



Challenges in Pulp & Paper Manufacturing

S-1041 Annual Meeting and Symposium

7/10/2017

Transforming the forest products industry through innovation

Outline

- Agenda 2020 Overview
 - Why Pulp & Paper?
 - Advanced Manufacturing Technology Development
- Nanocellulose Development



Agenda 2020 Technology Alliance

Mission:

***Promote the development of
advanced manufacturing technologies for
transformational impact
on pulp and paper manufacturing***

Identify

- Technology needs
- R&D priorities

Inform

- Government agencies, universities, research institutes

Promote

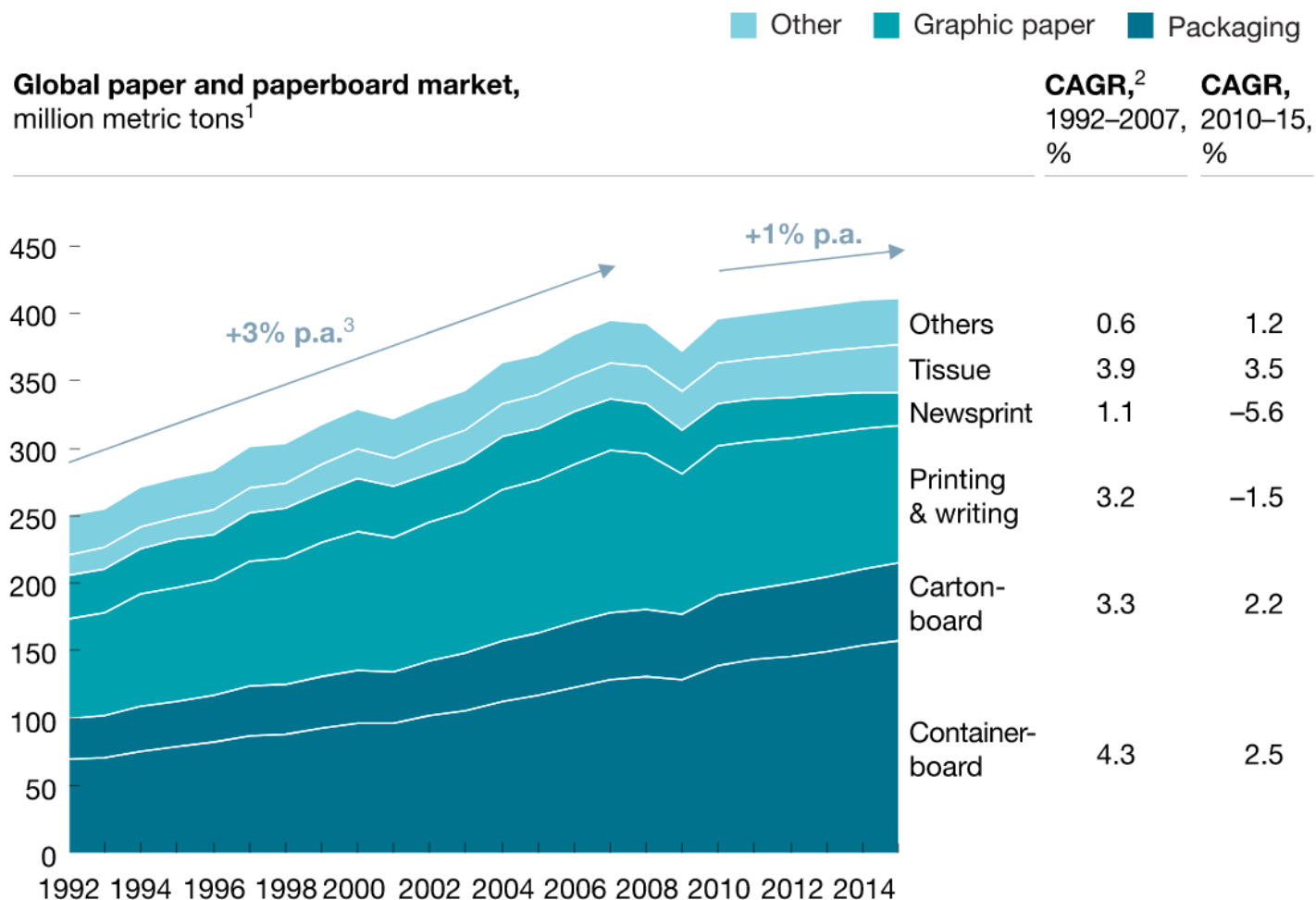
- Projects
- Public-Private Partnerships



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Why Pulp & Paper?

The global paper and paperboard industry continues to grow despite decline in the graphic-paper segment.



¹Metric tons: 1 metric ton = 2,205 pounds.

²Compound annual growth rate.

³Per annum.

Energy Intensive Industries

Why Pulp & Paper?

Primary Metals

1608 TBTU



Petroleum Refining

6137 TBTU



Chemicals

4995 TBTU



Wood Pulp & Paper

2109 TBTU



Glass & Cement

716 TBTU



Food Processing

1162 TBTU



Why Pulp & Paper?

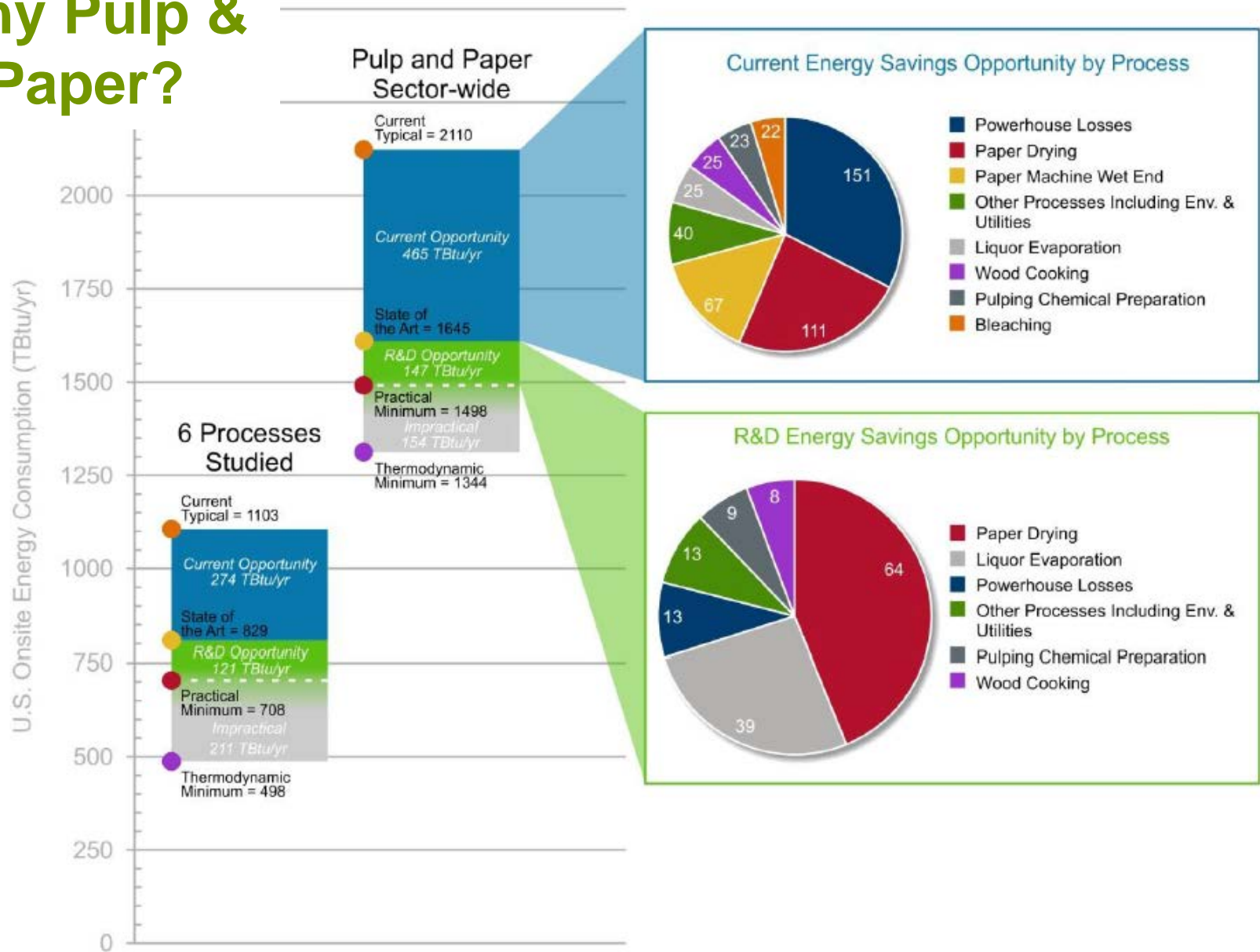


Figure ES-1. Current and R&D Energy Savings Opportunities for the Nine Processes Studied and for Pulp and Paper Sector-wide

<https://energy.gov/eere/amo/downloads/bandwidth-study-us-pulp-and-paper-manufacturing>

Why P&P? - Industry Sustainability

AF&PA's Better Practices, Better Planet 2020 Goals

- Increase paper recovery for recycling to exceed 70%.
- **Improve energy efficiency in purchased energy by at least 10%.**
- **Reduce greenhouse gas emissions by at least 20%.**
- Increase fiber procured from certified forest lands or through certified sourcing programs, and work with stakeholders to reduce illegal logging worldwide.
- Improve our safety incidence rate by 25%.
- **Reduce water use by 12%.**

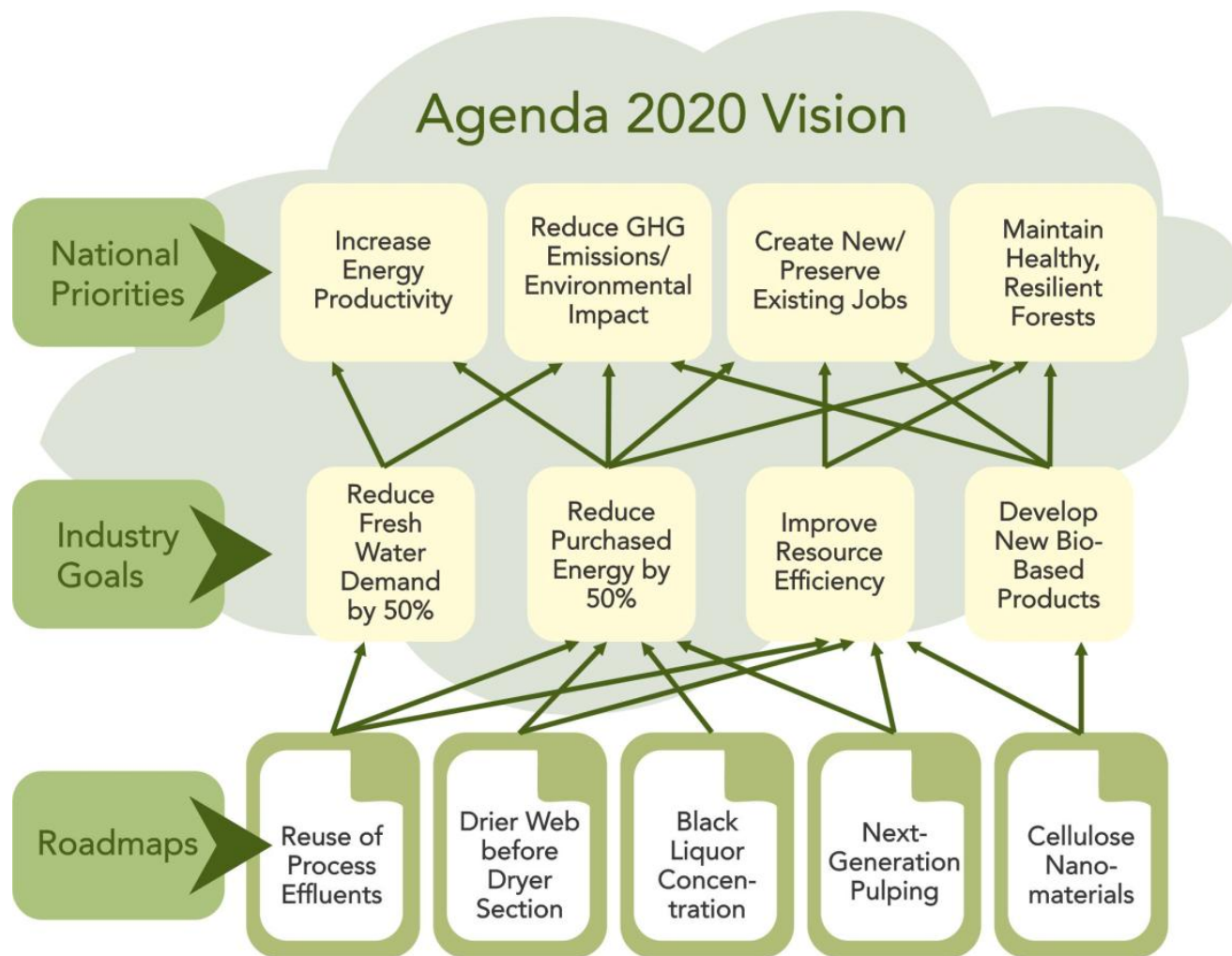


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Next Generation Improvements

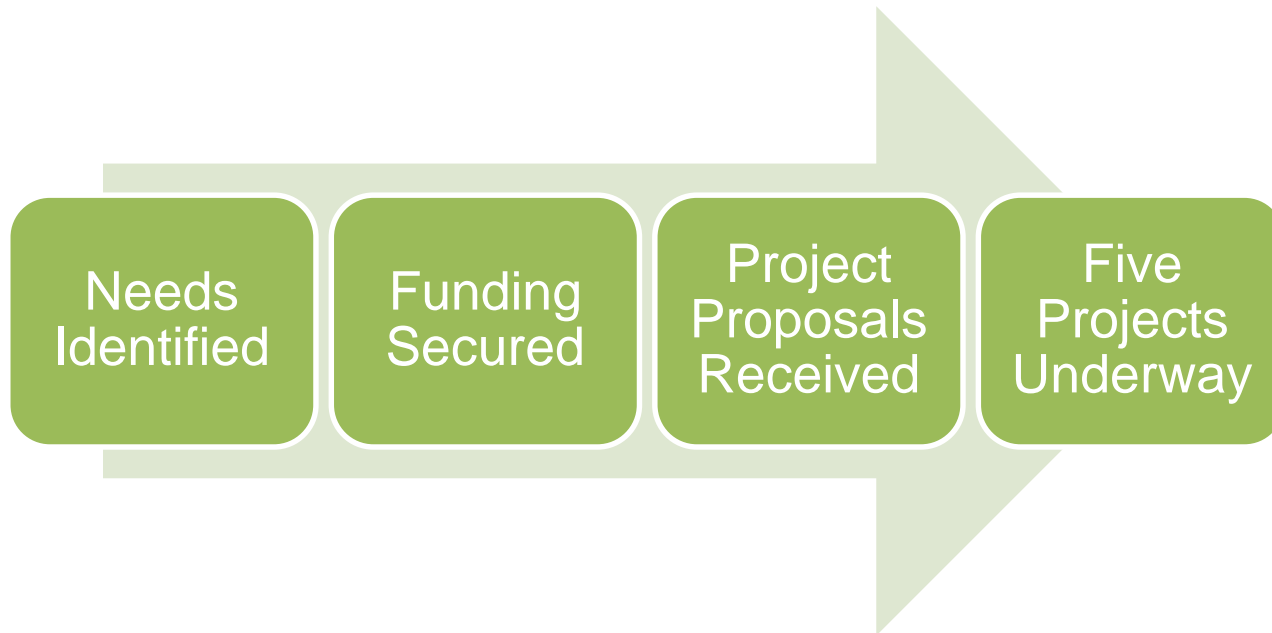
Roadmap Targets

- \$1.5B in cost reduction
- > 200 Trillion BTU energy savings
- 480 Billion gallons water reduction
- Protect 380,000 jobs



From Roadmaps to Road Trips

**Built system to create RFPs,
select, fund and manage projects**



Next-Generation Pulping

Goal	Reduce total energy 25%. Increase yield 5 percentage points. Reduce BOD/COD
Value	\$900 MM, 70 TBTU (\$6MM/yr 1000 tpd mill)
Strategy	<ul style="list-style-type: none">Develop advanced pulping technologies to increase the fiber yield and strategies to keep the yield gains throughout the bleaching process



Priority Projects



- **Yield-protective pretreatment** - *Develop pretreatments or in situ pulping additives that reduce the impact of the peeling reaction on the kraft pulping yield*
- **Accelerate delignification** – *Develop strategies or in situ pulping additives that increase the rate of delignification without increasing the rate of carbohydrate degradation*
- **Catalytic delignification** - *Evaluate transition or main group metals that can perform two-electron oxidation and/or serve as a delignifying chemical system*
- **Improve O₂ delignification selectivity to enable higher-kappa** - *Develop methods to delignify higher-yield (higher Kappa) pulps to conventional residual lignin levels through enhanced oxygen delignification*

Project Portfolio

Increasing Pulp Yield by Minimizing Primary Peeling through Pretreatment with Methyl Mercaptan before Kraft Pulping

- PI: Adriaan Van Heiningen, University of Maine

Increasing Kraft Linerboard Yield with High Kappa Pulping and Lignin Modification (NC State: Hasan Jameel, PI)

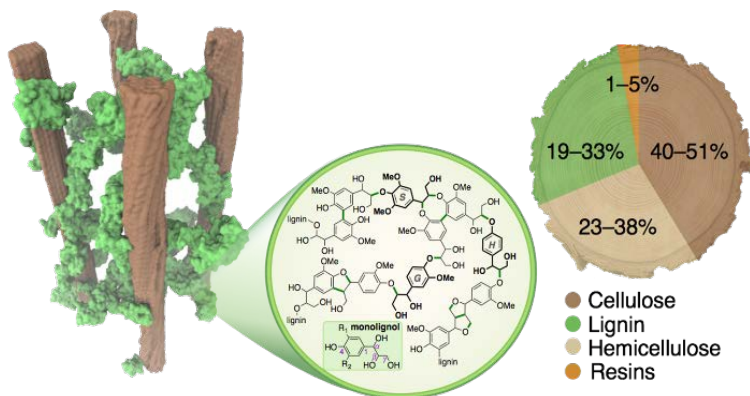
- PI: Hasan Jameel, North Carolina State University

Modernization of Kraft Pulp Mills with Alkylene Carbonate Pretreatment for Lignin and Hemicellulose Extraction and Enhanced Pulp Production

- PI: Andreas Bommarius Georgia Tech



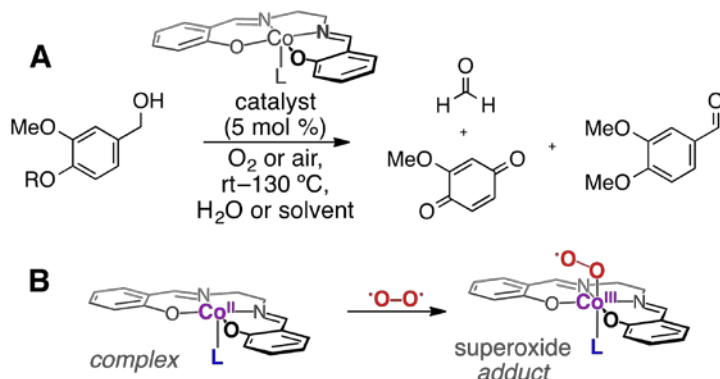
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Catalytic Pulping of Wood

- Small molecule catalysts offer alternative for lignin removal. Focus is on cobalt-based oxidative catalysts
- Iterative design leverages experimental data and quantum mechanical simulations to screen leads
- Laboratory testing on model compounds and wood
- Increase yield, reduce energy
- ORNL, University of Tennessee, USFS and Forest Products Laboratory

Cobalt-Catalyzed Delignification



Black Liquor Concentration

Goal **Develop a more energy-efficient method to remove water from kraft black liquor** (164 TBTU/yr, ~7%)

Value \$95 MM, 23 TBTU

Strategy

- Overcome issues with membrane separation technology
- Develop more fundamental understanding of issues

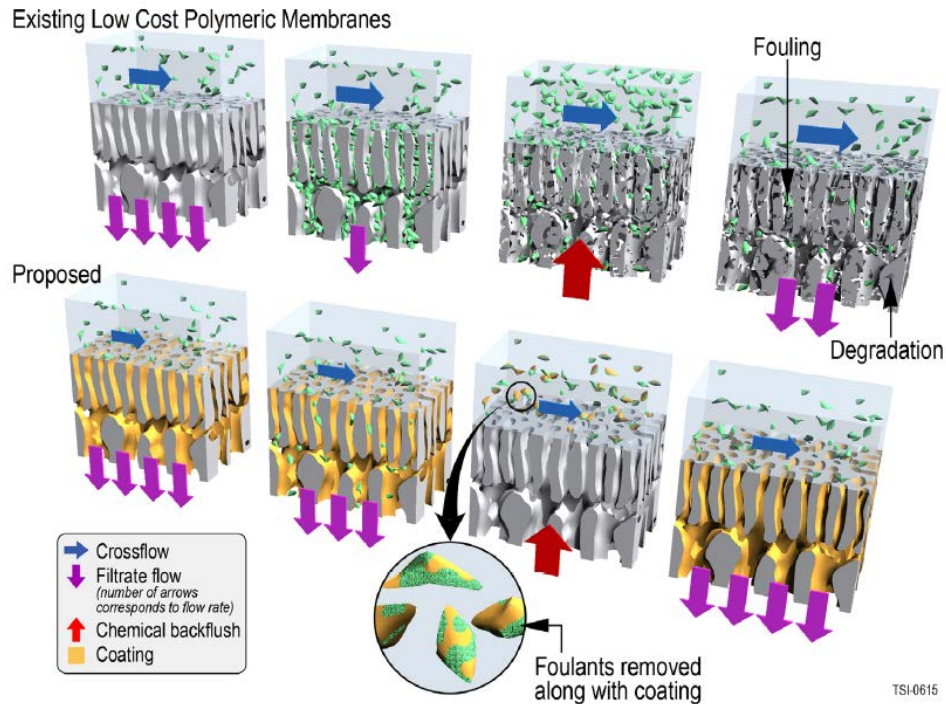


Challenges



- Optimal separations of water, ions, and organics
- Robust membrane materials to withstand high temperature, high pH environments
- Advanced high-flux membrane systems
- Membrane fouling resistance/system availability
- Process optimization and integration with existing pulp mill systems

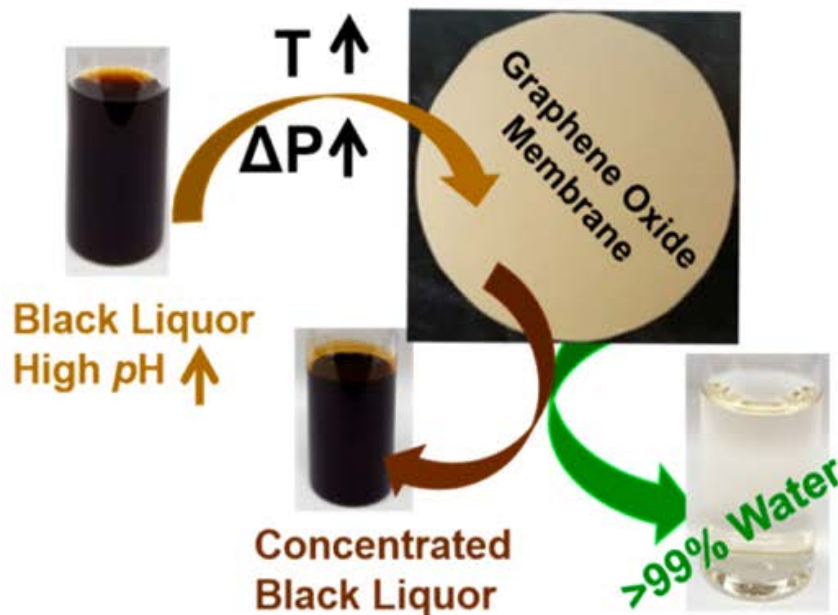
Collaboration – Technology Provider - DOE Project: Sacrificial Membrane Coatings Approach – Teledyne



A protective coating (yellow) on the polymer membrane will provide chemical and fouling resistance. Removing the foulants and/or coating during chemical backflush and subsequent in-place regeneration increases longevity. *Photo courtesy of Teledyne*

- Teledyne producing sacrificial coating that resists fouling and protects the underlying membrane
- TRL5 trials at kraft mill with black liquor side streams

Collaboration – University - Sponsored Project: New Membrane Materials Approach – Georgia Tech RBI



- Completed year 3 material investigations; filed patents on new materials, > 99% lignin rejection
- GT RBI - new project - cross flow apparatus to demonstrate system selectivity - new / existing commercial membrane systems
- Planning next stage of work

Picture from:

"Graphene Oxide Membranes in Extreme Operating Environments: Concentration of Kraft Black Liquor by Lignin Retention"
Fereshteh Rashidi, Nikita S. Kevlich, Scott A. Siquefield, Meisha L. Shofner, and Sankar Nair; ACS Sustainable Chem. Eng., 2017, 5 (1), Published: December 9, 2016



Drier Web before Dryer Section

Goal	Increase dryness of paper webs entering dryer section by ~ 30% (from 45-55% up to 65%)
Value	\$250 MM, 80 TBTU
Strategy	<ul style="list-style-type: none">• Develop a fundamental understanding of rewet and technologies to control or eliminate it• Develop advanced fiber matrix to facilitate water release without impacting sheet strength and uniformity



Priority Projects

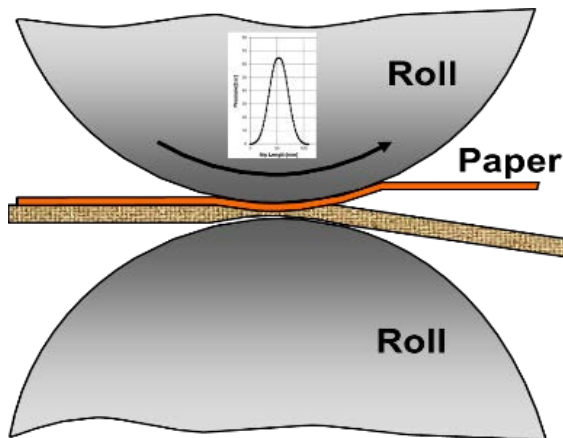


- **Decoupling Strength and Water Removal** – *Develop approaches to decouple strength and water retention through chemical bonding strategies or use of alternative fiber types and minerals*
- **Modeling Rewet** - *Develop general mathematical model describing water flow rate and direction in the complex 3-D porous media*
- **Measuring Rewet** - *Develop measurement techniques to visualize and quantify rewet under dynamic conditions*
- **Adaptive Felt Materials** - *Develop “adaptive” felt materials or structures*
- **Unidirectional Membrane** - *Identify or develop a membrane that will support preferential flow of water away from the fiber web*



Model deformation and dryness of paper/felt to optimize wet pressing

- Develop integrated, multi-physics modeling framework as critical step to improve dewatering
- Information can only be obtained by computer simulation
- Provide industry with insights to inform the designs of more energy efficient processes and equipment



Reuse of Process Effluents

Goal	Reduce average water usage by half
Value	~ 5K gal/ton, >\$300MM, 45 TBTU, 480B Gal
Strategy	<ul style="list-style-type: none">• Identify target areas for reuse and establish water quality requirements• Develop cost-effective, broadly applicable technical solutions to address contaminants that inhibit reuse• Focus on Paper Machine Whitewater Reuse and Reuse of Biologically Treated Effluents



Priority Projects

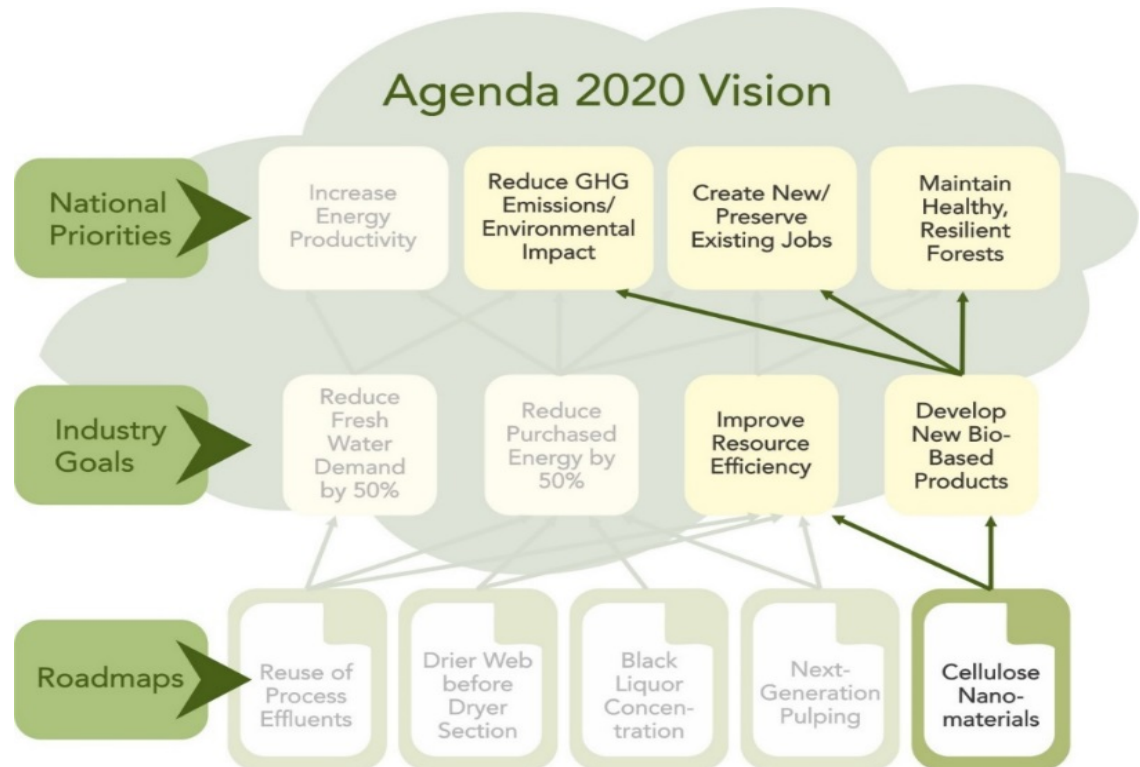
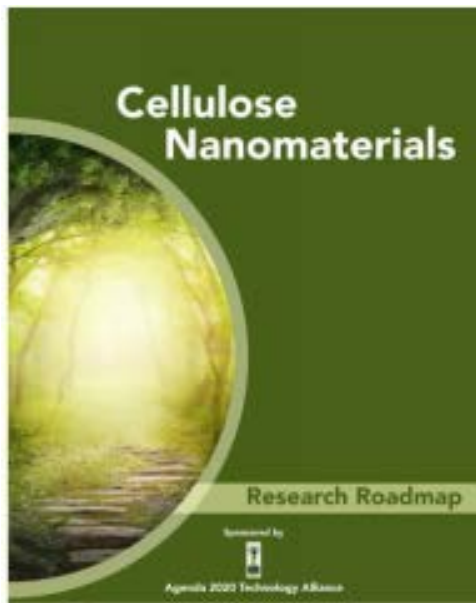


- **Model development** – *Develop predictive process and economic model to determine possible water reuse options*
- **Removal of suspended solids 10-40 μm** – *Develop processes to separate particles based on material properties other than size*
- **Removal of dissolved organic and colloidal substances** – *Evaluate technologies utilized in other industries*
- **Removal of inorganic constituents** – *Explore feasibility of chemical agglomeration and filtration, surface passivation, or both*

Cellulose Nanomaterials

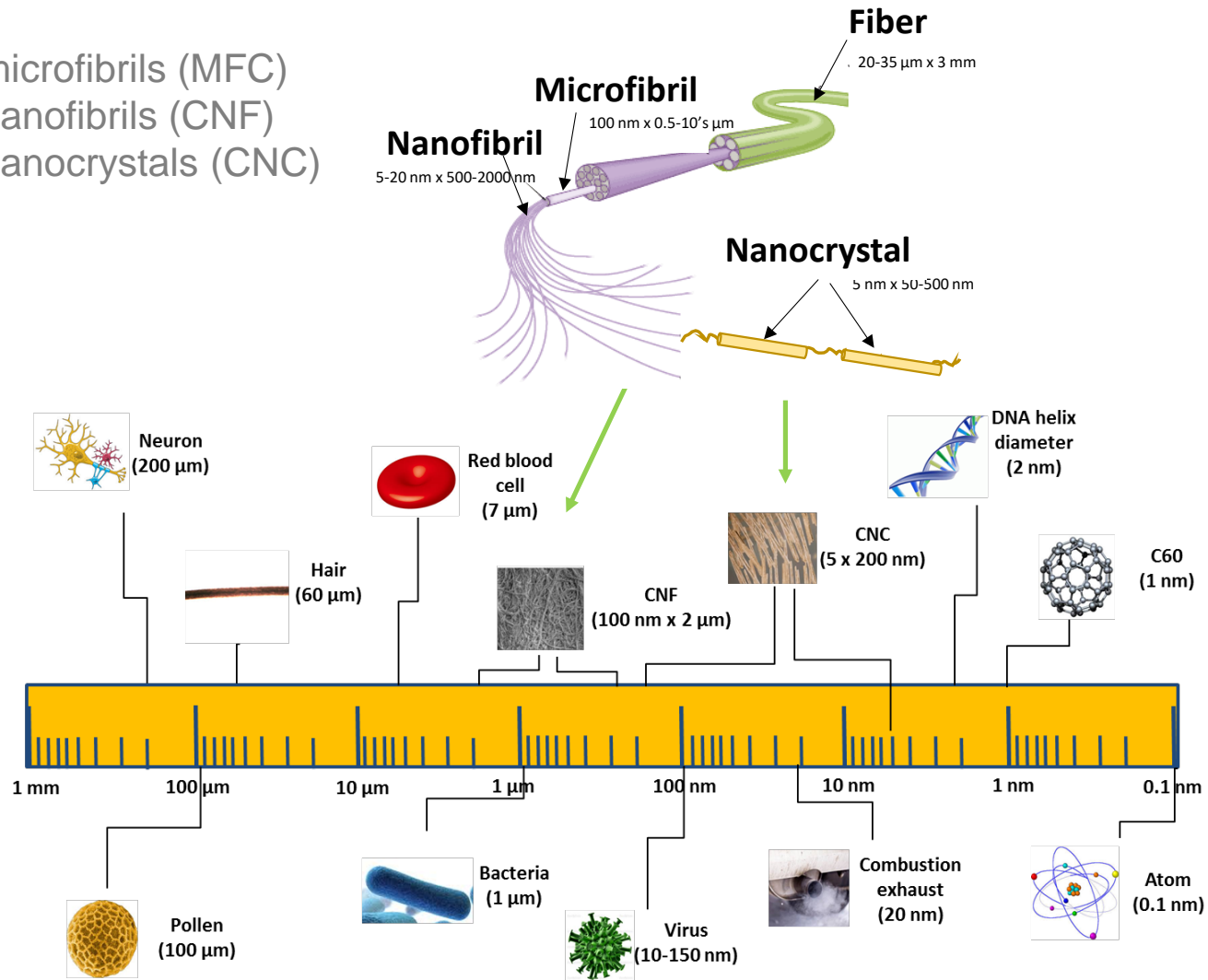
Technology Research Roadmap

Goal: Identify technology gaps to facilitate broad range of commercial advances through development of pre-competitive technologies



Nanocellulose

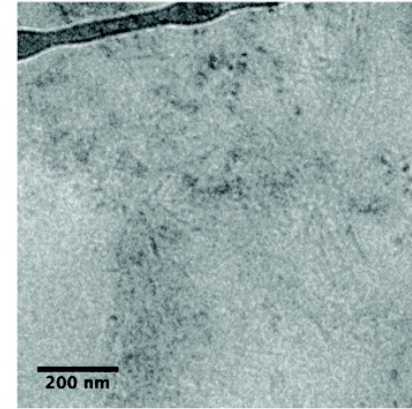
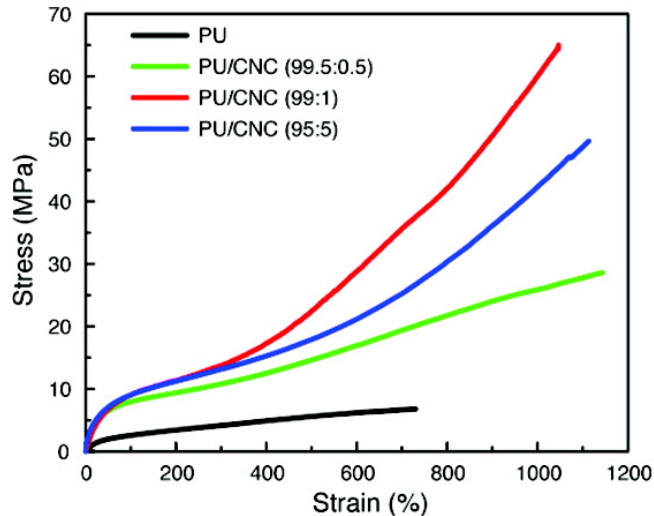
Cellulose microfibrils (MFC)
Cellulose nanofibrils (CNF)
Cellulose nanocrystals (CNC)



Nanocellulose - Material Characteristics

- Abundant
- Renewable
- Recyclable
- Compostable
- Biocompatible
- Non-toxic
- Lightweight and strong
- High strength / weight ratio
- Dimensionally stable
- Shear thinning
- Optical transparency
- High thermal conductivity
- Low oxygen permeability
- Can make foams

Nanocellulose can improve mechanical properties in polymer composites



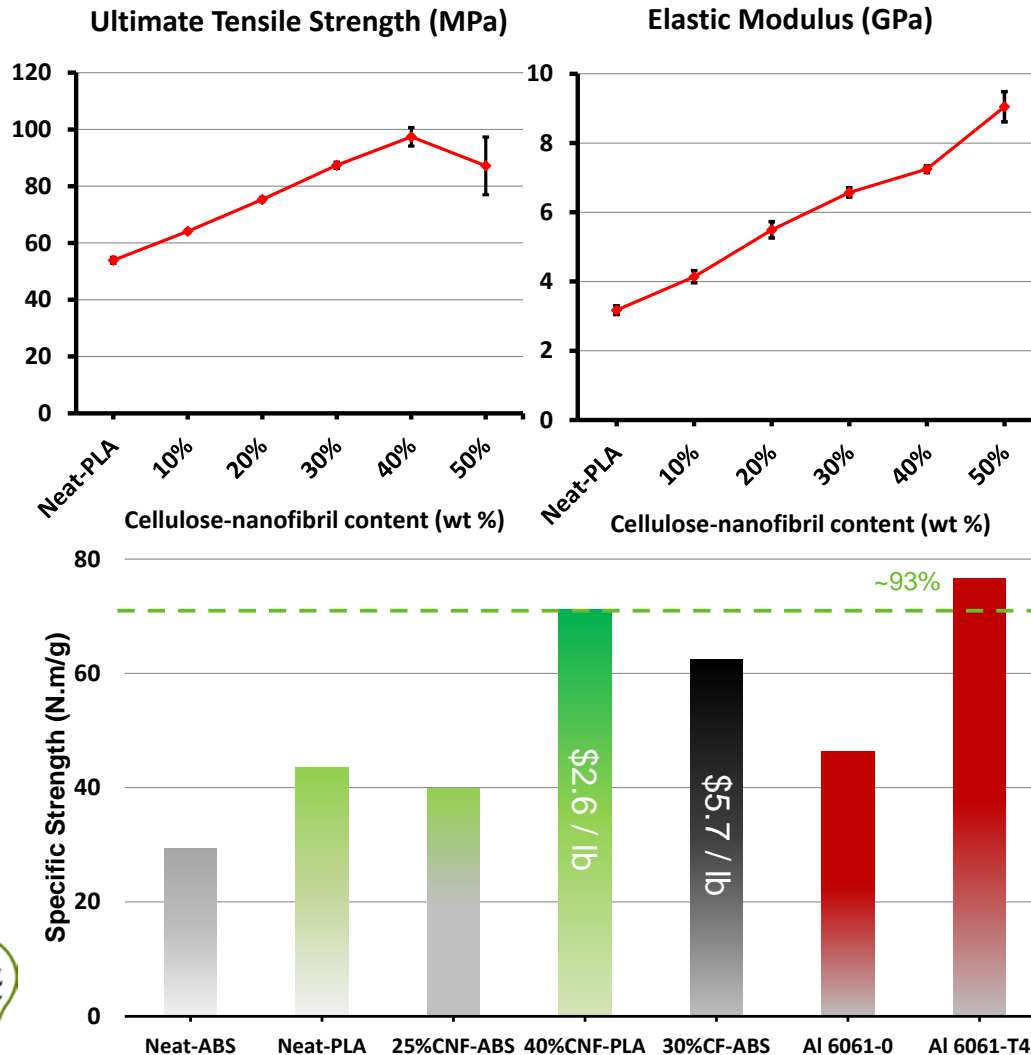
PU/CNC (95:5)

PU: polyurethane CNC: cellulose nanocrystals
(weight ratio in parentheses)

Pe, Malho, Ruokolainen, Zhou, Berglund, Macromolecules (2011)

- Improvements in tensile strength, modulus, and strain to failure possible with rubbery matrices
- Improvements in tensile strength and modulus generally with rigid matrices

Oak Ridge National Lab PLA Composites



Goal to produce low cost, lightweight bio-based composites for 3D printing automotive parts

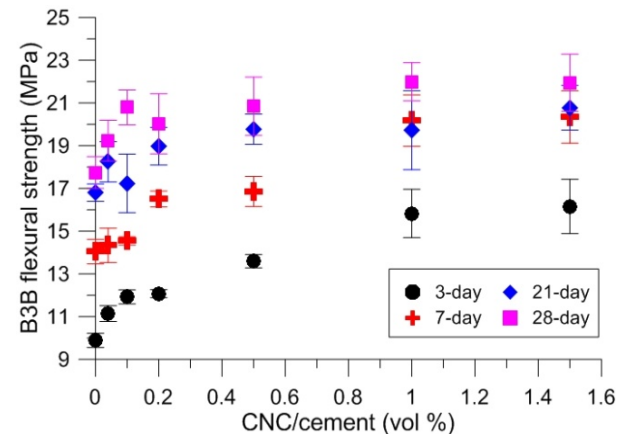
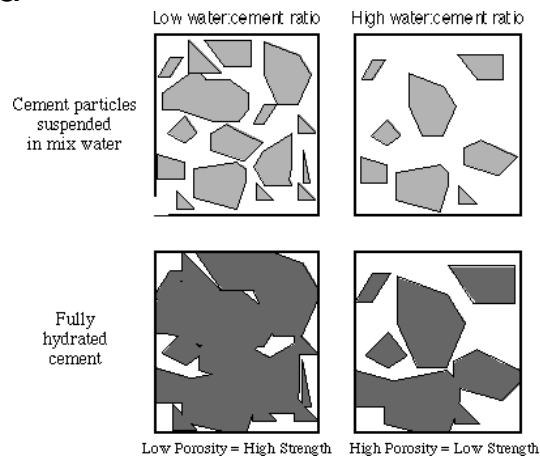
40%CNF-PLA

- ~93% of specific strength of Aluminum 6061-T4 alloy.
- Stronger and lower cost than CF-ABS composite
- 100% BIO

- 40%CNF-PLA: $0.4 \times \$2/\text{lb} + 0.6 \times \$3/\text{lb} = \$2.6/\text{lb}$
- 30%CF-ABS: $0.3 \times \$12/\text{lb} + 0.7 \times \$3/\text{lb} = \$5.7/\text{lb}$

High-Strength Concrete

- Cement industry accounts for ~5% of global CO₂ emissions.
- Cellulose nanocrystals increase the strength of concrete by 30-50% at very low loadings
 - Increases degree of hydration of cement mixtures, allowing more of it to cure and reducing voids
 - Lowers the amount of cement required for a job at a given strength
 - Makes the concrete cheaper and environmentally friendly as less cement is used



*High Performance Cement via Cellulose Nanocrystal Addition. Jeff Youngblood, Purdue, 2014 TAPPI International Conference

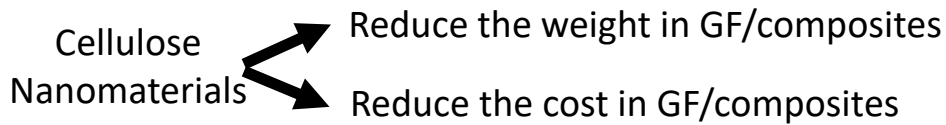
Cellulose Nanomaterials in Automotive Applications

Automotive industry needs: Lightweight, high-performance materials for fuel-efficient vehicles without cost penalty

Nanocellulose can be the answer:

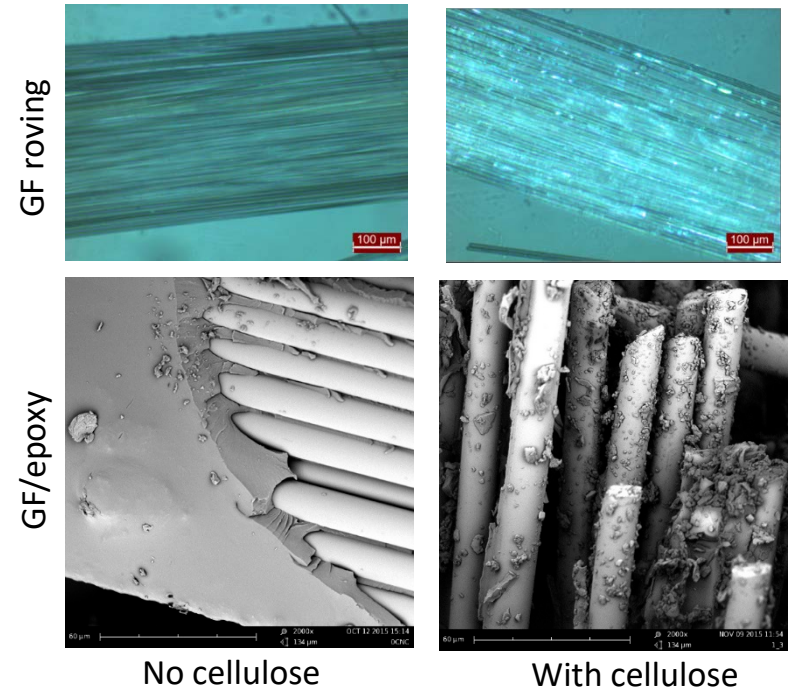
- Abundant, renewable, natural, non-toxic
- Enhances properties of polymers
- Enhances properties of composites
- Results in light-weighting of composites

Where we are:



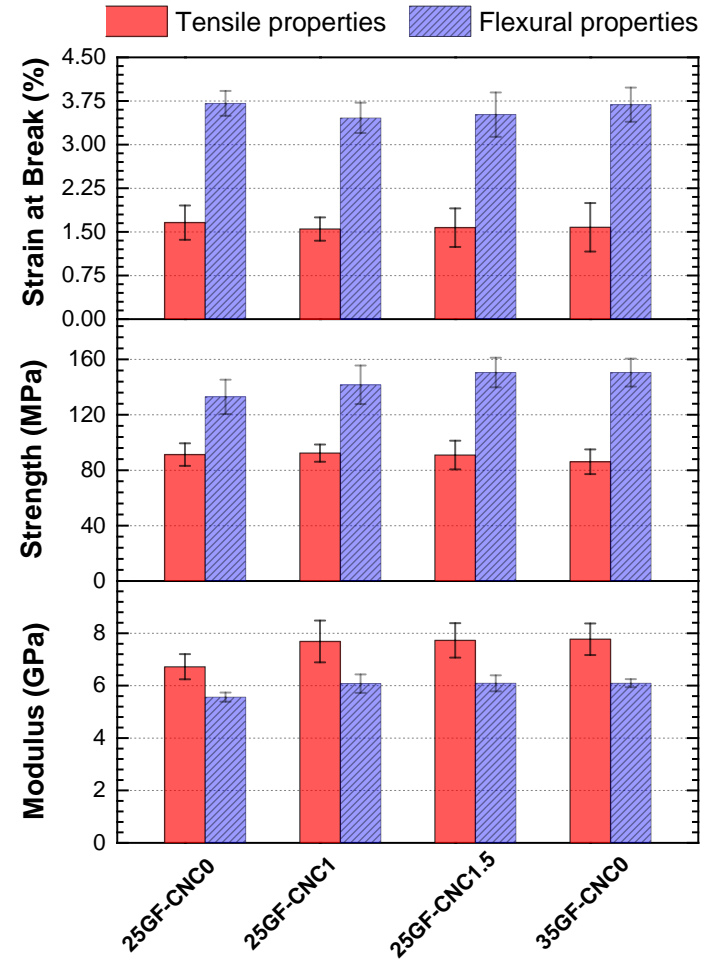
Where we need to be:

- Understand interfacial interactions
- Demonstrate manufacturability & scale-up
- Reduce cost



Source: Kyriaki Kalaitzidou, Georgia Institute of Technology

Cellulose Nanomaterials in Automotive Applications

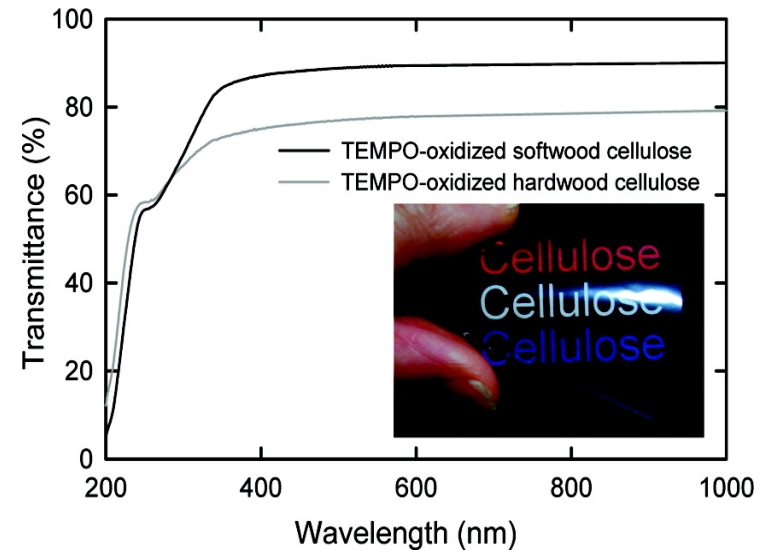


Nanocellulose films provide opportunities for transparent/translucent materials

Neat Films



Nogi, Iwamoto, Nakagaito, and Yano; Adv Mat (2009)



Fukuzumo, Saito, Iwata, and Kumamoto, Biomacromolecules (2009)

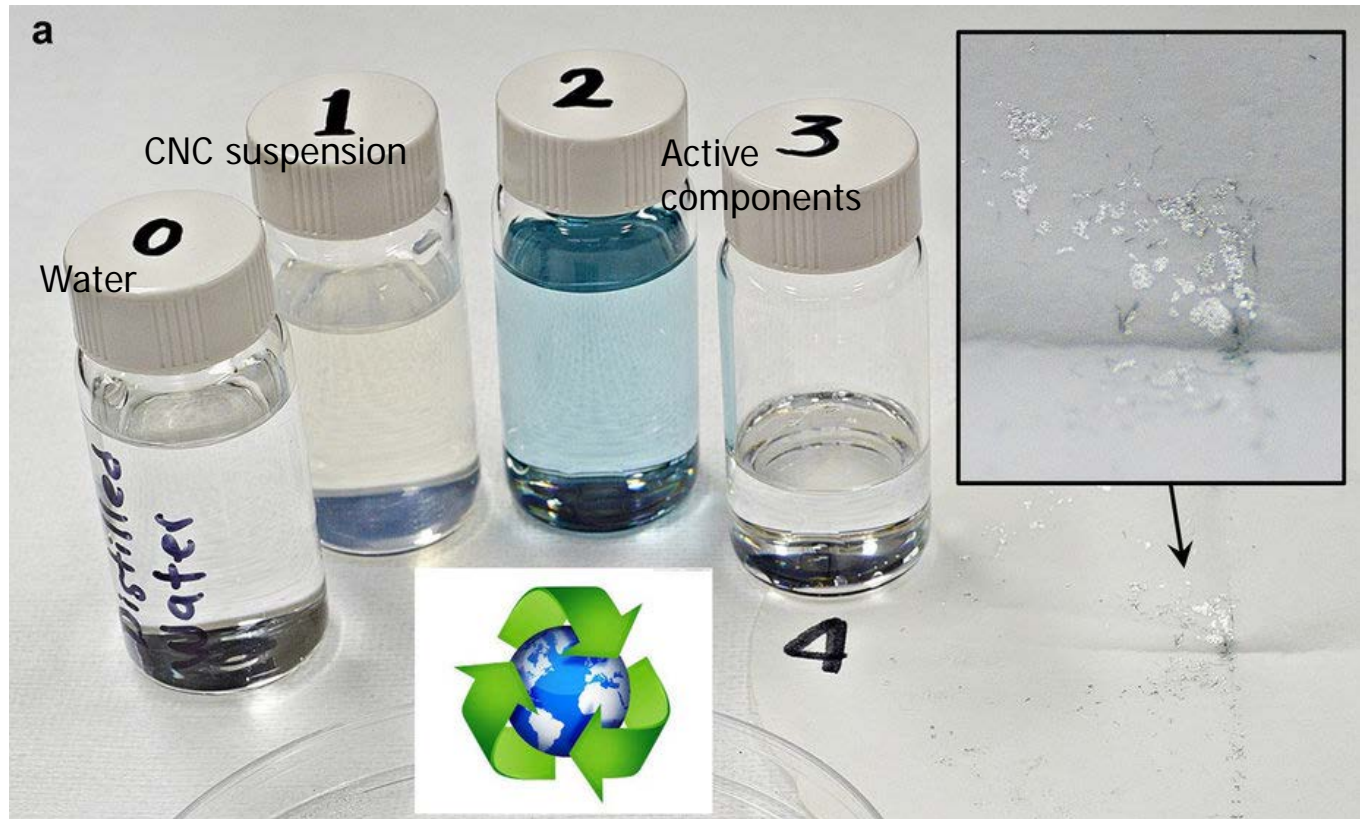
Nanocellulose/ polymer composites



Girouard, Schueneman, Shofner, and Meredith; Polymer (2015)

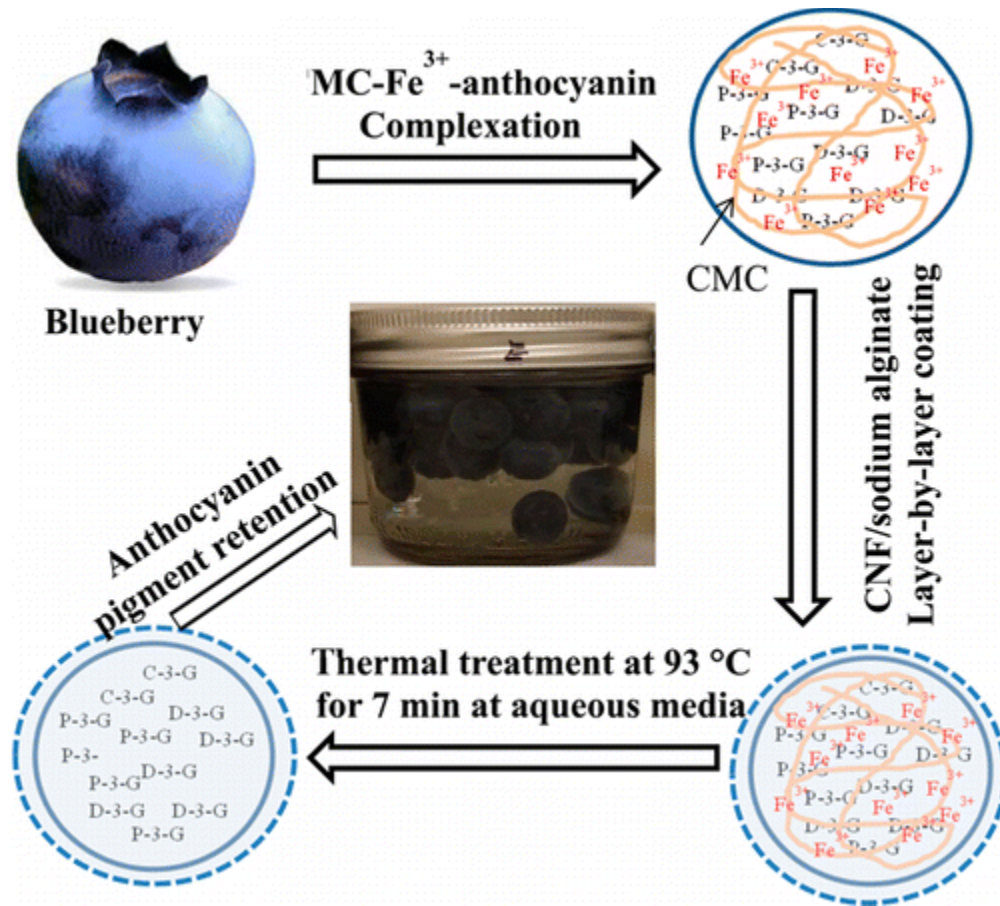
Nanocellulose can be used as a platform for producing recyclable electronic devices

Deconstruction of an organic solar cell



Zhou, Fuentes-Hernandez, Khan, Liu, Hsu, Shim, Dindar, Youngblood, Moon, Kippelen, Scientific Reports (2013)

Nanocellulose can be used as a coating to preserve food quality



Edible coatings of CNF/sodium alginate used to retain nutritionally beneficial compounds in thermally processed foods

Jung, Cavender, Simonsen, and Zhao, Journal of Agricultural Food Chemistry (2015)

Global Market Potential = 35 MM tpy



Reinforced Plastics



Polyurethane Foam



Superabsorbent



Body Amor & Bullet Proofing



Ink



Concrete



Cosmetics Skincare



Cosmetics Pigments



Oil & Gas Drilling



Paper & Board



Edible Barrier Coatings



Carbon black replacement



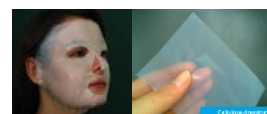
Water & Grease Resistant Textiles



Rigid & Flexible Plastic Packaging



3D Printing Resin



Wound Care Dressings



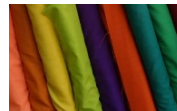
Adhesives & Sealants



Paper & Board Coatings



Paint



Rayon Textiles



Particleboard Binder



Tissue Engineering

Recent Milestones

FINLAND 2016: Stora Enso announces partnership with Elopak using MFC to light weight paper-based packaging for liquid food.



FINLAND 2016: UPM commercializes GrowDex® cellulose nanofibril hydrogel for advanced 3D cell culture applications in the biomedical field.



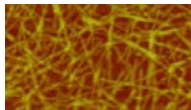
JAPAN 2016: Oji Holdings to launch “Aurovisco” cellulose nanofiber product for thickening applications



JAPAN 2015: Mitsubishi Pencil Co Ltd and DKS Co Ltd commercialized a gel ink containing cellulose nanofiber (CNF) as a thickener.



JAPAN 2015: Oji Holdings announces joint development with Nikko Chemicals for CNF in cosmetic applications.



JAPAN 2015: Nippon Paper commercializes deodorant adult diapers using TEMPO CNF.



CANADA 2015: Schlumberger invests in Celluforce for CNC to enhance productivity of oil and gas wells.



THE WORLD IN 2025
10 PREDICTIONS OF INNOVATION

2014: Thomas Reuters names nanocellulose as one of the top 10 technologies that will change the world by 2025.



CANADA 2016: Fibria invests in Celluforce for exclusive right to sell and manufacture CelluForce NCC™ in South America

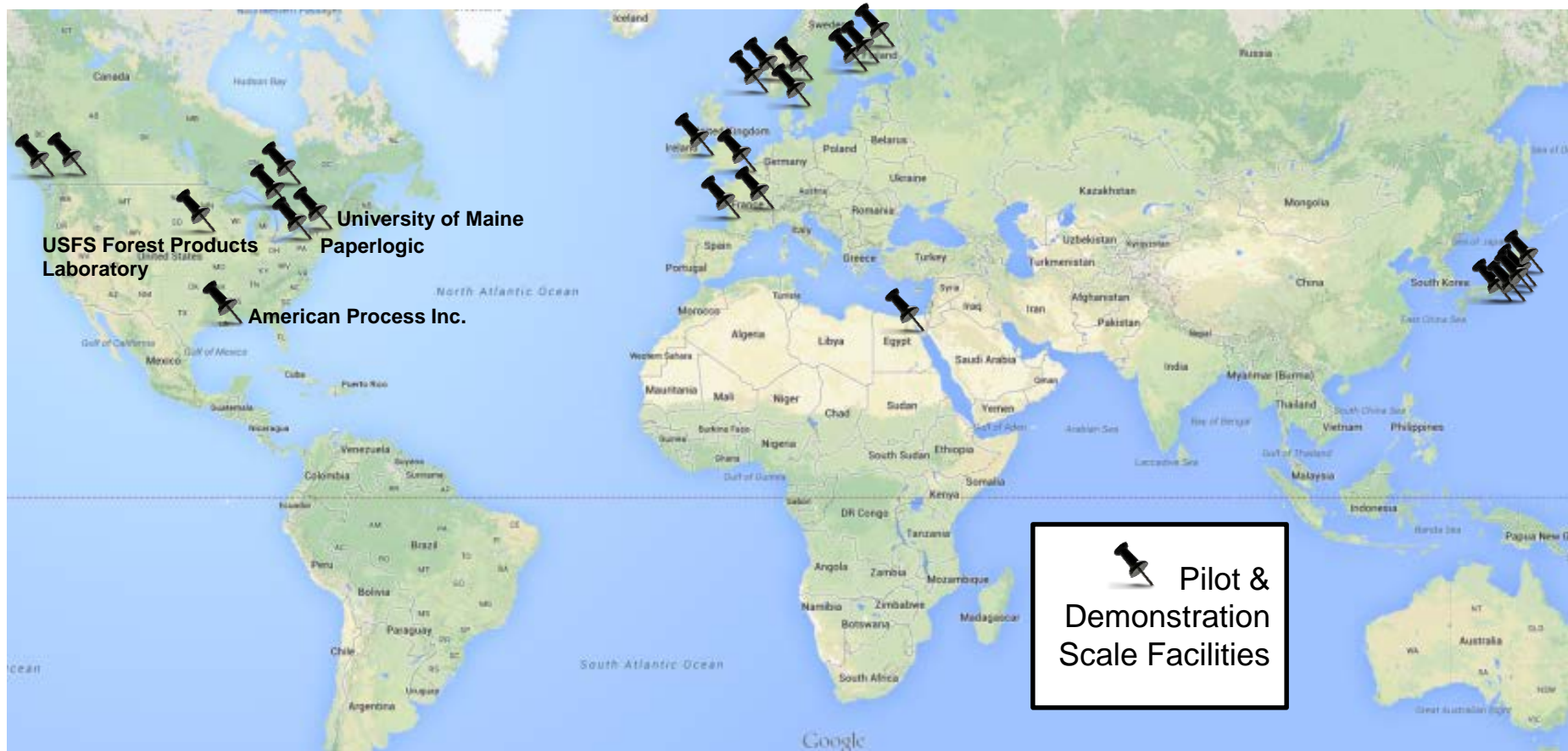
FRANCE 2016: IMERYS announces exclusive negotiations with Omya to form JV for MFC across various applications



USA 2017: American Process and Aditya Birla Carbon establish Joint Development Agreement for nanocellulose and carbon black in tires



Production is Ramping Up

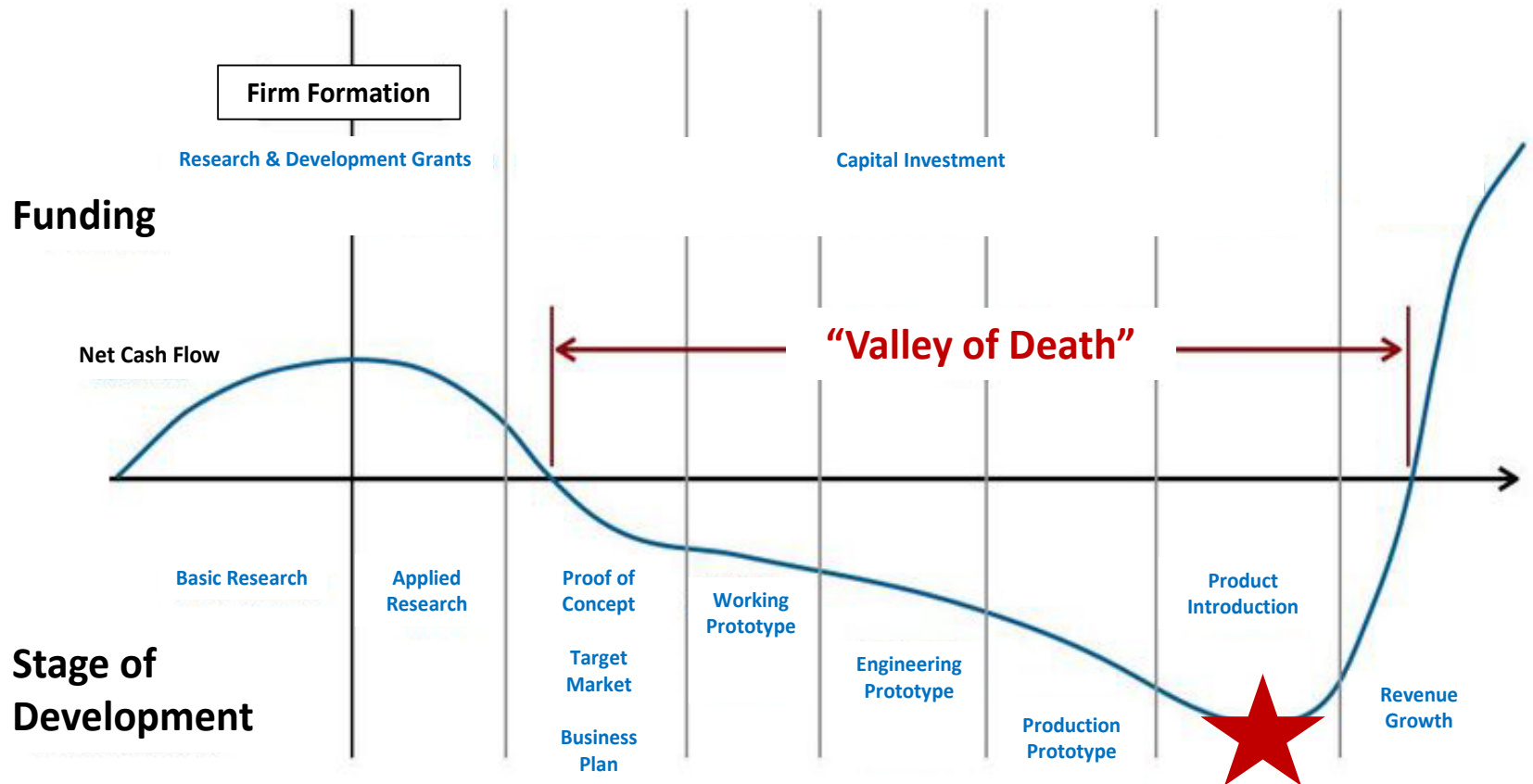


Imerys operates two commercial microfibrilated cellulose (MFC) facilities, one in southeastern USA and one in Asia

Source: Jack Miller, 2016 TAPPI International Nanotechnology Conference, Grenoble, France

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Commercialization Lifecycle Status



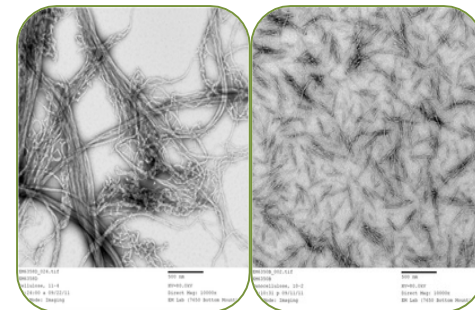
Cellulose Nanomaterials – Agenda 2020

Goal

Facilitate broad range of commercial development through development of pre-competitive technologies

Strategy

- Develop production methods (focus on issues of drying and dewatering)
- Characterize morphology and properties
- Pre-competitive research to enable applications



Priority Projects

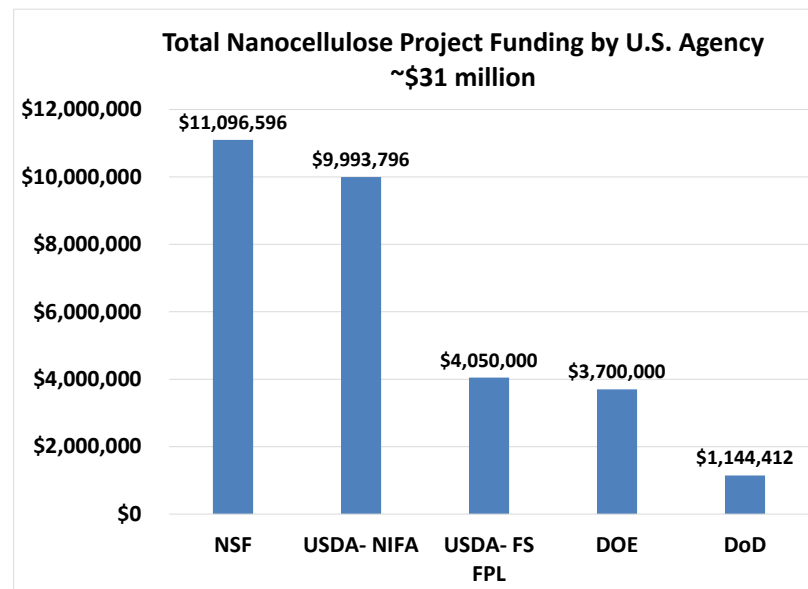


- **GRAS designation** - *Conduct toxicological investigation to obtain FDA Generally Regarded As Safe designation*
- **Dewatering/redispersion methods** – *Investigate ways to modulate hydrophilicity, drainage rates, rheology; create temporary or reversible flocculation; explore alternative solvents*
- **Drying/redispersion methods** – *Explore drying technologies for nanomaterials via literature review and evaluations; explore chemical aids to prevent agglomeration/hysteresis*
- **Develop characterization standards**
- **Facilitate application in high-volume composites** - *Develop scalable dispersion technologies by investigating alternative modes to incorporate nanocellulose including surface functionalization*

Federal Nanocellulose Research Investments

There is growing interest among US Federal Agencies in nanocellulose research. Total funding to date is ~\$31 million.

- DOE's 2017 SBIR funding solicitation topics:
 - Manipulation of Nanocellulose into High-Value Products
 - Energy- and Cost-Effective Generation of Nanocellulose
 - Surface Compatibility of Cellulosic Nanomaterial in Hydrophobic Matrix Materials
- Governments throughout the world recognize the potential economic and societal benefits of nanocellulose and have made significant R&D investments*:
 - CANADA: ~\$71 million
 - US: ~\$31 million
 - EUROPE: ~\$25 millionAnd Japan invests ~\$38 million *annually*!



Summary

- *Nanocellulose is an abundant renewable material that has been shown to improve performance of many other materials and systems*
- *While we've seen significant benefits, additional work is needed:*
 - *Further work to improve the compatibility of nanocellulose materials in hydrophobic material matrices*
 - *Work at pilot and demonstration scale to produce and further demonstrate the benefits in composites*
 - *Increasing awareness of the potential benefits of the material among end users in applications like vehicle components*
- *Engage with Agenda 2020 in your area of expertise*
- *Roadmaps available at*
<http://www.agenda2020.org/technology-roadmaps.html>



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Thank You

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