Integrating Nanomaterial Applications in the field of Sustainable Biomaterials

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Where do we see the Challenges and Opportunities for Sustainable Nanomaterial Applications into the Future?

Premise: Our Current Research defines where **we all** believe the future lies. Reviewers for funding agencies that support the research also of course believe in the same future.

Question:

These are Critical Areas of Research Focus: But are they what the Public considers as "Forest Products" and should they be categorized as such?

AMO Objectives – Focus Areas

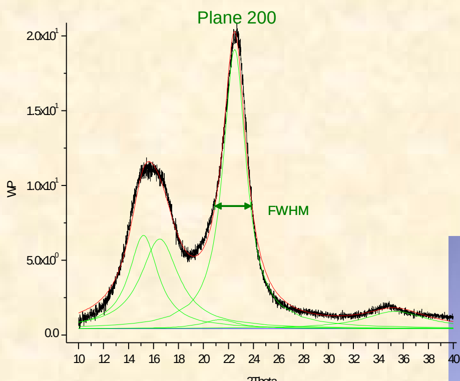
- Nanocomposites using Cellulose and Lignocellulose Nanomaterials
  - Structural panels and composite structures
- Photonics and Electronics
  - Smart materials, smart packaging, printed electronics
  - Energy storage devices
- Health and Personal Care
  - Artificial body parts, tissue scaffolds, targeted drug delivery
- Improved Strength to Weight Performance of Paper and Board
  - Strength enhancement in paper, paperboard, and wood building products
- Understanding the Control of Water-Lignocellulosic Interaction for Modification of Properties

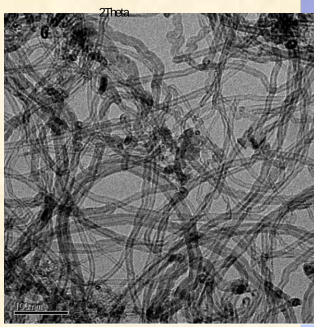
Barrier packaging – nanocoatings on paper and plastic webs for vapor barrier

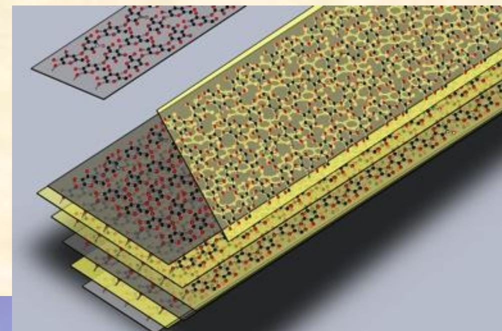
AMO Focus Area I

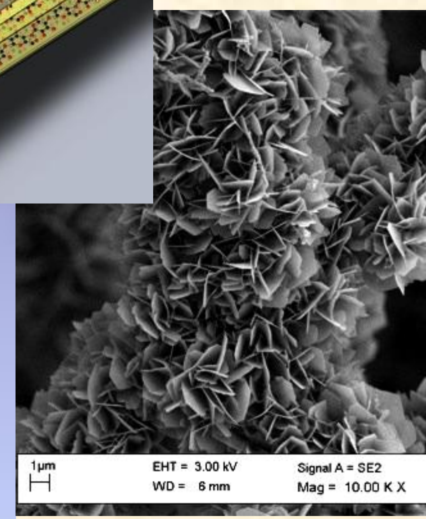
Nanocomposites using Cellulose and Lignocellulose Nanomaterials: Structural Panels and Composite Structures

(S. Renneckar, C. Frazier and the NSF I/UCRC WBC)









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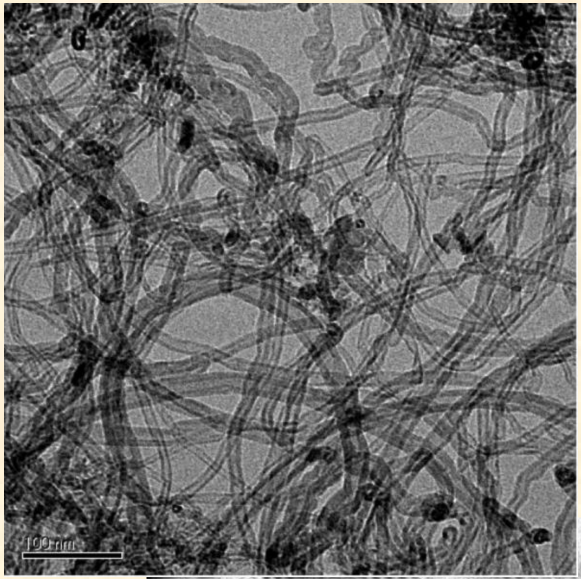
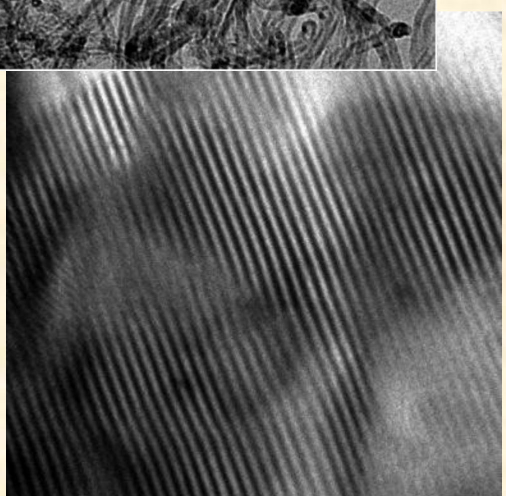
CNT & Graphitic carbon from biomass for reinforcement of Polymer Matrix Composites in Structural Applications



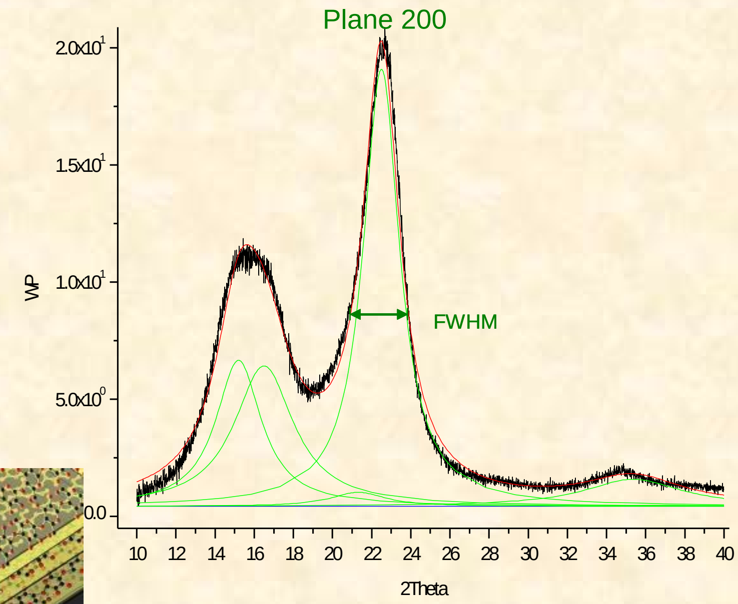


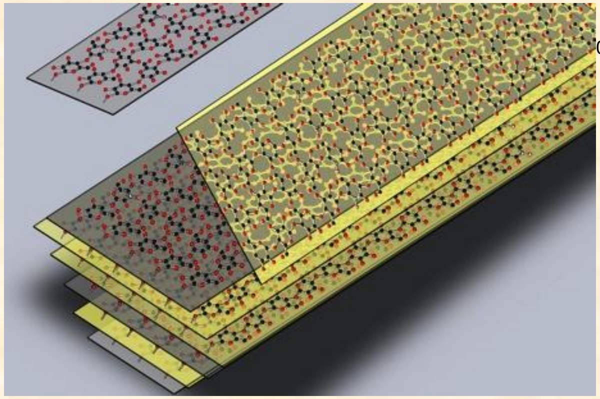
Size, Structure, and Biomimetic Materials of nanocellulose for applications in composites: Renneckar Group

Table 2 Statistical values for length, thickness, and aspect ratio of nanocellulose as a function of sonication time

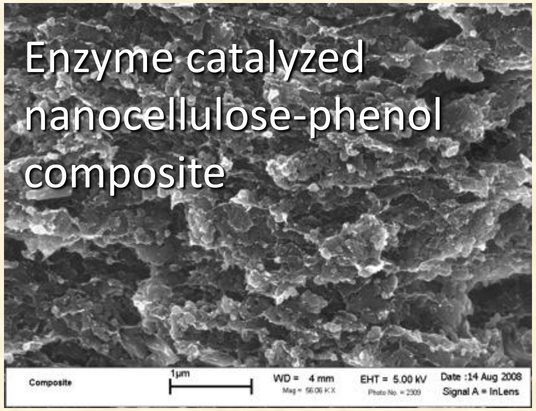
Sonication time (min)	Length (nm)		Thickness (nm)		Aspect ratio	
	Mean	SD	Mean	SD	Mean	SD
30	580	330	1.38	0.71	530	420
60	400	230	1.08	0.72	500	420
120	330	210	0.81	0.61	580	440
240	260	160	0.74	0.43	450	340

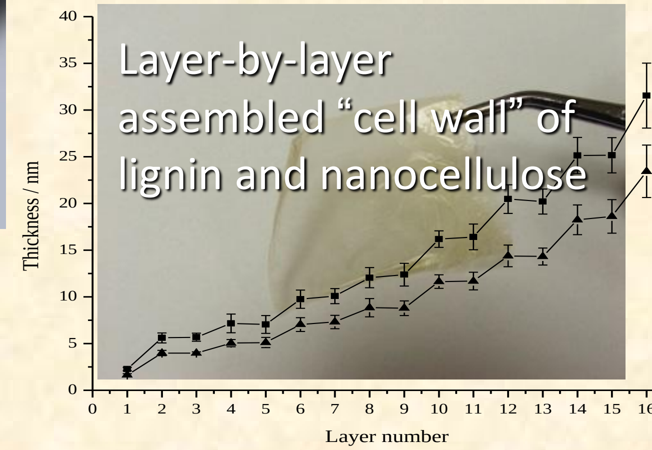
Li, Q. and S. Renneckar (2009). "Molecularly thin nanoparticles from cellulose: isolation of sub-microfibrillar structures." Cellulose 16(6): 1025-1032.





Li, Q. and S. Renneckar (2009). "Supramolecular structure characterization of molecularly thin cellulose 1 nanoparticles." Biomacromolecules 12:650-659





Li, Z., S. Renneckar, and J. Barone. 2010. Nanocomposites prepared by in-situ enzymatic polymerization of phenol with TEMPO-oxidized nanocellulose. Cellulose 17(1):57-68

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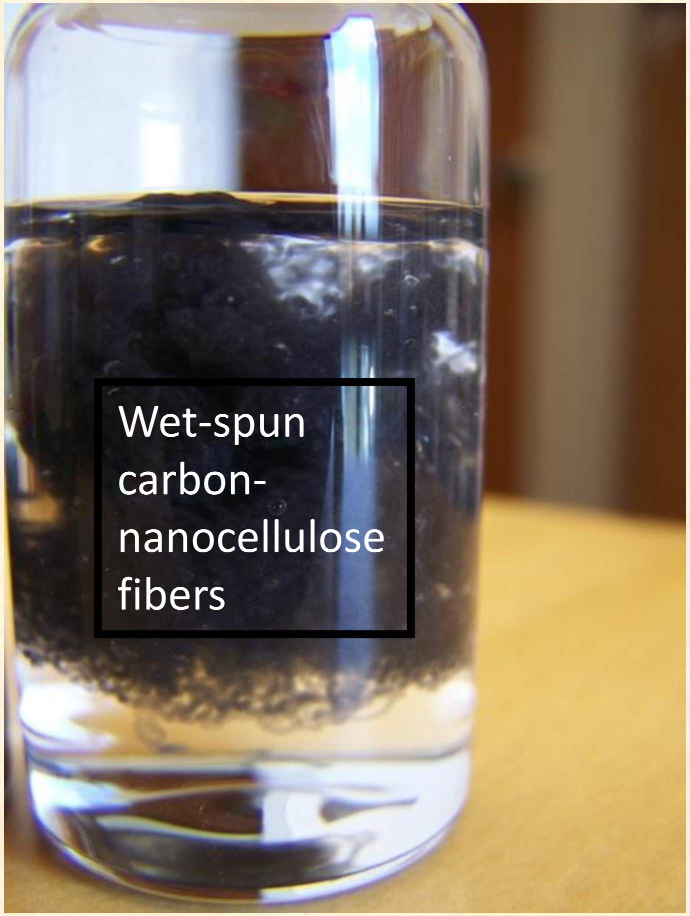
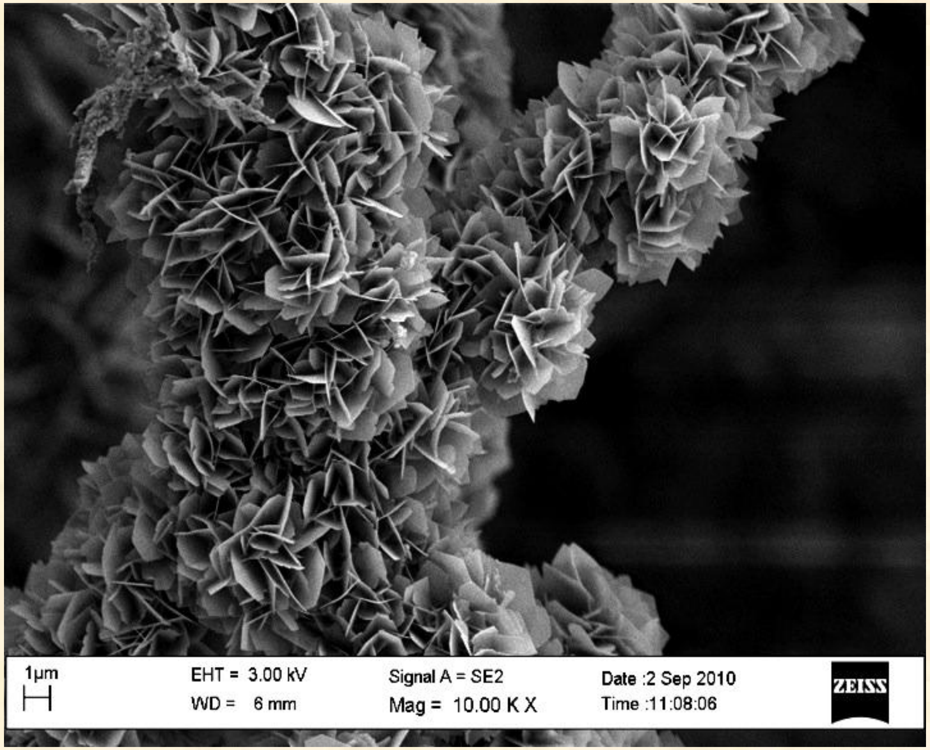
High-value Hybrid Nanocomposites: Renneckar Group



Conductive textiles

Hydroxyapatite - electrospun cellulose fibers



Tissue engineering scaffolds

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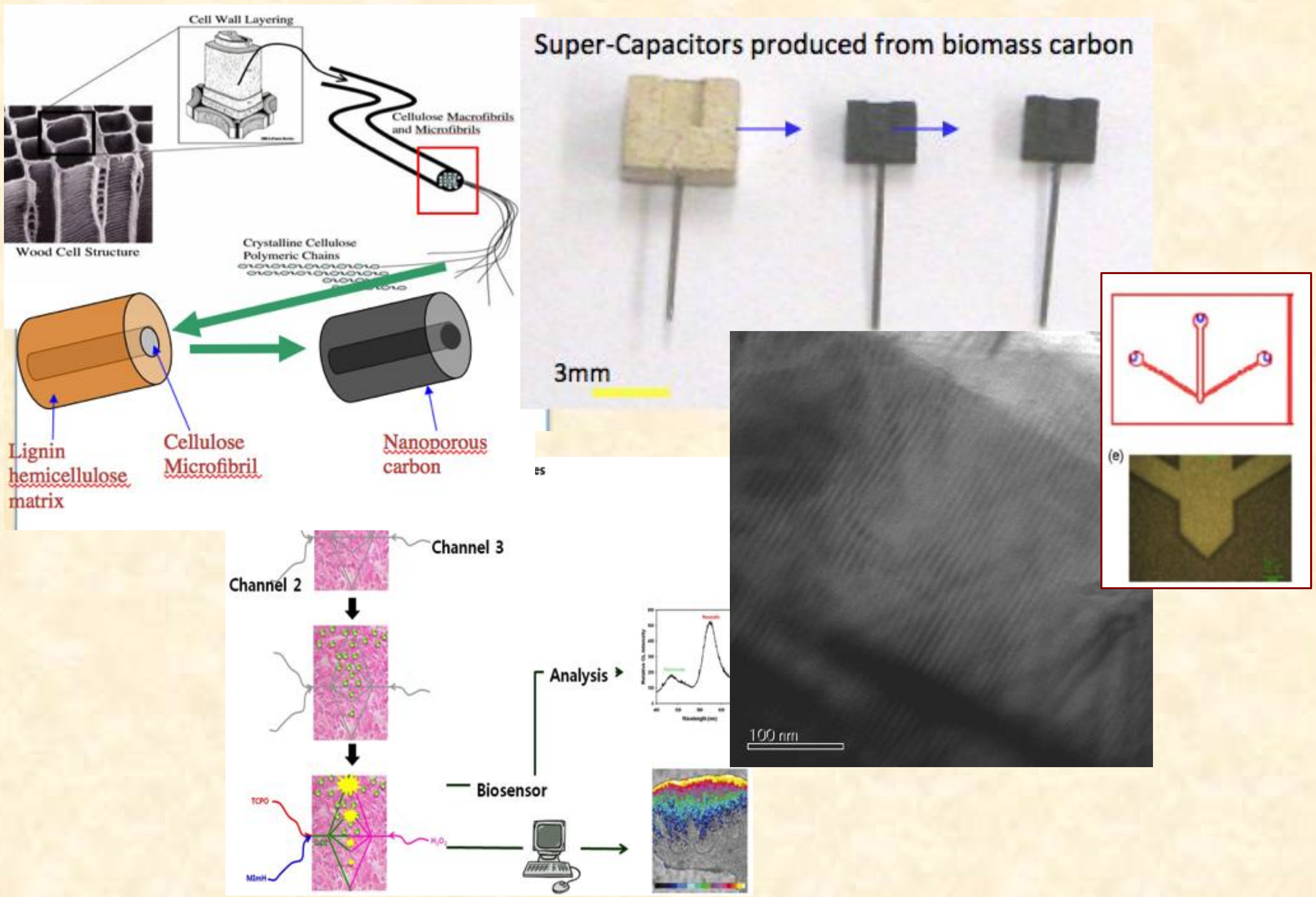
AMO Focus Area II

Photonics and Electronics: Smart materials, Smart packaging, Printed electronics; Energy Storage Devices

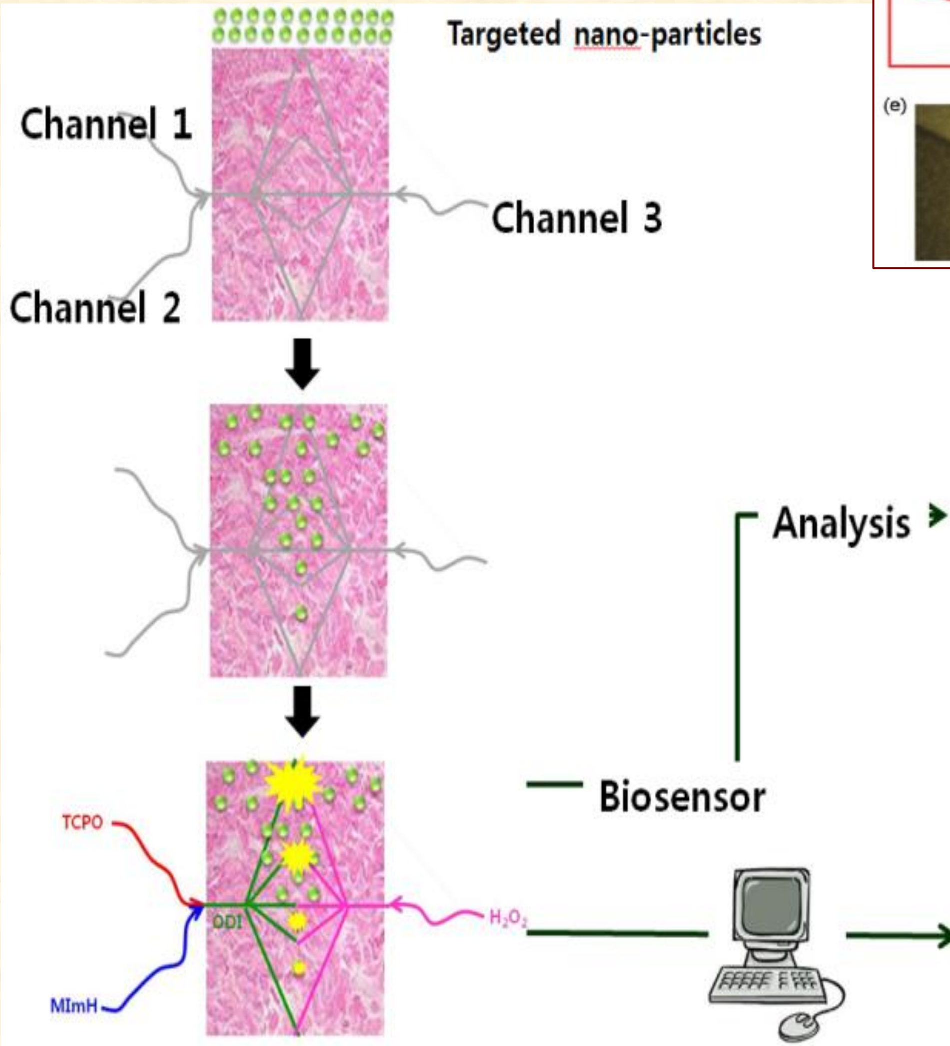
(M. Roman, Y. T. Kim, , S. Renneckar, B. Goodell)

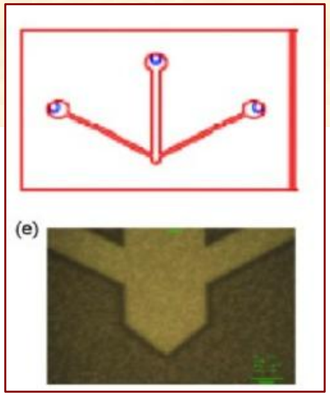


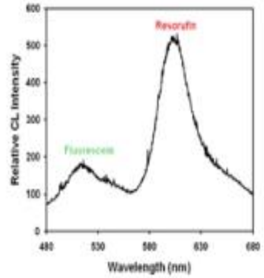
"SKIN-on-a-CHIP technology" pat. pend.

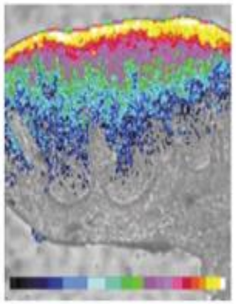
Y-T Kim Research

- Tissue cultures of human skin grown on chips permits monitoring (chemiluminescence) of nano-particles from TiO_2 to antimicrobial compounds through skin.
- APPLICATIONS: Dynamic detection of nanomaterials used in cosmetics, food, and other life science industries.









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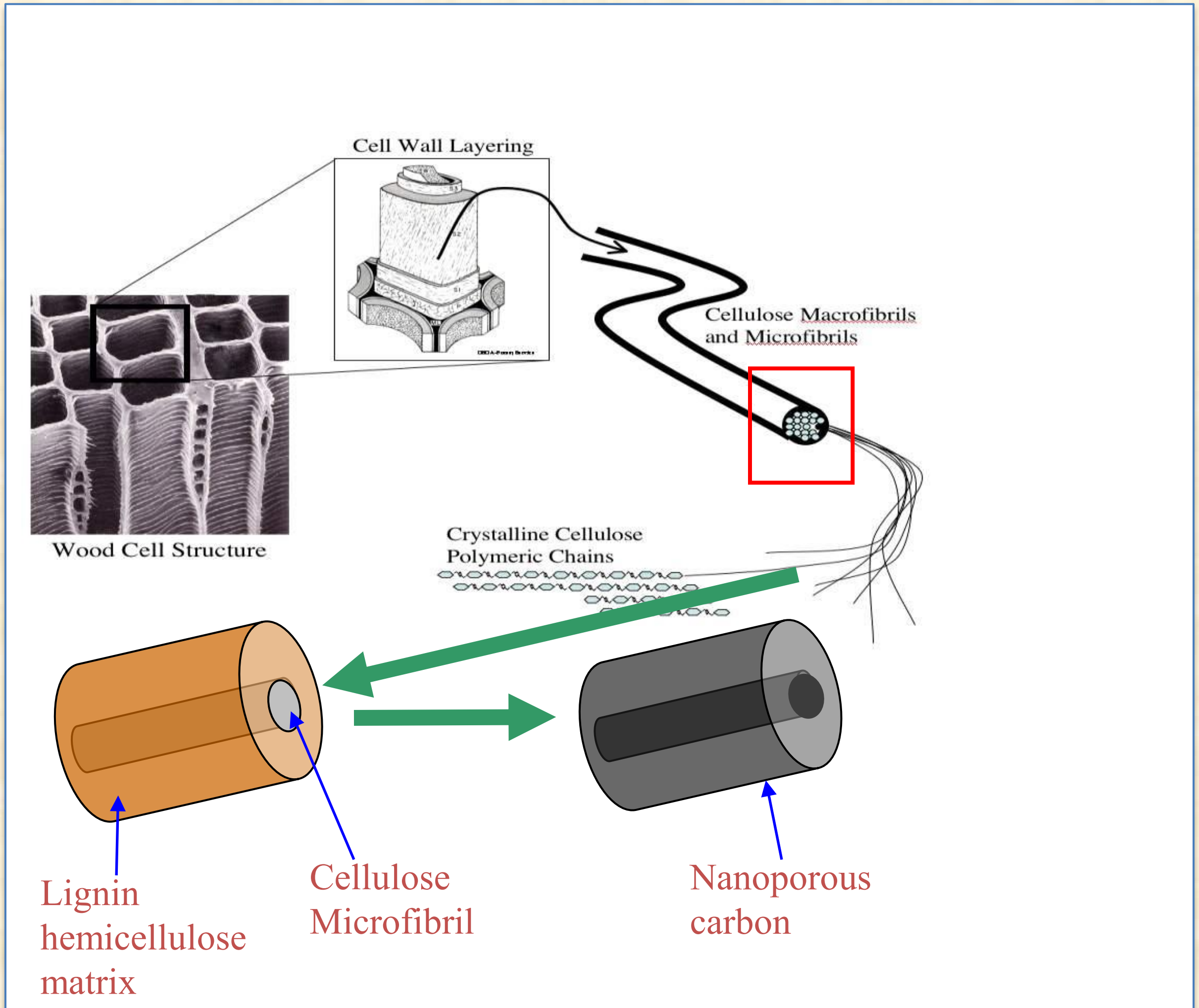
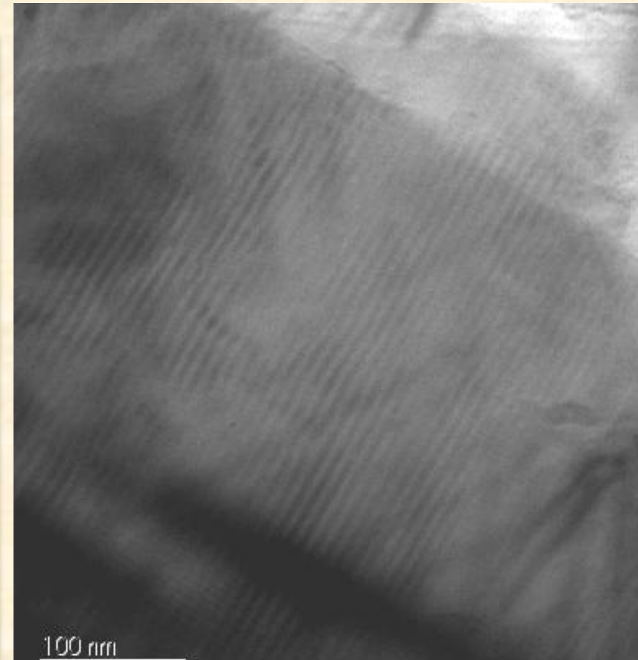
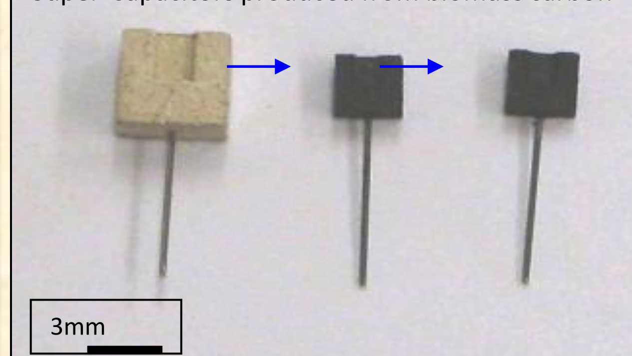
Engineering carbon electrodes from lignocellulosic materials

Highly ordered mesoporous and nanoporous carbon in experimental super-capacitors





Super-Capacitors produced from biomass carbon



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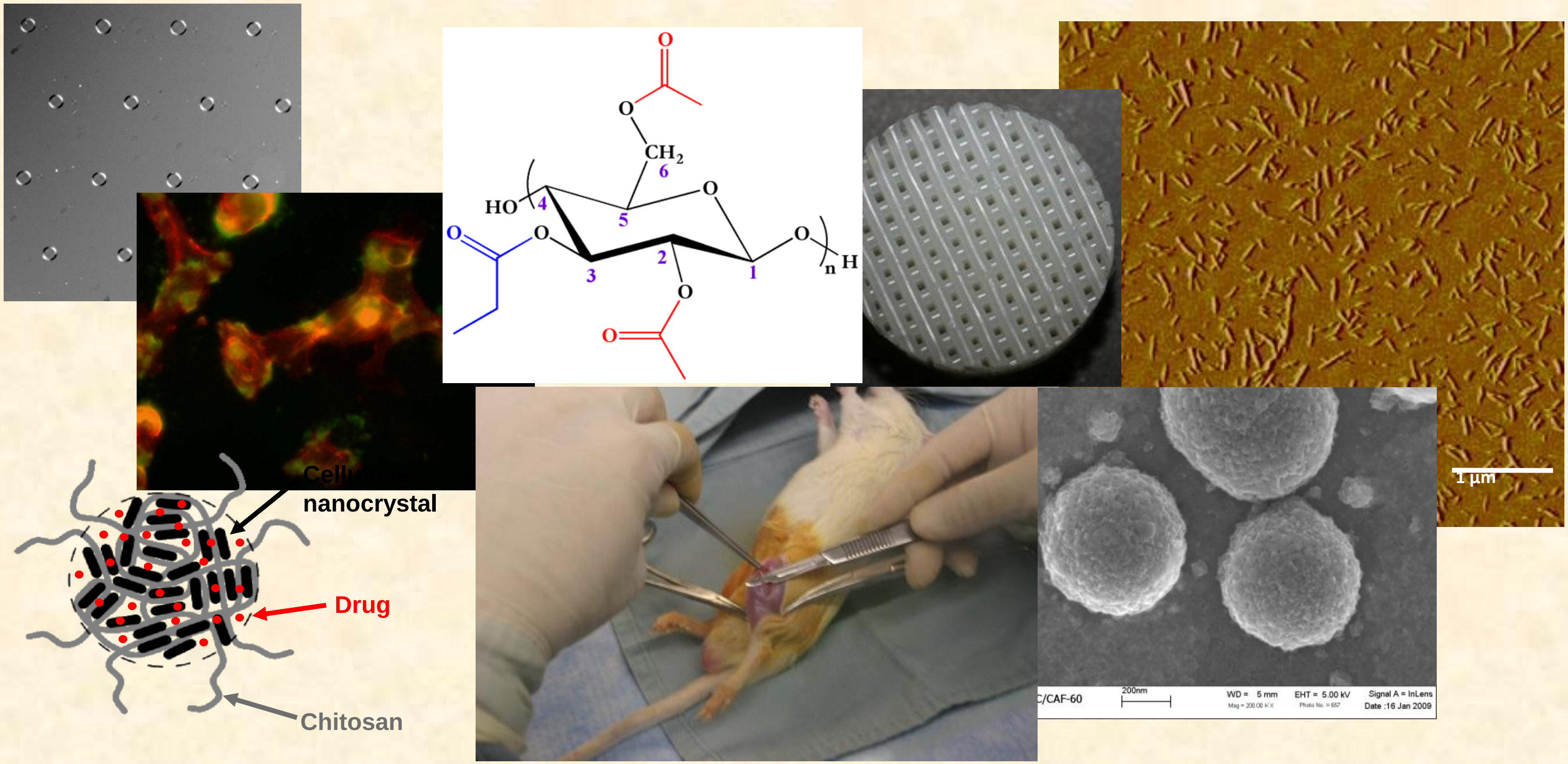
Nanocarbon – Nanocellulose Hybrid Composites for Energy Storage: Renneckar Group

Electrodes for Li Batteries

AMO Focus Area III

Health and Personal Care: Artificial body parts, tissue scaffolds, targeted drug delivery

(K. Edgar, M. Roman, S. Renneckar)



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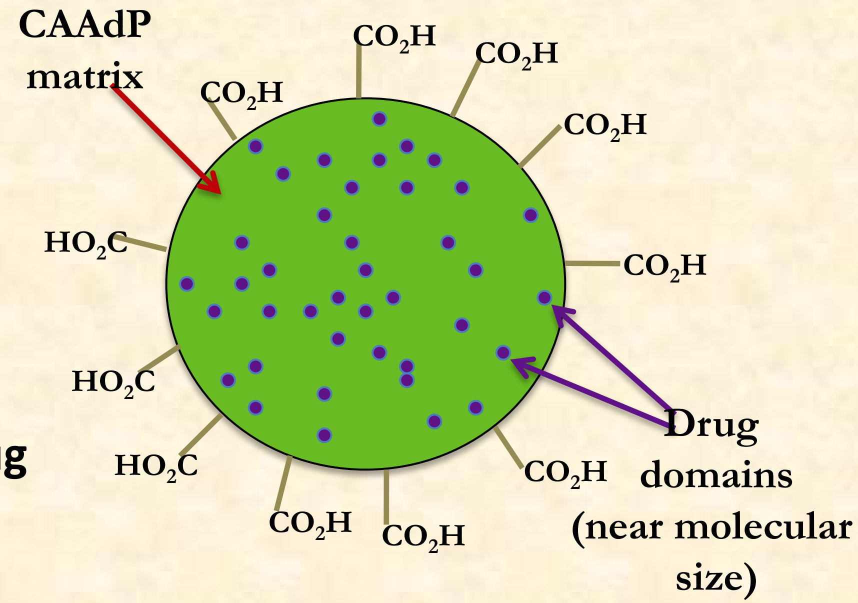
Renewable Biomaterials and Human Health

“Dissolving bricks”; polysaccharides in drug delivery:

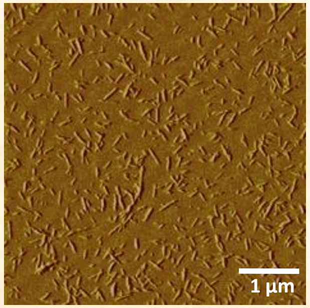
- **Poorly soluble in bloodstream**
- Wastes money, drugs get into wastewater (resistant organisms), harms patients
- E**nhancing drug solubility (novel cellulose esters including CAAdP with colleagues at Purdue) by making nanodispersions of drug in polymer**.
- Further improvement if we make nanodispersion particles < 250 nm diameter



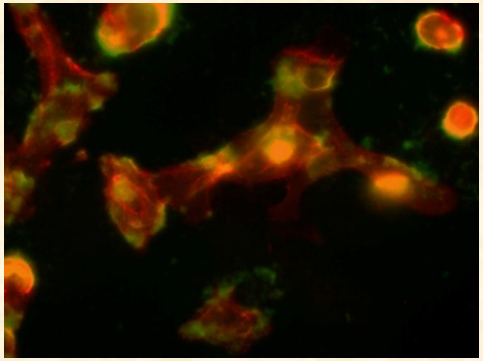
Delivering the undeliverable; cells, proteins:

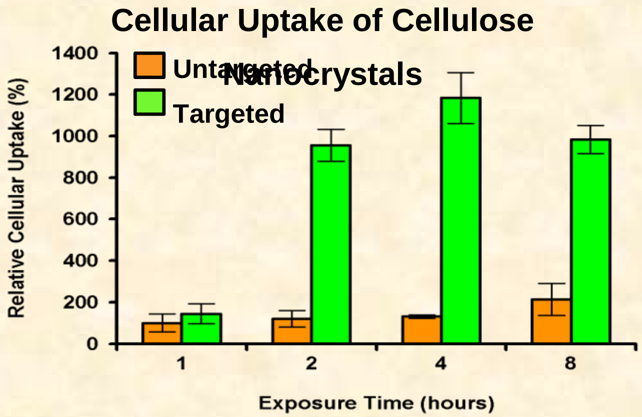
- Developed first-ever solvents for alginate (from renewable seaweed)
- Solvents help us make new alginate derivatives that make great nanogels for delivery of cells and other delicate things
- Artificial pancreas for diabetics, protein drugs for cancer; protection from immune system and effective delivery

Cellulose Nanocrystal Mediated Bioimaging and Drug Delivery

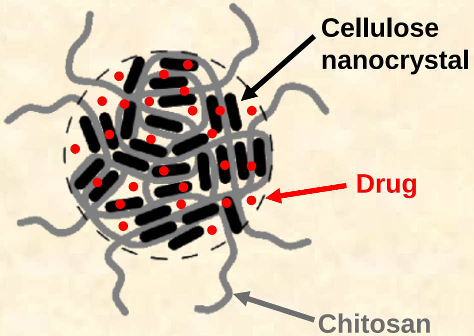


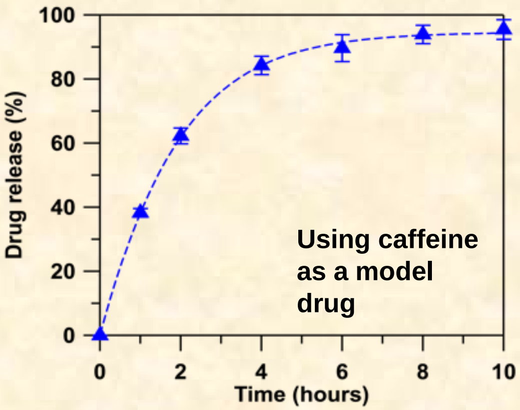
1. Targeted Intracellular Drug Delivery

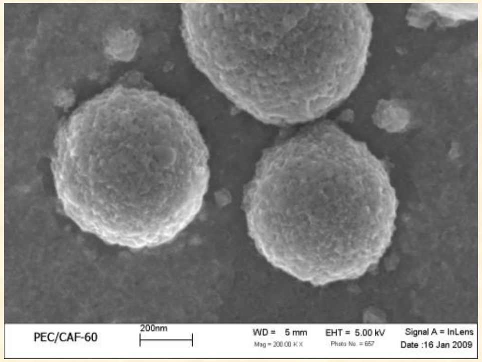




2. Oral Drug Delivery







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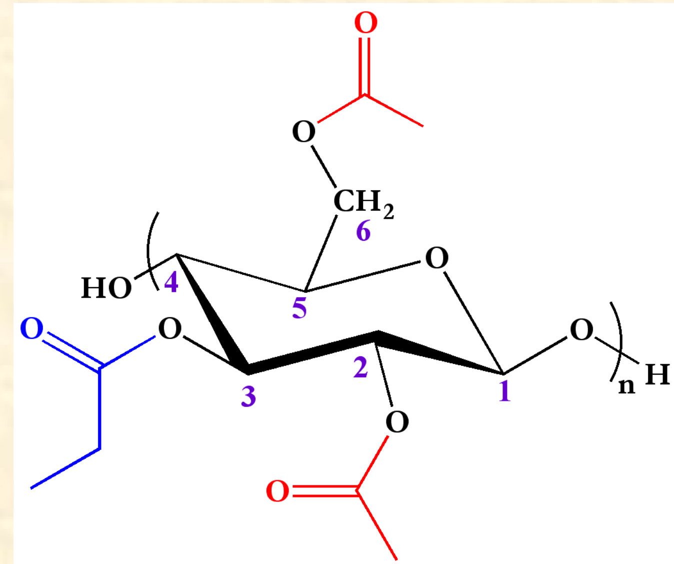
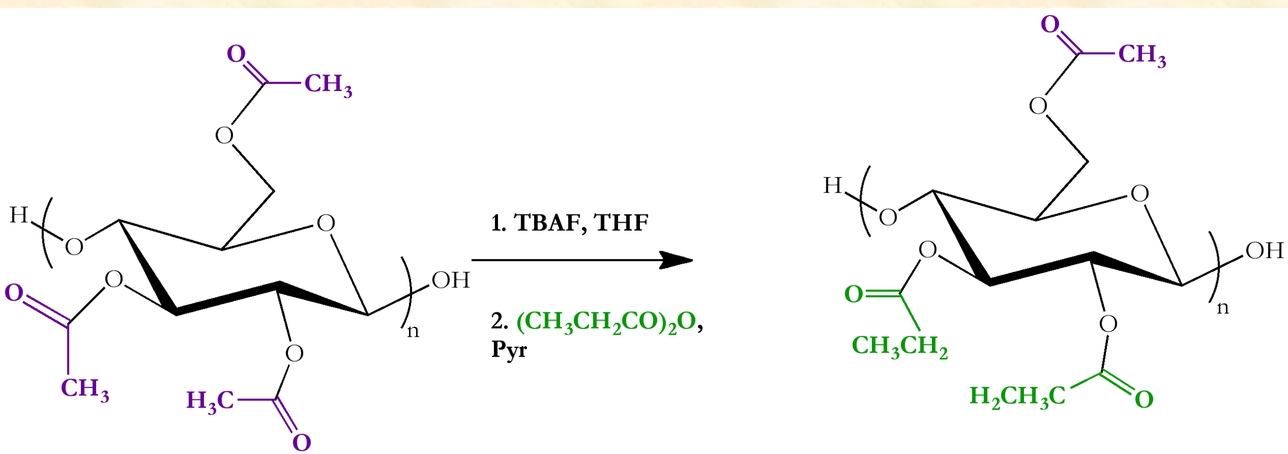
Novel, functional nanomaterials from renewable feedstocks:

Regioselective synthesis of cellulose ethers and esters

edgarresearch.org

- Regioselective substitution of polysaccharides on nanometer and subnanometer scale is VERY difficult due to their poor solubility, low OH reactivity (H-bonding, steric hindrance).
- Polysaccharide derivatives are very important economically (**e.g. flat screen displays, drug delivery, selective permeability**), end their properties depend heavily on regioselectivity
- Edgar lab is making good progress against this problem; first ever synthesis of 2,6-diesters,, 2,6-A-3-B-triesters, new process to make 6-monoesters and 23-A-6-B-triesters in 1-2 steps with no need for protecting groups.





Commercial cellulose acetate

6A23P

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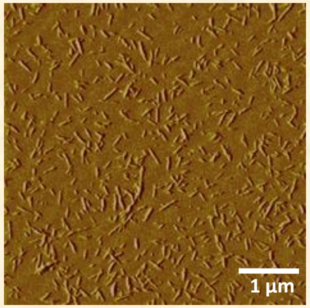
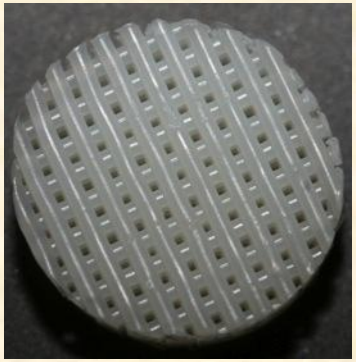
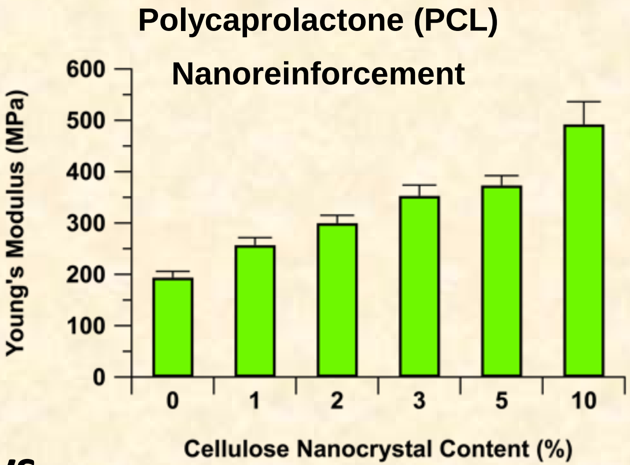
Cellulose Nanocrystal Applications in Medical Devices

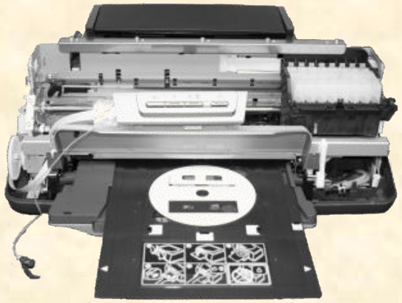


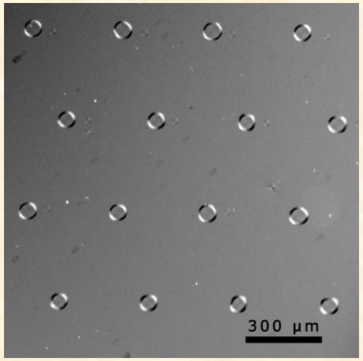
1. Cellulose Nanocomposites for Bone Scaffolds

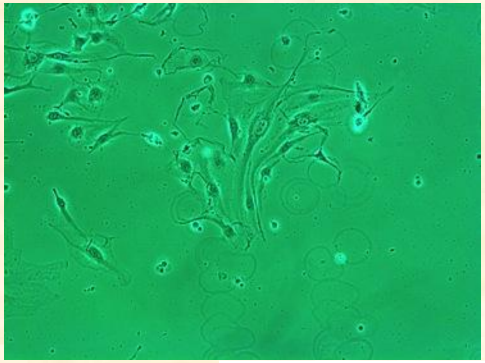




2. Inkjet Printed Micropatterns for Biological Assays







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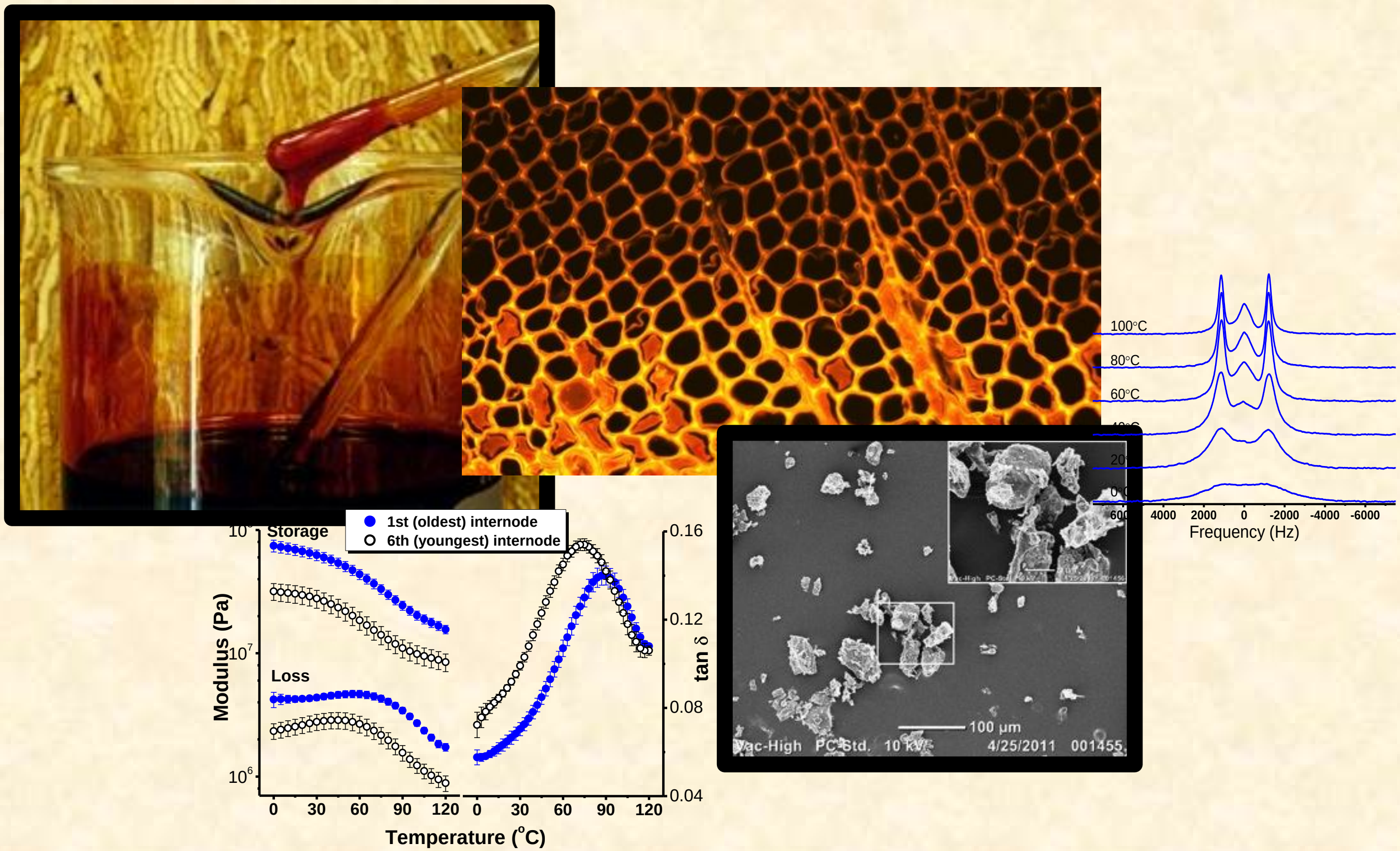
AMO Focus Area IV

Improved Strength to Weight Performance of Paper and Board: Strength Enhancement in Paper, Paperboard, and Wood Building Products

(Y. T. Kim, C. Frazier, S. Renneckar)



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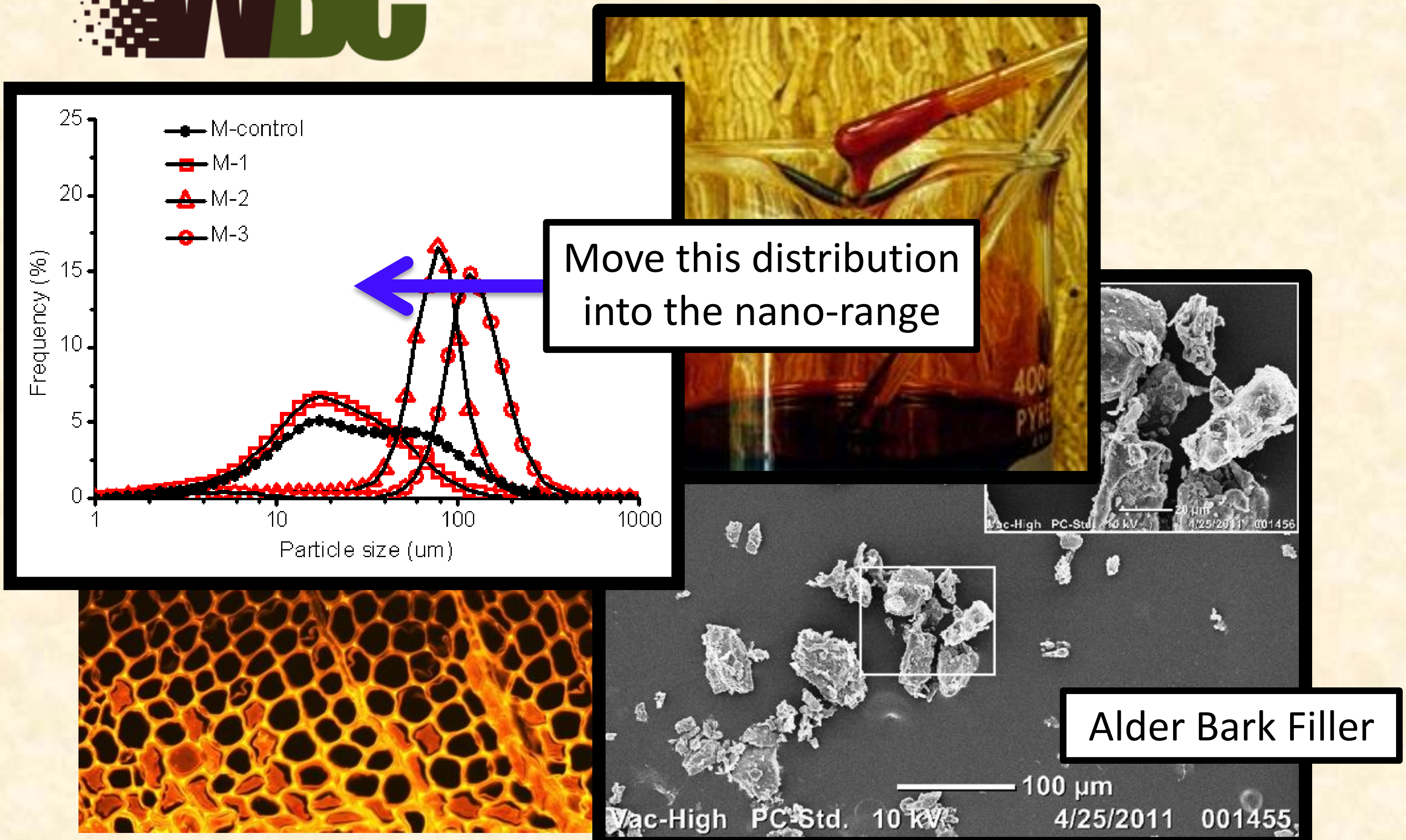
Organic fillers in phenolic adhesives:

- Benefits?
- Can they be effectively dispersed?
- Industrial cost effectiveness?

WBC



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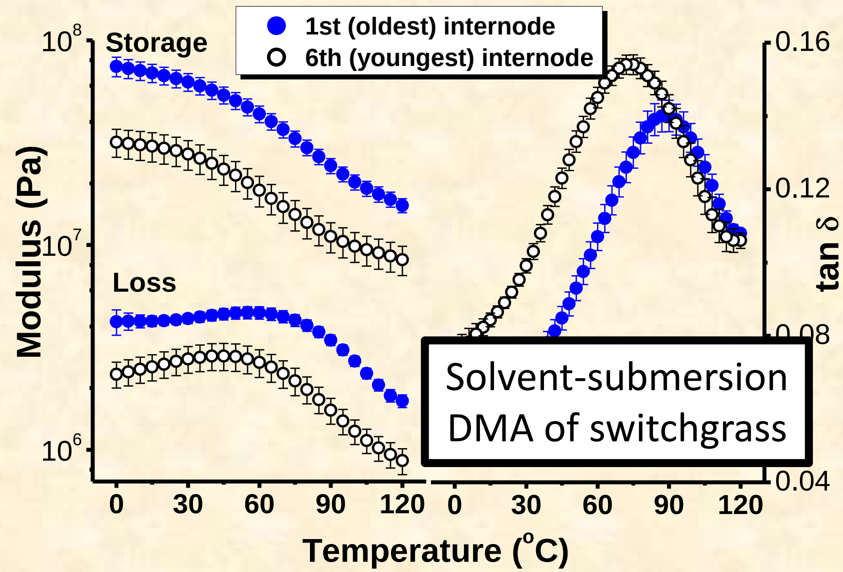
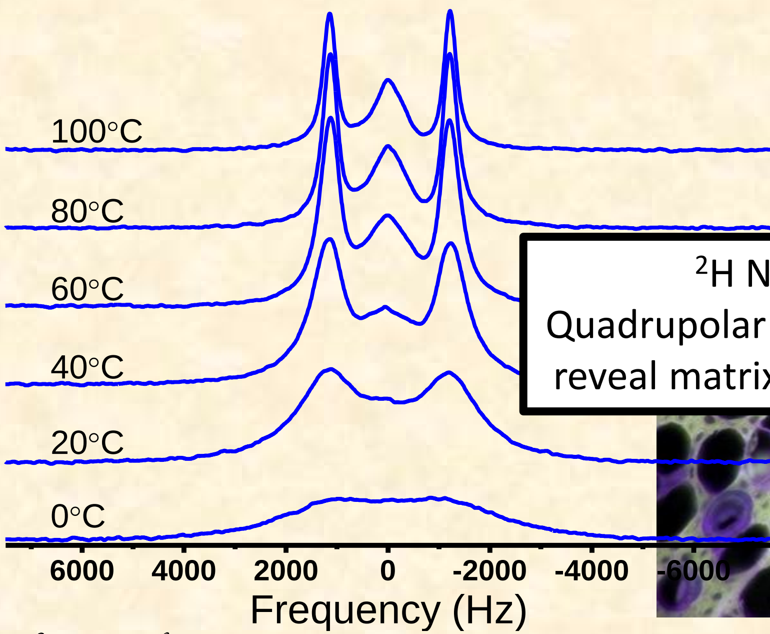
Materials science of lignocellulose: Frazier Research Group

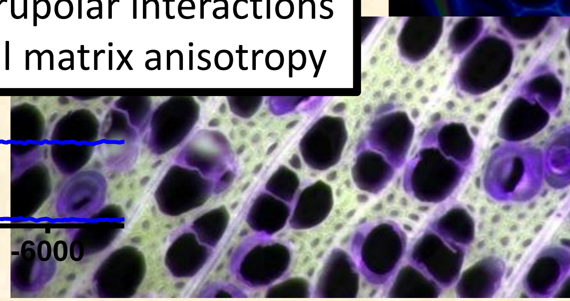
- Adhesion & renewable adhesives
- Formaldehyde generation in, and emission from, wood.
- Rheology of switchgrass and wood.
- **Novel analytical methods towards nanoscale morphological models**

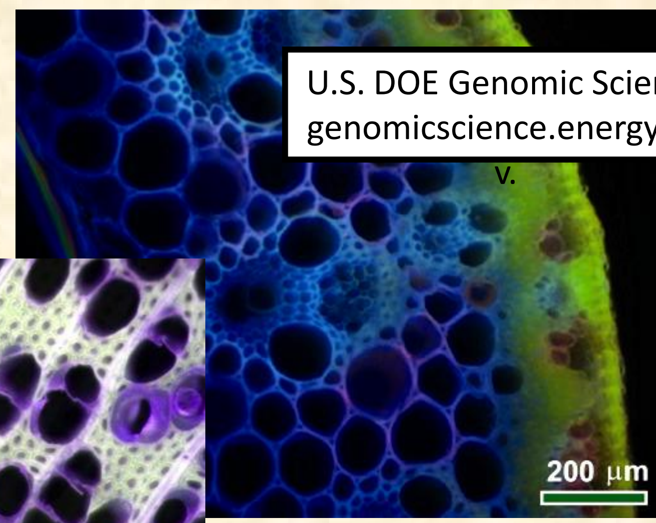


Solvent-submersion DMA of switchgrass



^{2}H NMR
Quadrupolar interactions reveal matrix anisotropy





U.S. DOE Genomic Science genomicscience.energy.gov.

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AMO Focus Area V

Understanding the Control of Water-Lignocellulosic Interaction for Modification of Properties: Barrier Packaging – Nanocoatings on Paper and Plastic Webs for Vapor Barriers

(Y. T. Kim, S. Renneckar)

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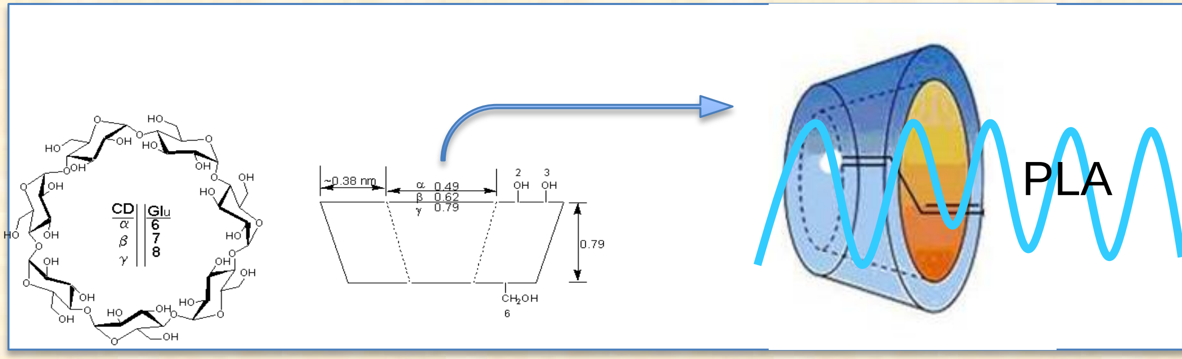
Sustainable Packaging: Barrier technologies and Inclusion technologies

- Bioplastics with included nanomaterials
- APPLICATIONS: Overcoming major drawbacks of existing bioplastics:
  - Thermal stability to Industry standards
  - Enhanced Gas Barrier Properties
  - Miscibility with many polymers

Examples technologies for enhanced Thermal Stability



ß-cyclodextrin & PLA

(cyclic oligosaccharide)

- High melting temperature (~ 290^{o}C)
- Hydrophilic exterior w/ hydrophobic central cavity
- Low miscibility with PLA, but permits the insertion of PLA (or other guest molecules) to provide a nonpolar-nonpolar inclusion-association

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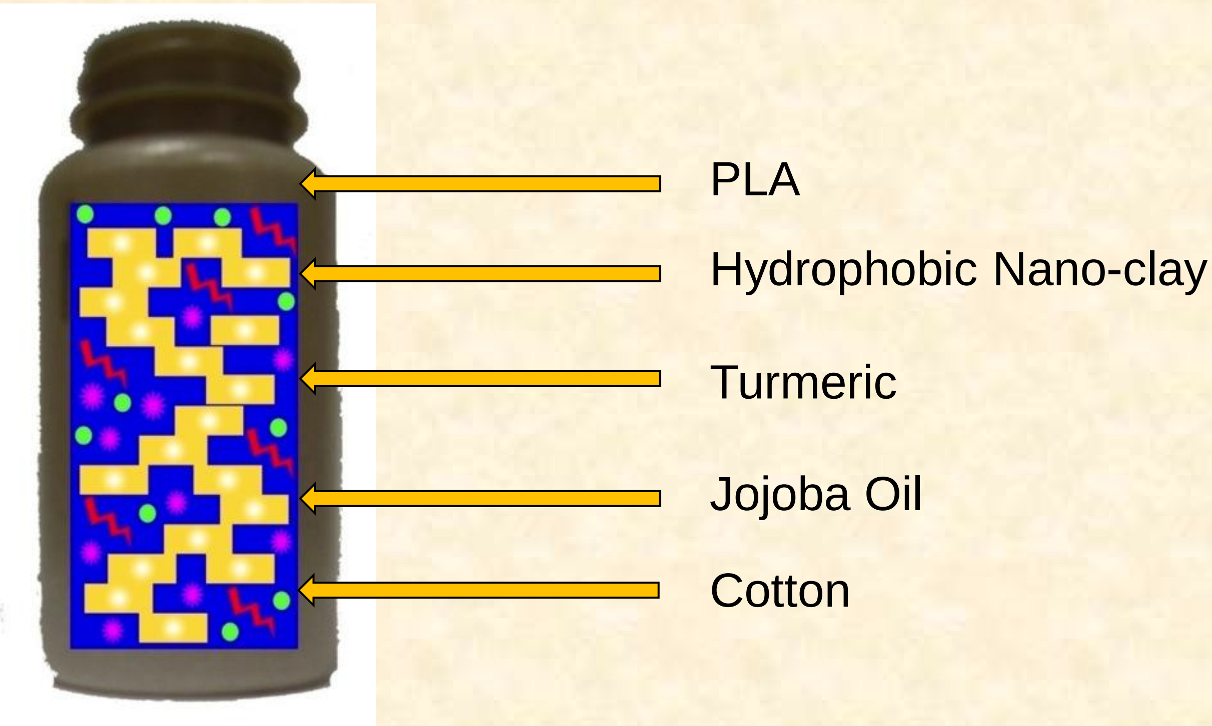
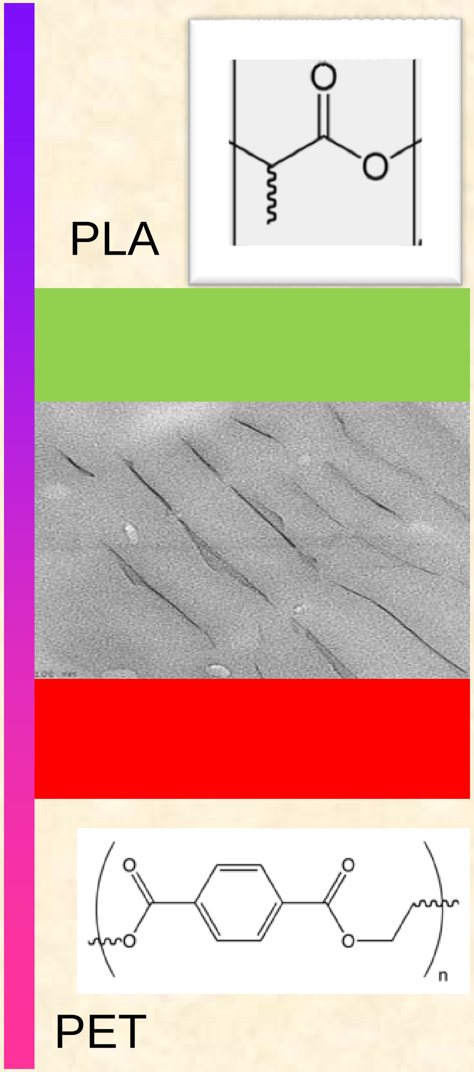
Gas Barrier Systems in Bioplastics: Y.T.Kim





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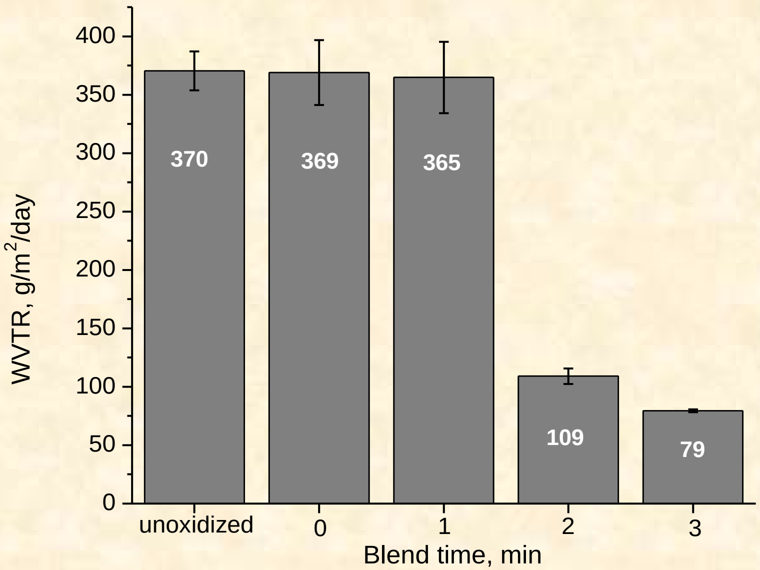
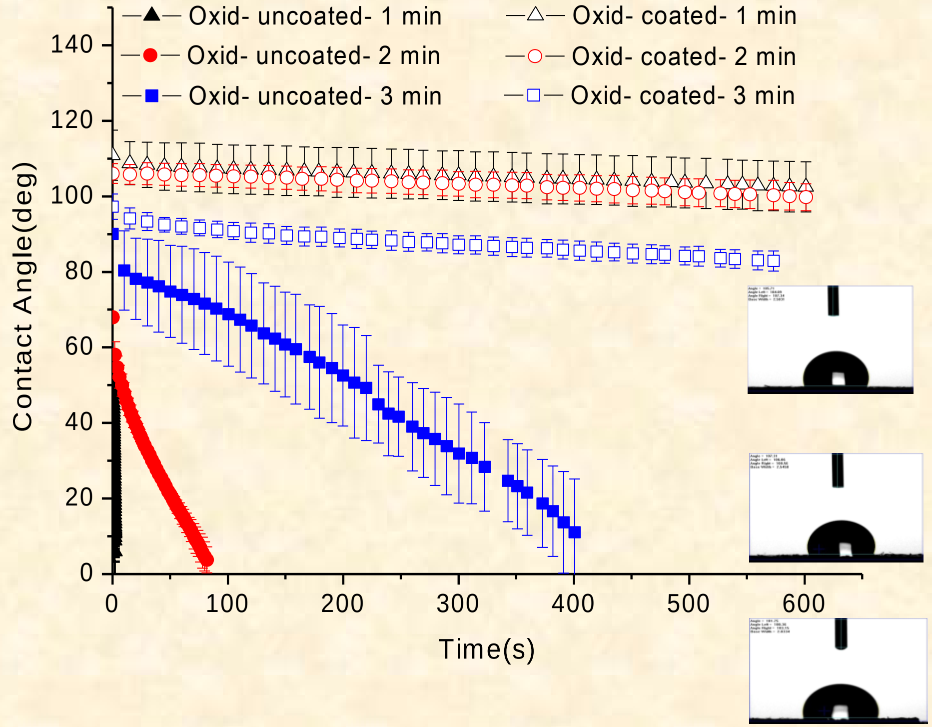
Nanocellulose Vapor Barriers and wettability modification:

Renneckar Group

Water Vapor Transmission Rate (TAPPI method)



Handsheets modified with nanocellulose



Change in wettability with handsheets modified with nanocellulose and modified with octadecylamine via ionic complexes.

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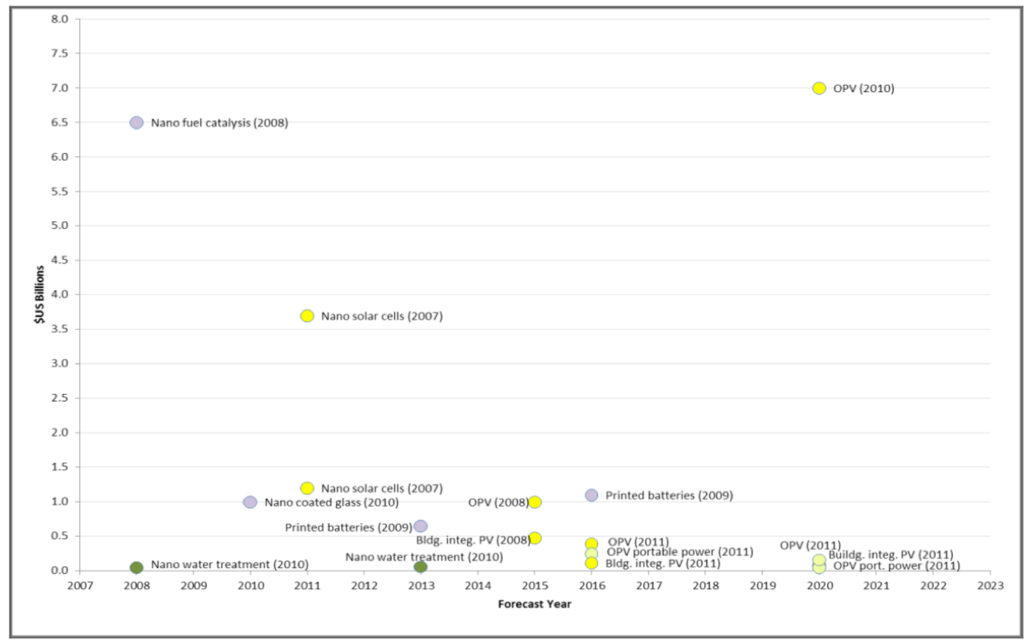
Global Economic Impact of ALL nanomaterials:

Global Market Forecast = $2.5 Trillion by 2014

Shapira and Youtie 2012. THE ECONOMIC CONTRIBUTIONS OF NANOTECHNOLOGY TO GREEN AND SUSTAINABLE GROWTH (Lux Research's 2009)

The Impact of Sustainable Nano-materials in Select "Green" Industries???: Less than **$25 Billion currently**.

Figure 1. Global Sales Forecasts – Selected "Green" Nanotechnologies



Source: Sources: Cientifica (2007); Lux Research (2007, 2010); BCC Research (2009); Global Industry Analytics (2012).

PV = Photovoltaic; OPV = Organic Photovoltaic. Year of estimate in parentheses. Color coding: Yellow = photovoltaics and solar; Green = water treatment; Purple = fuels, batteries, and materials.

Shapira and Youtie. 2012. International Symposium on Assessing the Economic Impact of Nanotechnology, Organisation for Economic Cooperation and Development and the US National Nanotechnology Initiative

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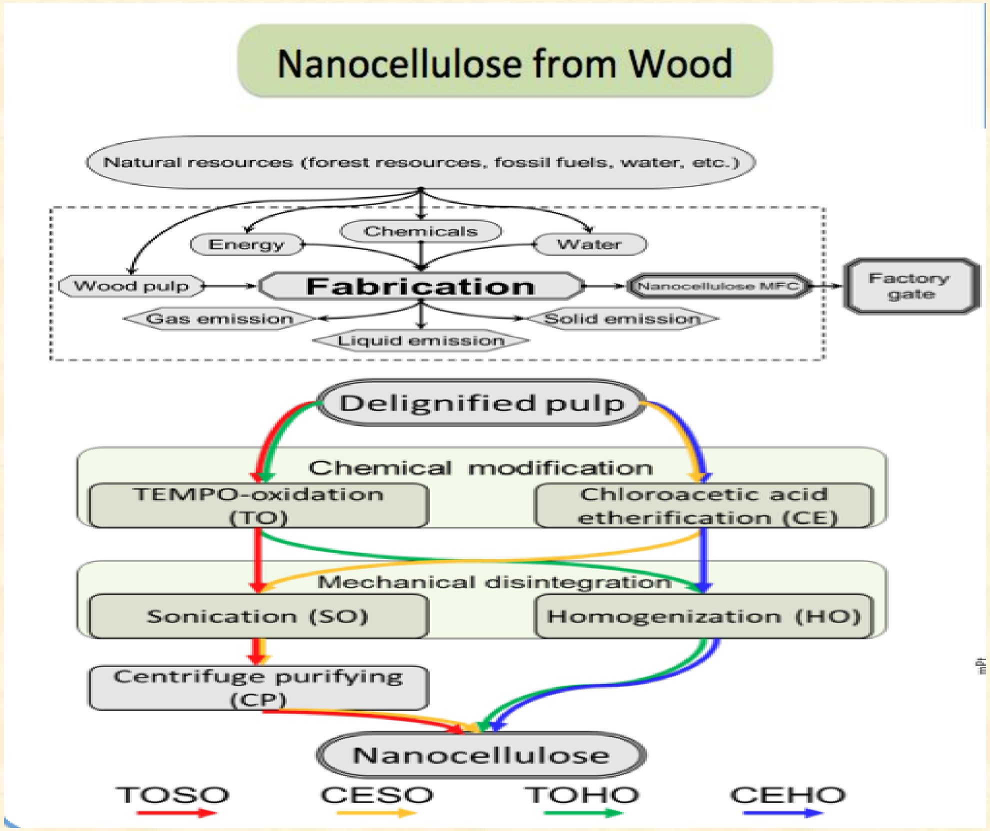
Life Cycle Assessment – A Case Study on Nanocellulose.

Renneckar Group



The big picture

- Nanocellulose fabrication presents a substantial environmental burden markup on kraft pulping process
- Energy consumption accounts for the majority of this environmental impact
- But energy consumption of its fabrication is only marginal of that of carbon nanotubes

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Commercialization of Nanomaterials: A model for the Future

The Virginia Tech Corporate Research Center

Translating Nanotechnology Research & Scholarship into Economic Growth

- **150 Businesses and Growing**
- **120 Acres - 1 million square feet of commercialization space**
- **2010 AURP Outstanding Research/Science Park**

micro act, inc.

NBE Tech, LLC.
Enabling nanomaterials

Emisshield

VirginiananoTech

BC Genesis

NANOSAFE INC.

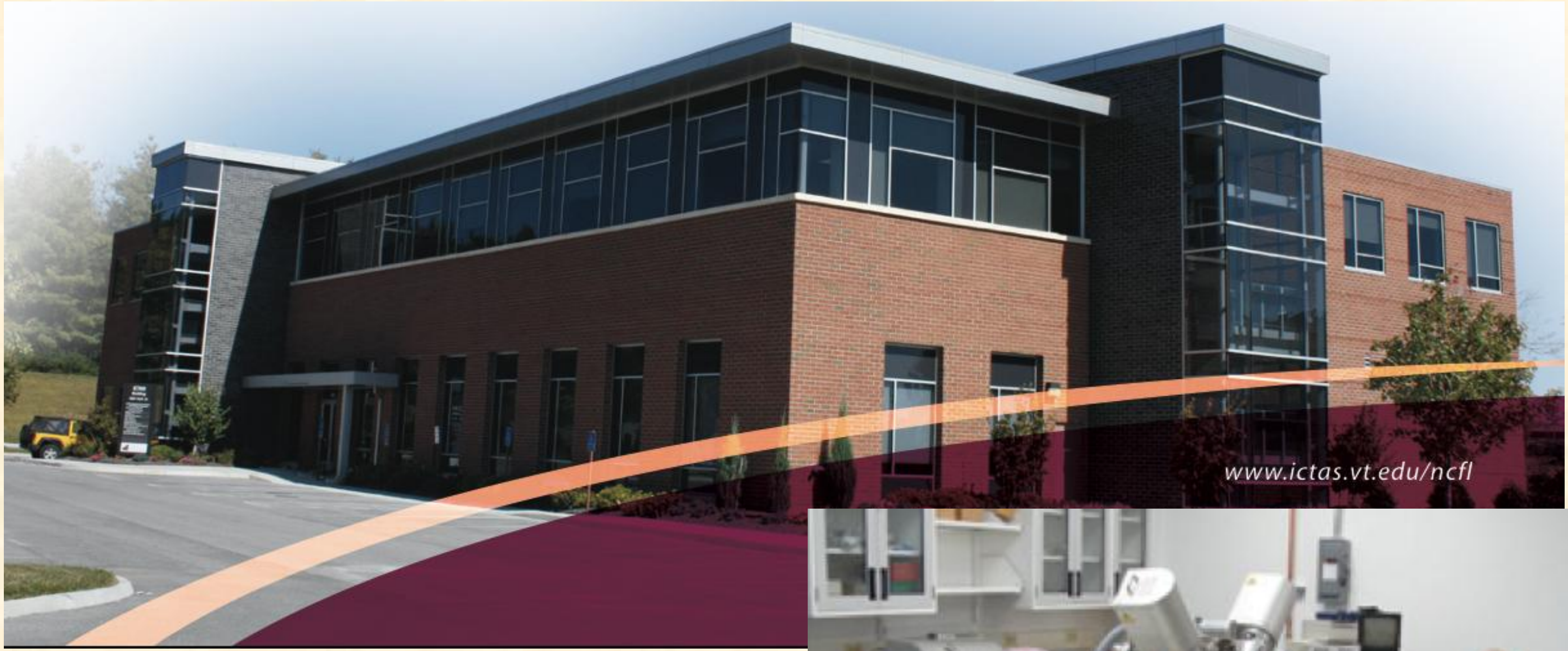
Techulon
applying science

The Department of SUSTAINABLE BIOMATERIALS

ICTAS
Institute for Critical Technology and Applied Science

1872 VirginiaTech
Invent the Future

ICTAS: Nanoscale Characterization and Fabrication Laboratory Located in the CRC-VT



The Department of SUSTAINABLE BIOMATERIALS

ICTAS Institute for Critical Technology and Applied Science

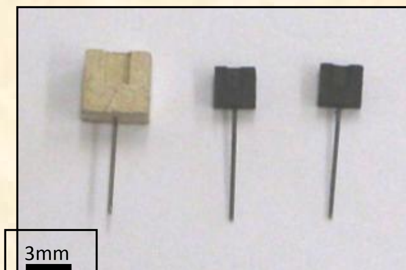
VirginiaTech Invent the Future

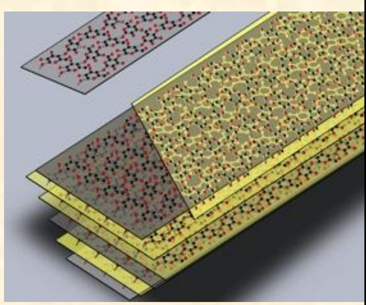
SUMMARY

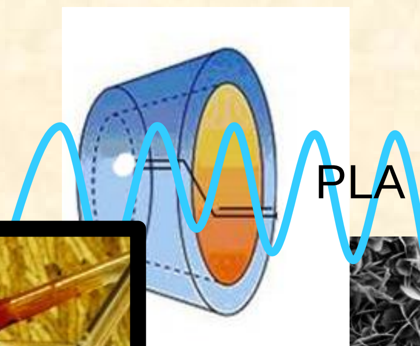
The future of Sustainable Nanomaterials
is in the Development of Ideas that we
are already advancing today
in
the field of Sustainable Biomaterials

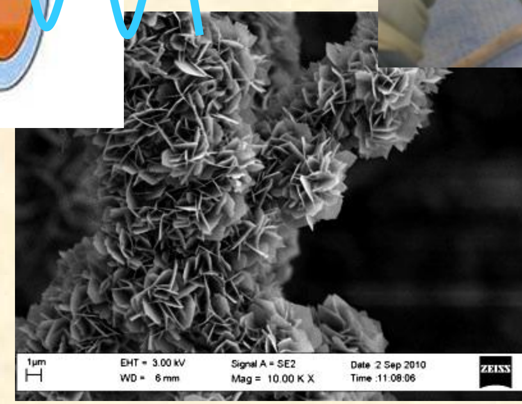
Sustainable Biomaterials contact:
www.sbio.vt.edu
goodell@vt.edu

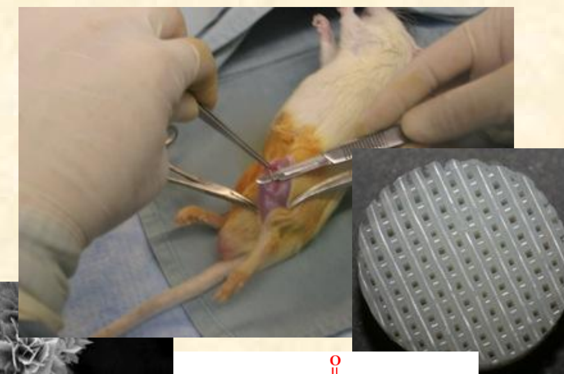
ICTAS contact:
www.ictas.vt.edu
mahull@vt.edu

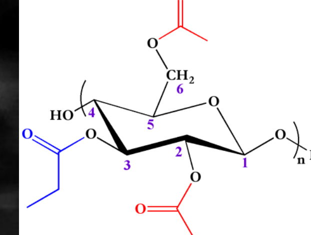












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