# TechnoBusiness Forum -- 2005 Open Innovation -- Enterprise Transformation --



Nanotechnology Innovation Directed to the Forest Products Industry Art Ragauskas – Institute of Paper Science and Technology at Georgia Tech

### Nanotechnology Innovation Directed to Forest Products Industry

What the Key Developments and Issues Are

Arthur J. Ragauskas School of Chemistry and Biochemistry Institute of Paper Science and Technology Georgia Institute of Technology

### **Basic Realities of New Millennium**

 Major forces of change will continually restructure all world economies

> Innovative method: Discover a new way to break from the market and develop new markets"

The Center for Paper B and Industry Studies

## What is Innovation?

"A change that creates a new dimension of performance" *Drucker* 

The successful exploitation of new ideas

Any new approach to designing, producing or marketing goods or services that gives the innovator/company an advantage over competitors

Innovation = Invention + Exploitation

### History of Innovation Paper Industry International Hall of Fame

#### Examples

- Charles Herty, technological contributions opened the door to the use of Southern pine as a fiber source, creating the Southern pulpwood industry.
- Dr. Mead's +40 U. S. patents used worldwide for the application of coatings on printing and writing grades of paper.
- Mr. Weyerhaeuser contributions include use of wood residuals to manufacture composite products; biomass fuels; recycled fiber for pulp and paper manufacturing.
- Mr. Kuchenbecker 79 U.S. patents in the area of package design directed toward the dairy, meat, frozen food, and other related businesses.

What's Common? What's Next????

# "The Future Ain't What It Used To Be"

### Yogi Berra New York Yankees

#### **Defining a New Nano-World and Systems Creation**

					Status: Today & Tomorrow						
S	ize	of	Struc	tures							
	0.1 m					Passive					
MACRO									NanoS	tructures	
	1 cm					In production					
	1	mm	i -	Active NanoStruc					uctures		
	0.1	1 mm						Prototypes			
MICRO	10	μm	Systems of								
						Nanosystems					
	1	μm	l		In research						
	0.1	μm	l						Molecular Nanosystems		
NANO	10	nm	i						In concept		
	1	nm	I								
	0.1	nm	I								
			1940	1960	1980	2000	2020	2040	2060		
							:			ity	NNI

### What New in Material Science Research Global Nano Technology Research 1997 2004

Potential Economic Impact in 15-20 vo							
TOTAL	~\$430M	~\$3000N					
OTHER COUNTRIES (FSU, China, Canada, Australia, others)	~\$ 70M	~\$750M					
WESTERN EUROPE	~\$125M	~\$600M					
JAPAN	~\$120M	~\$800M					
USA	~\$115M	~\$750M					

Potential Economic Impact in 15-20 years "NANO INSIDE - \$ 1 T"



Nano-Patenting Trends

The Business Review – 2003 "Small is big and it's getting bigger"



US has about 61% of NT patents - USPTO

Institute of Paper Science

Tech M and Technology

Georgia

✓ Nano-patents in the exponential phase moving into application development and the second wave of patenting

- Commercialization potential is broad multi facilitated field
- Patents may be only barrier of entrance
- ✓ Direct pulp/papermaking patents Very limited
- Associated patents are growing approximately 400 few from paper industry

What is Nano???

## What is Nano???

# What is Nano???

What is Nano???

Nanotechnologies are characterized by structural elements in the  $\sim 1 - 100$  nanometer range

1 m = 1000 mm = 1, 000, 000 μm = 1, 000, 000, 000 nm



# Behavior of Materials at the Nanoscale is NOTHING Like That at the Large Scale



#### Nanocrystalline Silver: Optical properties



The Center for Paper Business and Industry Studies Georgia Institute of Paper Science Tech∥ and Technology

### Common Day Nano - Applications BC-Applications

Nanoclay: rubber Composite

**Nano-Materials** 

Lycurgus Cup Mesopotamia 4,500 BC

✓ • Sunscreens and cosmetics

✓ Stain-free clothing and mattresses

 $\checkmark$  Aspen Aerogel Inc.: Sub nanoporous lattice materials with a very high surface area Yielding two to six times more insulating power than other commonly used materials.



Carbon Nanotubes Composite

# Nanotechnology in Forest Products Where are We - Where are We Going?

091

#### The Center for Paper Business

Georgia Institute of Paper Science Tech and Technology

### Current Nanotechnologies in Modern Pulp Mill

countries





Printing speeds continue to increase Consumer demands more/sharper colors

 ✓ Silica nanoparticles for highperformance retention/drainage providing better formation
 -Silica sol 1<sup>st</sup> generation 1980s
 -350 paper machines/25

Georgia Institute of Paper Science Tech and Technology

### Current Nanotechnologies in Modern Pulp Mill



New nano-sizing technologies to improve surface sizing

Nanoparticles – Improved coating hold out – Improved print quality



 ✓ Silica nanoparticles yielding a favorable open sheet structure for select bag applications

EKA Chemicals Inc.

16

nm

### **Hierarchical Structure of Paper**



Lignin/cellulose/hemicellulose, Cellulose crystallinity/fibrils Hydrogen Bonds, Acid-base Interactions

Fiber Wall

Fiber-wall thickness/layers, Cellulose fibril angle

Bonding between fibers and response to refining

Fiber Network

Fiber type & dimension, Propensity for fiber collapse, Curl/kinks, Fiber strength

Fiber

Paper making, refining fiber mixtures, papermaking chemicals, fillers



#### Fiber Scale

mm

# Polymer-Nanoclay Composites



The thickness of nanoclay in the composite is about 1nm.

Barrier coating for food containers and paper packages

Water and vapor resistance, fatty and oil resistance, board strength



## Polymer-Nanoclay Composites Drs. A.J. Ragauskas, Y. Deng, Z.L. Wang/GA Tech



barrier by 100%, target for waxcoated paper container

#### Nano Cellulose:Clay Composites

✓ 3% nanoclay in wax can increase

water-barrier by 50%, and gas

Relationship between barrier properties (WVTR and COBB) of waxed liner paper and nanoclay content. Wax used: Paraffin wax.

Nanoclay – Wood Composites ✓ Novel water repellency properties for OSB, MDF, PB





## NanoCoating Program



Both receding and advanced water contact angles above 150°. Surfaces with water contact angle of more than 150° may be developed only by introducing proper roughness on materials boundary having low surface energy – *Lotus Effect* 

## NanoCellulose Whiskers/Balls A.J. Ragauskas/GA Tech







Height 37.93 nm



Data type

Z range



2.50 µm 0 Amplitude Data type 0.1500 V 2 range 2.50 рм Phase 15.00 de

#### Nanocellulose Whiskers/Balls

### NanoCellulose Program

#### Cellulase **ECF Kraft Pulp**

PT





Polyacrylate

**PLA** 

#### **Research Goal: New Properties and Applications**

## Polymer - Composites Z. John Zhang/GA Tech



# **Road to Future**

# Nano Forest Products Future

#### Nanotechnology for the Forest Products Industry

Vision ••• Technology Roadmap



Contribute to the development of new markets, new high-value renewable forest products, utilizing the intrinsic manufacturing knowledge of the industry and lead in nanotechnology



Representatives from Academia, Industry, Government, and Technical
Organizations were Chartered with:
✓ Develop a vision/roadmap for nanotechnology in Forest Products Industry
✓ Identify potential applications, knowledge gaps, and research needs
✓ Foster collaboration among industry, academia, and government to fill knowledge gaps
✓ Interest federal funding in nanotechnology for the Forest Products Industry

Topic 1. Polymer Composites and Nano-Reinforced
Topic 2. Self-Assembly and Biomimicry
Topic 3. Cell Wall Nanostructure
Topic 4. Nanotechnology in Sensors and Process Control
<u>Topic 5. Analytical Methods for Nanostructure</u>





Biological Contribution ✓ Develop fundamental genetics/ biotechnology to control nanocellulose ultrastructures and properties

 Facilitate the commercialization of growing tailored bionanotubes for new applications





#### **Transmission Electron** Achromatic Microscope



Lawrence Berkeley National Laboratory **Analytical Capabilities Develop new and improved** measurement techniques to characterize nano lignocellulosics structures

#### Key Role for US National Laborate

DOE Nanoscale Science Research Centers



Time sequence of high-resolution images taken by NCEM scientist at the only existing spherical aberration-corrected microscope (Jülich, Germany) showing removal of a single atomic column at a gold surface.

Enhanced nanocharacteriz Will Accelerate Practical **Developments** 

Design and develop a new generation of Electron microscope in which the two major lens deficiencies that limit performance, when optimized should allow direct spatial resolution to 50 pm



Materials Sciences at ORNL





Center For Functional Nanomaterials at BN

Molecular Foundry at LBNI



Center for Nanoscale Materials at Argonne



Center for Integrated Nanotechnologies





**Directed Design of Nanomaterials With and From Lignocellulosics Materials** 

Engineering New Paper, New Packaging, Paper, Hygiene Properties via NanoStructures





Abstracting Nano Structures Nanocellullose balls whiskers - Nano-hemicelluloses/lignin

Particles

Biorenewable Resource
Novel Properties
Environmentally Compatible
New Composites

Active/SmartPaper

### Nanotechnology Comprises Many Very Different Issues and Research Areas that Will Impact Forest Products

Nanocoatings/Barriers: Secure Environment Packaging

- ✓ Food/Pharmaceutical
- ✓ Electronics
- ✓ Defense

29

Homeland Security

- Tamper proof
- Counterfeit resistance
- Security Paper/Branding

Provide controllable inner environment for packages: - CO<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>

Defense systems for bacterial/fungus growth - Passive - Active

- Spoilage/Flavor Control
- Long Term Storage
- Spoilage Indicators
- New biocomposite packaging materials

# Nanobiofunctional Fibers

Bacteriophage Structure



Bacteriophage are virus and the legs are used to bind to assorted hosts – 10<sup>9</sup> different binding codes... could provide genetic code to provide Innovative Wet/Dry Strength Aids Functional Tissue/Towel



Enzyme grafted paper/fibers - Improved food packaging - storage - odor control - flavor control

- Biosensors

- Integrated hygiene applications



**Operations Opportunities** 



Pulping/Bleaching Catalysts Improved Drying Reduced re-wet Reduced Corrosi





Georgia Institute of Paper Science Tech∥ and Technology

The Center for Paper Business

Nanotechnology Comprises Many Very Different Issues and Research Areas that Will Impact Pulp and Paper





 Directed self assembling nanocoatings

 Improved gloss/printing
 Reduced capital cost
 New products including.



- R<sub>f</sub> version of thermal paper
 - Integration of advanced digital electronics into paper

New felts with revolutionary sheet formation capabilities> No rew
Elimination of hornification
On demand hydrophobic/hydrophilic paper



a below aron't DKA agis they're almost ry, A D6(A helix is about ) etal strucch are at least out which we like a set in the te a burnan hair's 6.000 cm diameter

plu that they the anosprings" could do no housy lifting in firm

ers, says 2kning When or of Georgia Institute Inology's Canaor for arsotechnology. Made from sine oxide, the oing they can transform

er namosaile ould then a sign ton perturbed by minute

with an oth

Nanotechnology Workshop – Top Ten Research Needs/Opportunities

#### Sensors



#### Li Shi/UT Austin

✓ Tampering Detection ✓ Health Diagnostics Pathogen Detection



✓ Security Features OLED

Piezolectric Nanosprings for Ultrasensitive Measurements of Pressure and Flow Rates (Z.L. Wang, MSE, Georgia Tech

(Z.L. Wang, MSE, Georgia Tech)



SEI 883 kw/h Lumen is a Beautiful Place!!!!

NSF/USDA/AFPA Sponsored Workshop – September 22/23, 2005 Defining the Opportunities, Challenges, and Research Needs for NanoBiomaterials Derived from Lignocellulosics/IPST@GT

**Program Objective:** 

Examine how recent advances in nanoscience and engineering can be employed lignocellulosics

Identify new and important opportunities for nanoscale lignocellulosics as structural and nonstructural materials

Identify fundamental research and development challenges, knowledge gaps, and research needs related to nanoscale lignocellulosics as structural and nonstructural materials **Consumer Demand** 

Value Added

Products

8

Materials

### Where Is This All Going?

Government

"Give me a lever, a fulcrum, and place to stand and I will move the world."

Archimedes ~200 BC Leveraging: Research and Development

# Partnership Industry, Universities, More Relevant Today!!!

Societal Demand for Carbon Neutral, Environmentally Friendly, Renewable and Sustainable Manufacturing Technologies

**Forest Products Community Innovative Products** "Nano-Inside"

Georgia Institute of Paper Science



### It is not necessary to change

'But'

#### Survival is not mandatory

#### W. Edward Deming

arthur.ragauskas@ipst.gatech.edu

ragauskas@hotmail.com