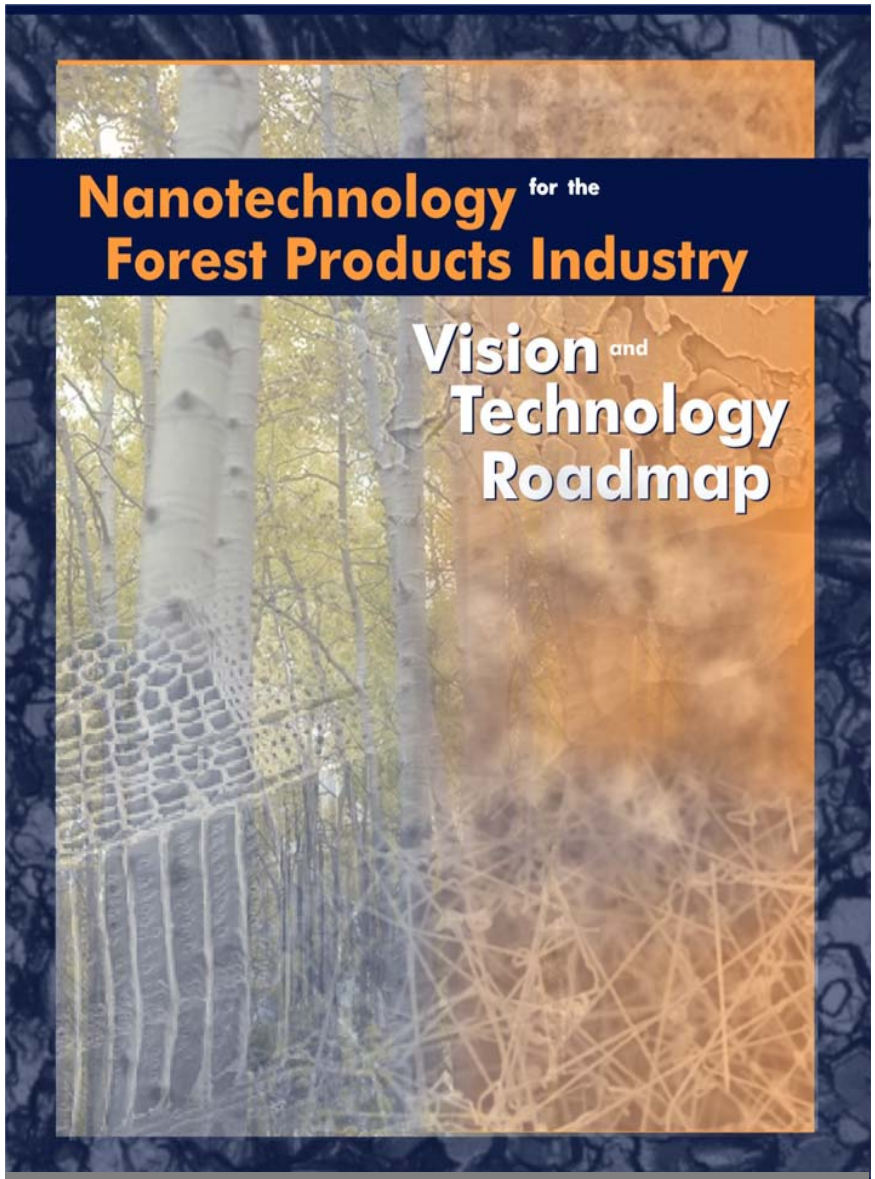

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www.fpl.fs.fed.us

www.tappi.org

Nanotechnology for the US Forest Products Industry

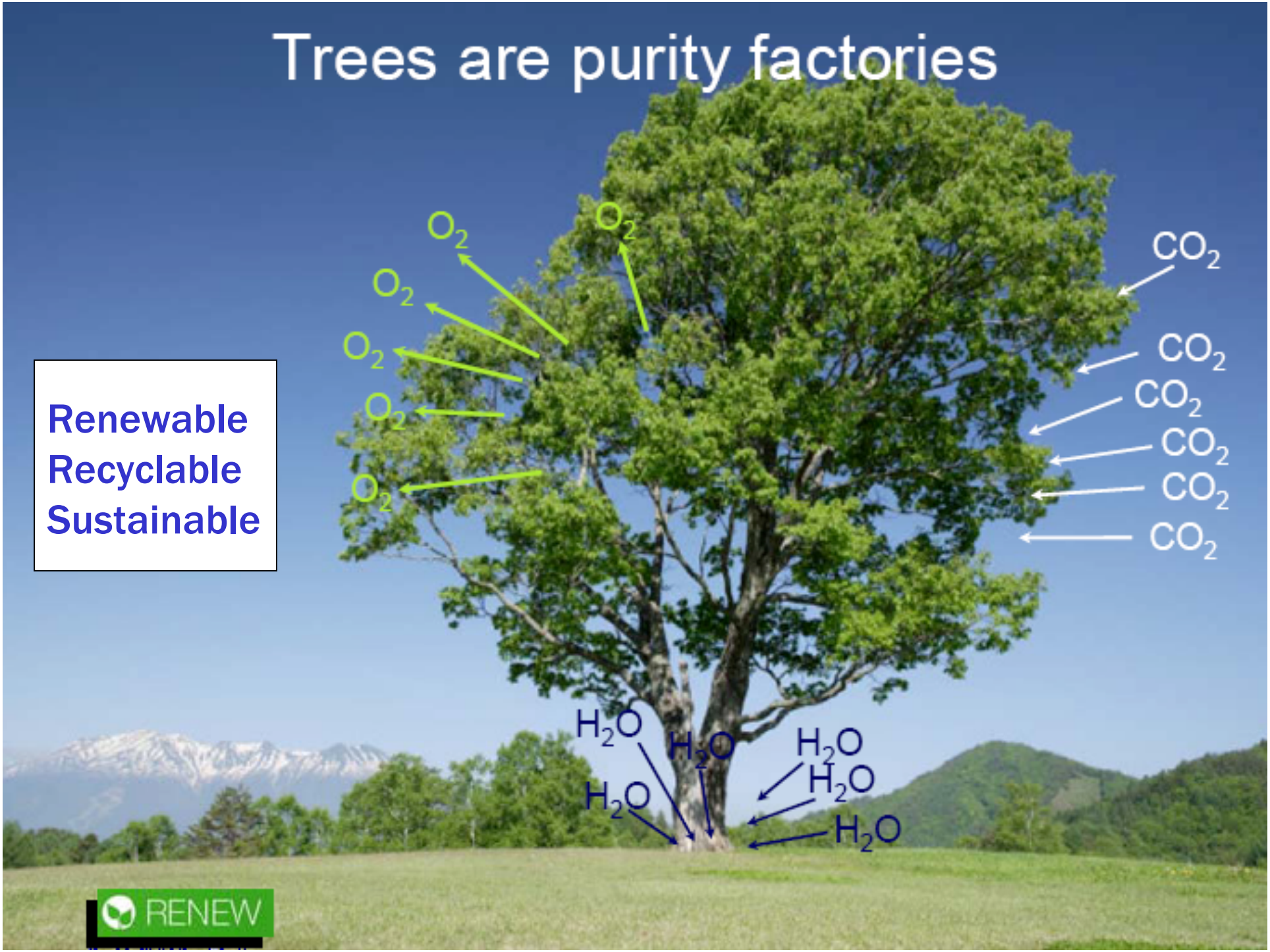
Agenda 2020 Program

Phil Jones
IMERYS

Ted Wegner
USDA Forest Products Laboratory

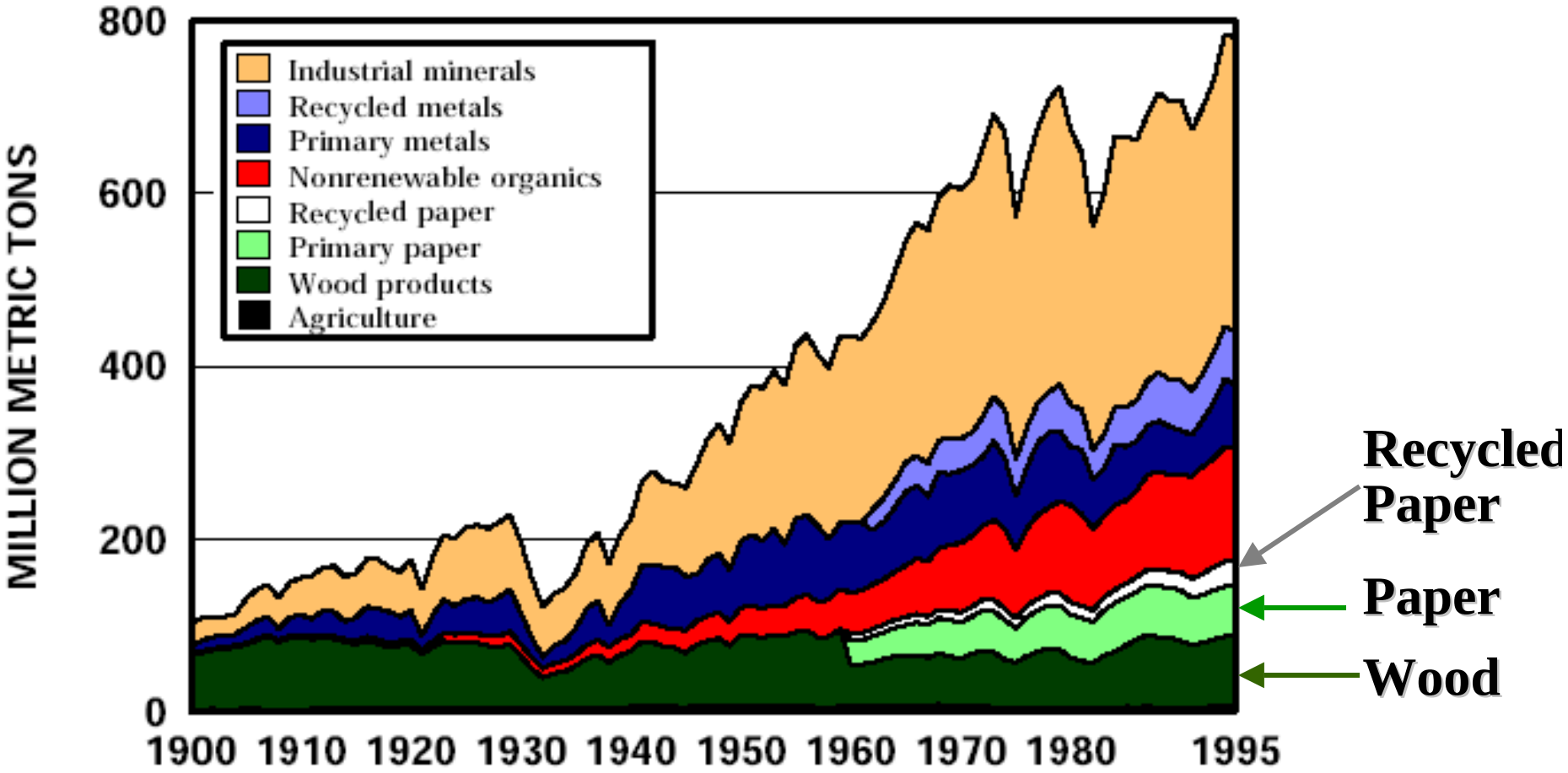
Dan Coughlin
SAPPI Fine Paper

December 3 2007


Trees are purity factories
Renewable
Recyclable
Sustainable
O_2
O_2
O_2
O_2
O_2
O_2
CO_2
CO_2
CO_2
CO_2
CO_2
CO_2
H_2O
H_2O
H_2O
H_2O
H_2O
H_2O
RENEW

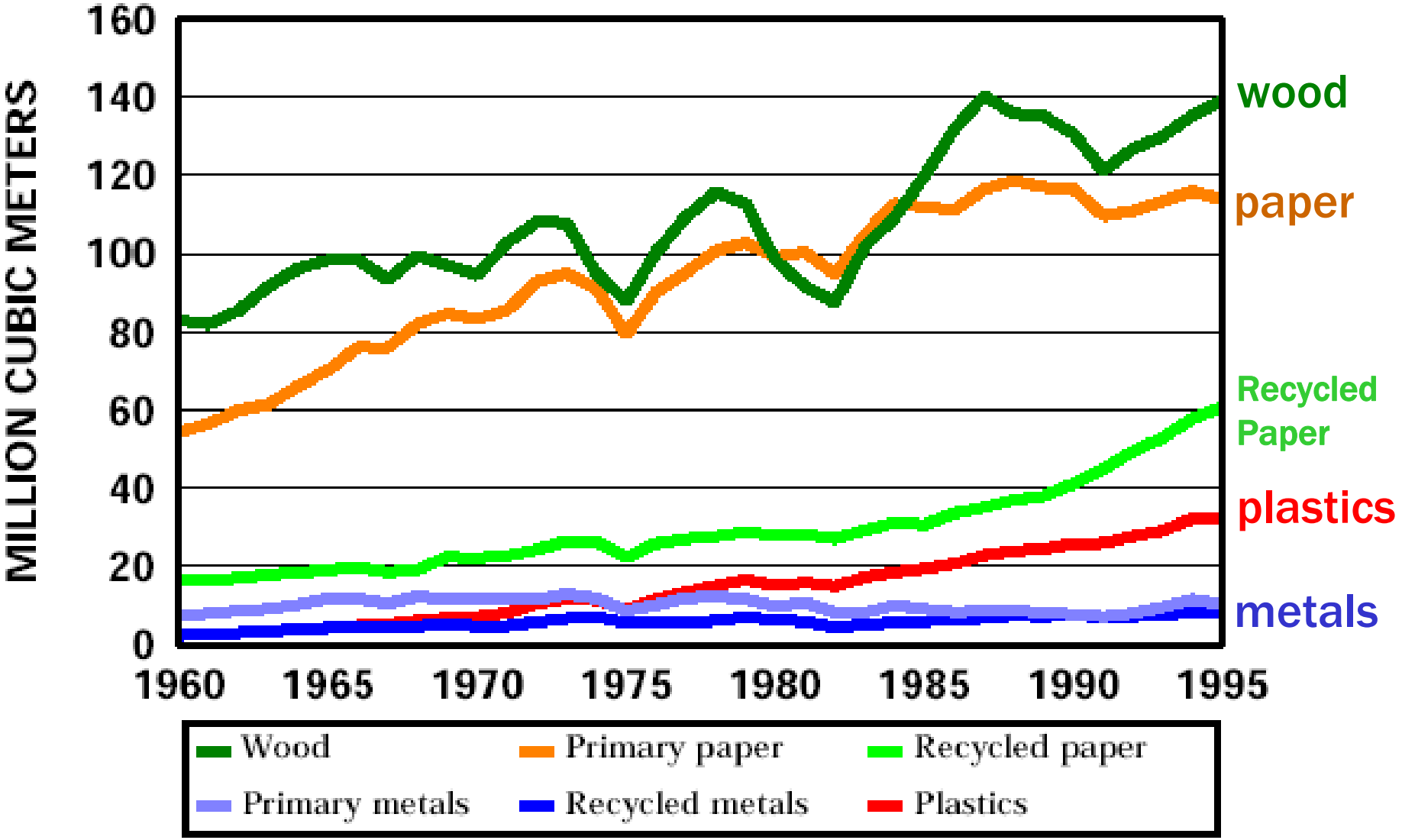

Forests are life – continuously
- SFI Certified Forest
- Forest inventory in North America today is up 30% since 1952
- 10 million more acres of forest than in 1996
-More trees are grown than are harvested
-Biodiversity is preserved
RENEW

Use of Materials in US 1995



Move to Green Chemistry

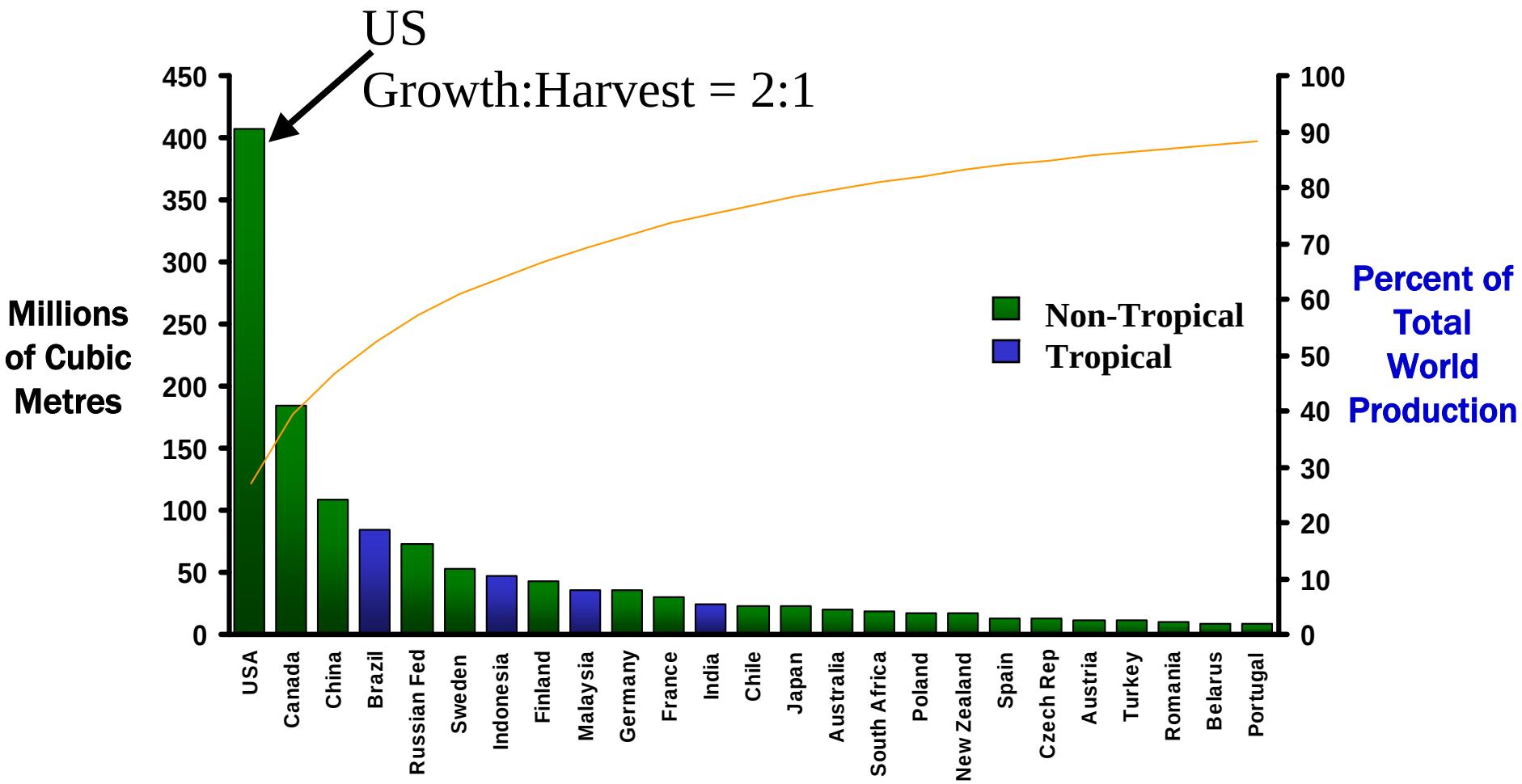
Volume Use of Materials in the USA



US Forest Products Industry: $260 Billion

Source: Matos & Wagner 2001

Forests a Major Sustainable Resource

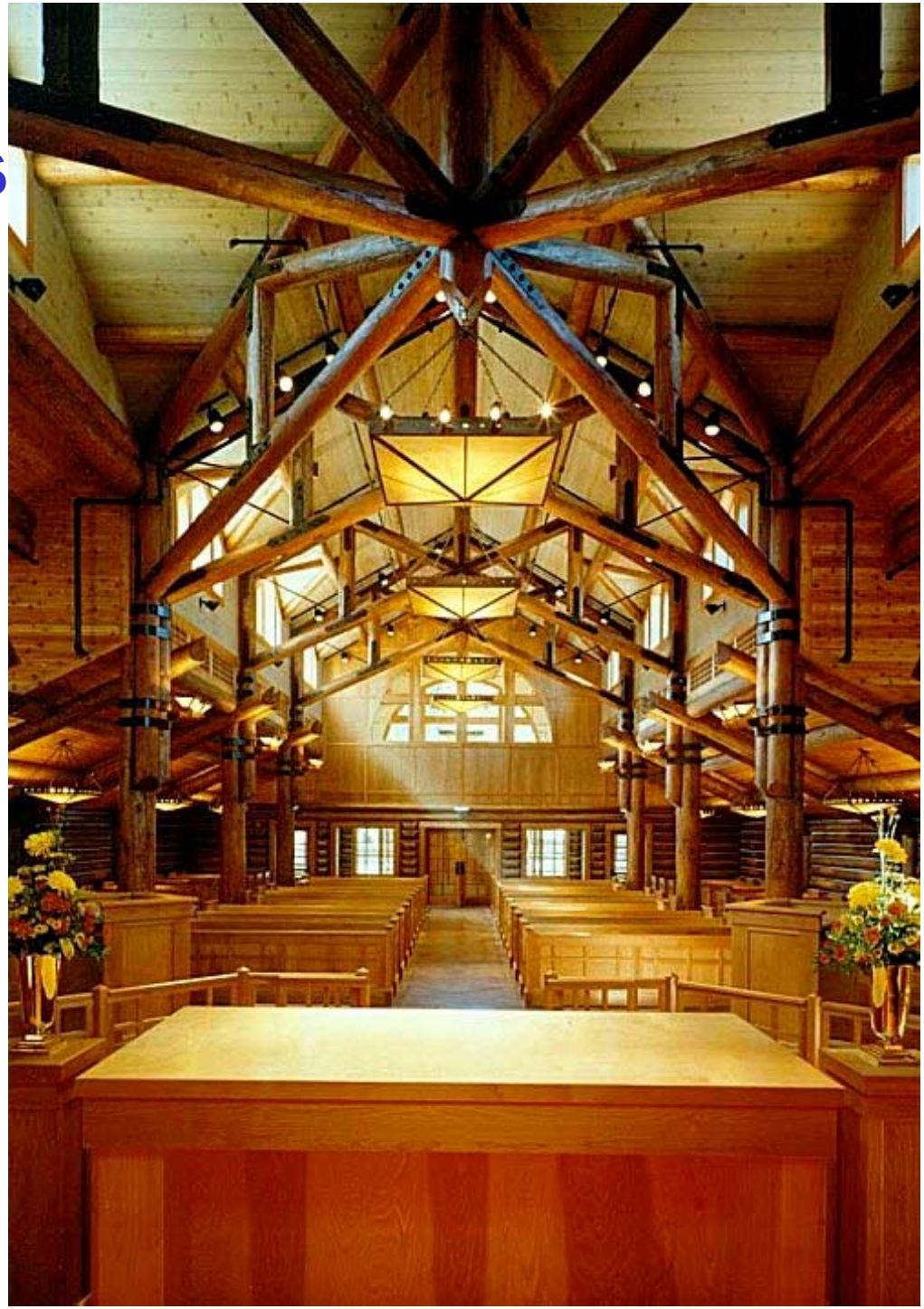


Source : FAO, SOFO 97, LEK analysis

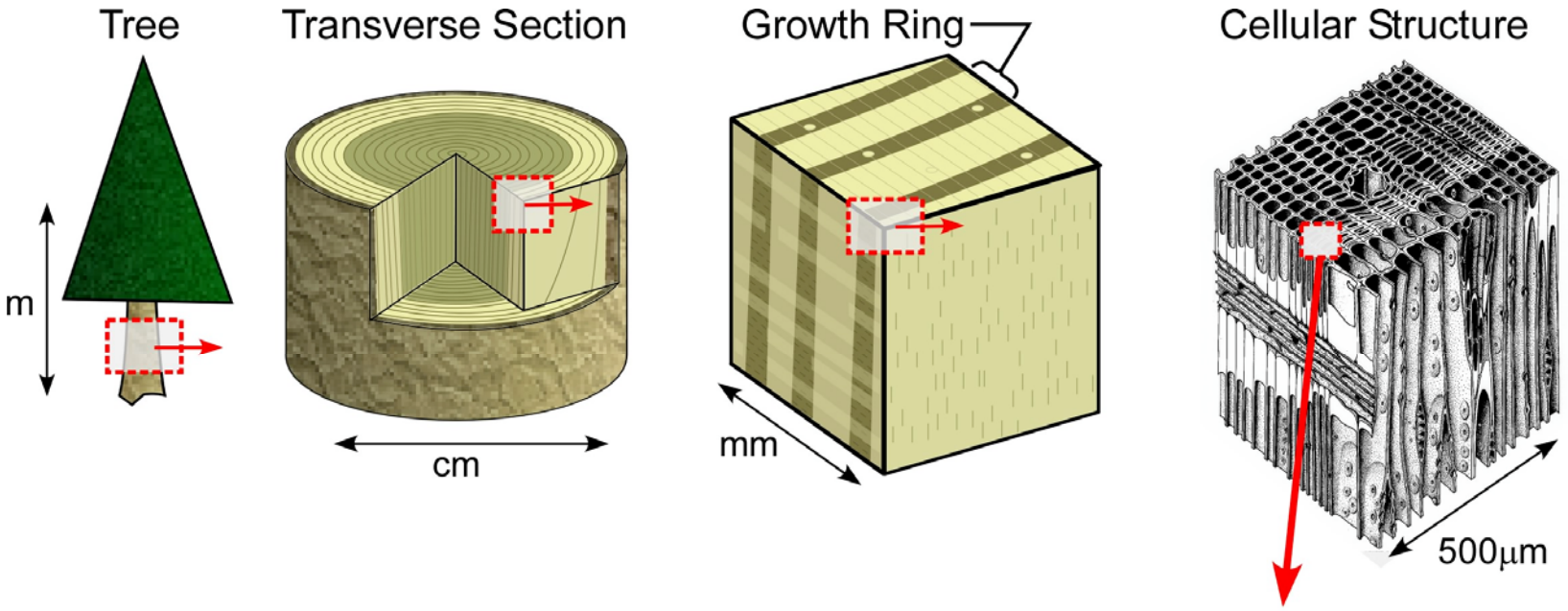
88% of Single Family Structures are Wood Frame Construction

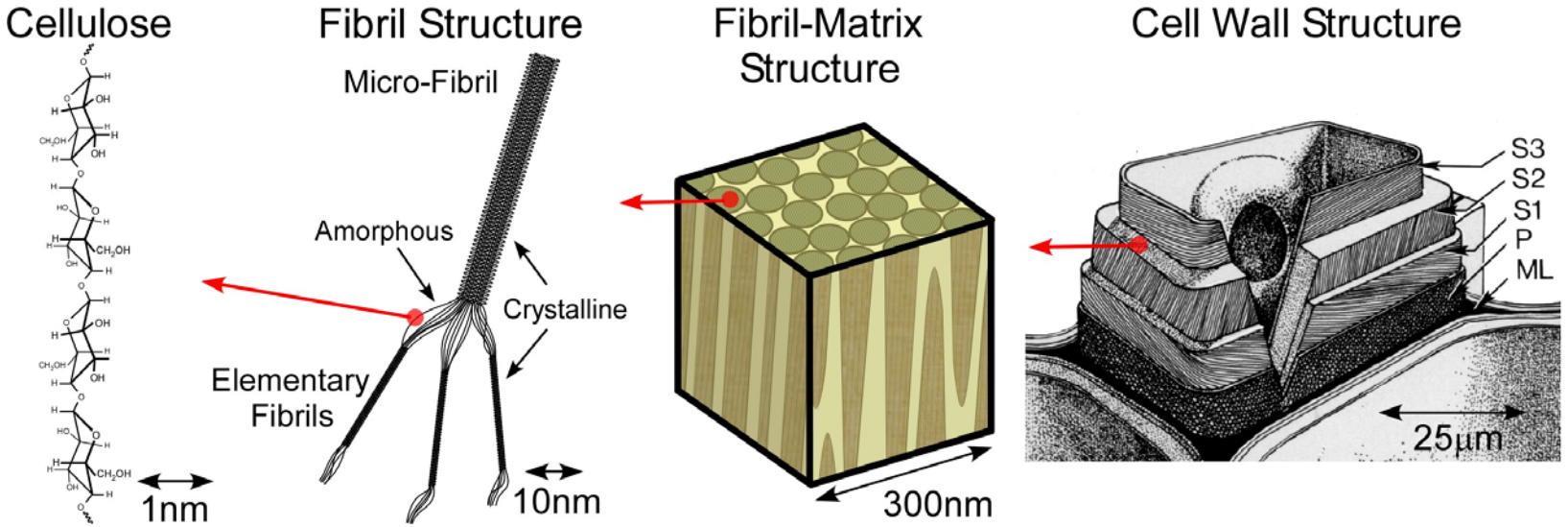
Housing & Non-residential Issues

- Durability
  - Moisture
  - Decay
  - Termites
  - Weathering
- Fire Performance
- Disaster Performance
  - Fire
  - Flood
  - Hurricane/Tornado /Wind storm
- Energy Consumption
- Integrated Building Systems

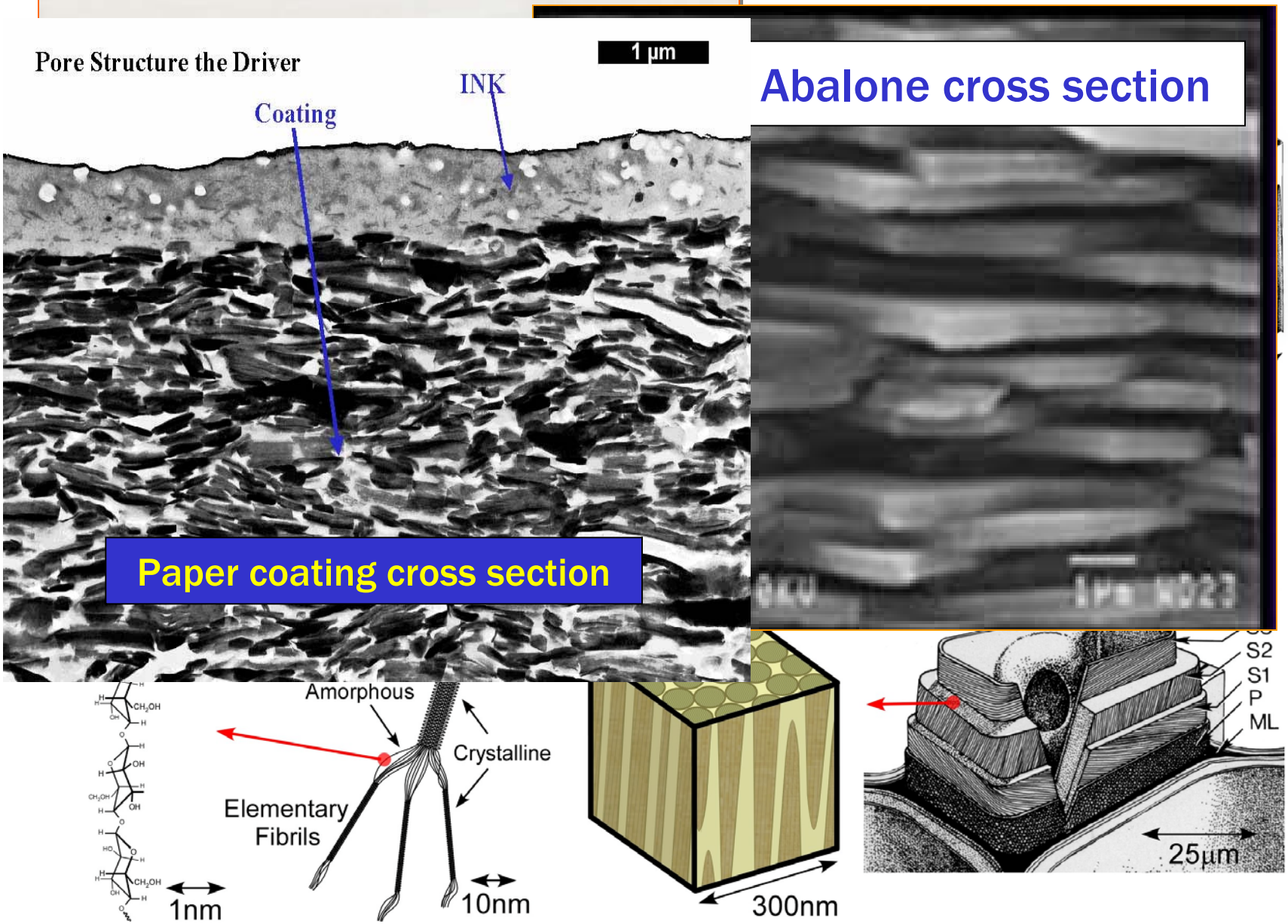


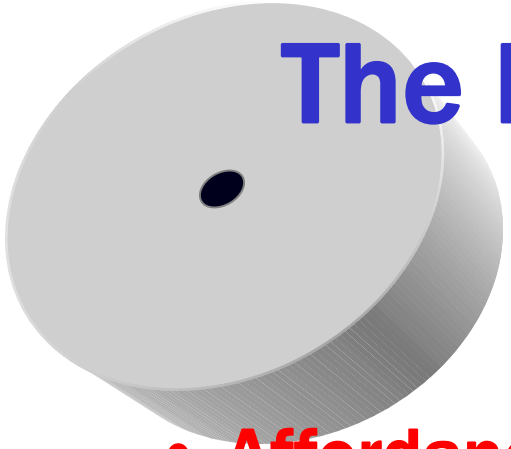
Wood a Nanocomposite





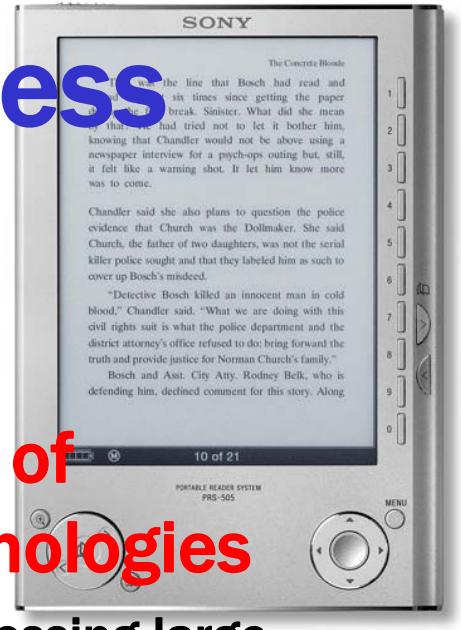
Biomimetic Structures





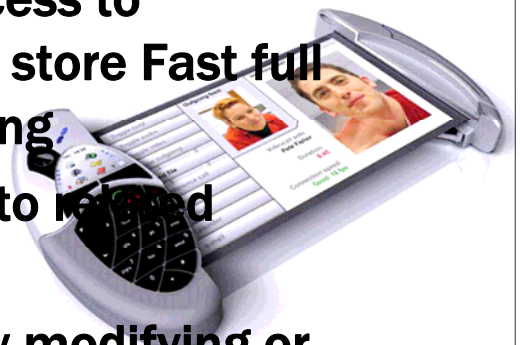
The Myth of the Paperless Office

A J Sellen & H R Harper 2002



- **Affordances of Paper**
  - –
  - Quick flexible navigation through and around documents
  - Reading across more than on document at once
  - Marking up a document while reading
  - Interweaving reading and writing

- **Affordances of Digital Technologies**
  - Storing & accessing large amounts of information
  - Displaying multimedia documents
  - Remote access to information store Fast full text searching
  - Quick links to related materials
  - Dynamically modifying or updating content



paper

the emotional connection

N 12804 201 C-60 cross-section

Paper coating

Self assembly at 100 kph

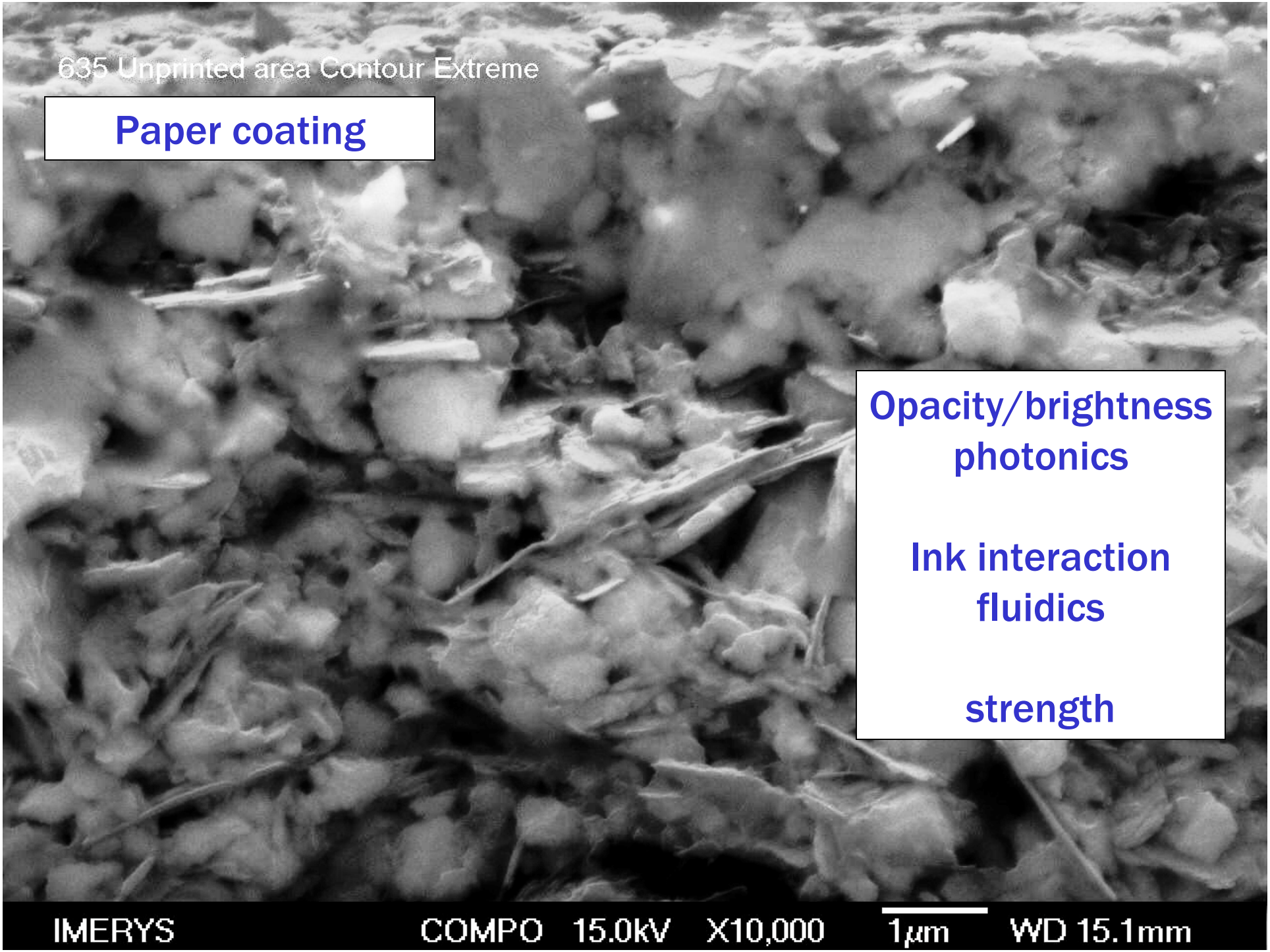
Opacity/brightness
photonics

Ink interaction
fluidics

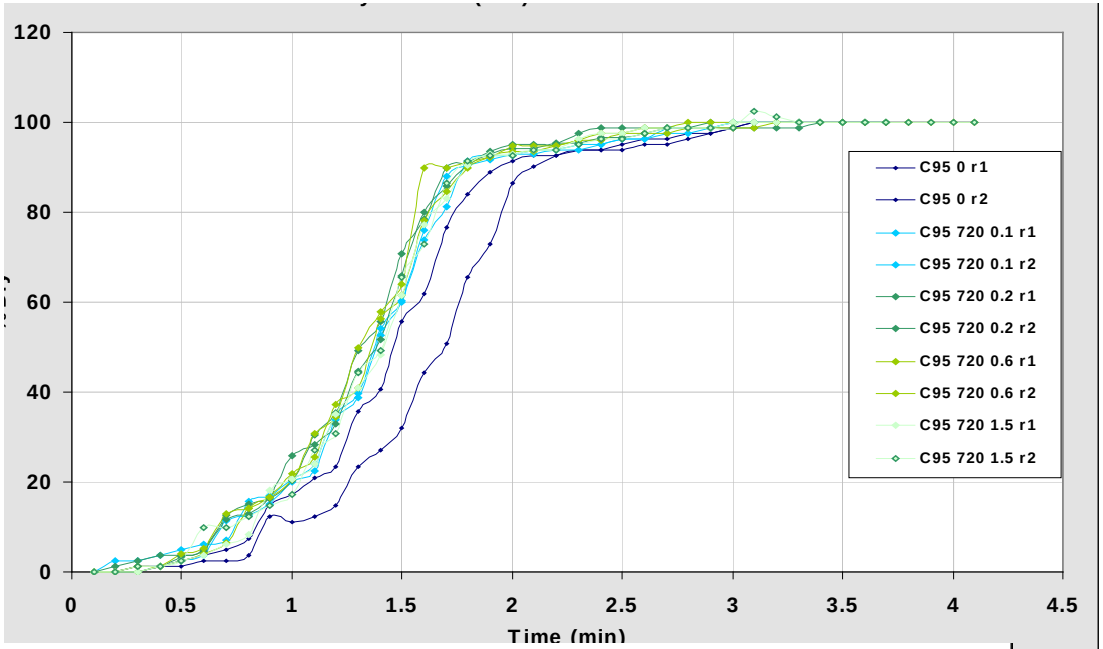
strength

paper

IMERYS LEI 5.0kV X900 10µm WD 14.4mm


635 Unprinted area Contour Extreme
Paper coating
Opacity/brightness
photonics
Ink interaction
fluidics
strength
IMERYS
COMPO 15.0kV X10,000
1µm
WD 15.1mm

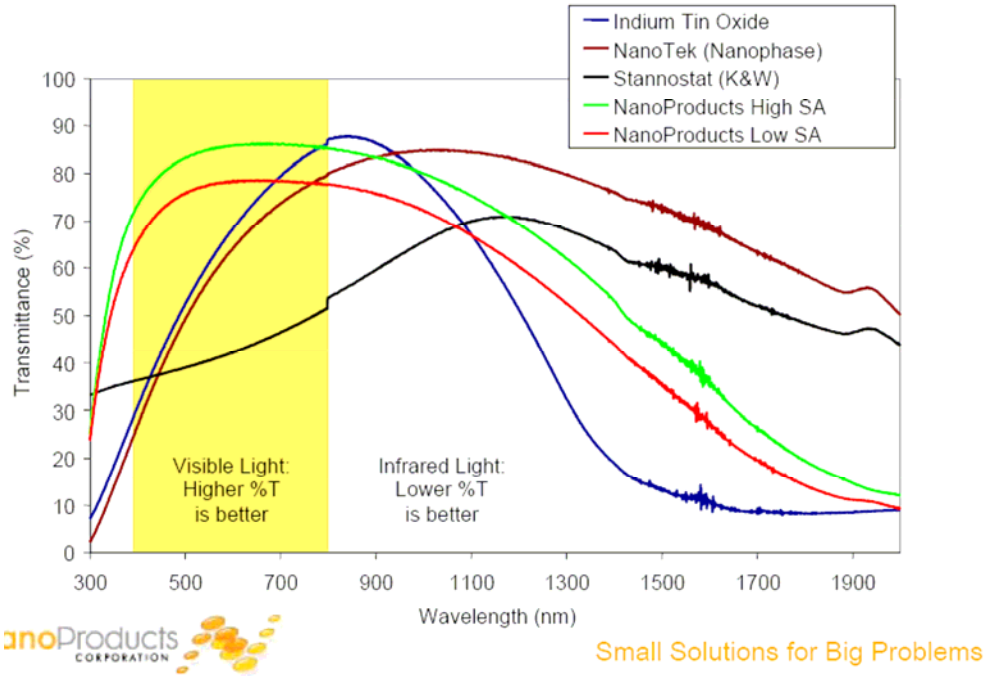
Infra Red Drying of paper



Water IR bands narrow

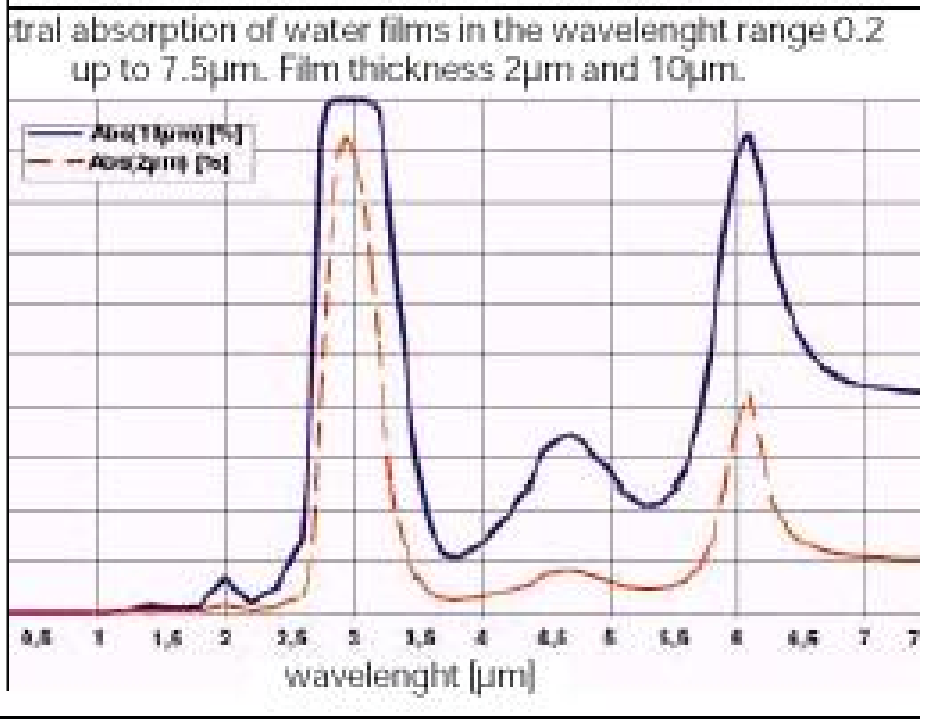
Need broader IR absorption

Nano core shell plasmonics?



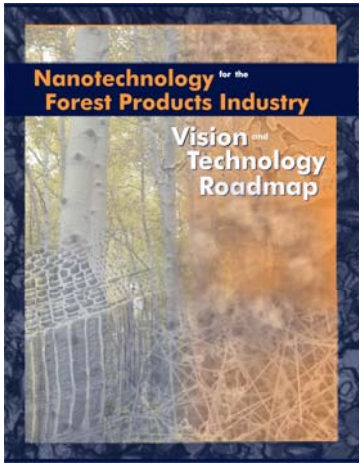
anoProducts CORPORATION

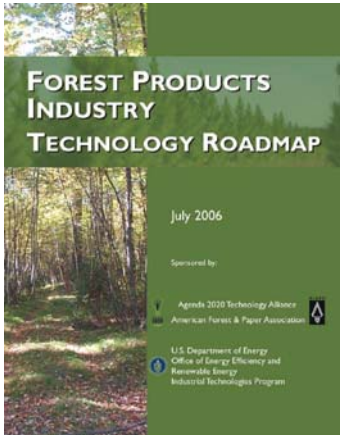
Small Solutions for Big Problems

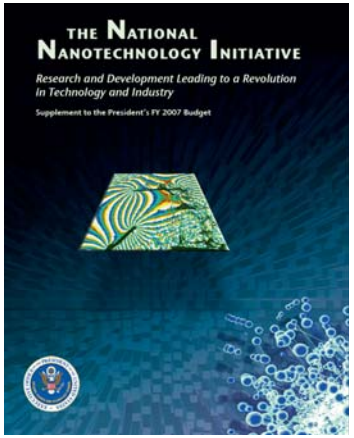


Forest Products Road-maps

- FPI Nanotechnology Roadmap (2005)
- AF&PA Agenda 2020 FPI Technology Roadmap (2006)
- Priorities Workshop (2006)
- NNI Forest Products Industry CBAN (2007)
  - Conversion of industry goals using industry jargon to underlying fundamental science needs
  - Link with other industry sectors to explore commonalities in fundamental science needed







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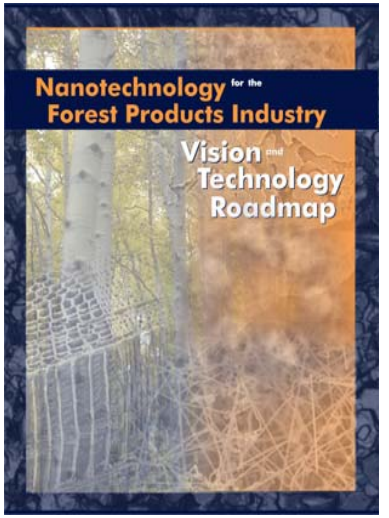
Key Forest Products Focus Areas

1. Improved strength, lighter weight
2. Forest Nano-materials
3. Water / lignocellulosic interactions
4. Nano-composites
5. Photonic, electronic properties
6. Energy

Nano Focus Areas

Focus Area 1
Improve strength weight performance

40% fewer materials for same performance
60# performance with 45# CWF
Mechanical (bonding) and optical performances

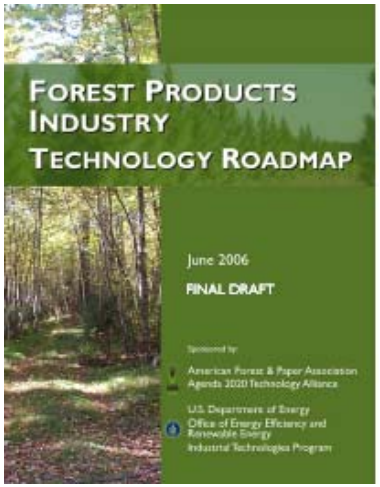


Focus Area 2: Forest Nanomaterials

Liberation and use of nanocellulose
Other nanomaterials from bio-resource
Non covalent disassembly/reassembly nano-fractionalization and nano-catalysis for separations;
Entropic effects in the assembly and disassembly of nanomaterials in forestry

Focus Area 3 : Understanding the control of water-lignocellulose interaction for modification of properties

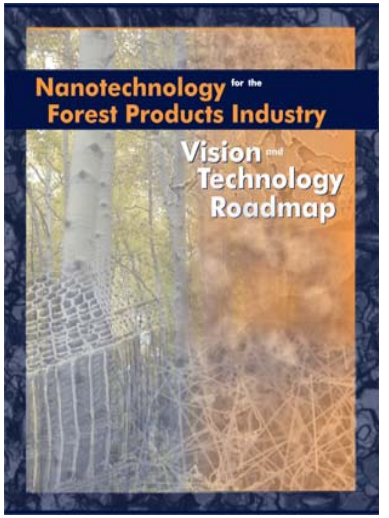
Water removal and in the end product
Energy cost of water, fiber swell in the presence of water
Control and manipulation of hydrogen bonding (7 types)
Control of mechanosorptive behavior
Water repelling, barriers
Control of degradation
Control/modification of surface chemistry



Nano Focus Areas

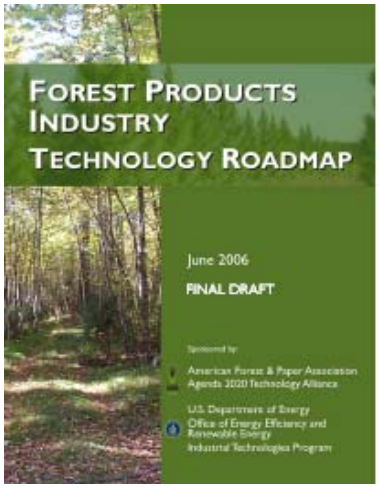
Focus Area 4
- Inorganic-organic nanocomposites
nanoscale surface modification

Paper, MDF, OSB are all composite materials
Compatibilization of hydrophilic/hydrophobic materials
Interactions at nano-scale



Focus Area 5 _
- Photonics and
Electronic/Piezo properties

Needed for light weight paper grades
100 % Opacity needed for ultra light weight
Coverage of v low brightness.
Beyond Kubelka-Munk and Mie scatter
Ordered structures



Focus Area 6 -
-Modifications for energy efficiency : Process related

Nano-catalysis in pulping and chemistry
Low temp pulping
Nano pores in felts
Water removal
Low corrosion materials

Industry

Connections

Industry needs to identify and use existing developments

Industry needs to communicate needs more widely

Industry needs to be more active in guiding programs

Thank You

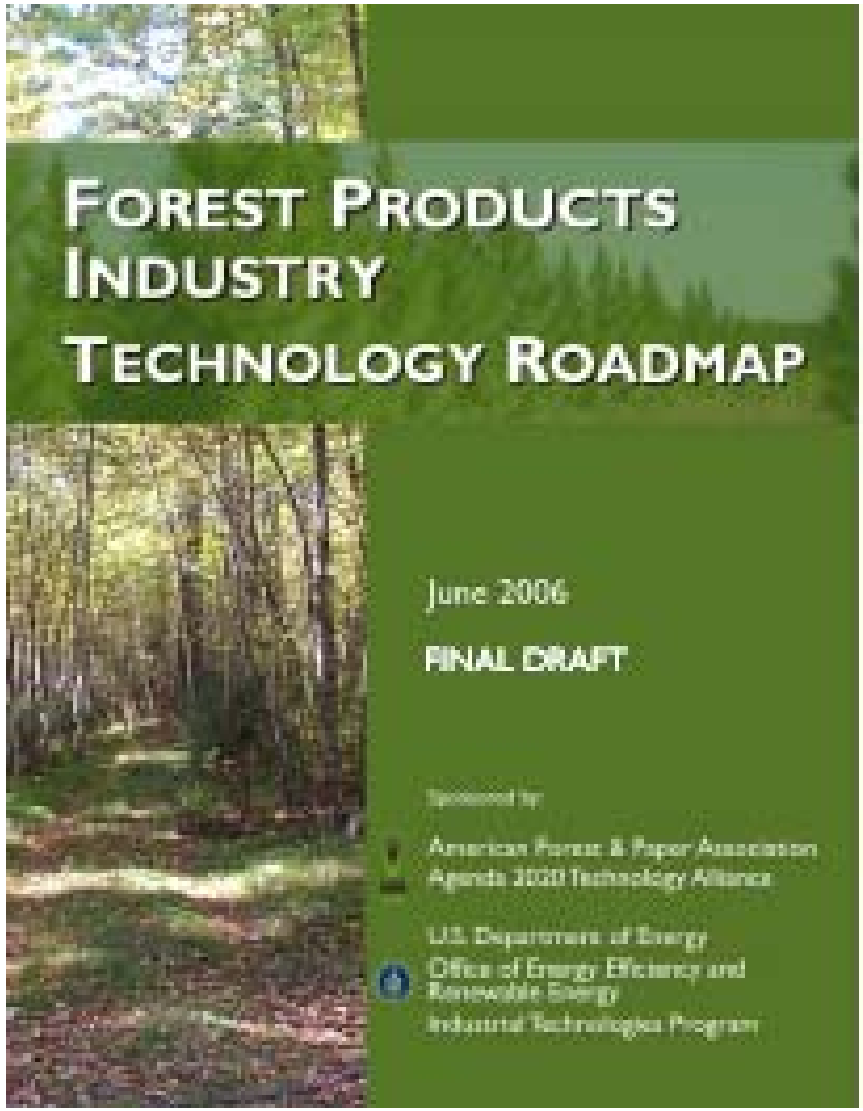
www.nanotechforest.org

pjones@imerys.com

Back up

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



Key Forest Products Focus Areas

1. Improved strength, lighter weight
2. Forest Nano-materials
3. Water / lignocellulosic interactions
4. Nano-composites
5. Photonic, electronic properties
6. Energy

Industry Cross-cutting Thematic Areas

- **Surfaces / Interfaces**

  High strength, light weight

- **Composites / Matrix / Bulk**

  Material, Photonic, Electronic

- **Non Covalent Bonded Interactions**

  High strength, lightweight

- **Separations and Fractionalizations**

  Nano cellulose

Surface/Interfaces

Develop the basic enabling scientific understandings of:

- Nano-dimensional surface chemistry and modification
- Nanoscale hydrophobicity/hydrophillicity (wetting/dewetting)
- Nanoscale assembly/aggregation
- The interaction and properties of varying combinations of nanoscale liquid-solid-vapor interphases

Nano-enabled Composites

Develop the basic enabling nanoscale scientific understandings of:

- **How nanomaterials of varying size, shape and mechanical, photonic, chemical, and electrical properties interact and hierarchically aggregate with other materials of varying sizes (e.g. nano, micro, macro), shapes**
- **Give rise to unique and tunable properties via:**
  - **Multiphase interactions**
  - **Intermixed phases**
  - **Interactions of materials and phases at interfaces**
  - **Interaction of biological (organic) and inorganic materials, dispersants**
  - **Assembly of materials into aggregates**

Non Covalent Bonding

Wood and paper held together by non-covalent bonds (hydrogen and Van der Waals)

- Understand bonding mechanisms
  - Hydrophilic / hydrophobic balance
- Identify novel ways to disassemble wood
- Use non-covalent bonding as a way to re-assemble forest based materials
- Quantify forces
- Identify solvents and chemicals that act on these non-covalent bonds

Separations and Fractionalization

Need

- Identify commercially attractive methods to liberate nanocellulose, in either the whisker or crystalline form
- Reduced energy in manufacture
- Characterize and stabilize those materials and incorporate into existing and new applications

Approach

- Investigate the science and engineering that will fully determine the properties and characteristics of cellulose and lignocellulose at the nanoscale
- Then develop technologies that will enable industry to produce advanced and cost-competitive cellulose and lignocellulose-based products
- Consider application of cellulose surface modification technologies to use under-utilized feedstocks, such as forest residuals and sorted wood wastes to supply nanoparticles for a wide-range of industries

Water

- Water at molecular and nano-scale
- Water near surfaces
- Water as a probe of wood structure (BET , calorimetry etc)
- Wetting, Drying, Diffusion, Transport
- Make products stronger and more robust
- Make products less sensitive to humidity, moisture and biological attack
- Enhance de-wetting and dewatering processes

Focus Area 1: Improve strength weight performance

Target:

-40% fewer materials for same performance
- 60# performance with 45# Coated Paper

- Mechanical (bonding) and optical performances

Technical Challenges

Control of Nanostructural and interface properties

Selection of “designer shapes” and multiple material compatibility

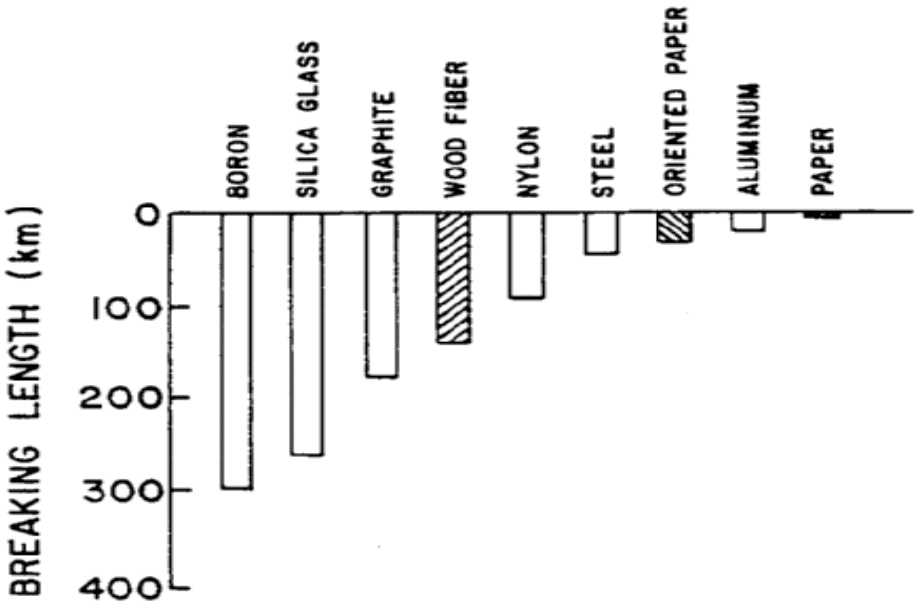
Control of hierarchical structures

Measurement of nano-scale strain , shear and bulk moduli

Adhesion and bonding at nano-scale

Focus Area 1:
Improve strength/weight performance

- Breakthrough approaches are needed
  - Reduce weight by 20-40% at same strength and stiffness
  - Significantly increase strength and stiffness at same weight
  - Biomimicry – learn from nature
  - Issues – bonding, fiber strength, opacity



G. A. Baum 2003

Wood fibers can be stronger than some metals!

Why is paper so much weaker than fibers?

Focus Area 2: Forest Nanomaterials

Target:

Liberation and use of nanocellulose building blocks

Technical Challenges

Nano-fractionalization and nano-catalysis for separations;

Non covalent disassembly/re-assembly

Entropic effects in the assembly and disassembly of nanomaterials in forest materials

Focus Area 3 : Understand the control of water-lignocellulose interaction for modification of properties

Target

Understand water forest materials interactions

Control effects of water on wood and paper properties

Shed water more efficiently

Technical Challenges

Interfacial properties at nanoscale

Production of hydrophilic/hydrophobic switchable surfaces

Biological activity control

Focus Area 4: Inorganic-organic nanocomposites

Target:
Paper and Paperboard are composite materials

Produce wider range of nano-composite materials from forest materials

Technical Challenges

Understand & control surface chemica reactivity

Characterization of structures at nanoscale

Measurement of physical properties a nanoscale

Multiple material compatibility

Directed self assembly of nano-components

Focus Area 5 - Photonics and Electronic/Piezo properties

Target

Produce Optically efficient structures

Control electronic properties of forest materials

Cellulose 5X piezoelectric properties of quartz

Technical Challenges

Selection of controlled size and shape building blocks

Characterization of physical structure, interfaces, material intermixing and defects

Self assembly of building blocks into controlled structures

Liquid crystal structures of building blocks (forest based and mineral)

Contact effects at nanoscale

Effect of dopants

Hybrid organic/bio/inorganic devices

Focus Area 6 - Reduced Energy Consumption and Reduced Capital Costs

Target
Reduce energy consumption

Catalysis with nanomaterials in pulping and other chemical reactions with wood and fiber

Nanoscale mixing of chemicals with fiber

Water removal in pressing and drying

Structural materials with lower corrosion rates

Technical Challenges

Understand nano-scale wet/dry interface

Low temperature nano-catalysis to de-lignify wood

Understand & control chemical reactivity

Nano-dimensional markers for fiber separation

Low corrosion nano-coatings

Robust nano-dimensional sensors (temp, press, tensile/compression forces)