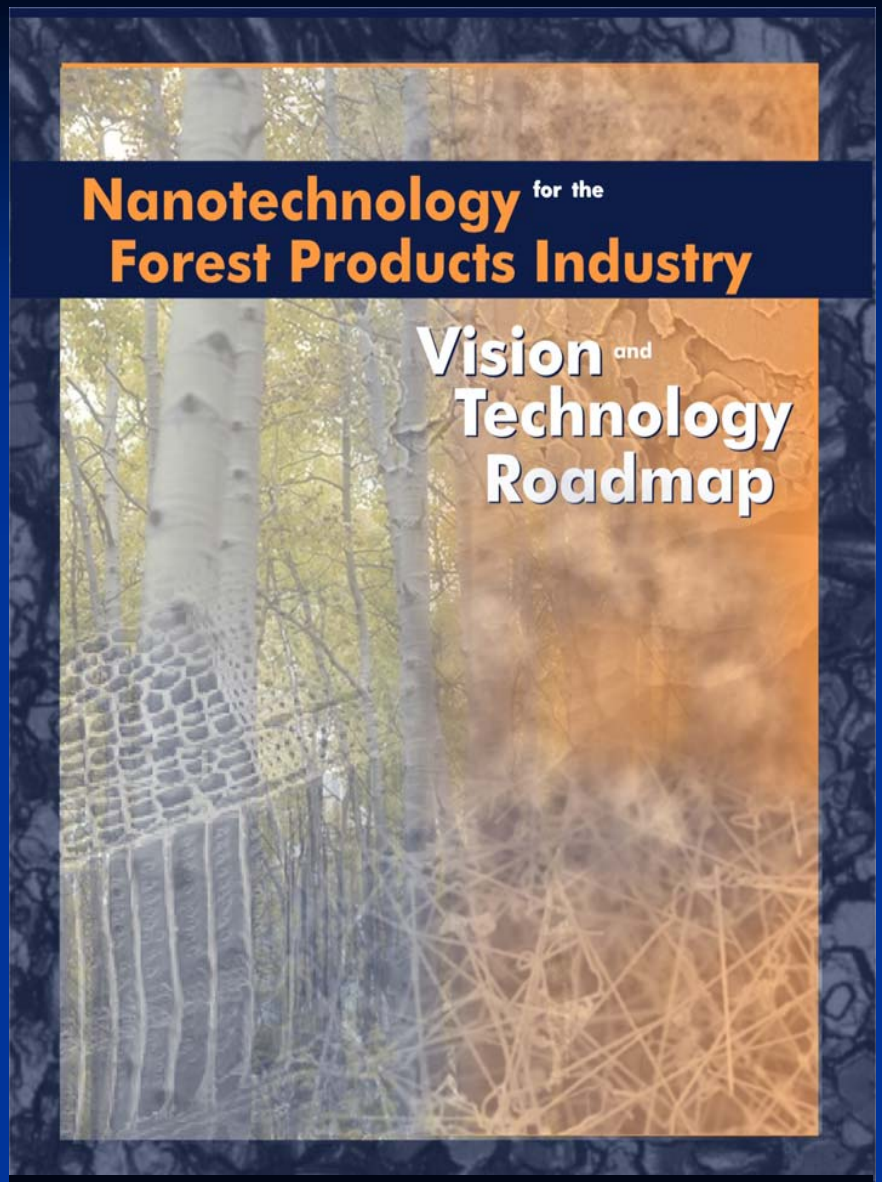


www.nanotechforest.org

www.fpl.fs.fed.us

www.tappi.org

Nanotechnology for the US Forest Products Industry

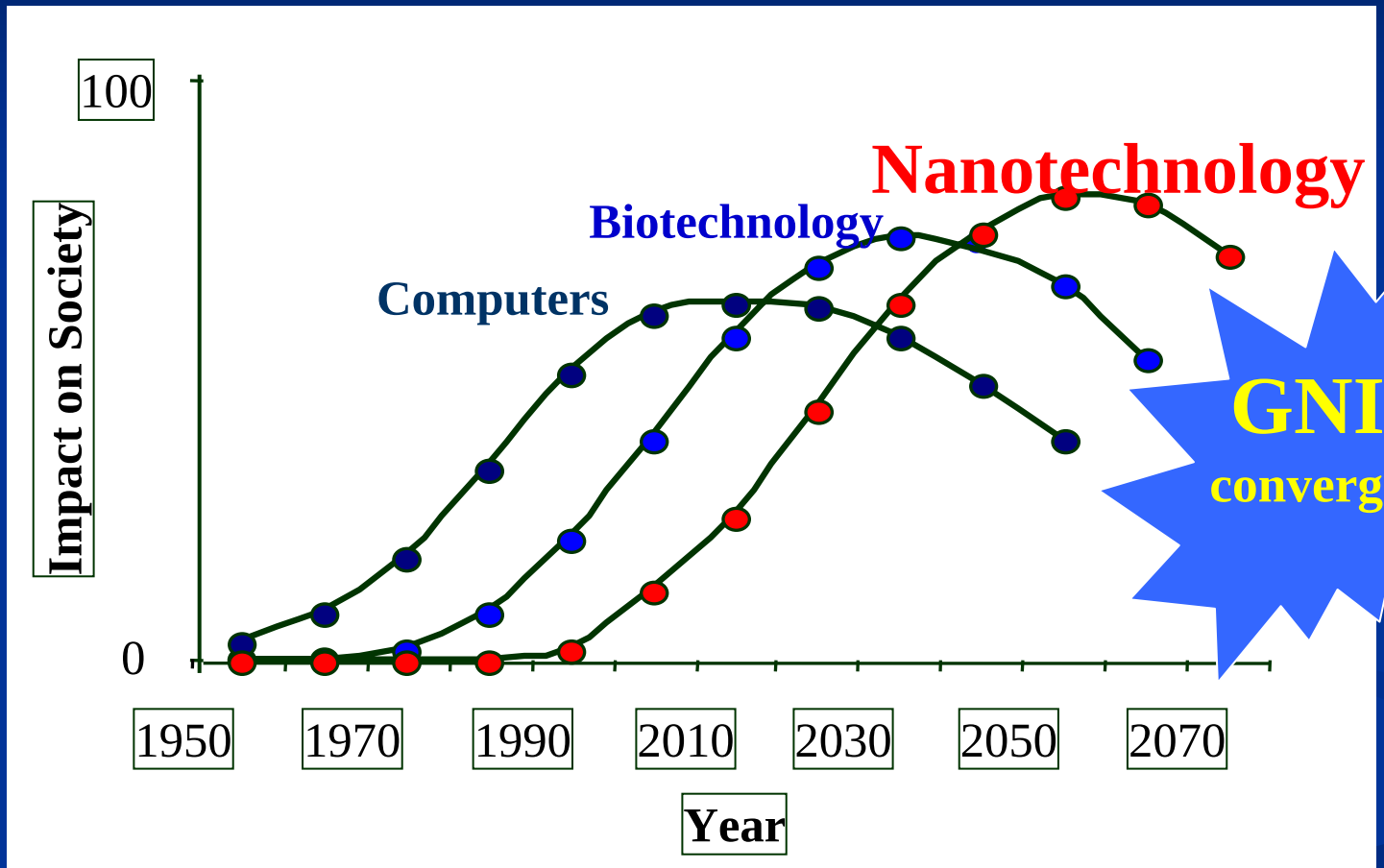
Agenda 2020 Program

Dan Coughlin
SAPPI Fine Paper
Phil Jones
IMERYS
Ted Wegner
USDA Forest Products Laboratory

May 2006

Nanotechnology,
"The Next Industrial Revolution"

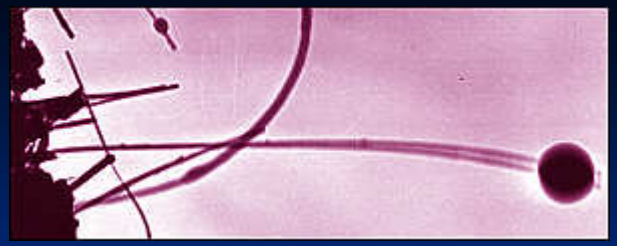
Dr. R. Siegel,



Nanotechnology: 1 to 100 nm

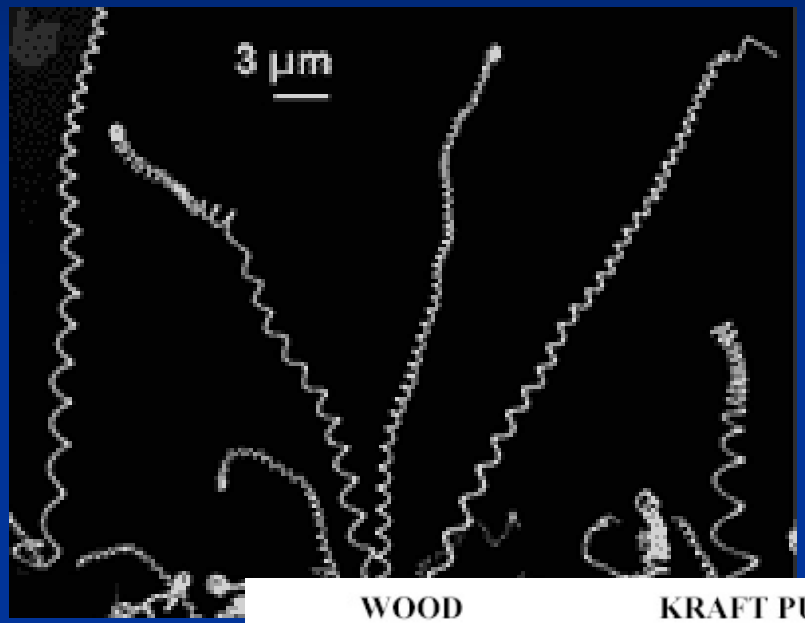
1nm Quantum ⟷ 100nm Bulk

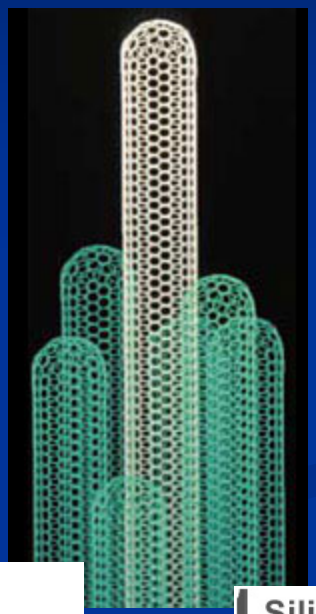
Genome
Information/ Computers
Nano

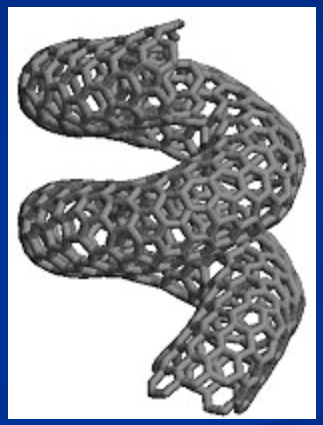


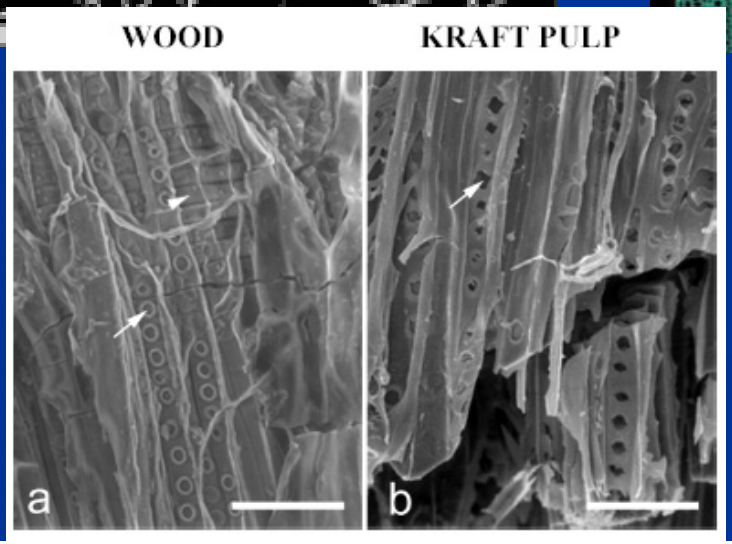
Soot :

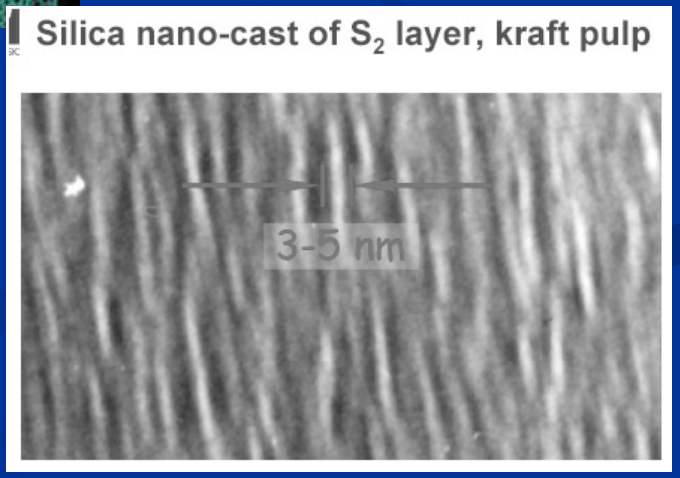
Contains Value





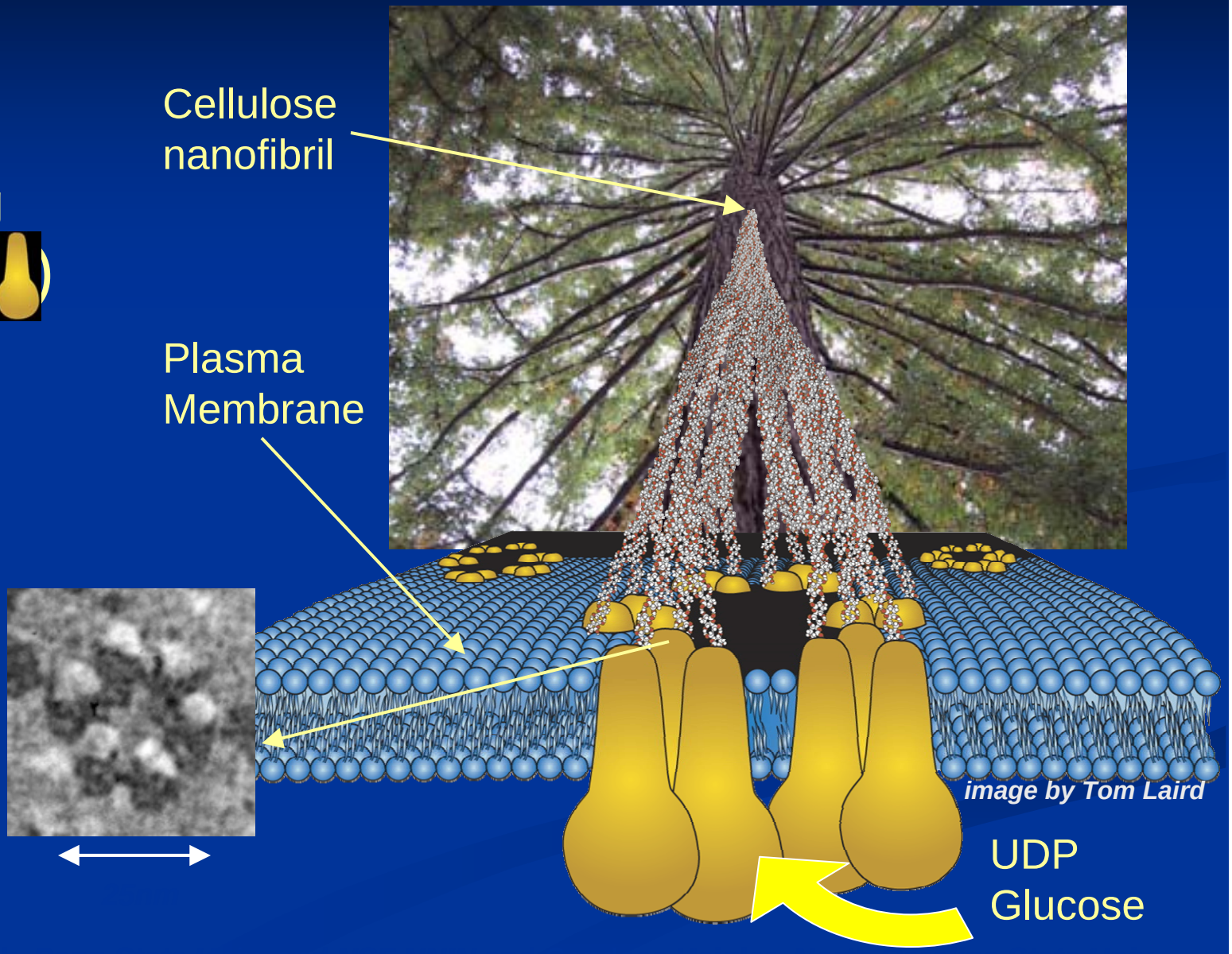


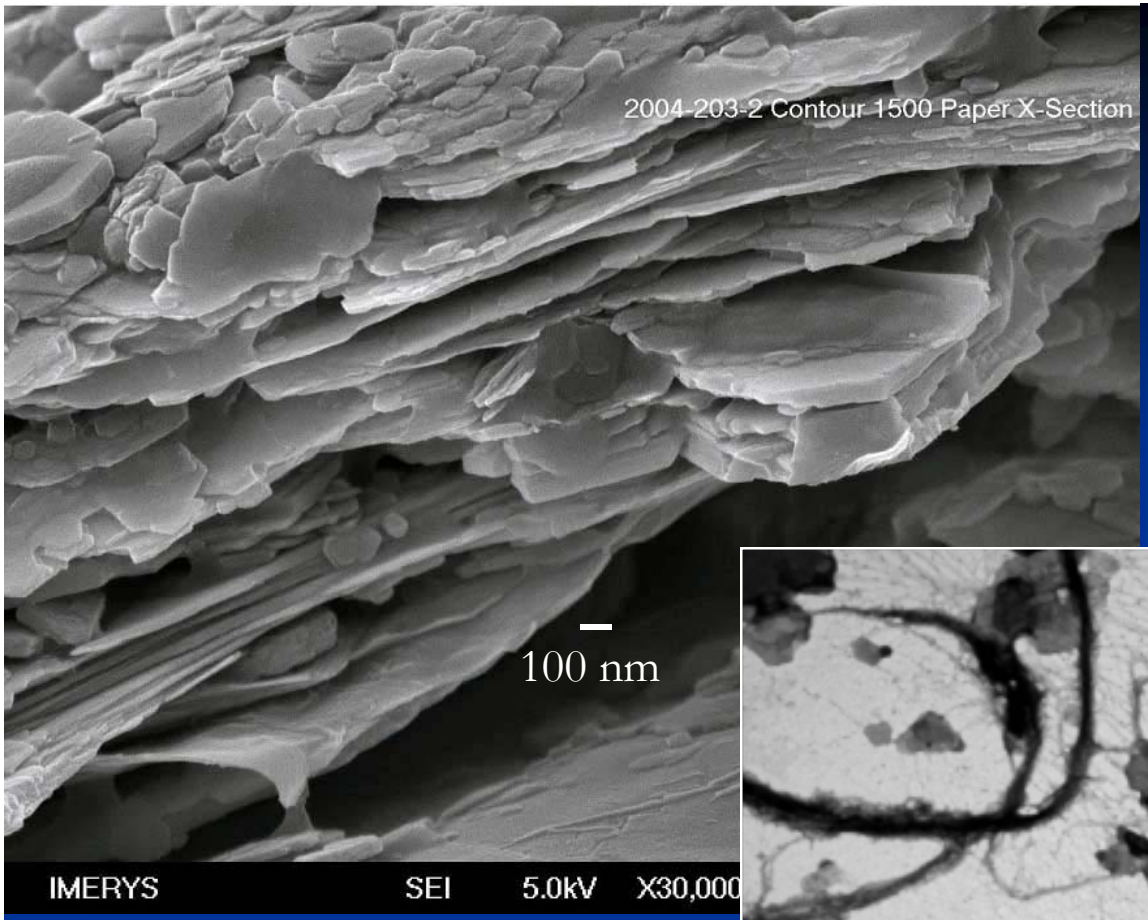




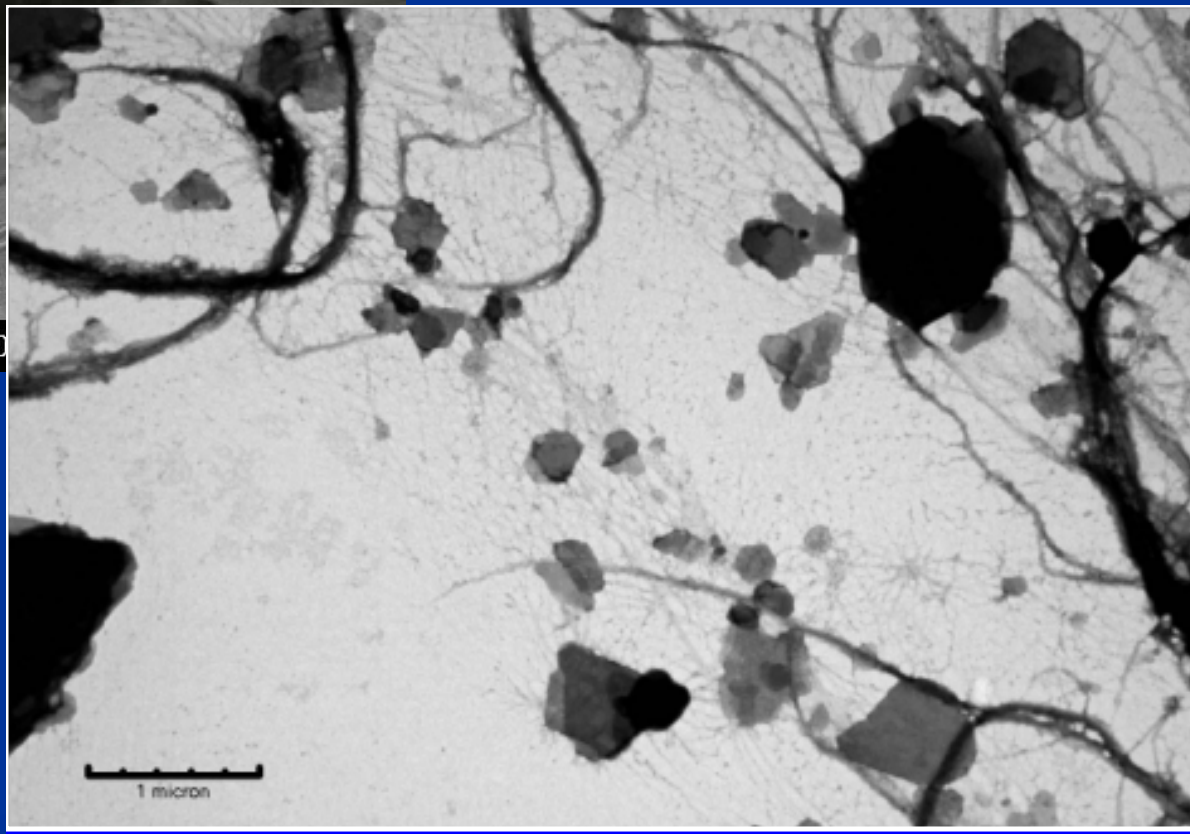
Cellulose Synthase Proteins: Nature's Molecular Assembly Machines

Cellulose producing proteins ( ) forming a 'rosette'





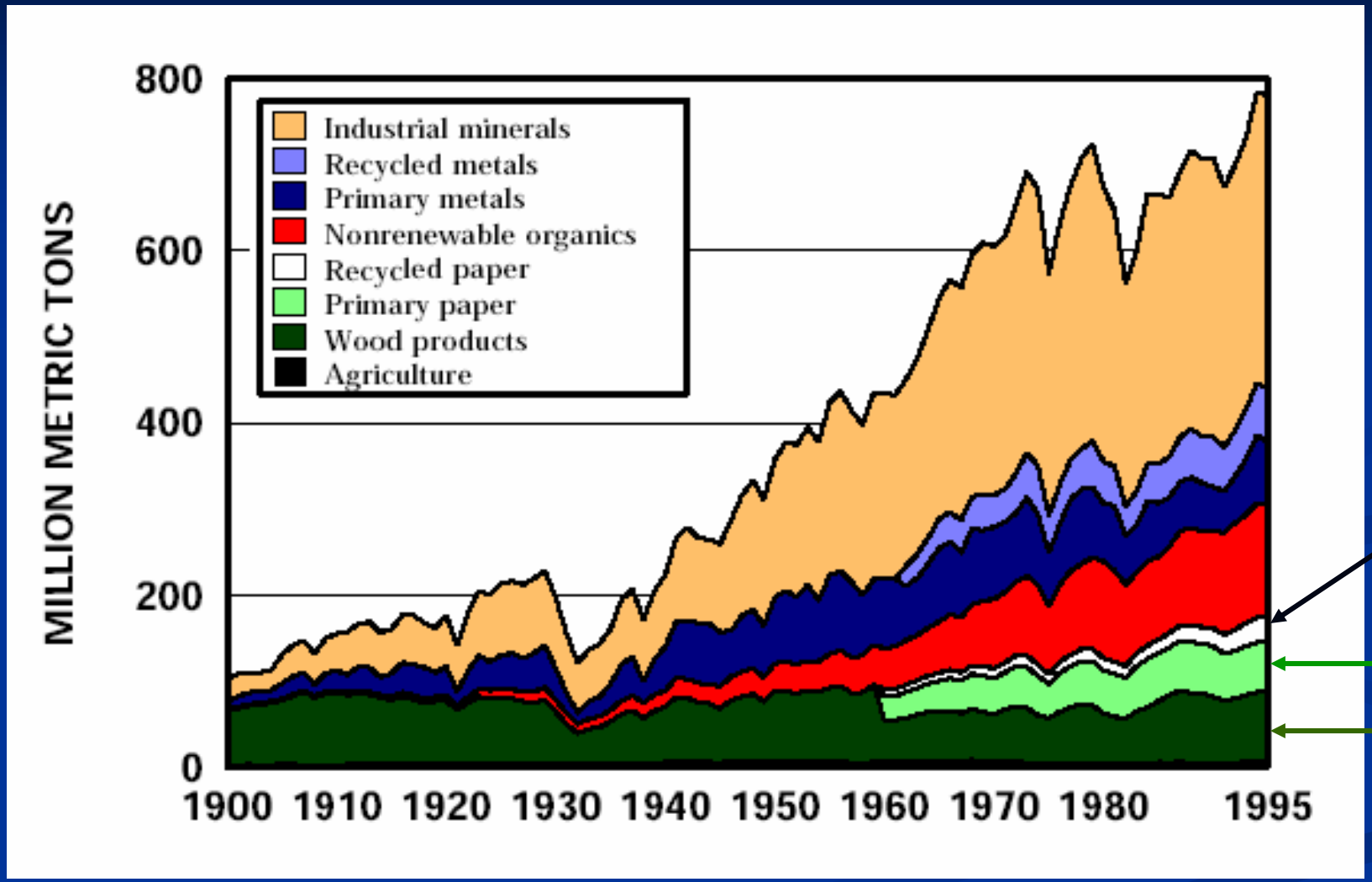
Nano-Dimensions: Coating Clay



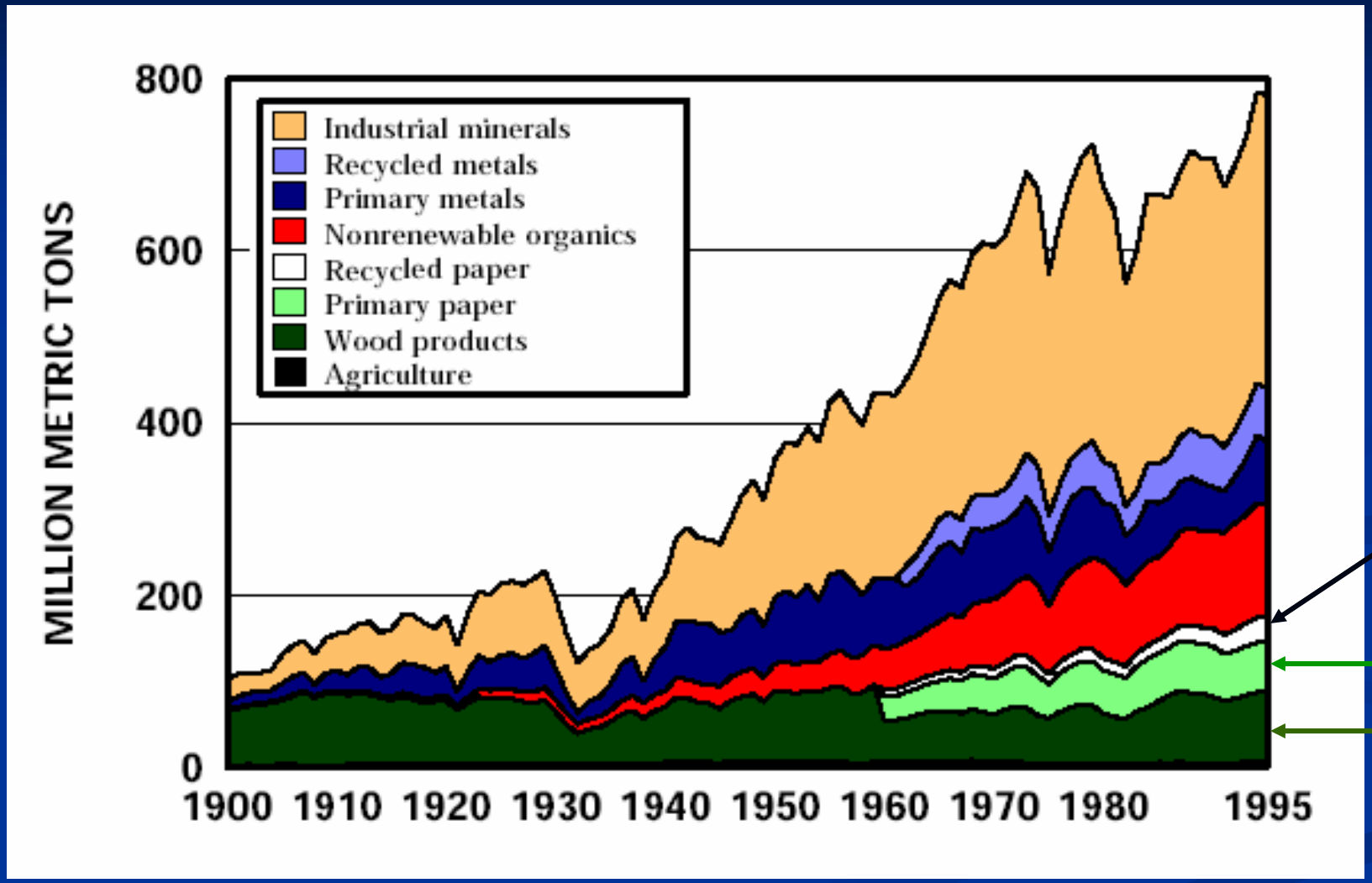
Source McNeal & Nanko & 2003

Nano-Fibrils

Use of Materials in US 1995



Use of Materials in US 1995



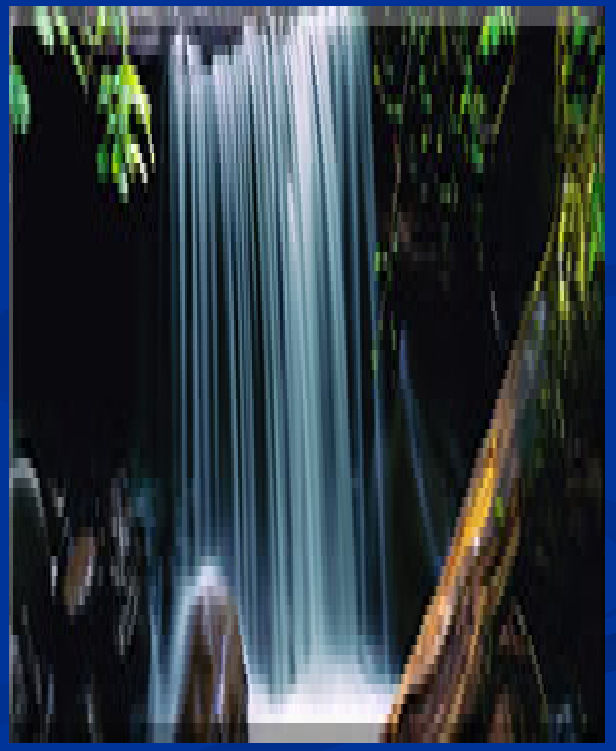
Move to Green Chemistry

Green Movement

Environmental Footprints

Dematerialization

Green Energy



12 Principles of Green Chemistry; after Anastas & Warner 1998

1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.

2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.

3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity

4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting.

5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions.

6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible.

7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials.

8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals.

9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.

10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances

11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses

12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents .

EPA

"Nanotechnology Research Needs for Environmental Applications

Green Manufacturing Research Needs

Nanotechnology offers the possibility of changing manufacturing processes in at least two ways:

(1) using less materials

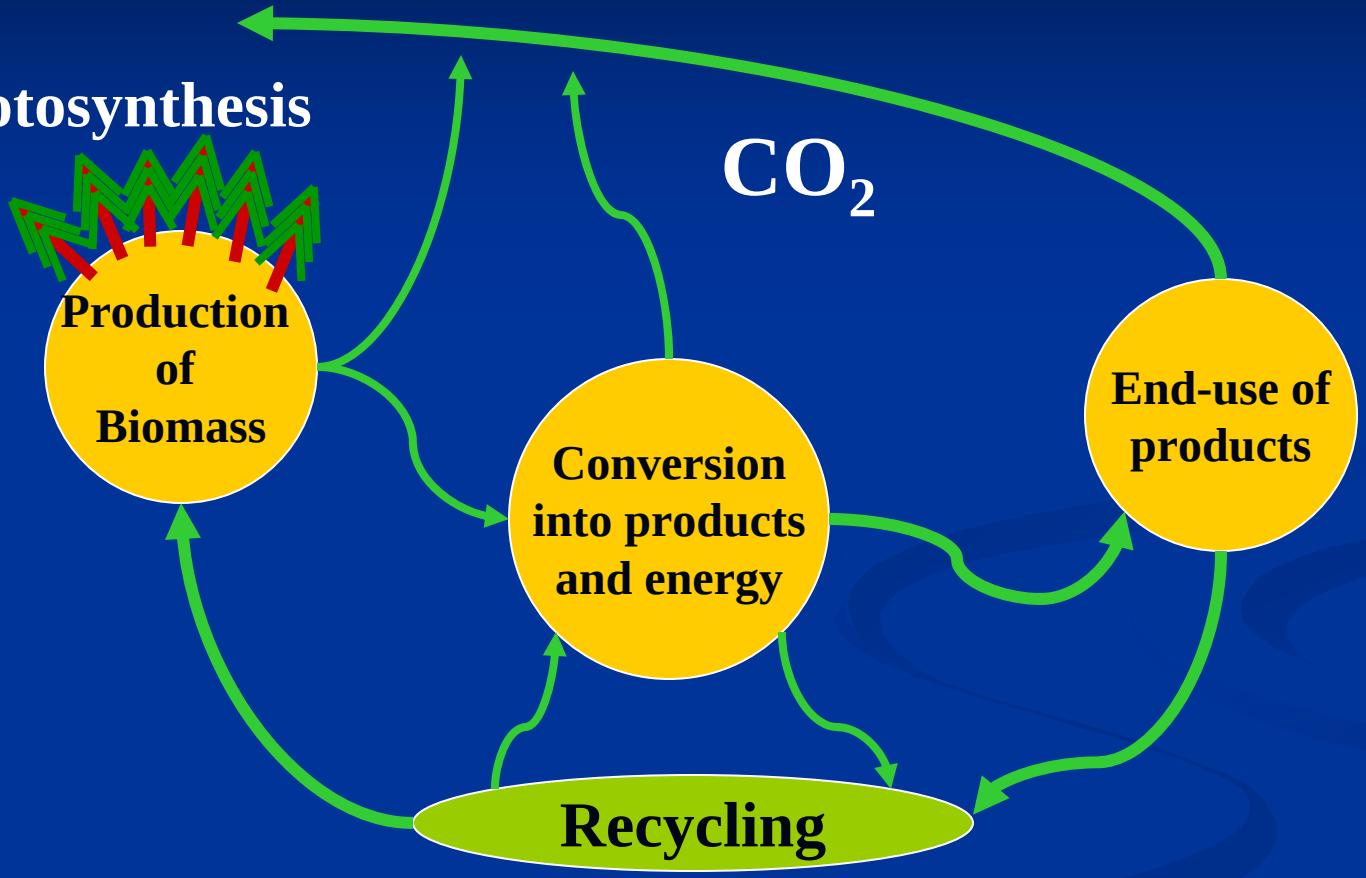
(2) using nanomaterials for catalysts and separations to increase efficiency in current manufacturing processes.

Nano-material and nano-product manufacturing offers the opportunity to employ the principles of green chemistry and engineering to prevent pollution from currently known harmful chemicals.
Research enabling this bottom-up manufacturing of chemicals and materials is one of the most important areas in pollution prevention in the long term. Research questions regarding green manufacturing include:

- How can nanotechnology be used to reduce waste products during manufacturing?
- How can nanomaterials be made using benign starting materials?
- How can nanotechnology be used to reduce the resources needed for manufacturing (both materials and energy)?
- What is the life cycle of various types of nanomaterials and nano-products under a variety of manufacturing and environmental conditions?"

Source: EPA Nanotechnology White Paper 2005

The Forest-based sector -- a closed carbon cycle



"Sunshine & Dirt"

Source: European Forest Technology Platforms 2006

Forest Products Nanotechnology & Science Collaboration

- TAPPI
- PIMA
- AF&PA
- SWST
- FPS
- Other Associations
  - ASME
  - MRS
  - AIChE
  - ACS
- PPERA
- Government Agencies
  - NSF
  - DOD
  - USDA
  - DOE
  - Homeland Security
  - Bureau of Engraving & Printing
- NSF Nano-centers
- National Labs
- Sentinel (Canada)

Agenda 2020 Focus for the Future

Meeting the Challenge of Deployment

Positively Impacting the Environment

- *Significant Reduction in Greenhouse Gases*
- *Decreased Ecological Footprint*

O_2 CO_2

Next Generation Fiber Recovery and Utilization

- ***Recycled Fiber Indistinguishable from Virgin Fiber***

Advancing the Forest "Bio-refinery"

- ***Sustainable Forest Productivity***
- ***Extracting Value prior to Pulping***
- ***New Value from Residuals & Spent Liquors***

Breakthrough Mfg. Technologies

- ***Major Manufacturing Cost/Capital Reduction***
- ***Significant Enhancement in Product Properties with Existing Assets***
- ***Substantial Improvement in Energy Efficiency for Existing Processes***

Advancing the Wood Products Revolution

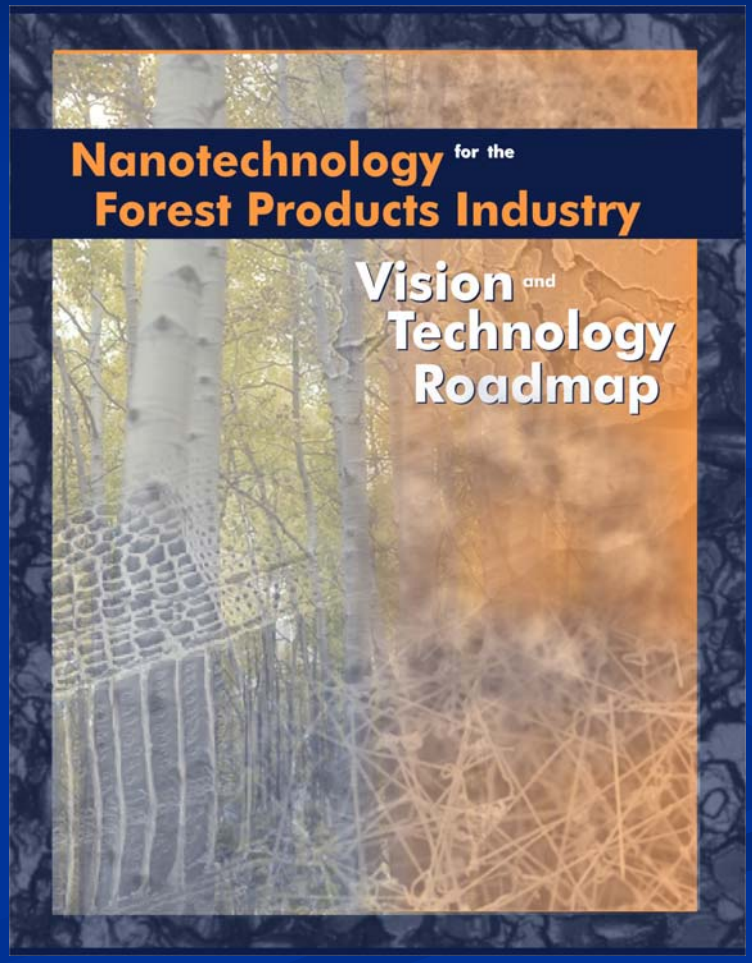
- *Improved Building Systems*
- *Reduced System Costs*

Technologically Advanced Workforce

- ***From Workforce to Knowledge Workers in 7 years***

Nanotechnology Workshop

- Held October 17 – 19, 2004
- Attendance – 112
  - Industry – 31
  - Academia – 37
  - Government – 28
  - NGOs – 4
  - Misc. - 12



2006 INTERNATIONAL CONFERENCE ON NANOTECHNOLOGY FOR THE FOREST PRODUCTS INDUSTRY

April 26 – 28, 2006
Atlanta, Georgia

Attendance 180+

National Science Foundation · USDA CSREES Education Research Extension · Agenda 2020 Technology Alliance · West Virginia University · University of Alaska Fairbanks Sitka Forest Products Program · Forest Service US Department of Agriculture · sappi · TAPPI people resources solutions

Opportunities for Forest Products

- *Sequestration of sulfur*
- *Wood as a source of nano materials*
- *Water use and reduction/removal*
- *Hygro-expansivity control*
- *Improved performance by weight*

Key Themes of Agenda 2020

Advancing the Forest Biorefinery

- Separation of Wood into Fundamental Constituents

Breakthrough Manufacturing

- Next Generation Pulping & Bleaching
- Reduced Energy in Paper Dewatering / Drying
- Sheet Properties with Less Energy and Materials
- Increased Filler
- Reduced Energy for Causticizing
- Reduced Energy for Black Liquor Concentration

Advancing the Wood Products Revolution

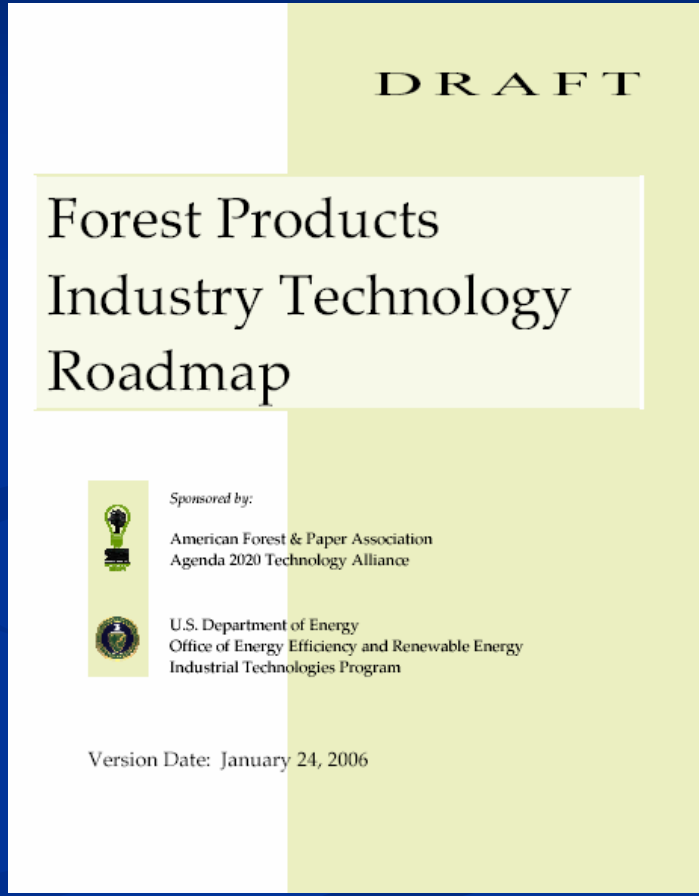
- Reduced Manufacturing Cost of Wood Products
- Improved Wood-Based Building Materials
- Integrated Wood-Based Building Systems

Next Generation Fiber Recovery & Utilization

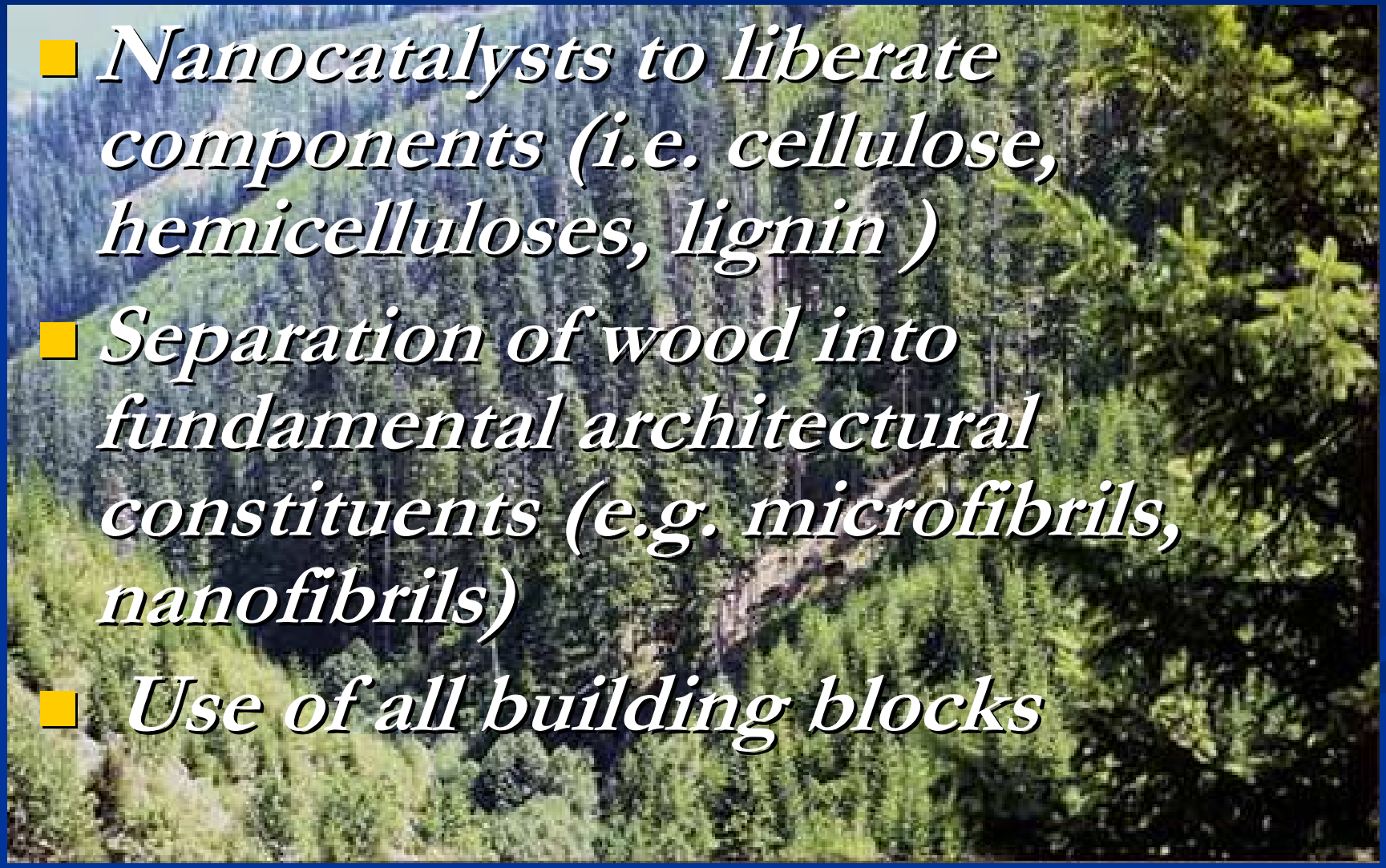
- Tag Components
- Novel Sheet Structures

Positively Impacting the Environment

- Uses for Solid Wastes
- Eliminate Detectable Odors



Advancing the Forest Biorefinery



- *Nanocatalysts to liberate components (i.e. cellulose, hemicelluloses, lignin)*
- *Separation of wood into fundamental architectural constituents (e.g. microfibrils, nanofibrils)*
- *Use of all building blocks*

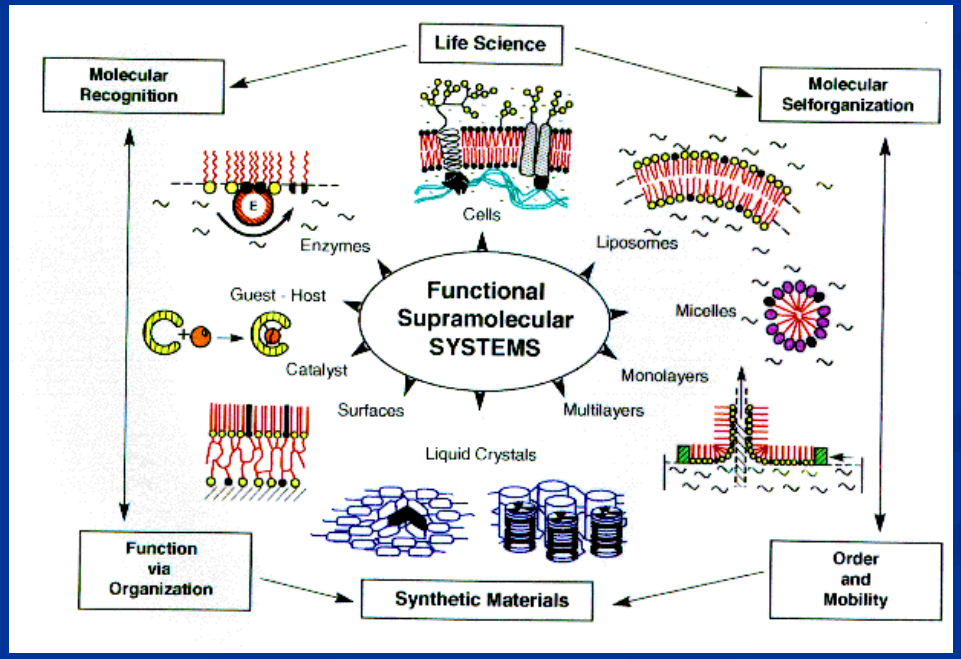
Breakthrough Manufacturing, Focus Area 1:
Reduce Energy in Paper Dewatering & Drying

- *Need for hydrophilic to hydrophobic switch*
- *Understand interaction of water and fibrils at nano-scale*
- *Dynamic dewetting*
- *Nano-filtration media*

Breakthrough Manufacturing, Focus Area 3:
Sheet Property Development Using Less Energy and Materials

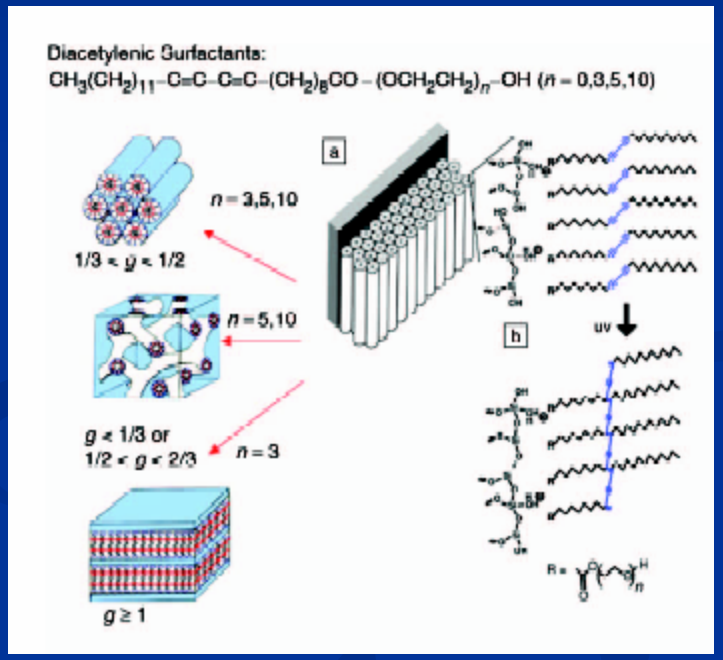
- *Separation of wood into fundamental units*
- *Nano catalysts for bleaching*
- *Sequestration of sulfur*
- *Replace petrochemicals with bio-based polymers*
- *Separation / Extraction of chemicals from pulping process*

- *Bonding of fibrils without compromising drainage or formation*
- *Self assemble of fibrils into useful structures*
- *Dramatic reduction in weight while maintaining mechanicals*
- *Nano-composite structures with other materials*
- *Nano-sensors built into sheet*
- *Hygro-expansivity control*



Breakthrough Manufacturing , Focus Area 4:
Increased Filler & Sustainable, Cost Effective Pigments

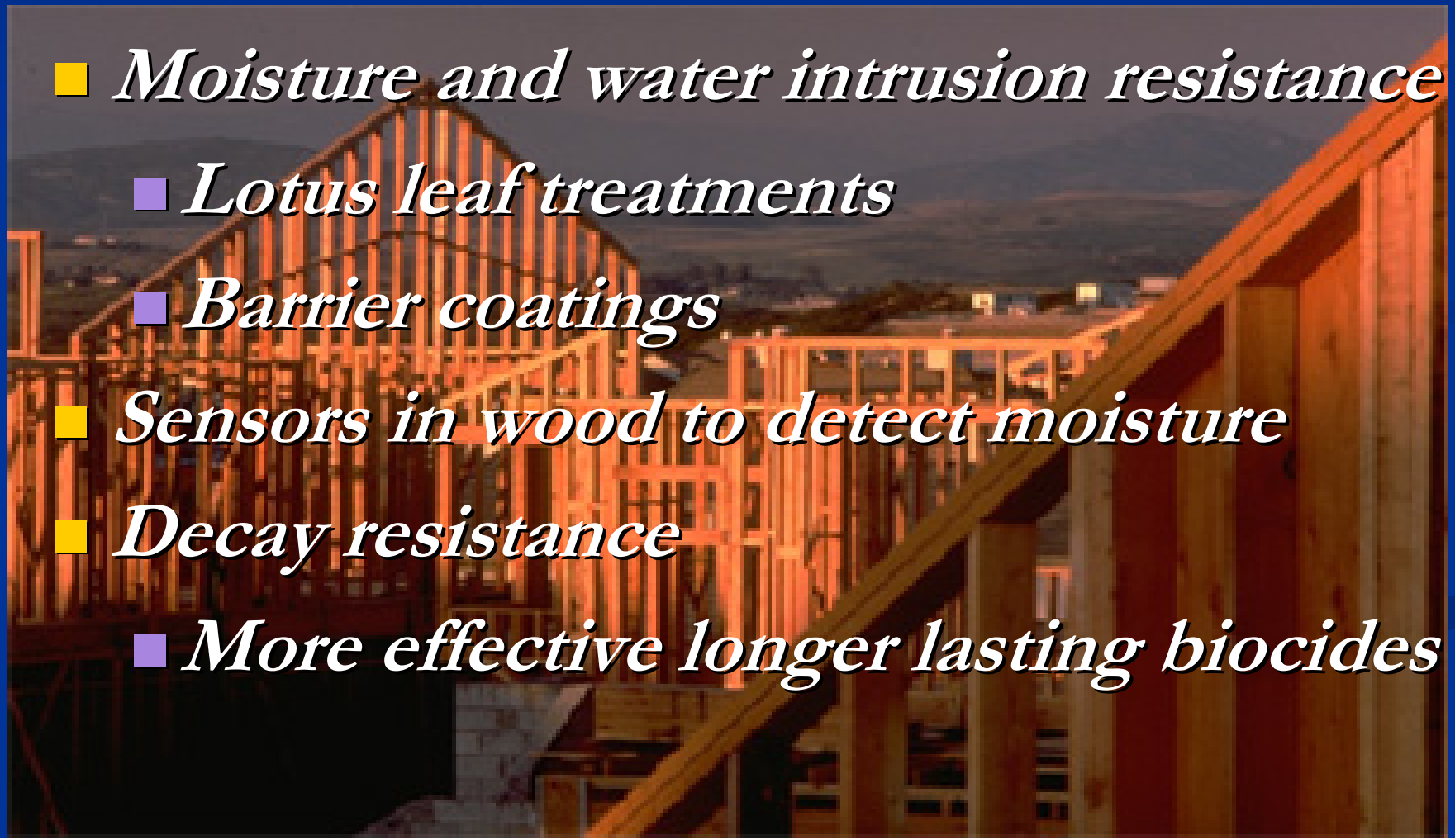
- *Novel materials & additive systems that deliver strength and optical properties at lower cost than fiber*
  - *Improve filler-fiber bonding*
  - *Improve pigment-coating bonding*
  - *Develop bio-based pigments and chemicals*
  - *Biomimetic structures*



Advancing the Wood Products Revolution, Focus Area 1: *Reduce Manufacturing Costs of Wood and Wood-Based Products*

- *Improved adhesives*
  - *moisture activated*
  - *reduced drying times*
- *Nanocatalysts or filters to deal with VOC & HAP during drying*

Advancing the Wood Products Revolution, Focus Area 2: *Wood-Based Building Materials and Systems Performance*



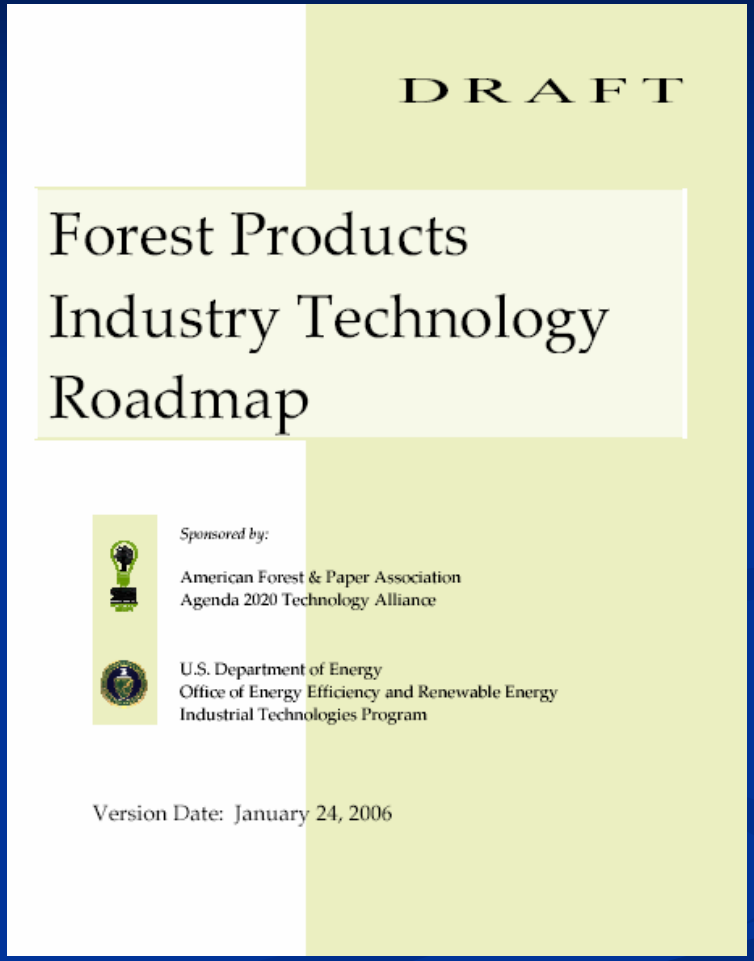
- *Moisture and water intrusion resistance*
  - *Lotus leaf treatments*
  - *Barrier coatings*
- *Sensors in wood to detect moisture*
- *Decay resistance*
  - *More effective longer lasting biocides*

Advancing the Wood Products Revolution, Focus Area 3: *Integrated Wood-Based Building Systems*

- *Methods & materials to enable systems approach*
- *Improved energy efficiency*
  - *Thermal barriers*
  - *Moisture barriers*
  - *UV Barriers*
- *Design for re-use*
  - *Modified bonding/adhesives*

Key Nano Themes

- Cellulose nano building blocks
  - Nanofibrillar cellulose
  - Adhesives
- Water / Cellulose interface
  - Dynamic Dewetting
- Barrier Coatings
  - Water, Oil, Vapor, Gases
  - Breathable
  - Weathering
  - Fire resistance
- Self Assembly
  - Nanofibrils
  - Nanocomposites
- Functional coatings
  - Water, Vapor and Gas Barrier
  - Thermal
- Biomimetic structures
  - Composites with strength of wood
  - Composites with strength of steel/silk
  - Low cost lignocellulosic construction materials
- Smart Paper
  - Display
  - Information
    - printed electronics/hybrid media
    - photovoltaic paper, electro-chromic paper
- *Bio-Active* / Nano biocides
  - Decay resistance
  - Self sterilizing surfaces
- Sensors
  - Smart building materials
  - RFID
  - Monitors: moisture, temperature, forces, decay, termites



Strategies

- Adapt & Deploy Existing Nanotechnologies
  - *Reduces costs by leveraging existing investments*
  - *Shortest time to deployment*
  - *Exploits existing nanotechnology knowledge base*
  - *Adds value and functionality to existing products*
- Create & Deploy Novel New Nanotechnologies
  - *Exploits the unique nanoscale components and properties of wood*
  - *Enables new generations of cost effective products & materials*
  - *Exploits the full potential of wood as the material for the 21st Century*
  - *Achieves maximum efficiency of material* use

Actions

- Appropriately link nanotechnology with other AF&PA Agenda 2020 platforms.
- Engage in appropriate interactions with academia, federal and state governmental agencies, laboratories and departments, the National Nanotechnology Initiative (NNI); and other entities.
- Facilitate appropriate interactions among all the groups, entities, partners and stakeholders that support and advance R&D nanoscale science, engineering, and technology of interest and importance to the forest products industry.