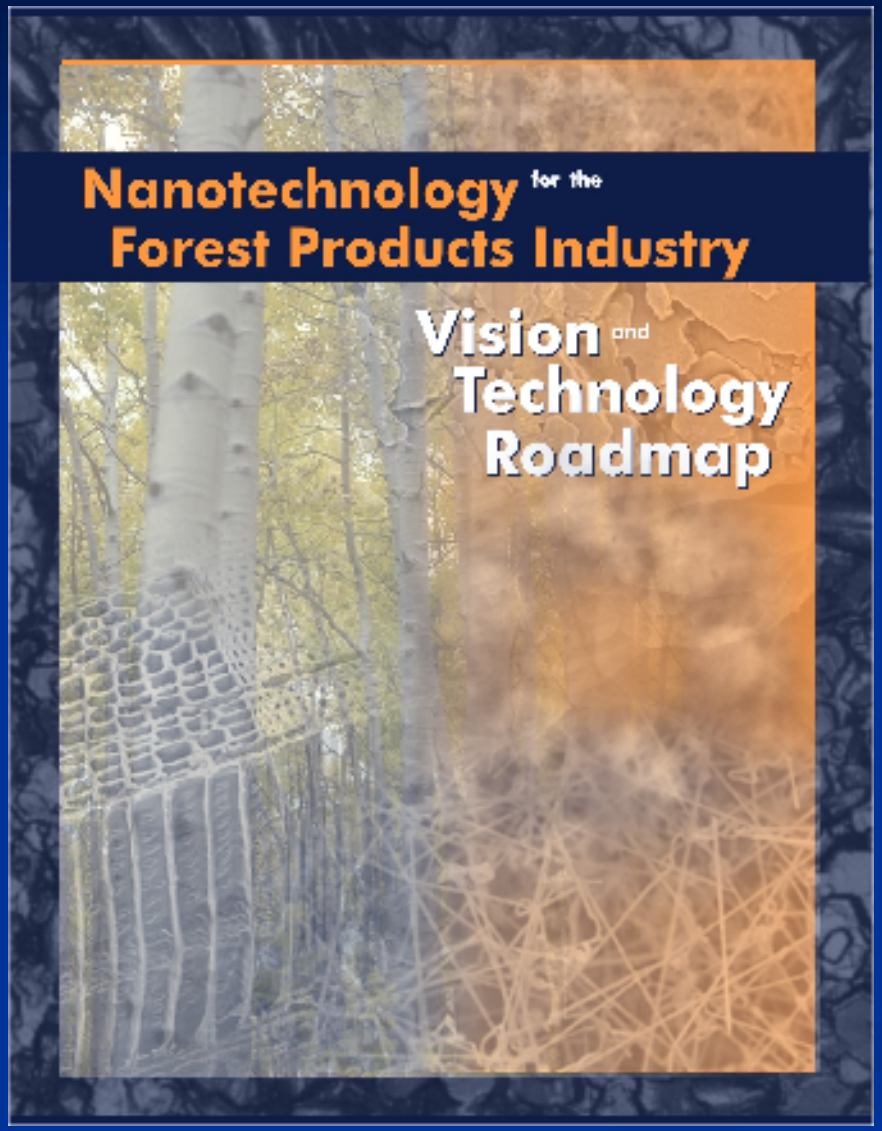


Nanotechnology in the Forest Products Industry: Update

Phil Jones
Ted Wegner

June 19, 2005

www.swst.org

www.nanotechforest.org

www.fpl.fs.fed.us

www.nano.gov

Presentation Overview

- Nanotechnology
  - What is Nanotechnology?
  - Why is it important?
  - National Nanotechnology Initiative
- Nanotechnology in the Forest Products Industry Workshop
  - Deliverables
  - Outcomes
- Next Steps

AF&PA Agenda 2020 Topic Areas

- **Nanotechnology** *(Approved @ December 2004 Agenda 2020 CTO meeting)*

Nanoscience and Nanotechnology

- The nanoscale is not just another step towards miniaturization. It is a qualitatively new scale where materials properties, such as melting point or electrical conductivity, differ significantly from the same properties in the bulk.
  - "Nanoscience" seeks to understand these new properties.
  - "Nanotechnology" seeks to develop materials and structures that exhibit novel and significantly improved physical, chemical, and tribiological properties and functions due to their nanoscale size.

- The goals of nanoscience and nanotechnology are:
  - to understand and predict the properties of materials at the nanoscale
  - to "manufacture" nanoscale components from the bottom up
  - to integrate nanoscale components into macroscopic scale objects and devices for real-world uses

The Scale of Things -- Nanometers and More

From ants to atoms

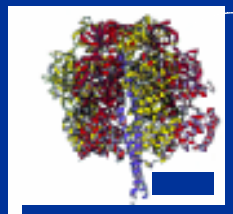
1

One millimetre = 1m nanometres (nm)

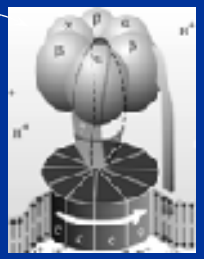
Item	Size in nm
Red ant	5m
Human hair (width)	80,000
Diameter of a typical bacterium	1,000-10,000
Average wavelength of visible light	400-700
Human immunodeficiency virus	90
Wavelength of extreme ultraviolet light	40
Cell membrane	10
Diameter of DNA	~2.5
Tier hydrogen atoms	1
Water molecule (width)	0.3

Sources: Wikipedia; National Institute of Standards and Technology; Institute Royal Society; R. Smalley

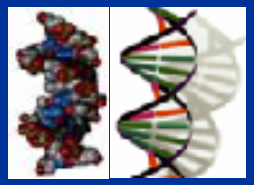
1 cm
10 mm
1,000,000 nanometers = 1 millimeter (mm)
Microwave
0.1 mm
100 μm
0.01 mm
10 μm
Infrared
1,000 nanometers = 1 micrometer (μm)
Visible
0.1 μm
100 nm
Ultraviolet
0.01 μm
10 nm
The Nanoworld
1 nanometer (nm)
Soft x-ray
0.1 nm



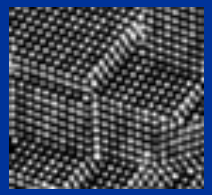
~10 nm diameter



ATP synthase



DNA
~2-1/2 nm diameter



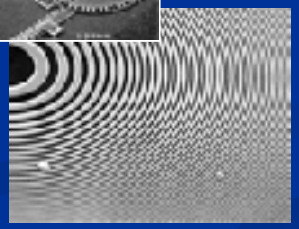
Atoms of silicon
spacing ~tenths of nm

Things Manmade

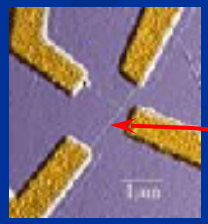
MicroElectroMechanical de
10 -100 μm wide

Red blood cells
Pollen grain

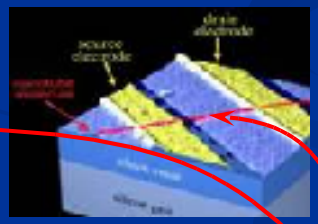
Intersection of quantum mechanics and continuum mechanics



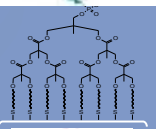
Zone plate x-ray "lens"
Outermost ring spacing
~35 nm

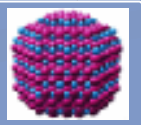


Nanotube electrode

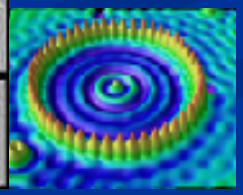


Nanotube transistor

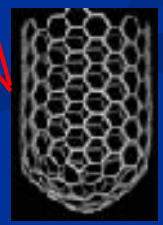




Combine nanoscale building blocks to make novel functional devices, e.g., a photosynthetic reaction center with integral semiconductor storage



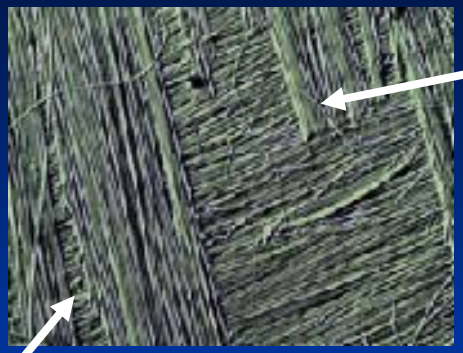
Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip
Corral diameter 14 nm



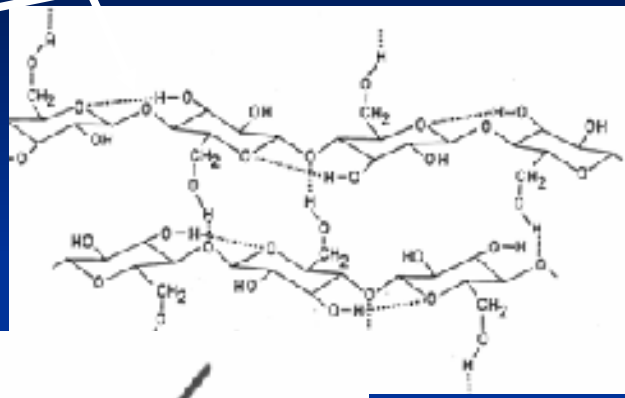
Carbon nanotube
~2 nm diameter

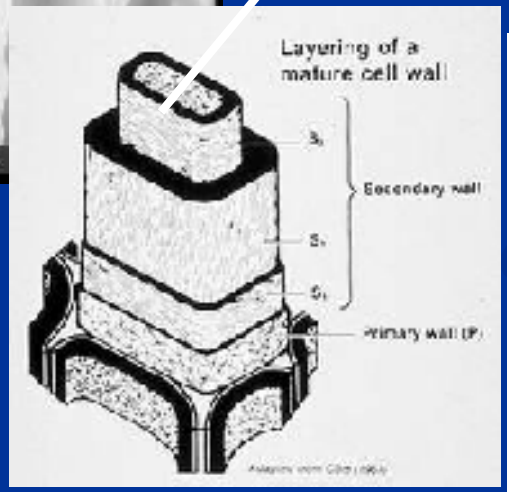
Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 03-05-02

Wood: Nature Working Across a Length Scale >10^{10}!



Cellulose nanofiber bundles





6 Assembly proteins (rosette) which produces cellulose nanofibers

www.ita.doc.gov/td/forestprod/
jupiter.phys.ttu.edu/corner/1999/dec99.pdf

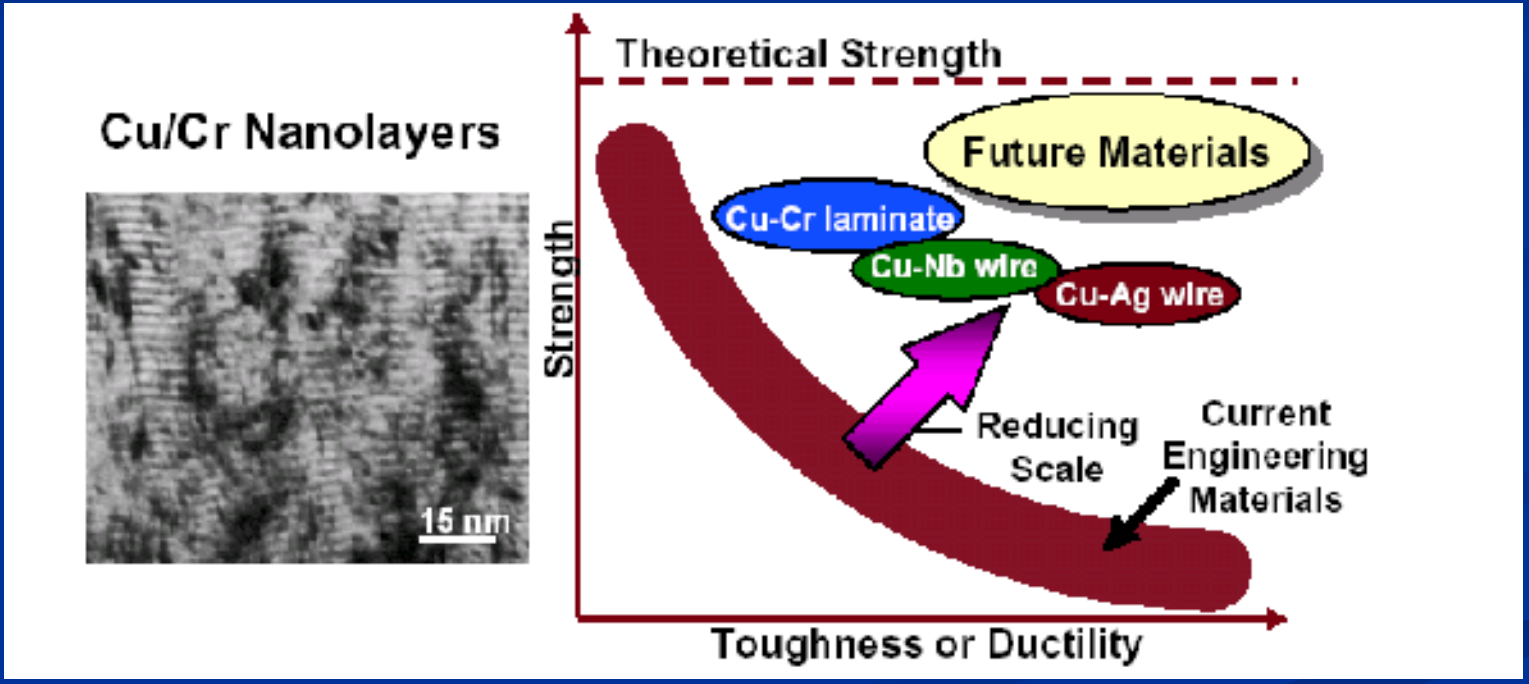
Source: Jeffery Catchmark , Penn State University

Candace Haigler and Larry Blanton, *Cellulose: "You're surrounded by it, but did you know it was there?"*

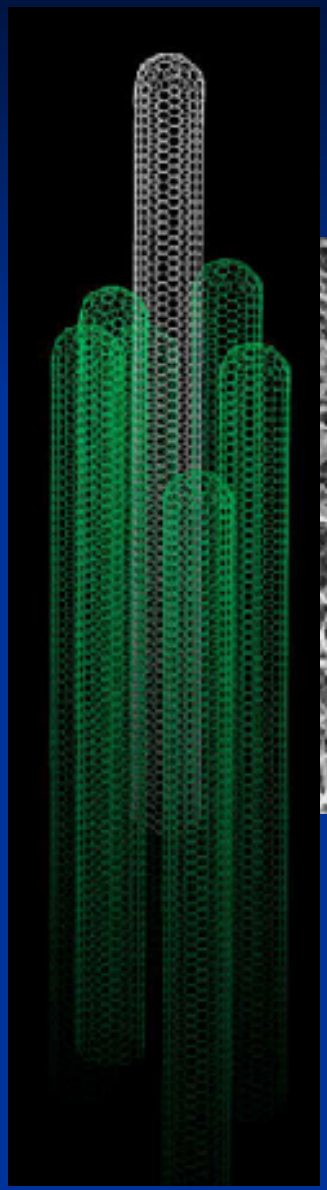
Definition of Nanotechnolgy

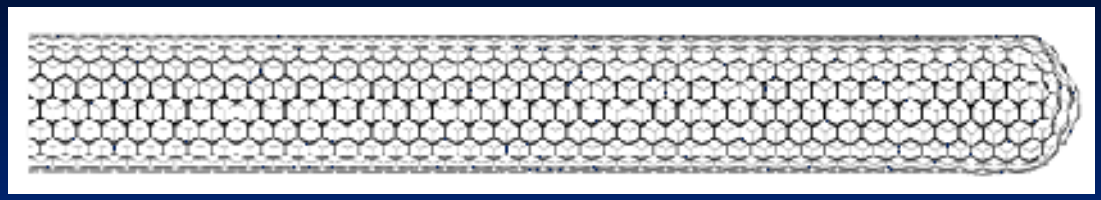
- Scale: 1 nm – 100 nm (nm = billionth of a meter)
- Creating nanoscale size materials does not mean nanotechnology is involved
- Material must have unique properties (e.g. electrical, physical, chemical, optical) that are different that the bulk properties
- Achieving those unique properties must be repeatable and controllable

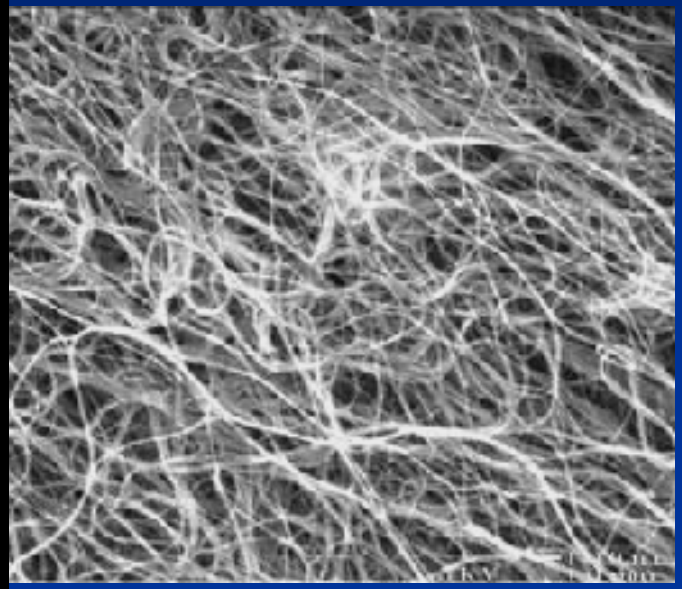
“New” Materials from “Old” Materials

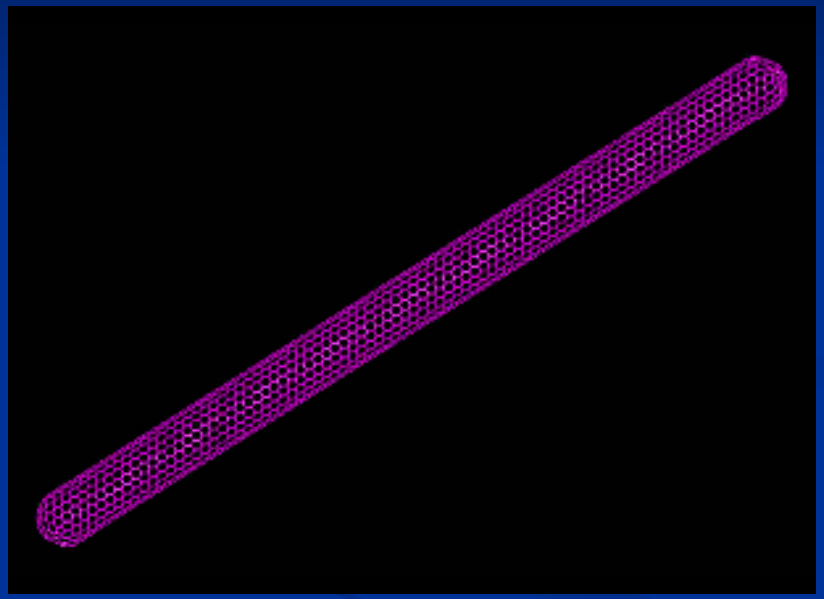


Molecular Perfection: The Fullerene Nanotube



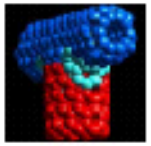


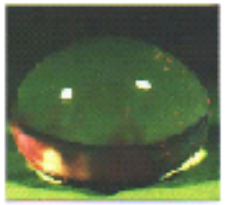




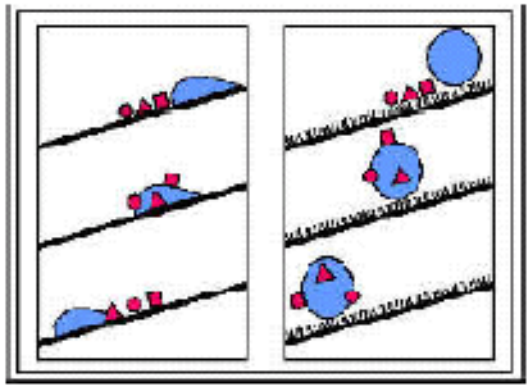
- The strongest fiber that will ever be made
- Electrical conductivity of copper or silicon
- Thermal conductivity of diamond
- The chemistry of carbon
- The size and perfection of DNA
- Can we harness this material?

Self-Cleaning Surfaces: Lotus Effect



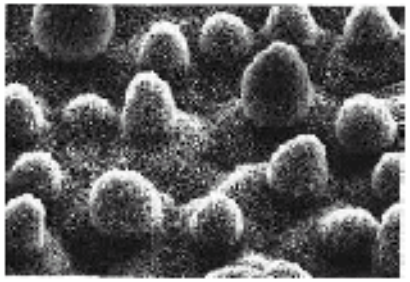


10 mm

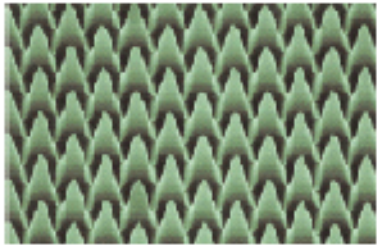


W. Barthlott, Univ. of Hamburg

On a smooth surface the contaminating particles are only moved by the water droplet (left). In contrast to that, on a rough surface they stick to the droplet rolling off the leaf thus being washed off (right).



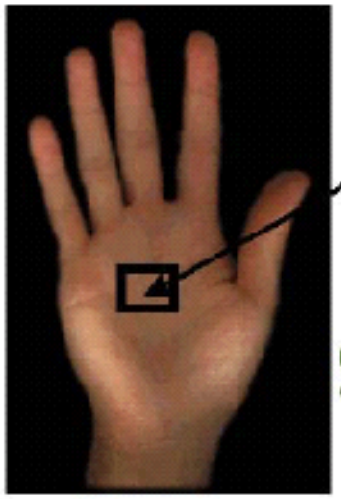
Epicuticular wax



(Source: Metin Sitti, CMU)

ART PROJECT: What does it feel like to be a bridge?

Your Hand



Tactile Nerve Implant

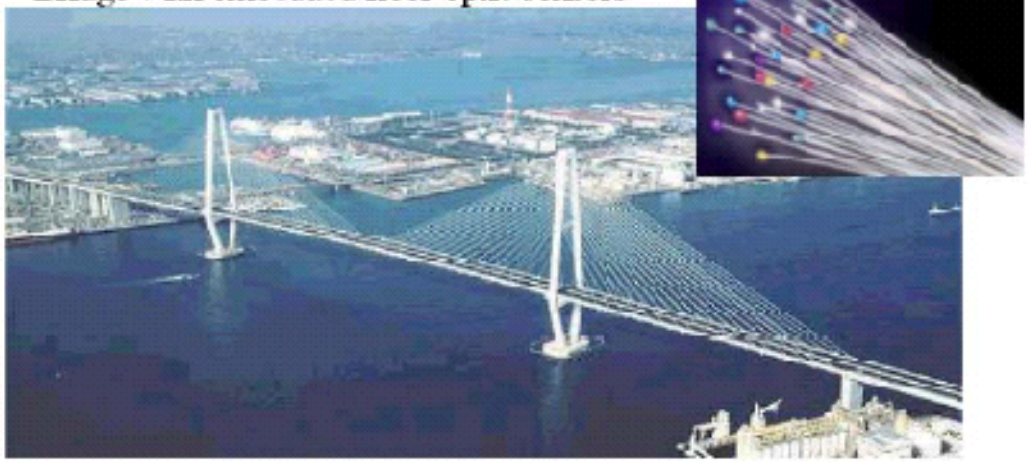
Computer and wireless relay statoin

(2) Processed signal to implant

(1) Signal from bridge sensors.

(3) Hand feels tickly.
"Traffic must be heavy today"

Bridge with embedded fiber-optic sensors



Artist's explorations into the aesthetics of new sensory modalities may shed light on the important cognitive-science question about the nature of "qualia".

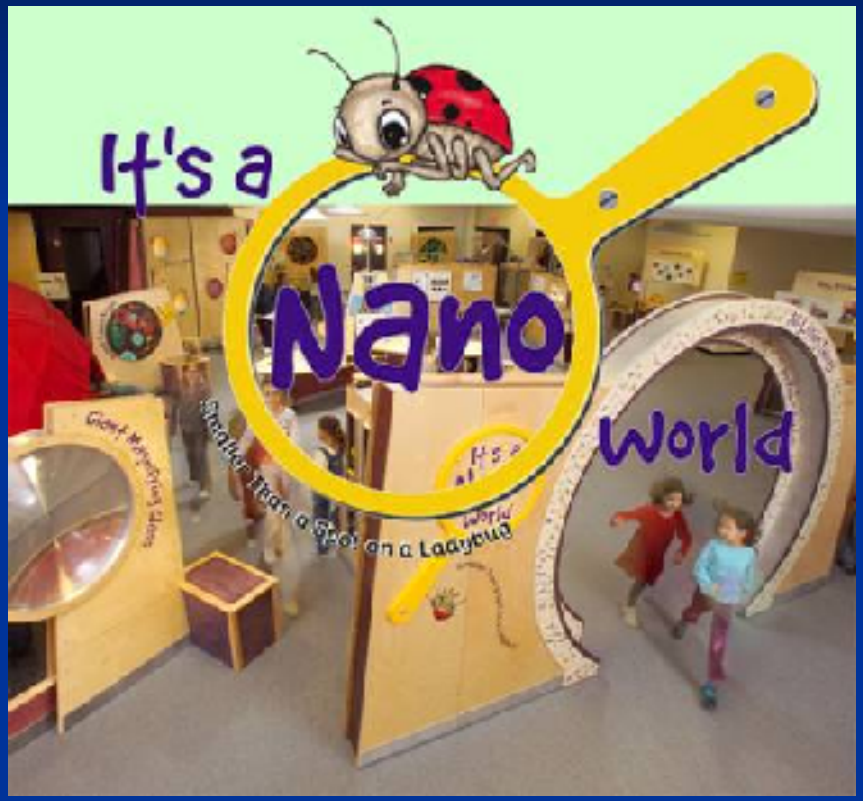
Nanomaterials Opportunities

- Nanomaterials offer the potential for unprecedented material performance that could
  - Solve major societal problems
    - (e.g., energy, medicine, environment, manufacturing, communications, computing, and security)
  - Energize the economy for decades
    - Revitalize existing businesses
    - Boost competitiveness globally
    - Create entirely new industries

Nanotechnology Market Opportunities > $1 Trillion

- Materials (market estimate $340 billion)
- Electronics and Photonics (market estimate $300 billion)
- Medical (market estimate $180 billion)
- Industrial Processing (market estimate $100 billion)
- Power (market estimate $45 billion)
- Agriculture (no estimate available)
- Construction (no estimate available)

US Nanotechnology Program



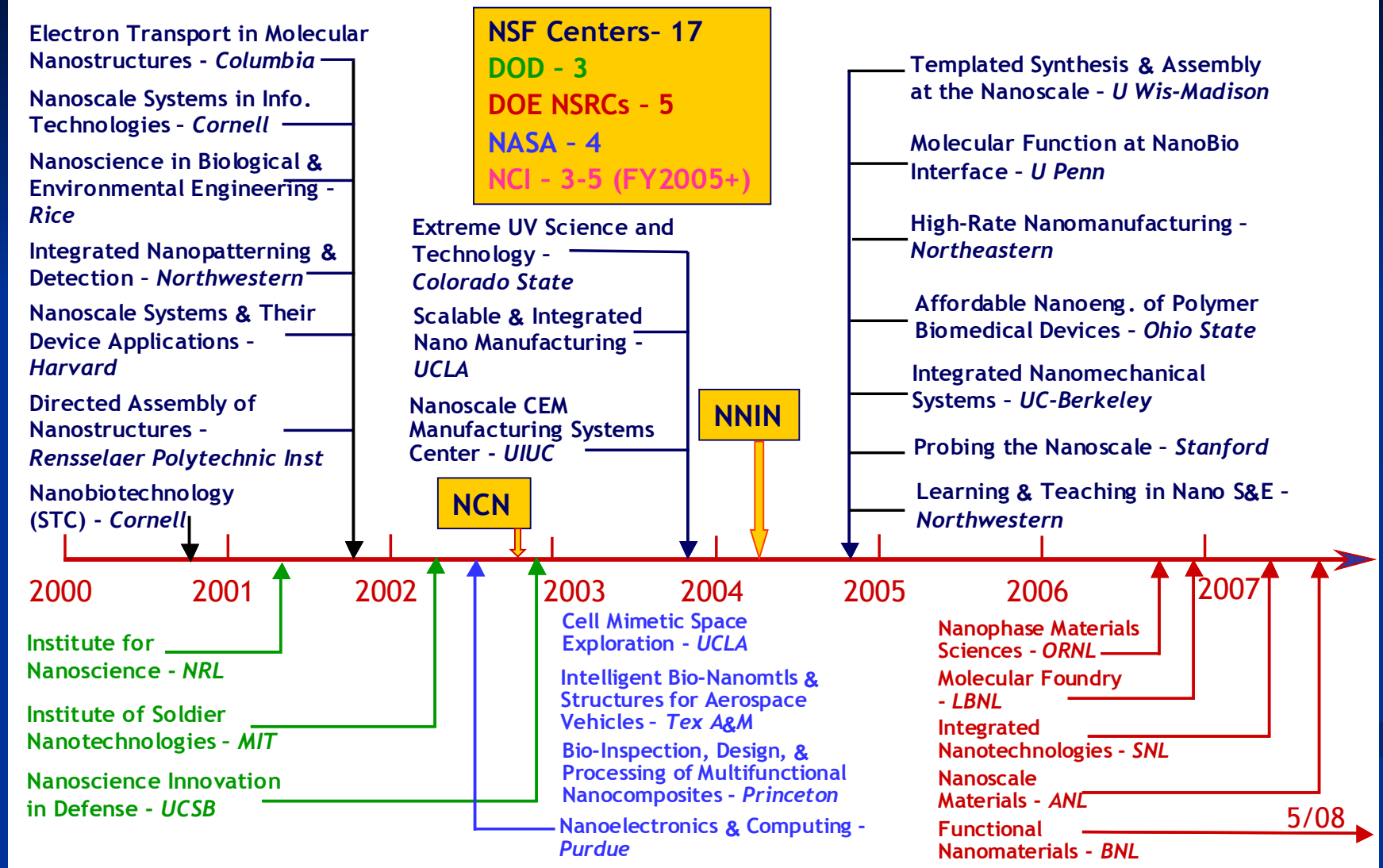
- National Nanotechnology Initiative (NNI) approved 1999 – Office of Science& Technology Policy – National Science & Technology Council
- 21st Century Nanotechnology R&D Act (PL 180-153) December 2003
- Nanoscale Science, Engineering, & Technology Subcommittee

U.S. National Nanotechnology Initiative

(Budget authority, US dollars in millions)

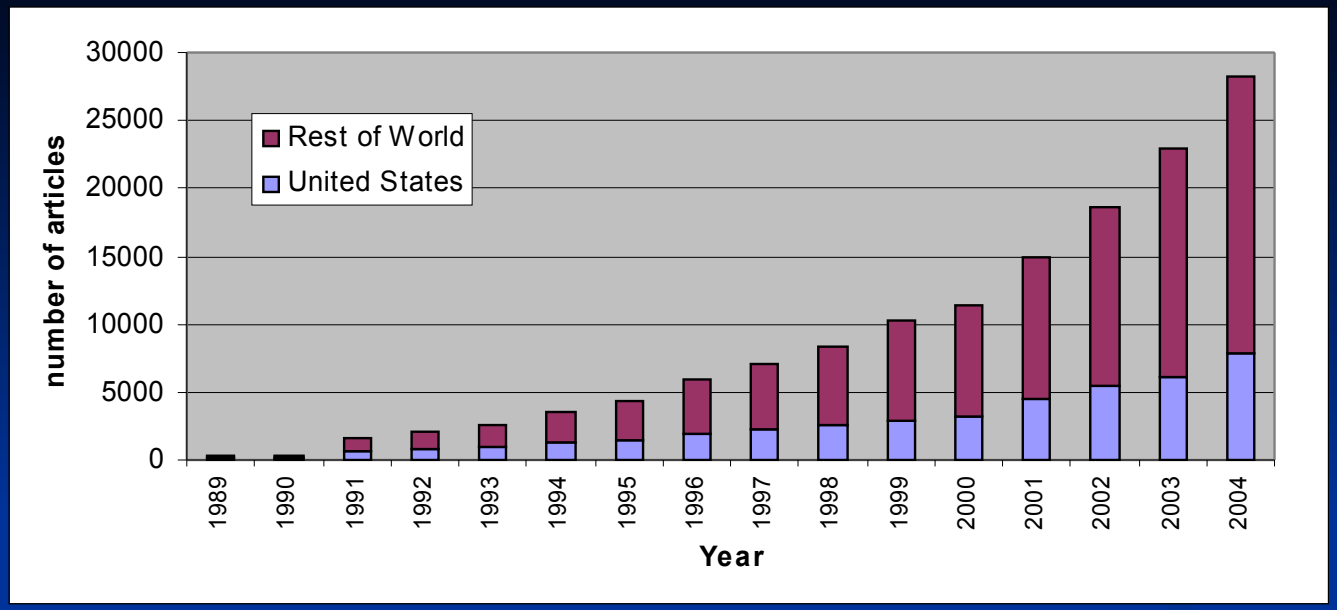
Fiscal Year	2001	2005	2006
National Science Foundation	150	305	344
Defense (DOD)	125	276	230
Energy (DOE)	88	211	207
National Institutes of Health	40	89	144
Commerce (NIST)	33	53	75
NASA	22	35	32
Agriculture (USDA)	0	5	11
EPA	5	5	5
Justice	1	2	2
Homeland Security	0	1	1
TOTAL	464	982	1054

NNI Centers and User Facilities



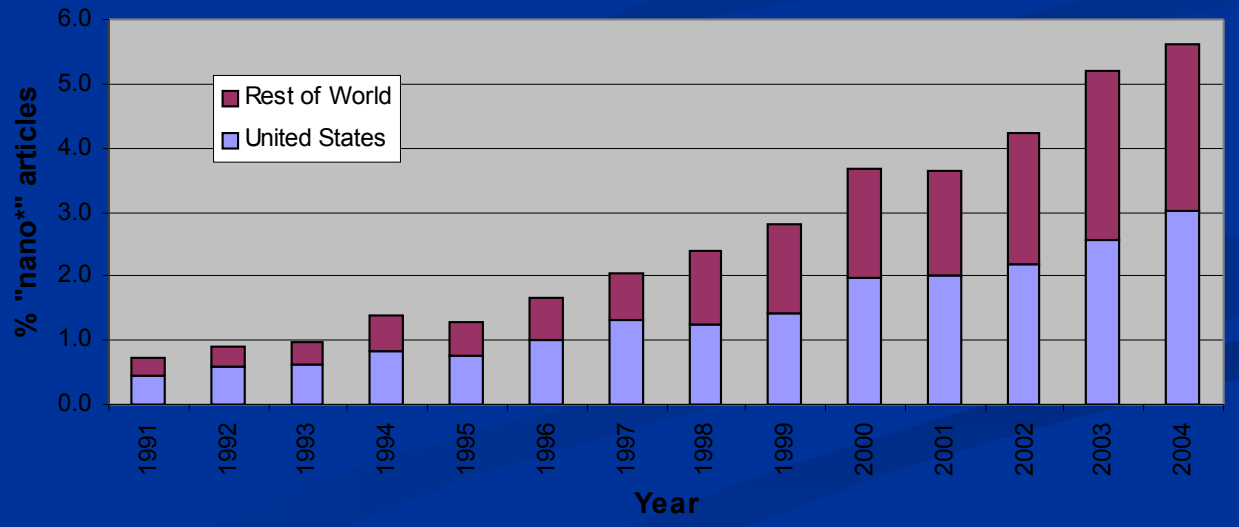
All Nanotechnology Research Papers

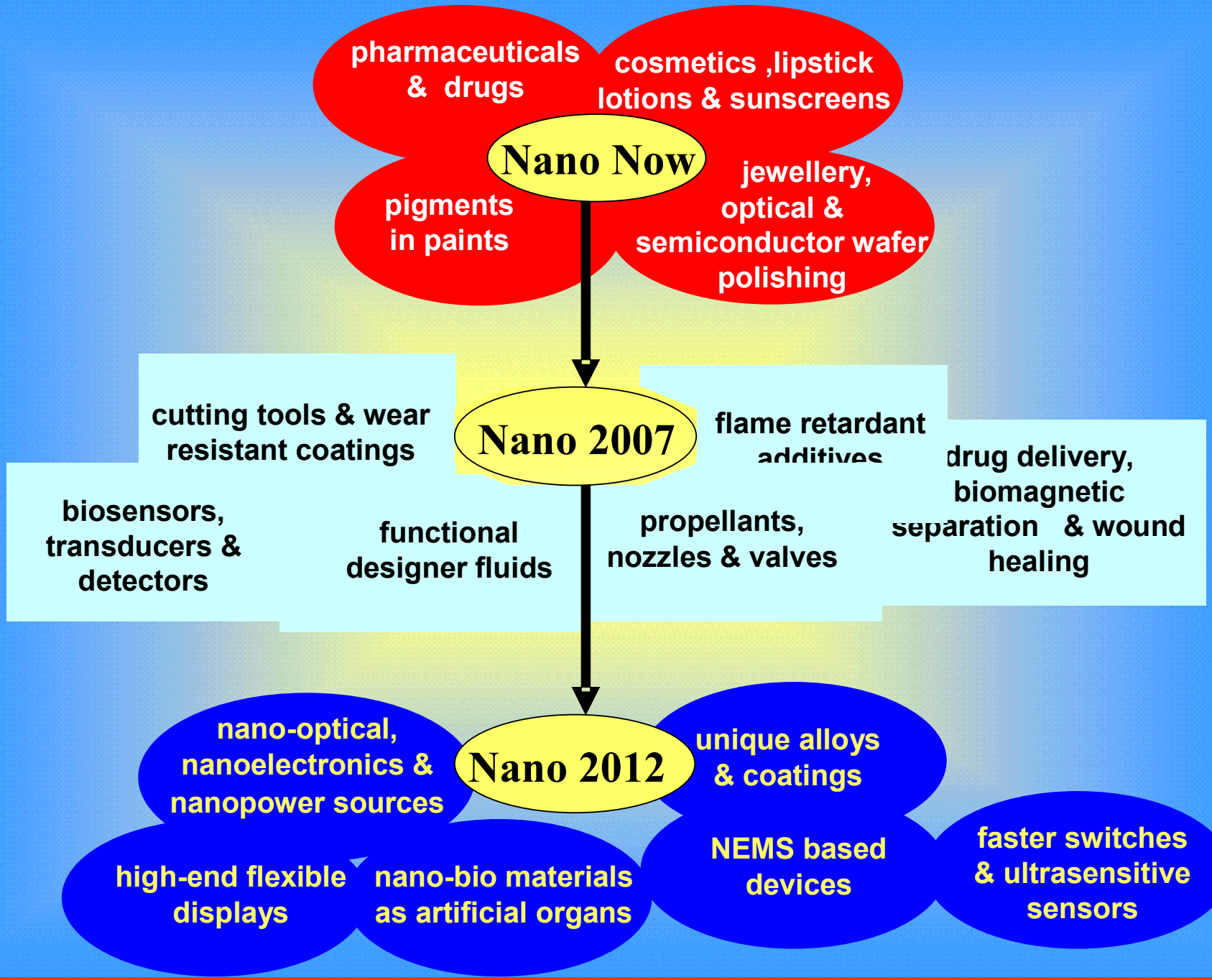
US ~30%



High Impact Journal Nanotechnology Research Papers

US ~ 50%




pharmaceuticals & drugs
cosmetics ,lipstick lotions & sunscreens
Nano Now
pigments in paints
jewellery, optical & semiconductor wafer polishing
cutting tools & wear resistant coatings
Nano 2007
flame retardant additives
drug delivery, biomagnetic separation & wound healing
biosensors, transducers & detectors
functional designer fluids
propellants, nozzles & valves
nano-optical, nanoelectronics & nanopower sources
Nano 2012
unique alloys & coatings
high-end flexible displays
nano-bio materials as artificial organs
NEMS based devices
faster switches & ultrasensitive sensors

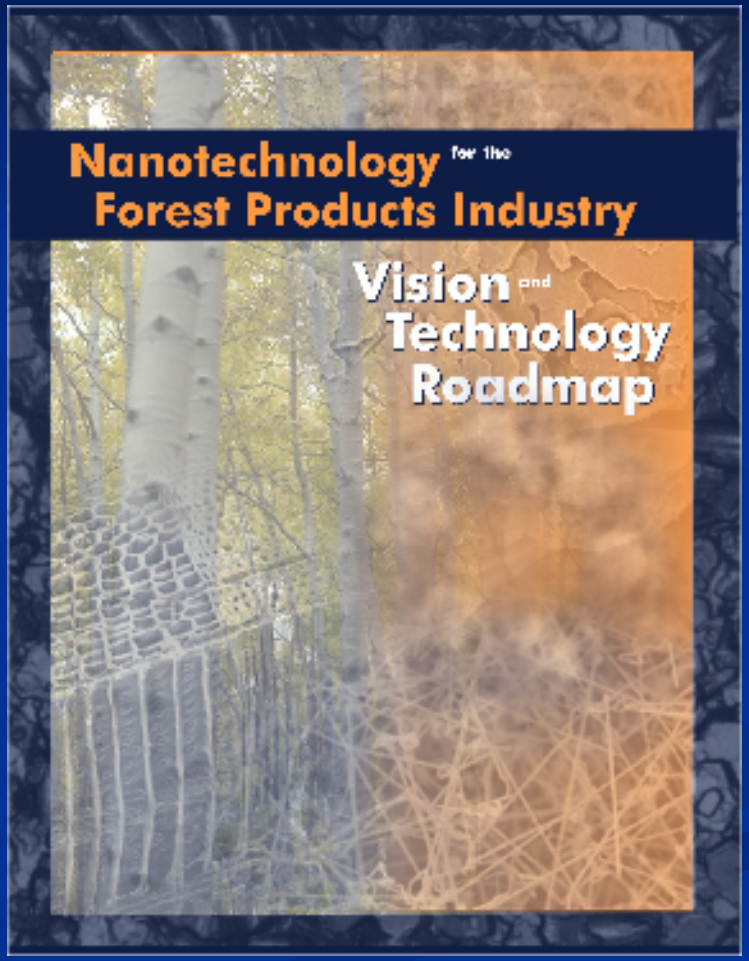
Nanotechnology & Wood

Wood / Lignocellulose

- One of the most abundant biological raw materials-ubiquitous
- Nano-fibrilar structure (source or substitute for nanotubes & nanowires?)
- Self-assembly—controlled
- Lignocellulose as a nanomaterial and its interact with other nanomaterials is largely unexplored
- Capacity to be made multifunctional
- New analytical techniques adapted to biomaterials are beginning to allow us to see new possibilities
- A cornerstone for advancing the biomass-based renewable & sustainable economy

Nanotechnology Workshop

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



Organizing Committee Institutions Represented

- IMERYS
- National Science Foundation
- DuPont
- Georgia Pacific
- MeadWestvaco
- TAPPI
- DOE Pacific Northwest National Laboratory
- Western Michigan University
- International Paper
- PAPRICAN
- Weyerhaeuser
- IPST@ Georgia Tech
- Sappi Fine Paper
- University of Tennessee
- Iowa State University
- USDA Forest Products Laboratory
- Washington State University
- North Carolina State University
- Pennsylvania State University

Nanotechnology Workshop Deliverables

- A vision for nanotechnology in the Forest Products Industry
- A roadmap for nanotechnology in the Forest Products Industry (identify potential applications and uses, identify knowledge gaps and the research needed)
  - Produce output in reader-friendly format

Nanotechnology Workshop Deliverables

- Promote cooperation and collaboration among industry, academia, and government by attracting a diverse group of workshop participants & promoting dialogue
- Make nanotechnology researchers more aware of self-assembling lignocellulosics and opportunities it provides for new generations of novel, high performance, high-value products

Nanotechnology Workshop Concurrent Sessions

1. Polymer Composites & Nano-reinforced Materials *(32)*
   - -Fiber composites/materials
   - -Polymer composites
2. Self-assembly & Biomimetics *(19)*
3. Cell Wall Nanostructure *(17)*
4. Nanotechnology in Sensors, Processing, & Process Control *(15)*
5. Analytical Methods for Nanostructure Characterization *(22)*

Vision Statement from Workshop

To sustainably meet the needs of present and future generations for wood-based materials and products by applying nanotechnology science and engineering to efficiently and effectively capture the entire range of values that wood-based lignocellulosic materials are capable of providing.

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

Research Areas

- Liberating nanofibrils
- Using nanomaterials, nanosensors, etc. to improve the raw material (60% reduction) and energy efficiency (50% reduction) of conversion processes
- Achieve directed design of biopolymer nanocomposites
- Developing biomimetic process for synthesizing lignocellulose nanomaterials
- Utilize self-assembly of nanodimensional building blocks for functional structures & coating
- Biofarming lignocellulosic materials with unique multifunctional properties
- Metrology – Developing instrumentation & properties measurement methodologies for lignocellulosics at the nanoscale

Opportunities for Forest Products

- Durability of sawn materials
  - Preservatives-TiO_2, ZnO, Ag
  - Fire retardants & biocides
  - Coatings & Films-weathering, wear, self-sterilization
- Adhesives (sawn & composites)
- Composites--Nanoclays/fillers as barrier coatings, stiffeners, viscosity modifiers

Opportunities for Forest Products

- Smart building materials—sensors embedded into lumber, panel products, structural composites—moisture, temperature, forces, loads, termites, decay
- Lighter weight, stronger composites

Actions Completed/Next Steps

- Roadmap document completed– March 2005
- Increase linkages with nanotechnology research community
  - National Nanotechnology Initiative (Roco)
    - NSET Participation--Forest Service, FPL
      - Presentation January 11, 2004 (Risbrudt & others)
  - National Science Foundation
    - NSF-NSE Conference (December 13 – 15, 2004)
    - Workshop on "Defining the Opportunities, Challenges & Research Needs for Nano-biomaterials Derived from Lignocellulosics" (SWST/PPERA) (IIIQ 2005)

Next Steps

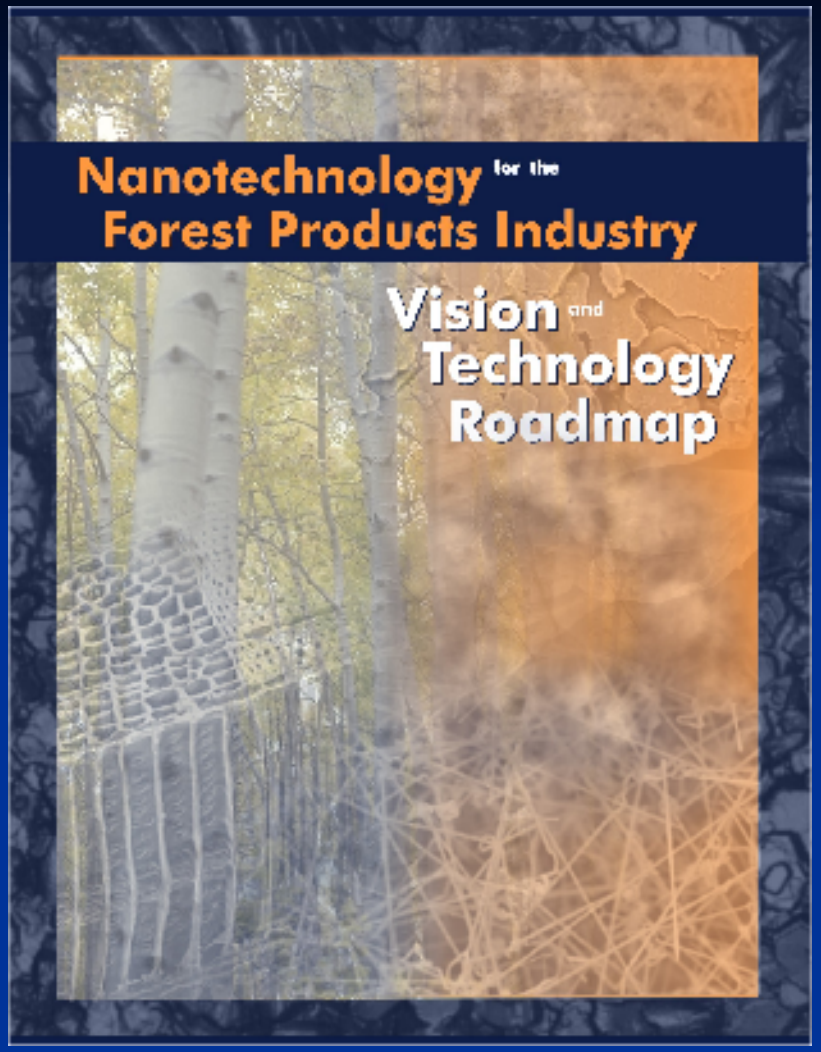
- Continue to build support for forest products sector nanotechnology research --Ongoing
  - Industry
  - Government (USDA FS & CSREES, DOE (Laboratories & Basic Energy Sciences)
  - Academia (SWST, PPERA & others)
- FS-FPL Continued participation on NSET – Ongoing
  - President's Supplemental Budget Listing FY2007

Next Steps-*continued*

- Develop and Implement FS-FPL R&D nanotechnology Program – October 2005
- Develop a Forest Products Industry Steering Committee involving all major stakeholders –IIIQ - IVQ 2005
  - Industry (AF&PA Agenda 2020 & others)
  - Academia (SWST, PPERA & others)
  - Government (USDA FS & CSREES, DoE BES & DOE National Labs, NIST)
  - Develop Consensus on Nanotechnology R&D priorities for the Forest Products Industry (FPI) –IIQ 2006

Next Steps-*continued*

- Link the FPI R&D community to the existing nanotechnology R&D community – Ongoing
  - Visits to NSF & DOE Nanotechnology Research Centers
  - Organize a US Nanotechnology Technical Conference– IIQ/IIIQ 2006
  - 2nd International Conference on Nanotechnology in Construction--November 2005
- Develop a portfolio of short-, mid-, and long-term R&D focused on the areas most critical to commercial production of nanomaterials and nanoproducts -- TBD
- Seek to establish a $40 - $60 million per year R&D program for the FPI -- TBD



www.swst.org

www.nano.gov

www.nanotechforest.org

www.fpl.fs.fed.us

Questions?