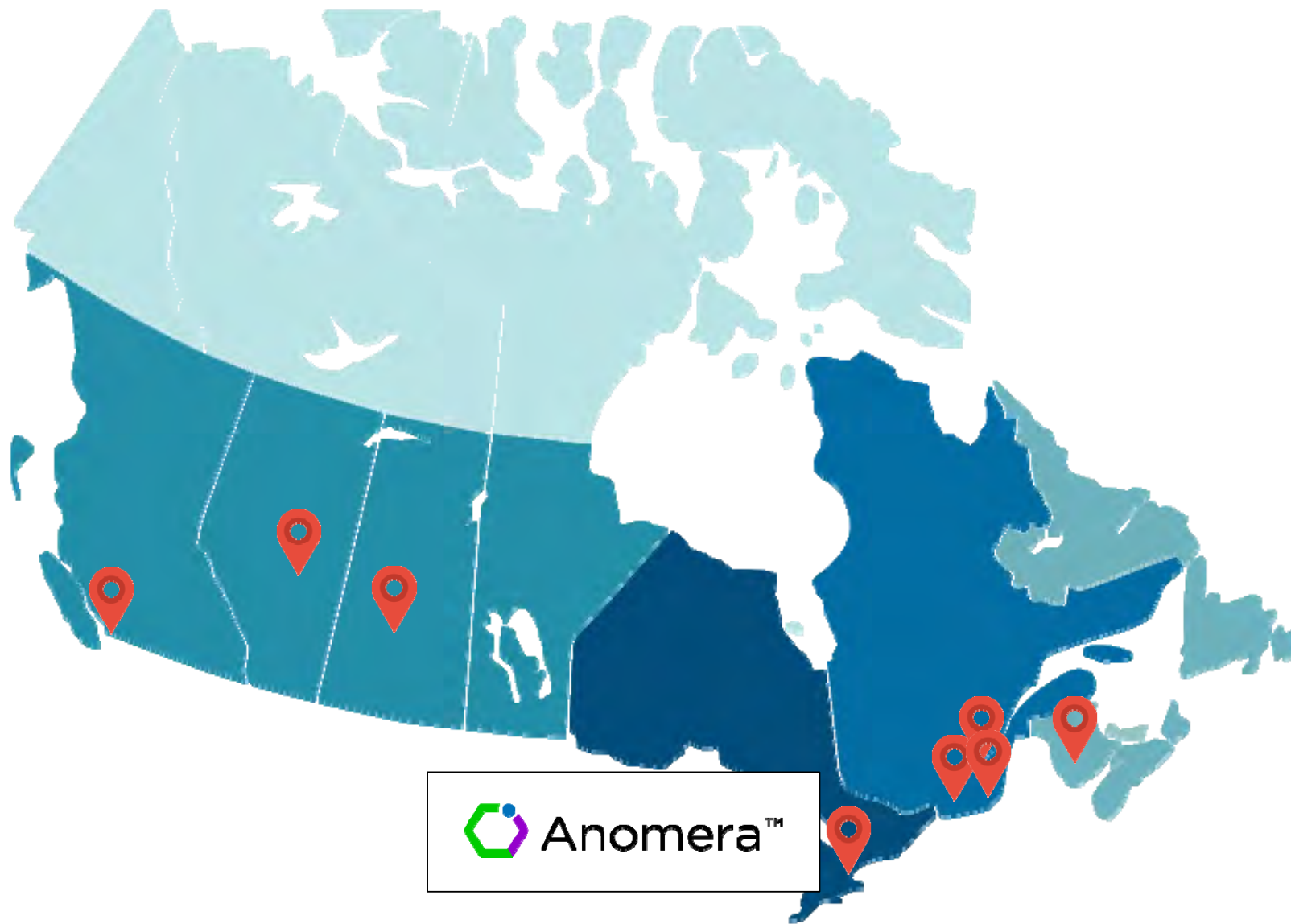
FPInnovations

- **Product: CNCs (sulfated, phosphated, carboxylated) and CF**
 - CNC: Dispersion in water or dry
 - CF: 20-40% solids, or fully dried
- **Process:** Acid hydrolysis, post-oxidation (CNC), purely mechanical disintegration (CF)
- **Feedstock:** Various
 - CNC: Bleached chem. pulps
 - CNF: Bleached SW/HW, (C)TMP, dissolving
- **Capacity - Pilot Scale:**
1.5 kg/day CNC and 150 kg/day CF
- **Applications/Research:**
 - Optimization of production & control systems
 - Scale-up of compatibilization process
 - Acid/carbohydrate separation technology



- | | |
|-----------------------|------------------|
| – Healthcare Products | – Nanocomposites |
| – Packaging | – Films |
| – Cement & Concrete | – Excipients |
| – Consumer Products | – Adhesives |
| – Specialty Paper | – Oil & gas |
| – Textiles | |

<https://fpinnovations.ca>



Anomera™

Anomera Inc.



- **Product: Carboxylated-CNC**
 - DextraCel™ - CNC fully redispersible powder
 - ChromaPur™ - CNC based cosmetic powder (replacement for plastic microbeads)
 - ChromAllur™ - CNC based pigments
- **Process:** Dilute aqueous hydrogen peroxide
- **Feedstock:** Softwood pulp
- **Capacity: 30 kg/day (current)**
 - 1 tonne/day (projected 2020 – demo)
- **Applications:**
 - Cosmetics
 - Medical/life science
 - Cement/concrete
 - Composites
 - Paints and inks
 - Coatings



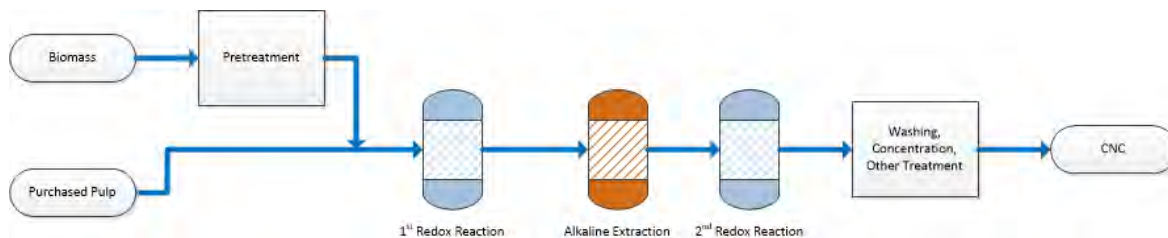
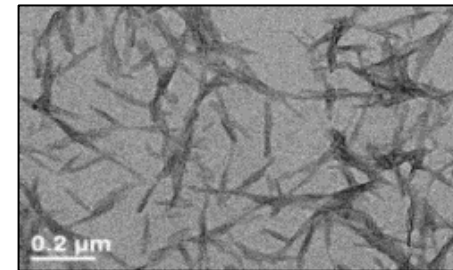
www.anomera.ca



Blue Goose Biorefineries



- **Product:** **Carboxylated-CNC** (BGB Ultra™)
– Aqueous gel (8% w/w)
- **Process:** Transition metal catalyzed oxidation
- **Feedstock:** Viscose grade dissolving pulp (and others)
- **Capacity:** **10 kg/day**



- **Applications:** Cementitious materials and other applications in various R&D stages

<https://bluegoosebiorefineries.com>



Al-Pac

(with NORAM & Alberta Innovates)

- **Product: Sulfated-CNC** (Aspen – 323)
 - Premium grade: food contact/medical/personal care & cosmetics
 - Performance grade: functionality, but lower purity
 - Spray-dried & never-dried (range of concentrations up to 8%)
- **Process:** Sulfuric acid hydrolysis
 - Continuous reactor
 - 3x reduction in acid usage
- **Feedstock:** Kraft (hard/soft) & dissolving pulps
- **Capacity: 500 kg/day (projected 2021)**
- **Applications:**
 - Food and beverage packaging
 - Dental/medical
 - Cosmetics
 - Chemicals
 - Tires and rubber
 - Drilling fluids and cements
 - Construction materials



ALBERTA
PACIFIC
FOREST INDUSTRIES INC

HOKUETSUGROUP



ALBERTA
INNOVATES



<https://alpac.ca>



InnoTech Alberta

- **Product: Sulfated-CNC and CNF**
 - CNC: Spray dried materials and low concentrations (<3%) never dried suspensions - No modification
 - CNF: Never dried suspension with up to 3% consistency, with modification (including TEMPO)
- **Process:** Sulfuric acid hydrolysis (CNC) and supermasscolloider (CNF)
- **Feedstock:** Various bleached soft/hardwood pulps
- **Capacity - Pilot Scale:**
1 kg/day CNC and 5 kg/day CNF
- **Partners:** Al-Pac and University of Alberta
- **Applications:** For academic/industrial R&D, coatings and plastics



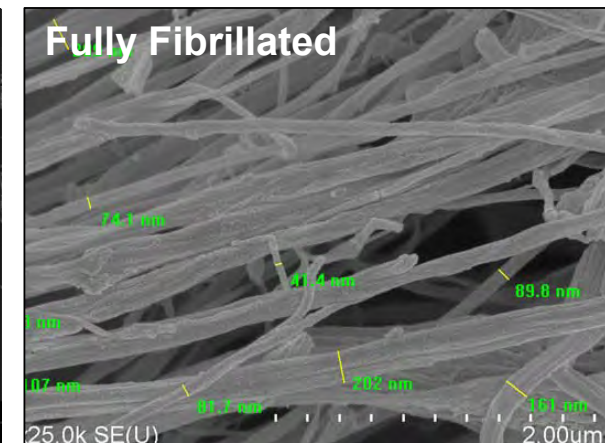
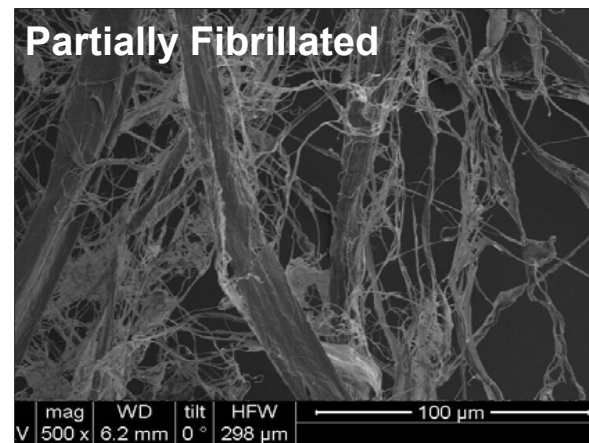
<https://innotechalberta.ca>



Performance BioFilaments

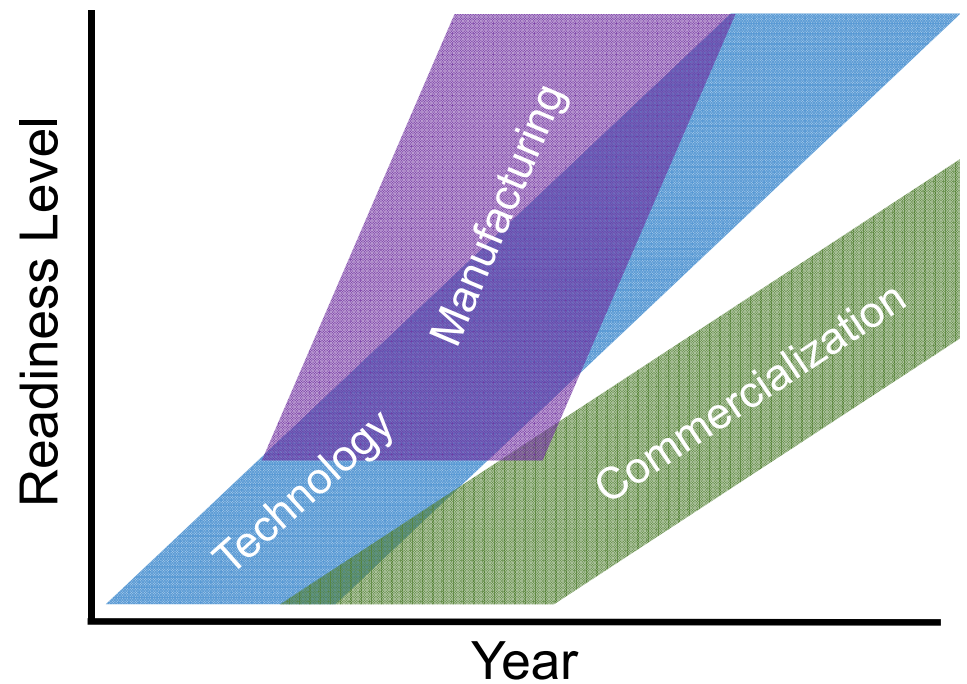


- **Product: Micro/nano-fibrillated cellulose (MNFC)**
 - Liquid, paste, crumb, dry fluff, viscosity-modified
- **Process:** Fibrillated by high-consistency mechanical refining
- **Feedstock:** Softwood kraft pulp
- **Capacity: Pilot Scale**
200 kg/day
- **Applications:** Specialty
 - Concrete & mortars
 - Industrial fluids
 - Nonwovens
 - Thermosets
 - Thermoplastics



<http://www.performancebiofilaments.com>

Application Development



Application Suites



Oil and Gas



Paints, Inks, Varnish
and Coatings



Adhesives



Food, Pharma,
Cosmetics



Consumer Products
& Specialty Paper



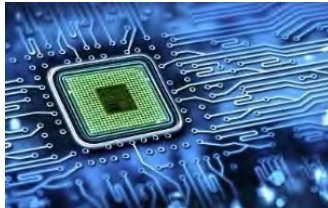
Cement &
Concrete



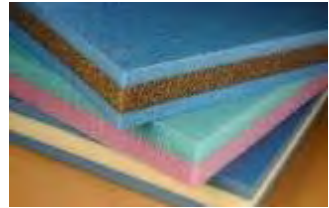
Plastics and
Composites



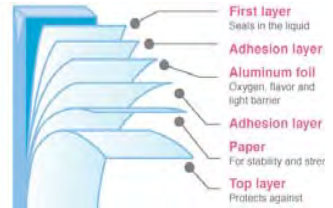
Rubbers and
Elastomers



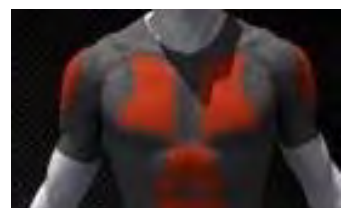
Electronics



Absorbents &
Porous Materials



Packaging

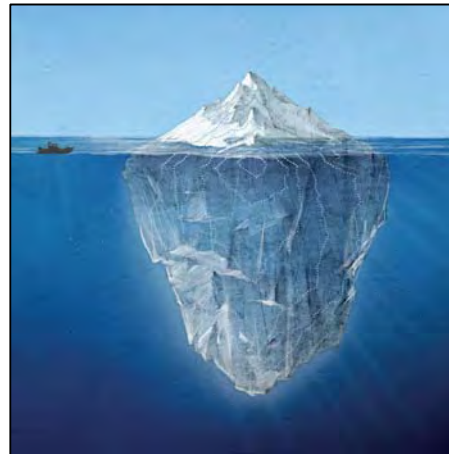


Textiles

Content: Richard Berry, CelluForce & Jimmy Jong, FPIInnovations

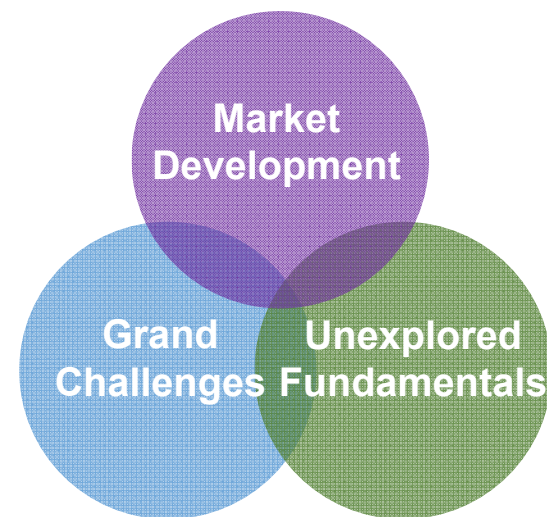
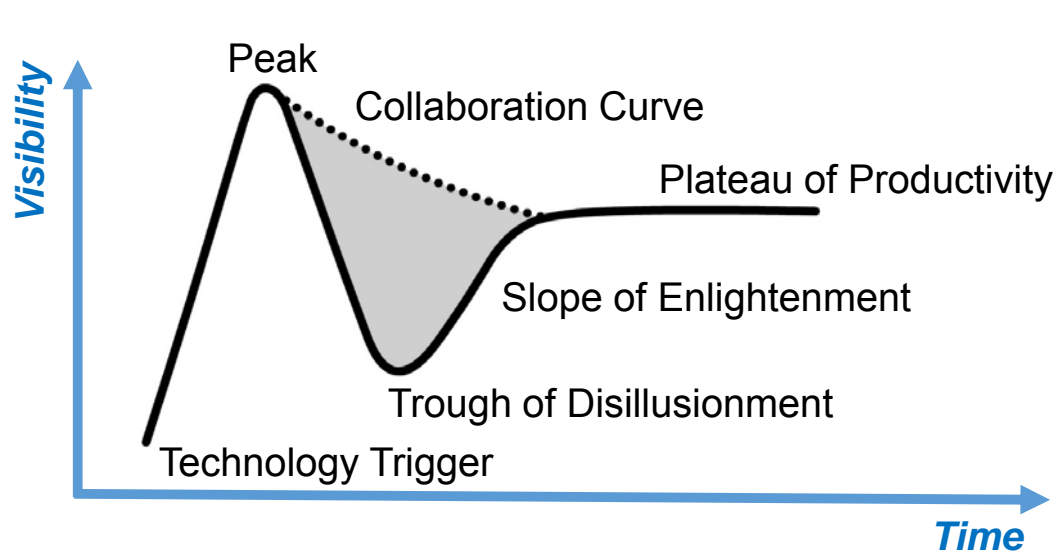
Commercial Products

- Wood adhesive
- Oil well completion fluids
- P&P water management
- Paint
- Film reinforcement
- Elastomers
- Anti fog coating - FogKicker
- Cosmetics
- Others



And Beyond...

- Community of believers with vision
- Resources (trees, universities, industries, government!)
- Full implementation (bridging gaps through collaboration)





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Chiba, Japan · 3 — 7 June 2019

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- **TAPPI Nano & Conference Organizers**
- **Content & idea contributors**
 - Richard Berry
 - Geoff Clarke
 - Lincoln Zheng
 - Stephanie Beck & Linda Johnston
 - Stephanie Kedzior
 - CelluForce and FPInnovations
 - All producers and professors
- *The Canadian & worldwide nanocellulose community!*

Thank you



Natural Resources
Canada

Ressources naturelles
Canada

The State of Canada's Forests 2018



<https://www.nrcan.gc.ca/forests/report/16496>



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