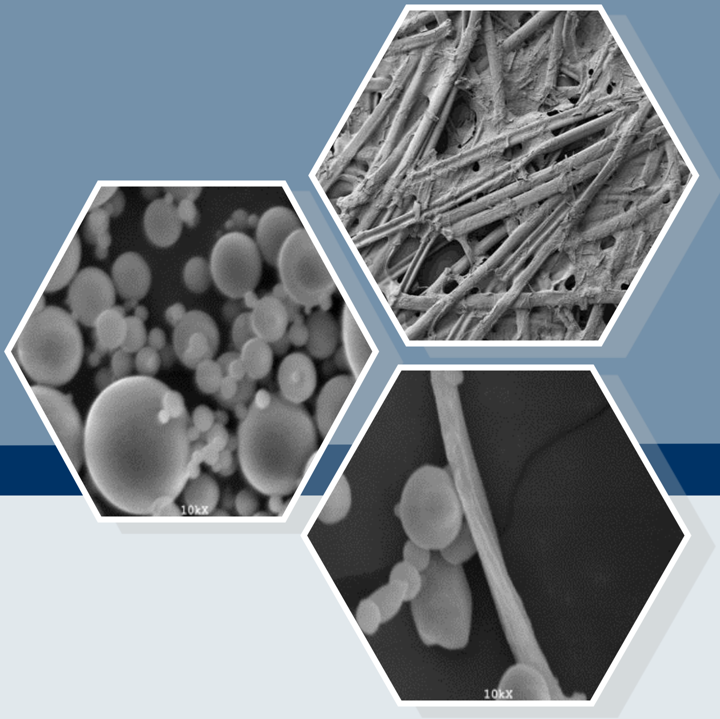
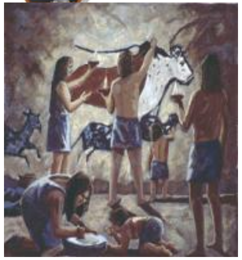
SUSTAINABLE NANOMATERIALS FROM FOREST PRODUCTS: UMAINE PERSPECTIVE

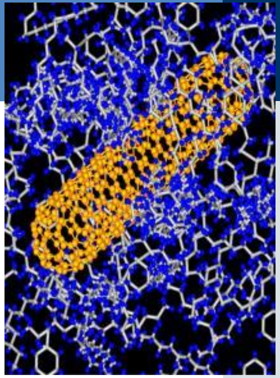


Douglas Gardner, PhD.
Advanced Structures & Composite Center
Forest Bioproducts Research Institute
School of Forest Resources, University of Maine

1 8 6 5 THE UNIVERSITY OF MAINE



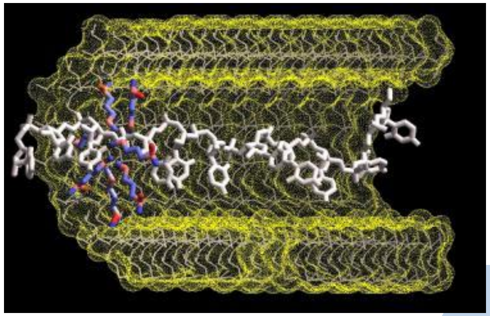




Stone Age ……. Bronze Age ………. Iron Age …………….. Nano Age?

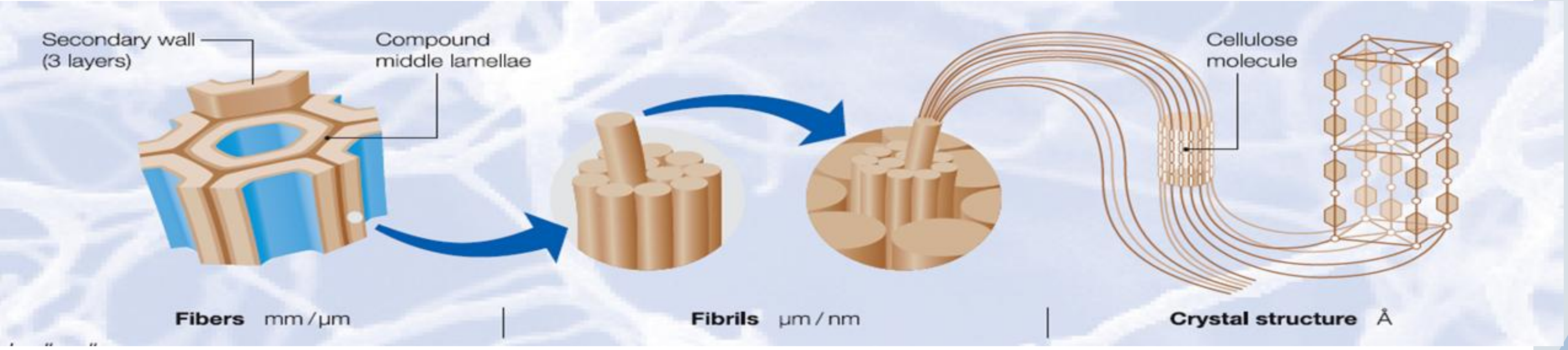
Ligno-Cellulose: Maine's Niche to Compete in Nanotech

"From the Sawmill to the Nanomill?"

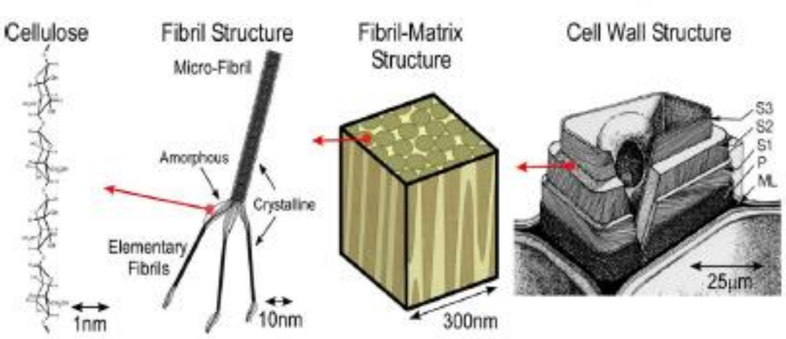


Overarching Research Focus

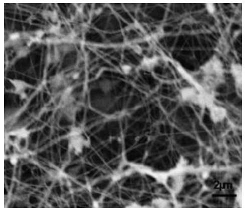
“Establish world-class R&D capacity in the field of ligno-cellulose derived nanomaterials leading to transformative technologies and industries that can change the face of Maine’s natural-resource based economy.”



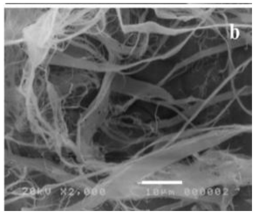
Nanocellulose is a renewable resource abundant in Maine



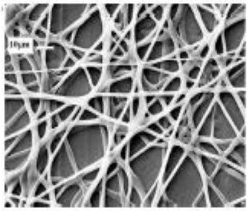
A Wealth of Cellulose Nanofibril Architectures are Possible



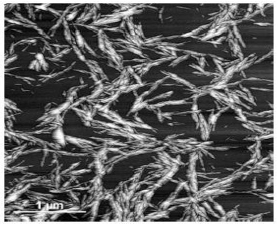
bacterial cellulose



nanofibrillated cellulose

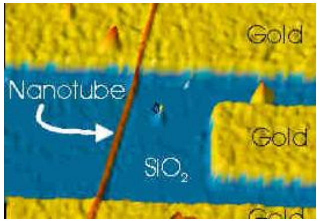


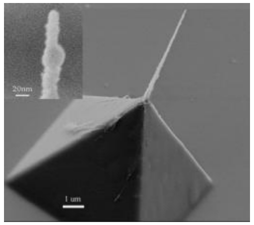
electrospun cellulose

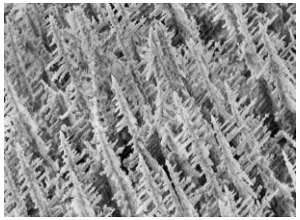


cellulose nanocrystals

Applications Range from Nano to Macro Components

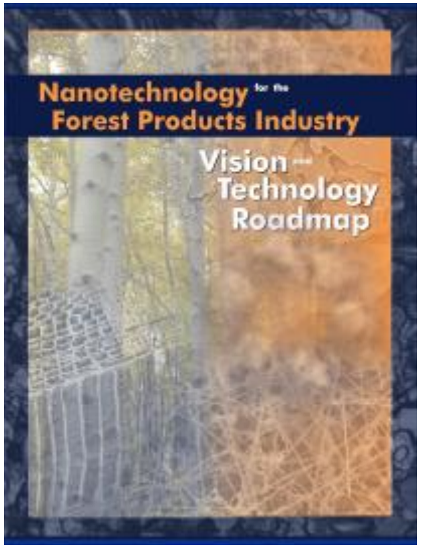






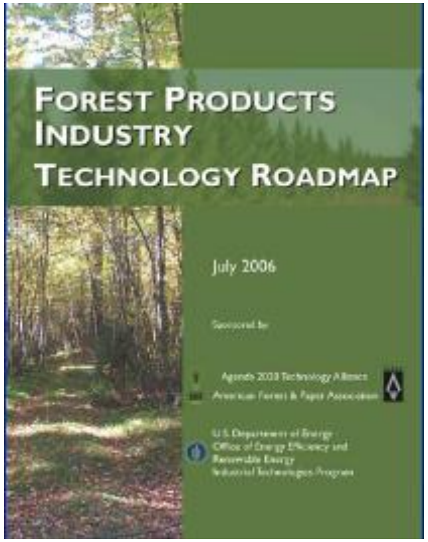
U.S. Forest Products Nanotechnology Research Roadmaps - Needs

2005



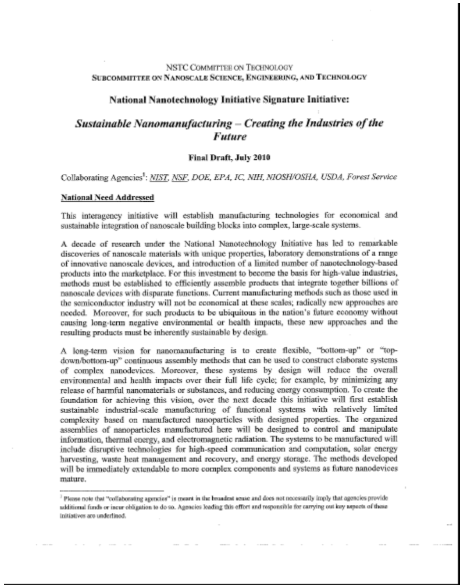
www.nanotechforest.org

2006



www.agenda2020.org

2010



NSTC COMMITTEE ON TECHNOLOGY
SUBCOMMITTEE ON NANOSCALE SCIENCE, ENGINEERING, AND TECHNOLOGY

National Nanotechnology Initiative Signature Initiative:

Sustainable Nanomanufacturing – Creating the Industries of the Future

Final Draft, July 2010

Collaborating Agencies[1]: *NIST, NSF, DOE, EPA, IC, NIH, NIOSH/OSHA, USDA, Forest Service*

National Need Addressed

This interagency initiative will establish manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems.

A decade of research under the National Nanotechnology Initiative has led to remarkable discoveries of nanoscale materials with unique properties, laboratory demonstrations of a range of innovative nanoscale devices, and introduction of a limited number of nanotechnology-based products into the marketplace. For this investment to become the basis for high-value industries, methods must be established to efficiently assemble products that integrate together billions of nanoscale devices with disparate functions. Current manufacturing methods such as those used in the semiconductor industry will not be economical at these scales; radically new approaches are needed. Moreover, for such products to be ubiquitous in the nation's future economy without causing long-term negative environmental or health impacts, these new approaches and the resulting products must be inherently sustainable by design.

A long-term vision for nanomanufacturing is to create flexible, "bottom-up" or "top-down/bottom-up" continuous assembly methods that can be used to construct elaborate systems of complex nanodevices. Moreover, these systems by design will reduce the overall environmental and health impacts over their full life cycle; for example, by minimizing any release of harmful nanomaterials or substances, and reducing energy consumption. To create the foundation for achieving this vision, over the next decade this initiative will first establish sustainable industrial-scale manufacturing of functional systems with relatively limited complexity based on manufactured nanoparticles with designed properties. The organized assemblies of nanoparticles manufactured here will be designed to control and manipulate information, thermal energy, and electromagnetic radiation. The systems to be manufactured will include disruptive technologies for high-speed communication and computation, solar energy harvesting, waste heat management and recovery, and energy storage. The methods developed will be immediately extendable to more complex components and systems as future nanodevices mature.

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[1] Please note that "collaborating agencies" is meant in the broadest sense and does not necessarily imply that agencies provide additional funds or incur obligation to do so. Agencies leading this effort and responsible for carrying out key aspects of these initiatives are underlined.

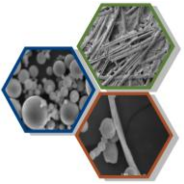
http://www.nano.gov/html/research/NNISigInitSustainableMfrFINALJuly2010.pdf

Nanomaterials From Forest Products
UMaine Research Projects

- **Scalable Production of Cellulose Nanofibrils: *A joint venture with USDA Forest Products Laboratory***
  - **Pilot-Scale Nanofibrillated Cellulose Production**
  - **Pilot-Scale Spray Drying Capacity**
- *In situ* surface modification of CNF during drying to promote improved polymer compatibility and thermal stability
- Ice-segregation-induced self-assembly (ISISA) to template lignin and cellulose nanofibers into a 3-D non woven mat that can be freeze-dried to liberate the nanofiber mat
- Carrier systems for CNF in hydrophobic polymer composites
- Renewable nanocomposites made from lignocellulosic fillers and transparent polymer matrices

Nanomaterials From Forest Products UMaine Research Projects

- Utilization of CNF in paper coatings
- Utilization of CNF in packaging applications
- Production of CNF Aerogels for structural insulating foams
- High CNF content materials including films, filters, etc.
- NFC-clay matrix composites
- Carbonized lignin nanofibers as an additive to create conductive polymers



Scalable Production of CNF

Objectives

- Demonstrate pilot scale capability to produce CNF using a scalable manufacturing process.
- Determine the effects of species (i.e. hardwood and softwood) and pretreatment parameters on CNF properties

Deliverables

- Develop capacity to provide pilot quantities of slurry and dry CNFs (NFC and CNC) to Consortium members
- Further scientific understanding of feedstock, pretreatment and processing conditions on CNF properties

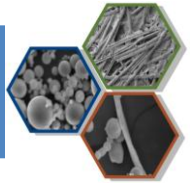
Scalable Production of CNF

Timeline

- Ultrafine Grinder
  - Bench unit is operational
  - Pilot-scale unit is ordered July installation
- Spray Dryer
  - Performance trials completed
  - Pilot-scale unit is ordered with an expected August shipping date
- Pilot-scale production of NFC
  - Aqueous suspensions expected Q3 2012
  - Spray-dried NFC, CNC and TEMPO (from FPL) expected Q4 2012

Broader Impacts

- **Scientific**
  - Ability to source NFC and CNC samples for fundamental research and application development
- **Industrial Relevancy**
  - Demonstrate the value of NFC/CNC in applications at a commercially relevant scale and a viable pathway to commercial production



Scientific Approach

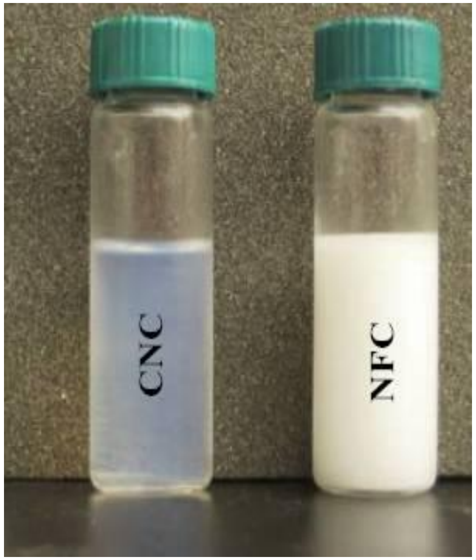
- **Production of aqueous suspensions of NFC via mild pretreatment and mechanical treatment of lignocellulosics**
- **Characterization of aqueous suspensions**
- **Production of dried NFC/CNC via spray drying of aqueous suspensions**
- **Characterization of spray-dried NFC/CNC**
  - Particle size
  - Morphology
  - Surface area/surface energy

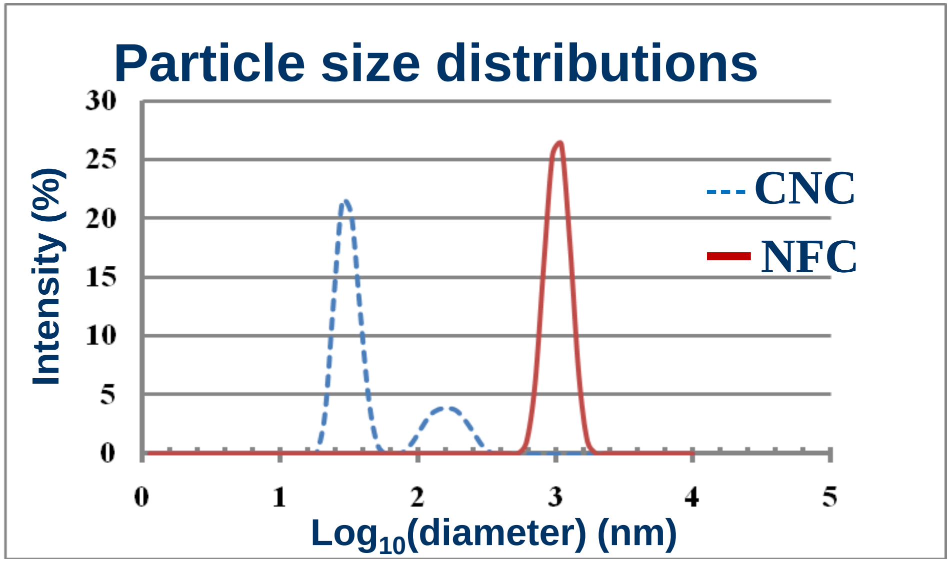
Key Findings – Aqueous Suspensions

Hydrodynamic diameters

CNC: 21 ~ 51 nm & 79 ~ 342 nm

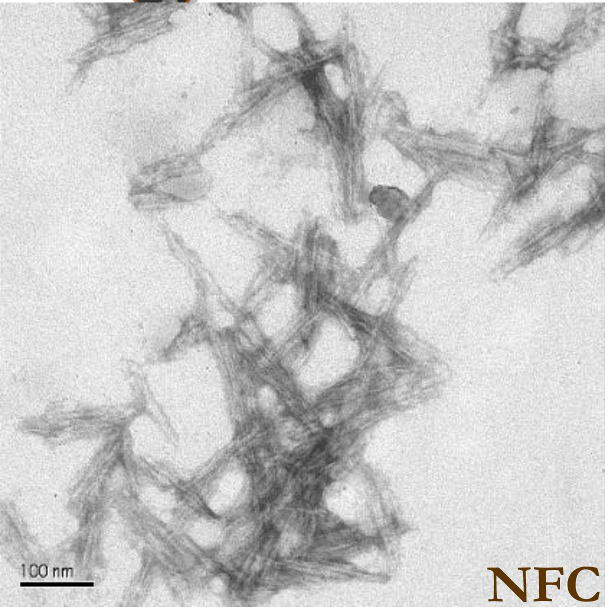
NFC: 712 ~ 1484 nm

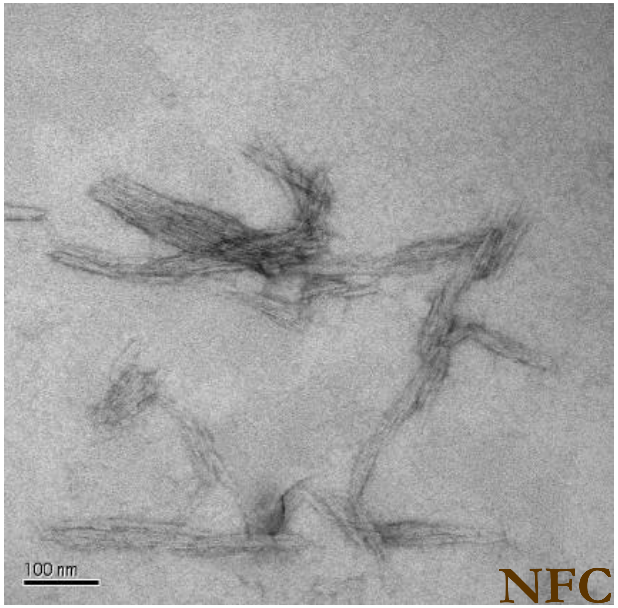


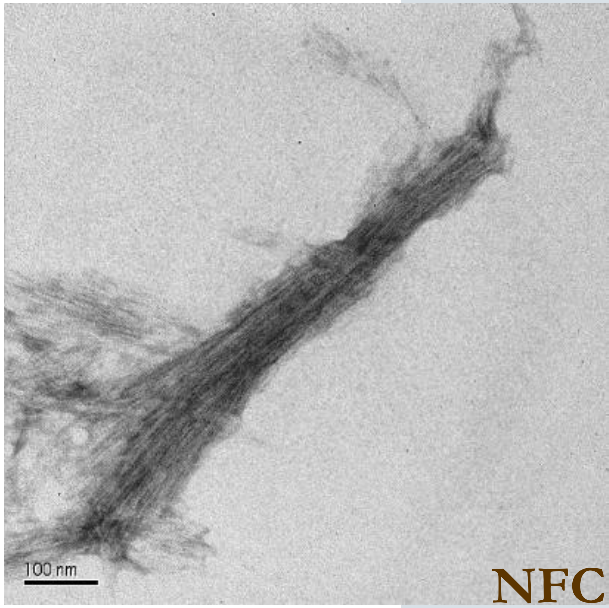

Particle size distributions

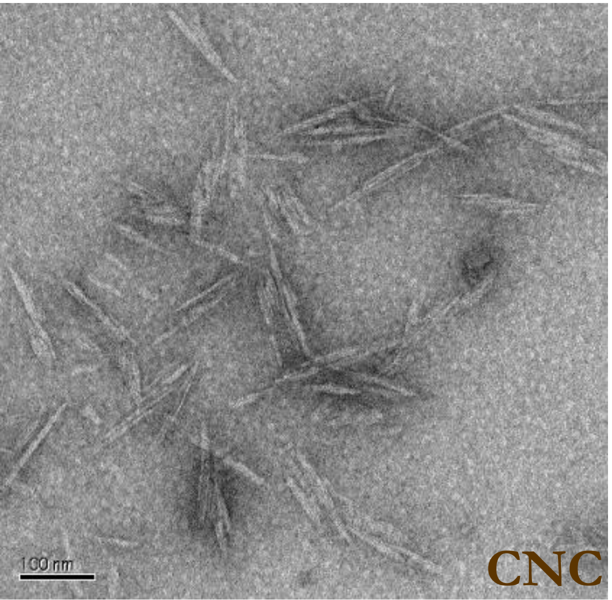
Dynamic light scattering results)

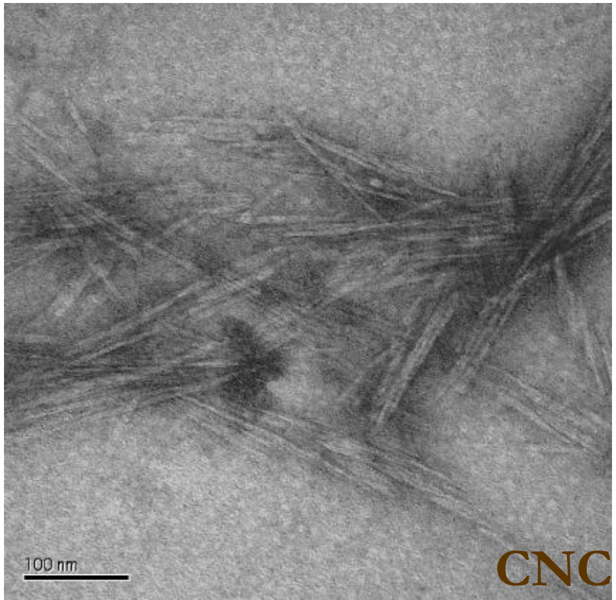
Key Findings –Aqueous Suspensions TEM

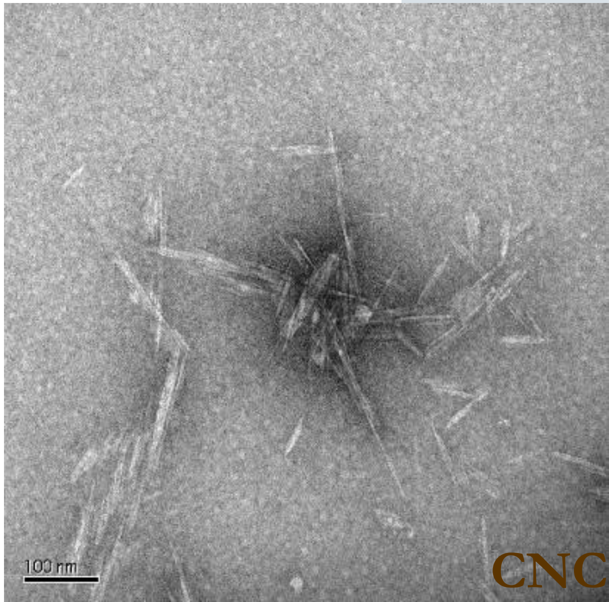




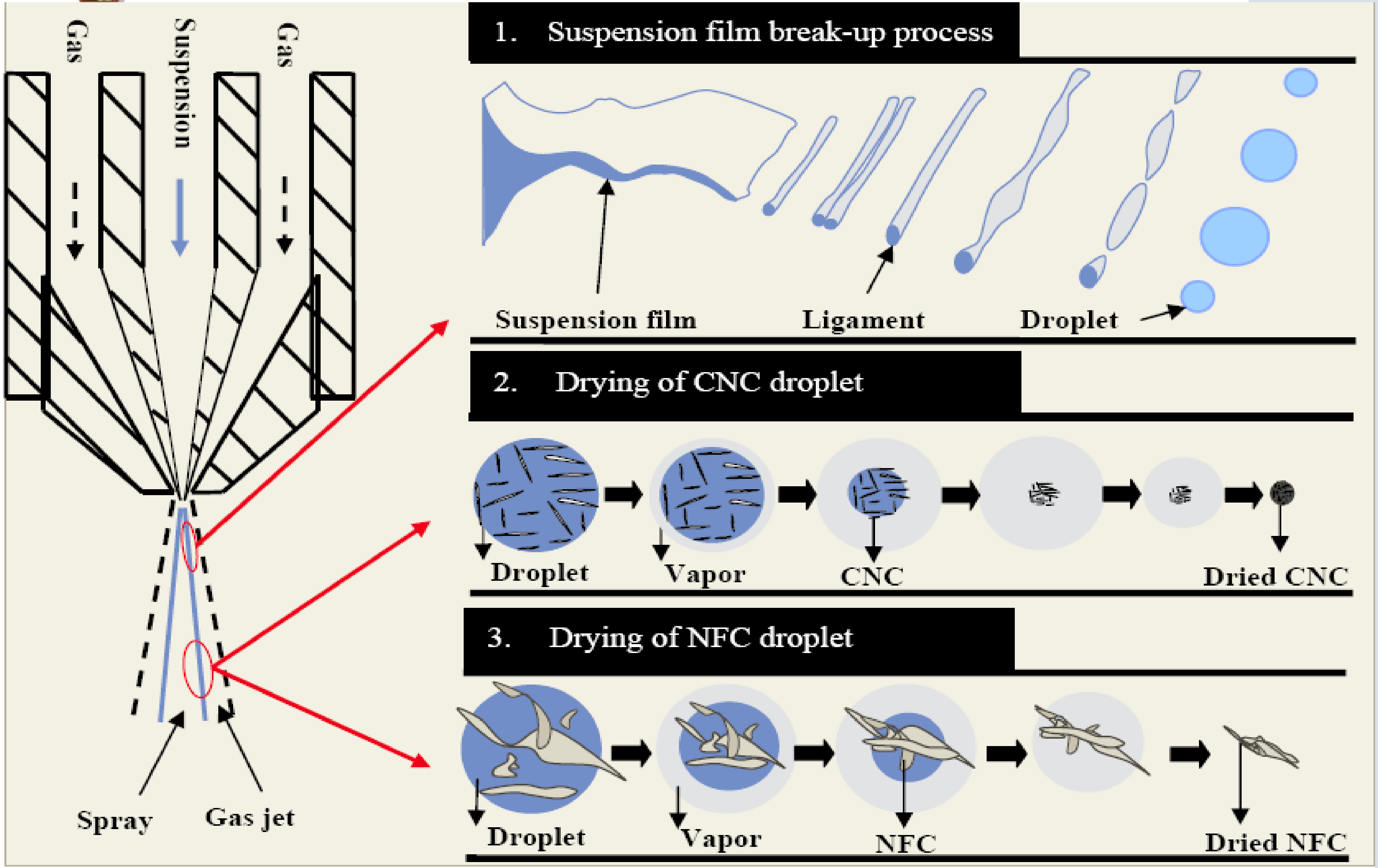






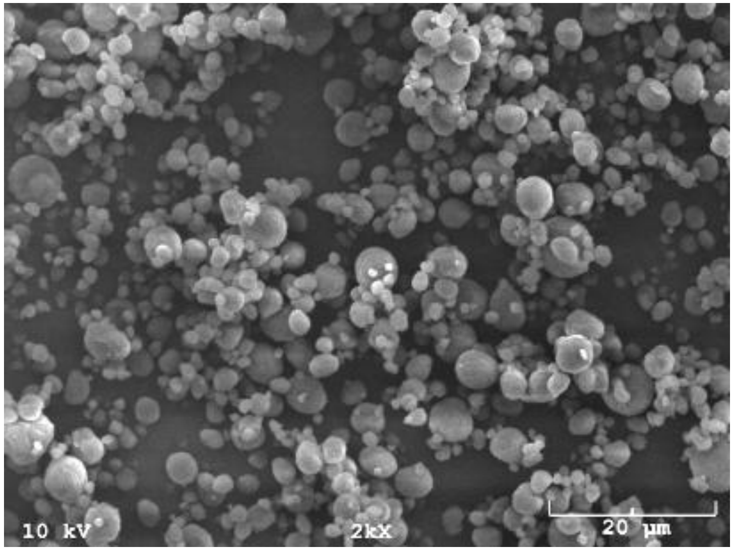


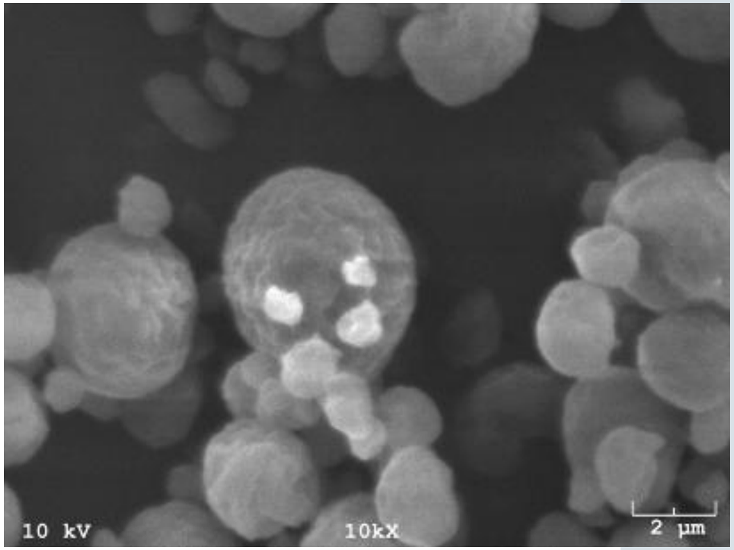
Spray Drying Schematic



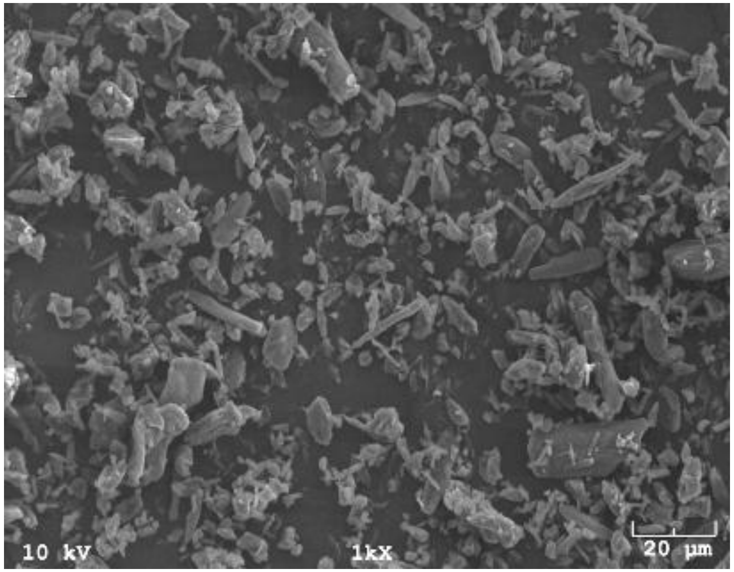
Key Findings – Spray Dried CNF

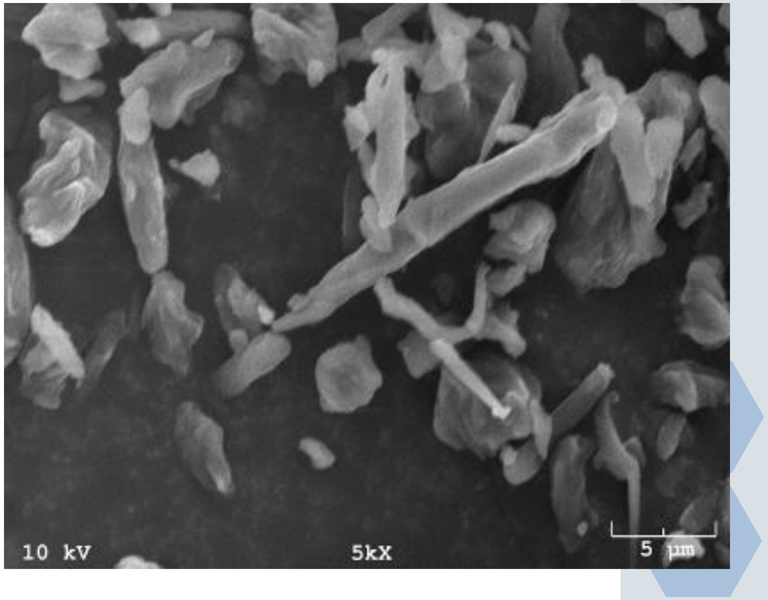
CNC





NFC

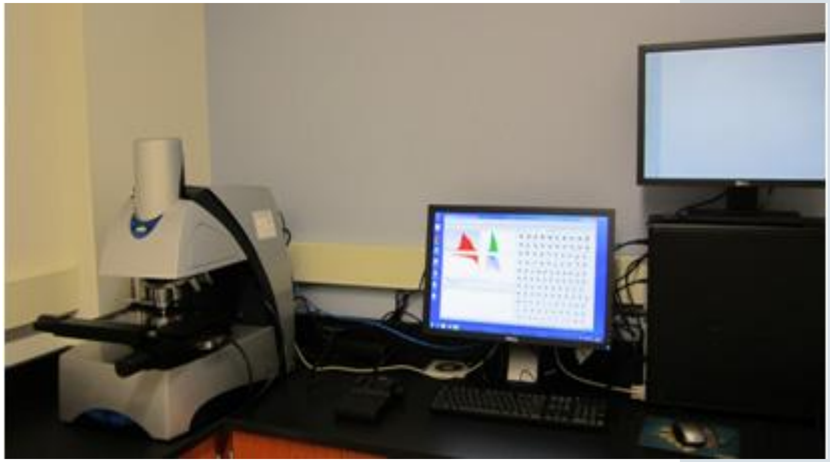


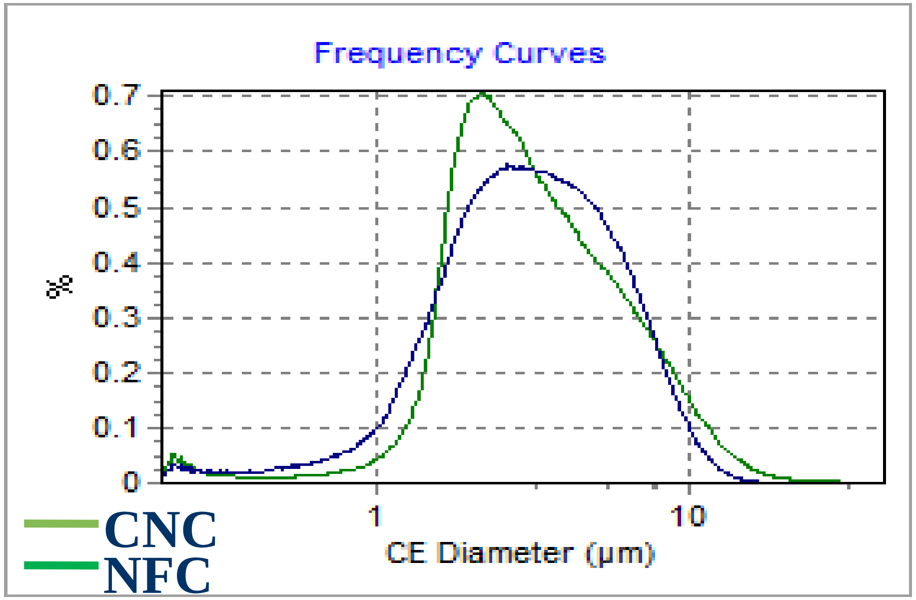


Key Findings – Spray Dried CNF

Morphologi G3S

Particle characterization based on image analysis of dry powder

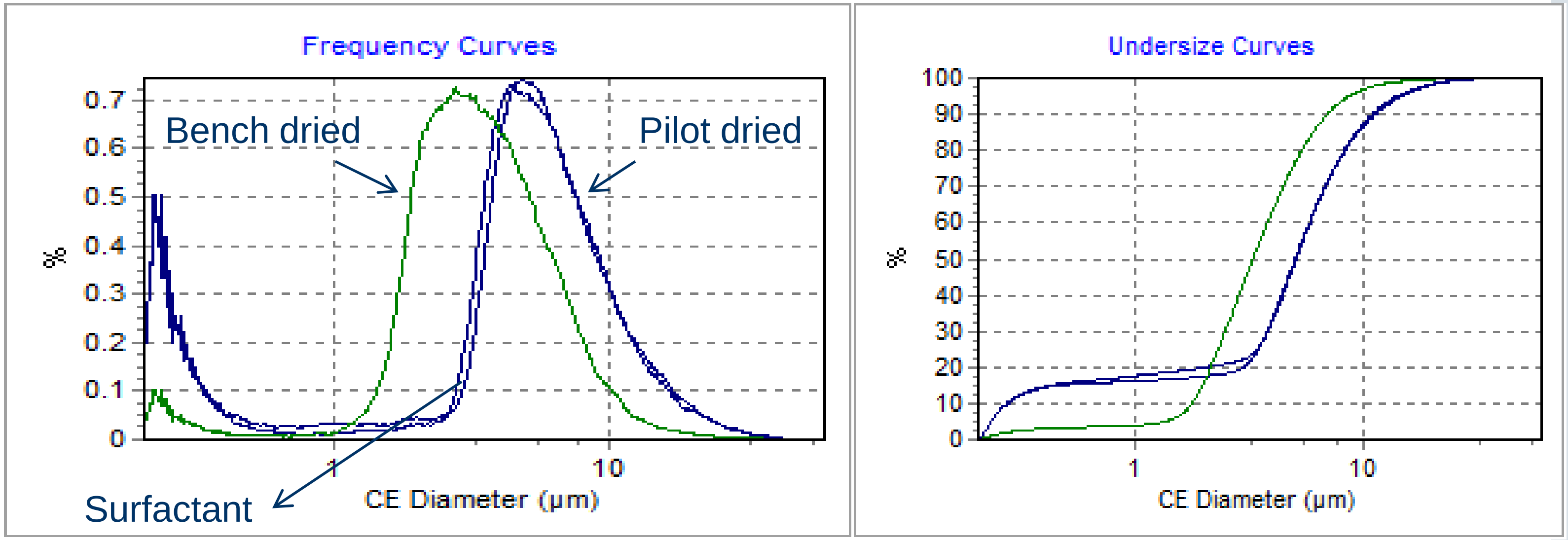




Sample	CE diameter (µm)		
	D(n,0.1	D (n, 0.5)	D (n, 0.9)
CNC	**1.31**	**3.06**	**6.76**
NFC	**1.59**	**2.96**	**7.48**

Key Findings - Spray Dried CNF

Scale up from bench to pilot scale



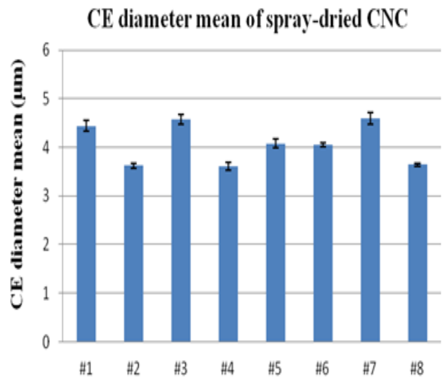
Particle size distribution of NFC analyzed based on image analysis

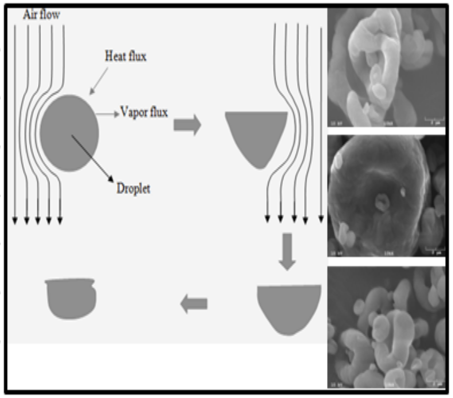
Sample	**Distribution pressure (bar)**	**d(0.1) (µm)**	**d(0.5) (µm)**	**d(0.9) (µm)**	**D[4,3] (µm)**	**D[3,2] (µm)**
NFC (Dried by Buchi B-290)	5	1.79	**3.30**	6.97	15.72	9.614
NFC (Dried by GEA)	5	0.28	**5.04**	10.93	18.93	13.66
NFC with surfactant (Dried by GEA)	5	0.27	**5.11**	11.33	20.33	14.47

In situ surface modification of CNF

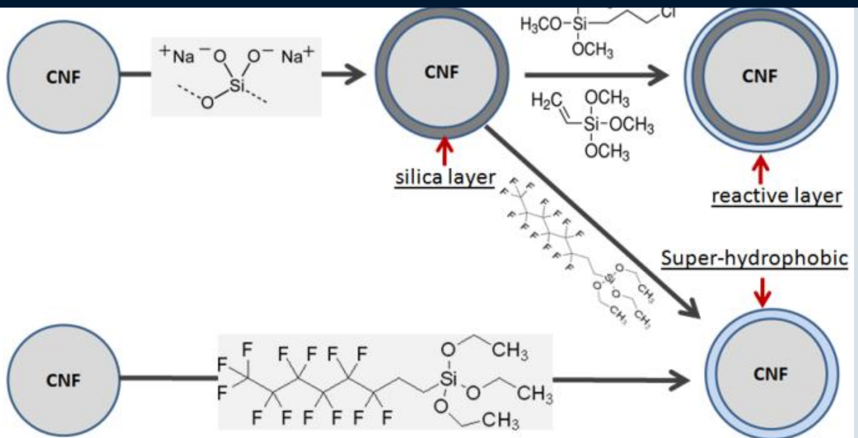
Scientific Approach

Optimization of drying process

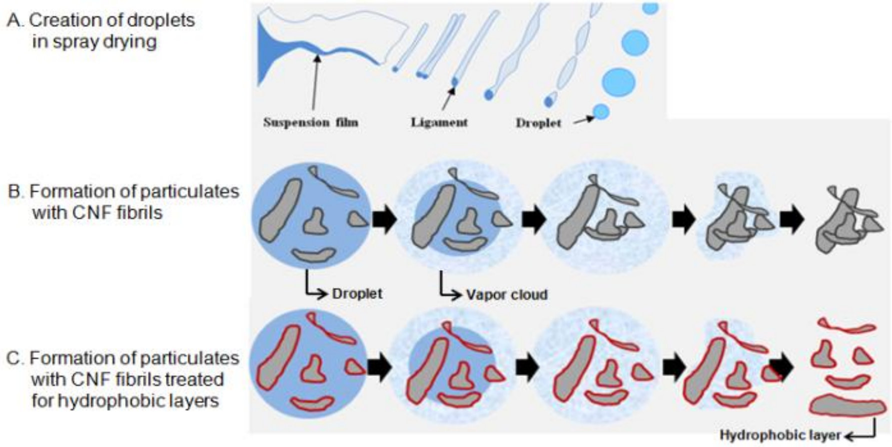




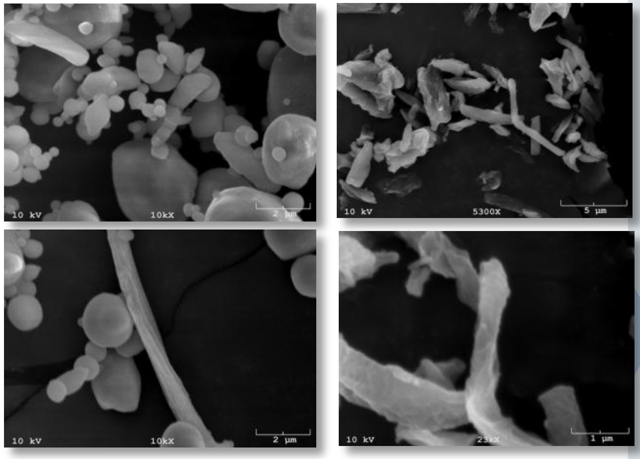
Design of chemical reactions



Application to the process



Characterization

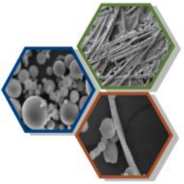


Cost estimates for CNF samples

Consortium Members

- **Aqueous suspension of NFC**
  - **$10.39 per dry lb of NFC - FOB Orono, ME, ~2% solids**

- **Dried NFC or CNC**
  - **Drying charge - $95.91 per dry lb of NFC or CNC**
  - **Does not include material costs or shipping**



Challenges

- **Control of CNF Morphology**
  - Dispersion of aqueous suspensions
  - During drying processes
- **Reduction of production costs**
  - Energy consumption
  - Pretreatment costs
  - Drying productivity
  - Economies of scale
- **Processing of CNF nanocomposites by classical methods (extrusion, injection molding)**

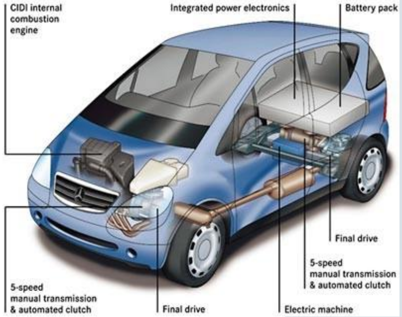
Benefits to Maine, the U.S. and Society

Benefits for Maine:

- Transform its Forest Products Industry
- Become an Active Player in the Nanotech Revolution

Benefits for U.S. and Society:

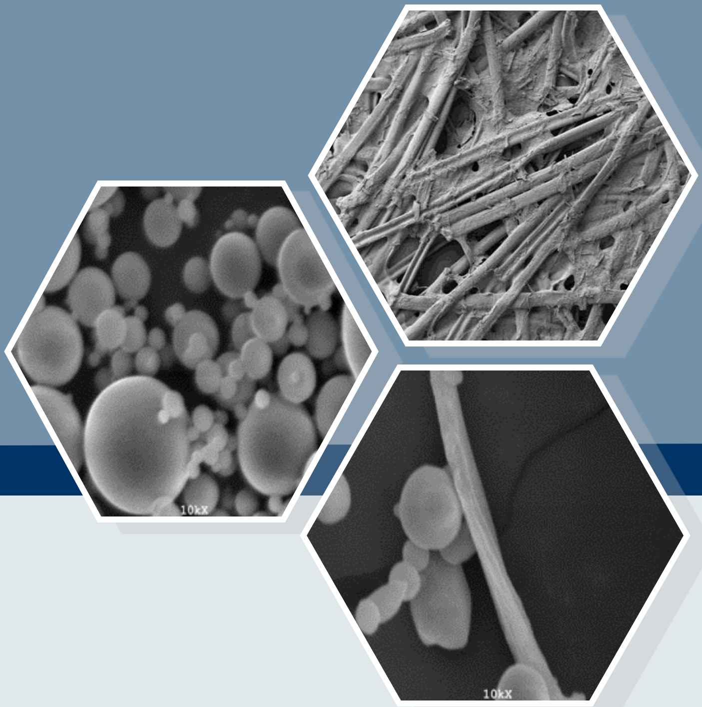
- Renewable recyclable, sustainable technology
- Intelligent products with nanosensors for measuring forces, loads, moisture levels, temperature.
- Building blocks of nanoproducts with substantially enhanced properties.
- Coatings for improving surface qualities to make existing products more effective.
- Basis for making lighter-weight products from less material and with fewer energy requirements.



20% lighter

Enables off-shore wind energy

100% more durable



Thank You!

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