Nanotechnology Enabled Biomaterials and Bioproducts: Clean, Green and More?

Lori Sheremeta, LL.M.

UNIVERSITY OF ALBERTA

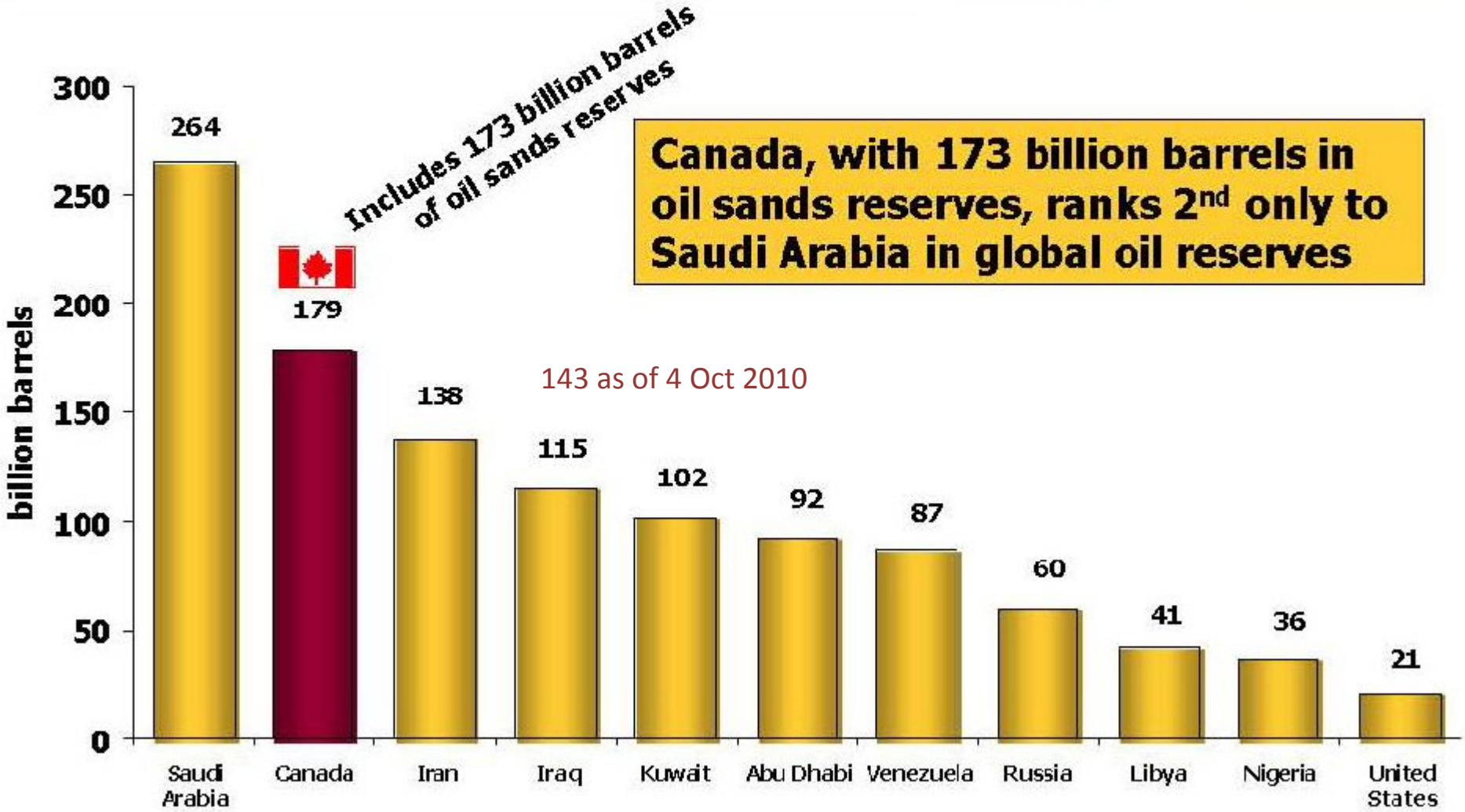
ENGINEERING UofA

Alberta Innovates Technology Futures

National Research Council Canada
National Institute for Nanotechnology

Conseil national de recherches Canada
Institut national de nanotechnologie

Global Crude Oil Reserves by Country



Source: Oil & Gas Journal Dec. 2007

Current Challenges

- Climate change/global warming
- Oil sands (and implications of continuing oil and gas exploitation)
- Lagging forest and agricultural sectors
- Nanotechnology (↑societal relevance)

Bad Press

"Ducks the new symbol of oil sands activism

Global increases in CO_2 concentrations are due primarily to fossil fuel use ... <u>IPCC at 37</u>.

RETHINK**ALBERTA**

Welcome to Alberta

Welcome
Traveler's Quiz
Things You Can Do
Things to Know
Alberta Facts
Press

Things You Can Do

Take the Pledge:

Take the pledge not to visit Alberta and tell your friends and family to do the same.

I pledge not to visit the province of Alberta until the Alberta Government does the following:

a. Halts the expansion of the Tar Sands.
b. Stops spending millions of dollars on public relations campaigns designed to keep the United States addicted to dirty Tar Sands oil.
c. Takes meaningful steps to transition its economy away from dirty Tar Sands oil to clean energy alternatives.

Signed,

Name:
Email:
Submit

Want to do more? Go to dirtyoilsands.org/action.

SPREAD THE WORD

Join us here:

Share this site:

More services

WHO WE ARE

Rethink Alberta is brought to you by an international network of citizen and indigenous groups that oppose the expansion of the Alberta Tar Sands and advocate for its cleanup, including:

UK TAR SANDS network

CORPORATE ETHICS

http://rethinkalberta.com

Corporate Ethics International

BP

Forest Sector in Canada & US

- Commodity based industry hit by worst recession in generations
- Increasing global competition
- Obvious opportunity to integrate bio-product opportunities within the industry's traditional operations.
- The game is changing; technological solutions are needed.

Nanotechnology: Market Potential

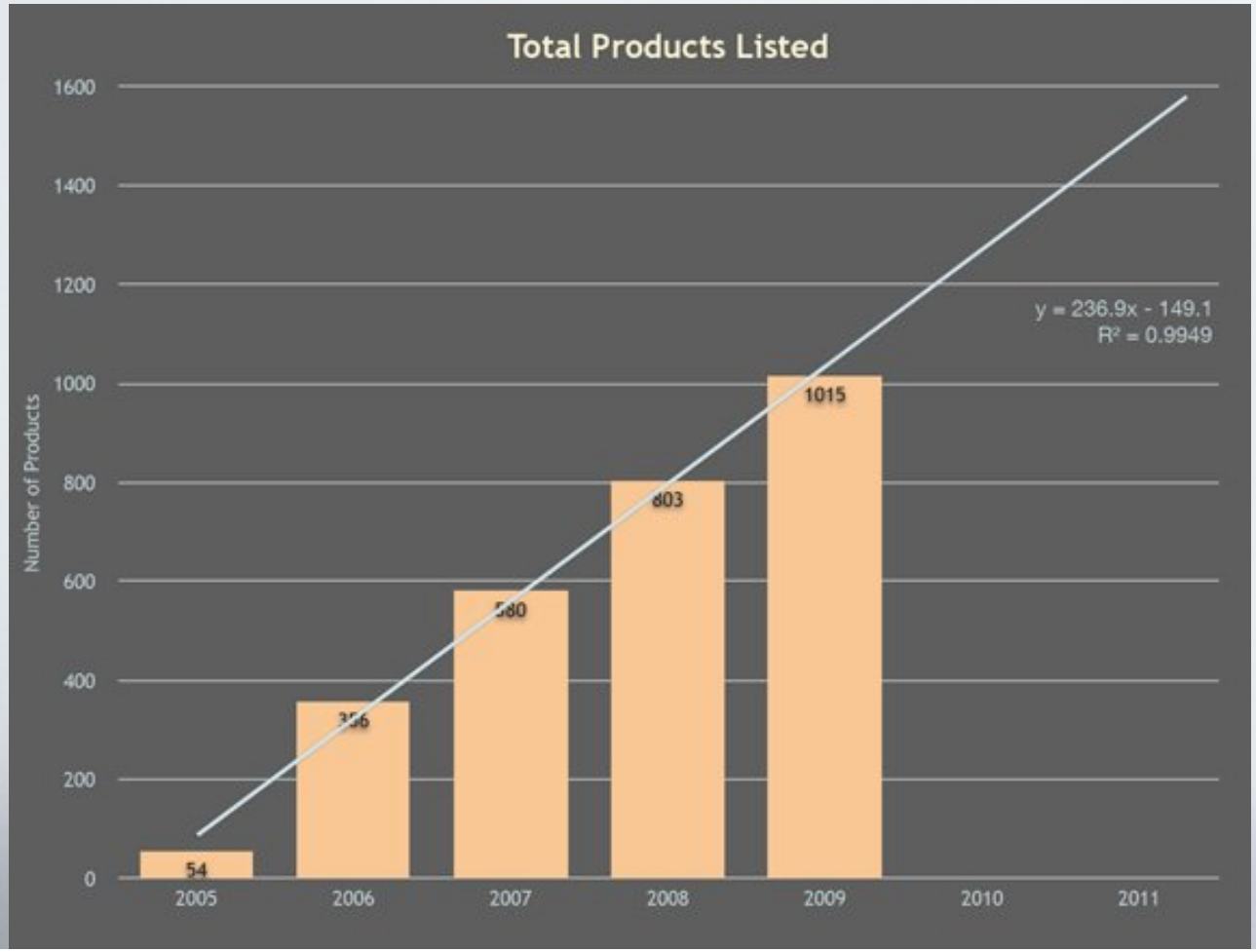
- Lux Research estimates of the global market for goods incorporating nanotechnology -
    - 2005 - $32 B
    - 2007 - $14 7B
    - 2015 – anticipated market: $3.1 T
- Number of nano-based products on market (and patent filings) have rapidly increased

Nano-Enabled Biomaterials and Bioproducts

Clean, Green & More

http://www.nanotechproject.org

Marketed Nanotech Products



Alberta's Commitment to Nanotechnology

- Alberta Nanotechnology Strategy, May 2007
- $130M/5y – expand research capacity and develop new commercial applications to support Alberta's traditional economic strengths
- **Goal:** Capture $20B market share of world's NT market by 2020

Nanotechnology Opportunity Assessment for Alberta

- If you had $100M to invest in Alberta, on one large scale initiative in the broad area of nanotechnology, what would you invest in?

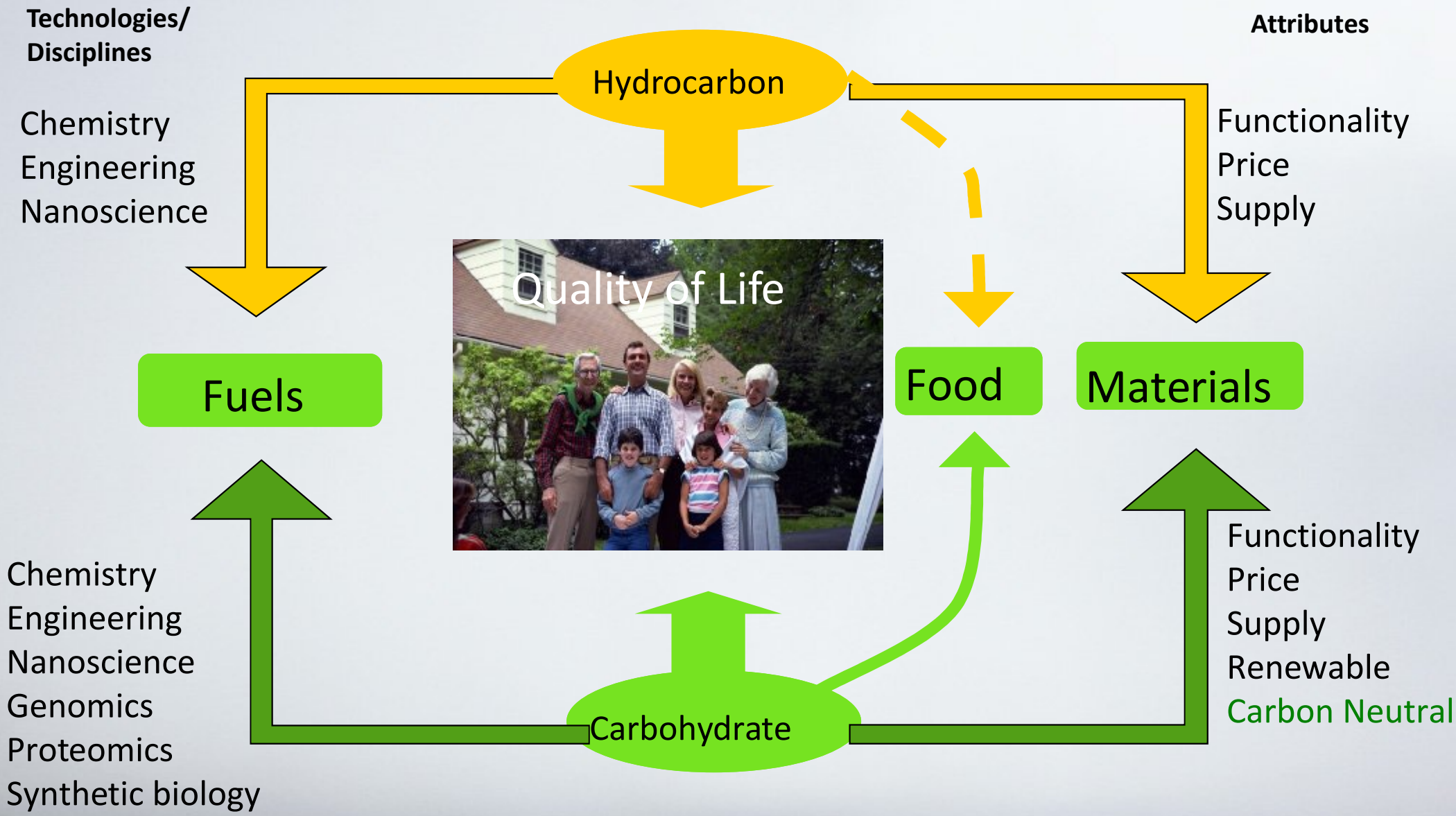
- Bear in mind that Alberta aims to:
- Diversify its economy;
- Become a world leader; and
- Accrue durable benefits to Alberta

"Nano-Enabled Biomaterials"

Extracting Value from Alberta's Vast Biomass Resource

- ***Biomass Conversion*** *– nano-enabled manufacture of chemicals, polymers and value-added materials from renewable biomass (biofuels + co-products).*
- ***Programmed Assembly of Biomaterials*** *– incorporation of biological tools to create functional membranes, biocatalysts, smart surfaces, sensors, electronics or photovoltaic devices.*
- ***Liberation of Naturally occurring bionanomaterials*** *– extraction of nanoscale biomaterials from natural sources (e.g. nanocrystalline cellulose, nanofibrillar cellulose from plants/algae).*

Why? ... Diversification, and Environmental Stewardship & Sustainability

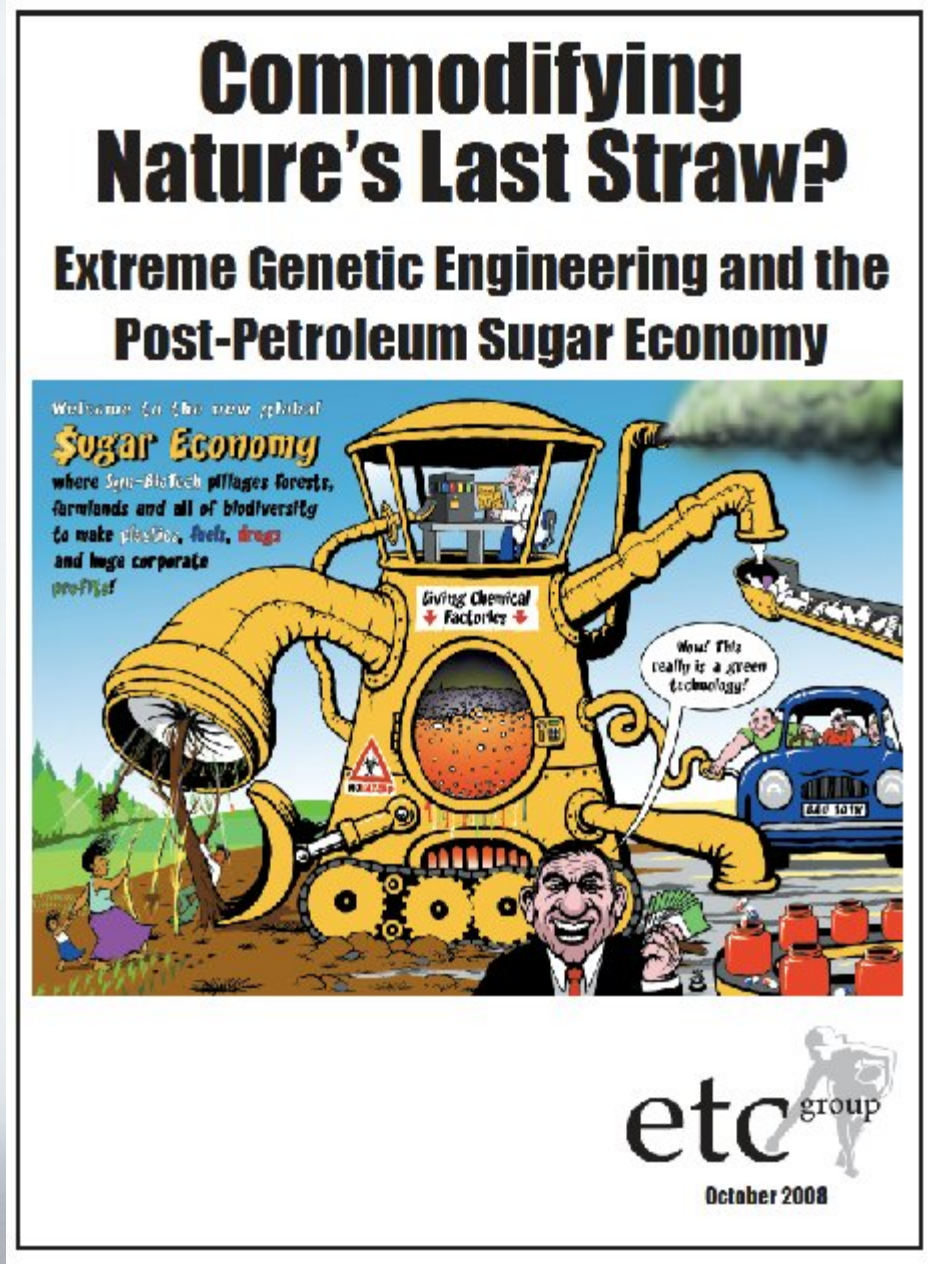


Adapted from Alberta Ingenuity Fund Retreat, August 2008

ETC Group, Canada

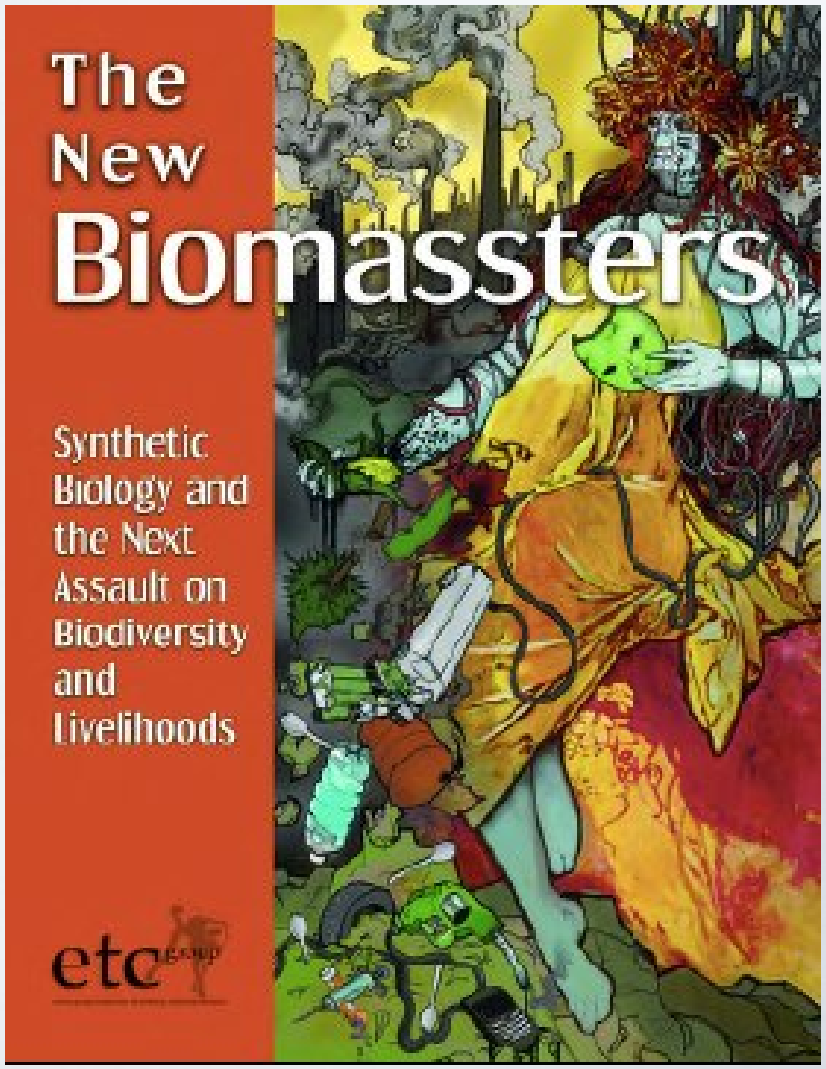
- Corporate enthusiasm for "biological engineering revolution."
- Skeptical of greener, cleaner post-petroleum future
- "Sugar Economy" will be catalyst for corporate grab on all plant matter.
- Enunciation of who the players are

http://www.etcgroup.org



ETC Group, 2010

- Food, energy and natural security are at stake
- Switching of petrochemical feedstocks to biomass
- Corporate interests: Energy, chemical, plastics, food, textiles, pharmaceuticals, paper products and building industries – plus the carbon trade ($17T combined market)
- Land use, biological diversity, environment, human well-being will be adversely impacted
- Exacerbation of North-South divide



http://www.etcgroup.org

ETC Group, 2010

Selling the switch

- Sugar dreams: The carbohydrate economy = $$$$$
- Green dreams: ‘Renewable resources’ and the hydrogen economy
- Cool dreams: The carbon neutral economy
- Patriot dreams: Energy independence
- Leapfrog dreams: Clean development and ‘green jobs’ movement
- **Geek dreams:** converging technologies and ‘cleantech’

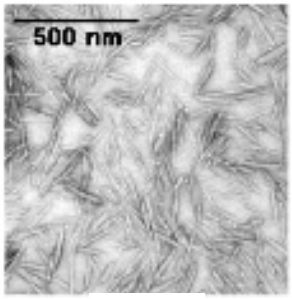
http://www.etcgroup.org

Nano-Crystalline Cellulose

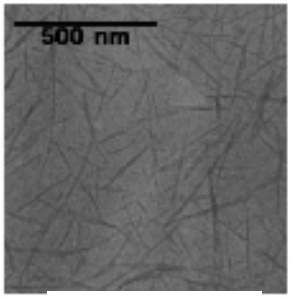
- Cellulose is integral part of tree's composition; pulp/paper is essentially made from cellulose fibres
- Nanoscale blocks of cellulose can be released through acid hydrolysis of cellulose resulting in NCC
- Many applications within and outside the pulp/paper industry: composite materials, biocomposites for regenerative medicine, pharmaceuticals, food packaging, food fillers …

General Characteristics

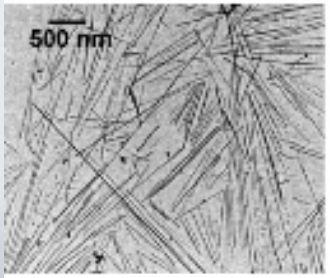
- Renewable
- Available from multiple sources
- Relatively low cost
- Low density; high specific strength
- Readily functionalized
- Supportive of nonfood agricultural economy
- Biodegradable?



Cotton



Sugar-beet pulp



Tunicin

Samir *et al*, Biomacromolecules 2005, 6: 612-26.

NCC Production in Canada: Present and Future

- **FPInnovations** – Quebec plant, in house production, 1kg/day (current); 1tonne/day by 2012
- **Alberta Innovates-Technology Futures** – Alberta plant, in house production, 1kg/week (current); 10kg/week (by end of 2011)
- **Biovision Technology Inc.** – Nova Scotia (NRC Partnership)

Key Question: Is NCC safe?

- Preliminary data suggests that it just might be …
- But, each nanomaterial must be evaluated on a case-by case basis
- Overall experience with toxicology testing of carbon nanotubes raises many issues

Nanotoxicology, September 2010; 4(3): 255–270 informa healthcare

An ecotoxicological characterization of nanocrystalline cellulose (NCC)

TIBOR KOVACS[1], VALERIE NAISH[1], BRIAN O'CONNOR[1], CHRISTIAN BLAISE[2], FRANCOIS GAGNÉ[2], LAUREN HALL[3], VANCE TRUDEAU[3], & PIERRE MARTEL[1]

[1]*FPInnovations – Paprican Division, Pointe-Claire, QC,* [2]*Environment Canada, Fluvial Ecosystem Research, Aquatic Ecosystem Protection Division, Montreal, QC, and* [3]*University of Ottawa, Centre for Advanced Research in Environmental Genomics, Department of Biology, Ottawa, ON, Canada*

Results

- Preliminary ecotoxicological characterization of NCC: no serious environmental concerns.
- But, further testing needed to complete the risk assessment for NCC.
- In Canada, this study represents an important proactive collaboration between industry, government and academia to ensure the responsible development of nanotechnology.
- Collaboration with NTP is developing. **Need additional sources of NCC for comparative assessment.**

Main Policy Challenge

- Maintaining public trust
- Opposition to oil sands exploitation on one hand and nanotechnology, genomics, synthetic biology on the other
- How to identify and assess risk(s) of doing (or not doing) something?
- Expect that something will go wrong
- Public trust is not unconditional
- Need a sound strategy to develop science to inform the multiple layers of the debate
- Difficult given that we can’t identify the base materials or the potential products at this time.

Acknowledgments

- University of Alberta/National Institute for Nanotechnology
- Alberta Innovates – Technology Futures
- Advanced Food and Materials Network

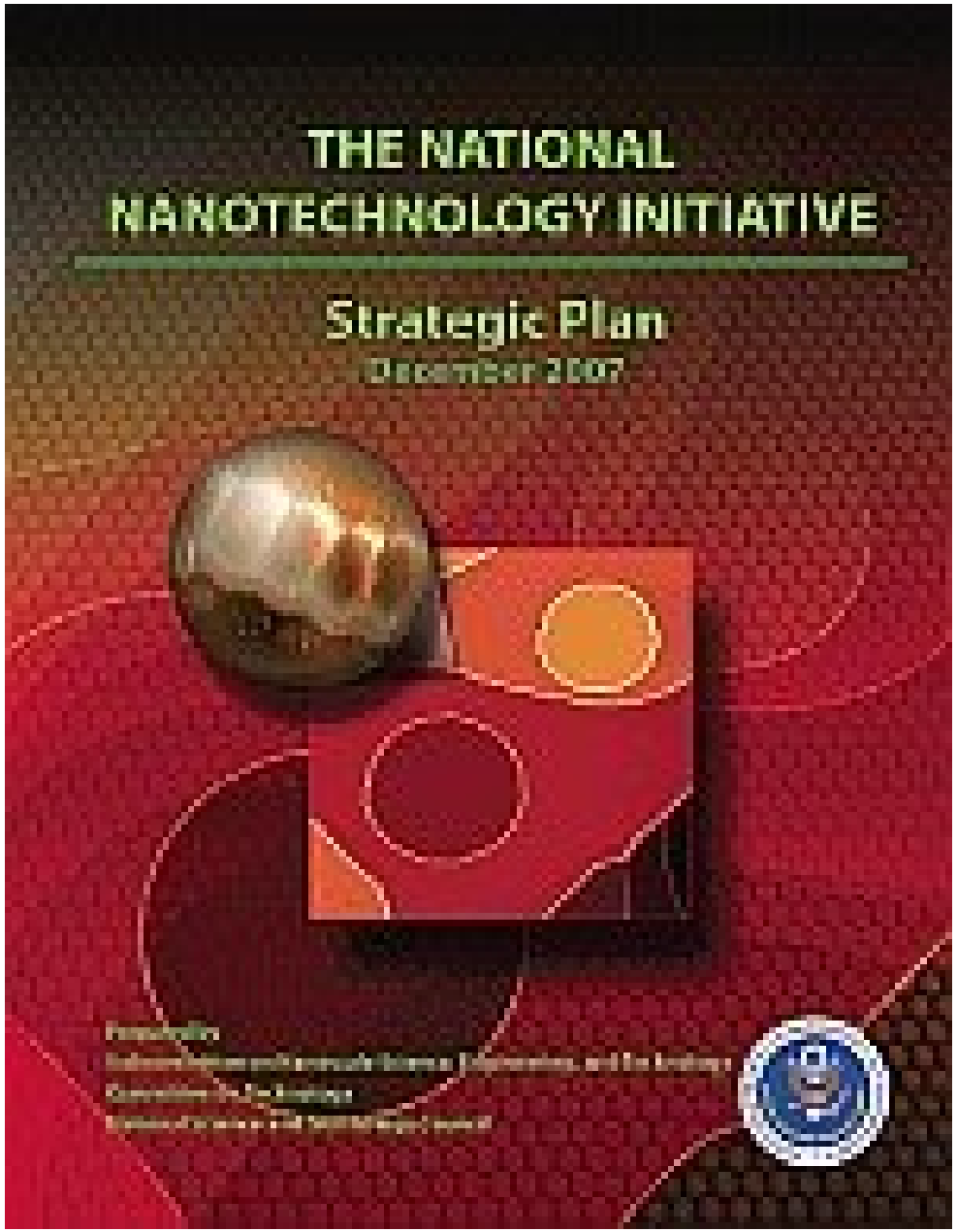
Nanotechnology-enabled Sensing

Summary of the NNI-sponsored Workshop

Roger van Zee
National Institute of Standards & Technology
Gaithersburg, Maryland

roger.vanzee@nist.gov

NATIONAL
NANOTECHNOLOGY
INITIATIVE



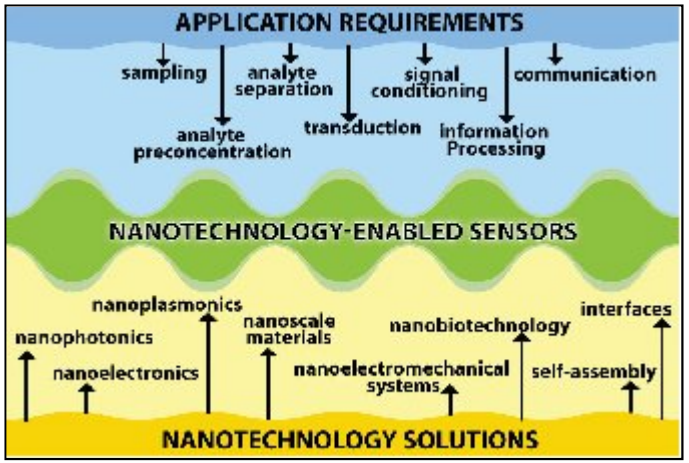
The Workshop

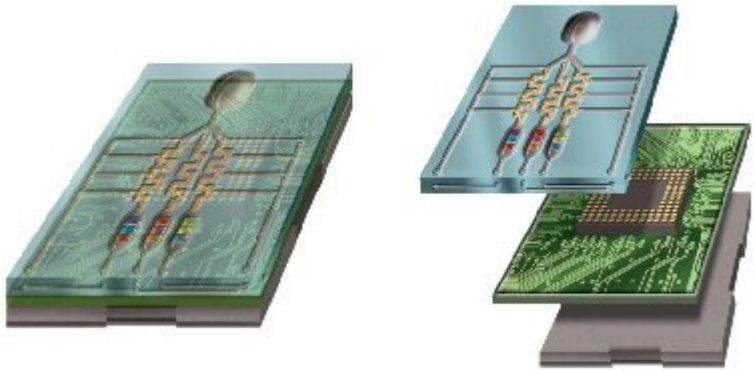
- What is the state-of-the-art.
- Identify and rank the scientific challenges and technical hurdles.
- Looking forward:
  - Identify visionary research targets.
  - Establish tangible measures of progress towards those targets.
- Recommend strategies to address the identified opportunities, challenges, targets and hurdles.

Outline

- Background
- Workshop findings
  - State-of-the-art
  - Transducers
  - Fabrication
- Other Issues

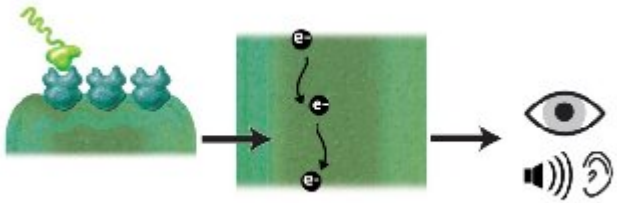
Background


APPLICATION REQUIREMENTS
sampling
analyte separation
signal conditioning
communication
analyte preconcentration
transduction
Information Processing
NANOTECHNOLOGY-ENABLED SENSORS
nanoplasmonics
nanophotonics
nanoscale materials
nanobiotechnology
interfaces
nanoelectronics
nanoelectromechanical systems
self-assembly
NANOTECHNOLOGY SOLUTIONS



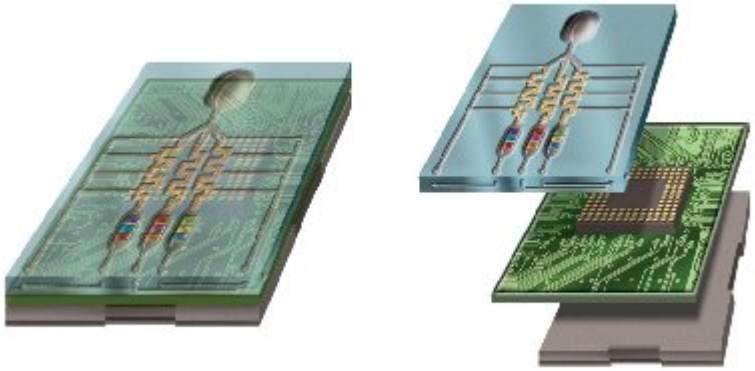
Sensors & Sensing Systems?

Sensor



Transforms a recognition event into an output (transduction).

Sensing System

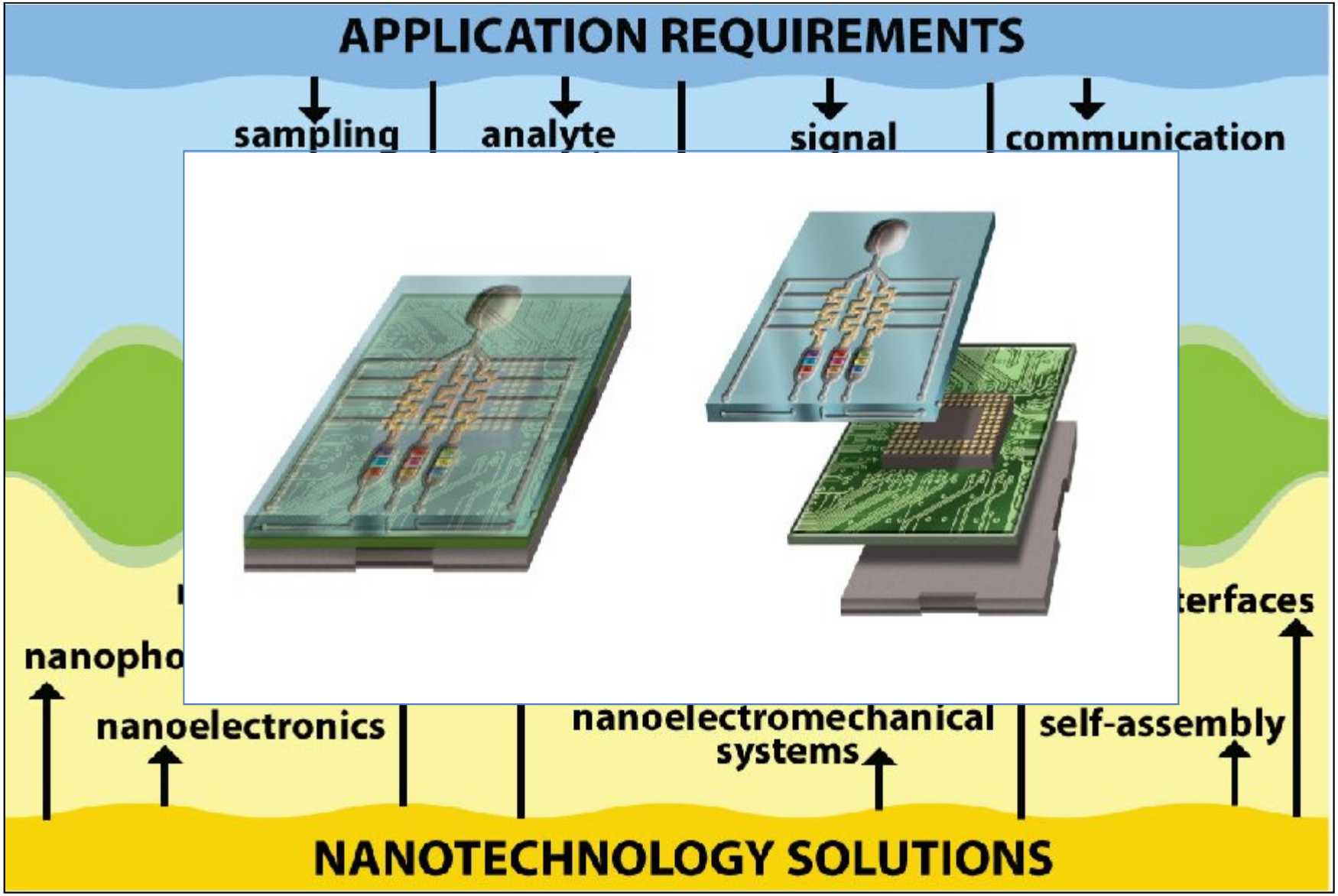


Integrates sampling, transduction, power and processing capabilities into a system.

Analyte -- Substance (chemical, protein, etc.) that is being sensed.

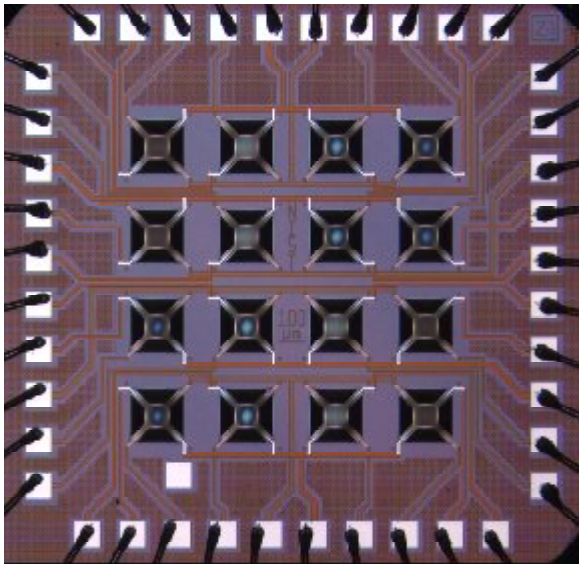
Transducer -- A material or device that converts a recognition event into a measurable physical phenomenon, such a change in electrical resistance.

Nanotechnology-enabled Sensing



State-of-the-Art

Directions

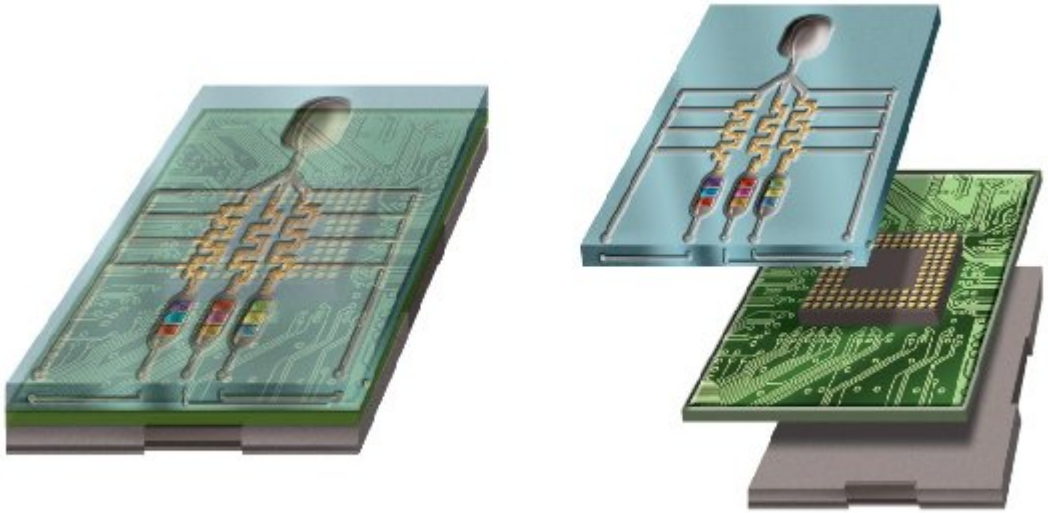


S. Semancik, NIST.

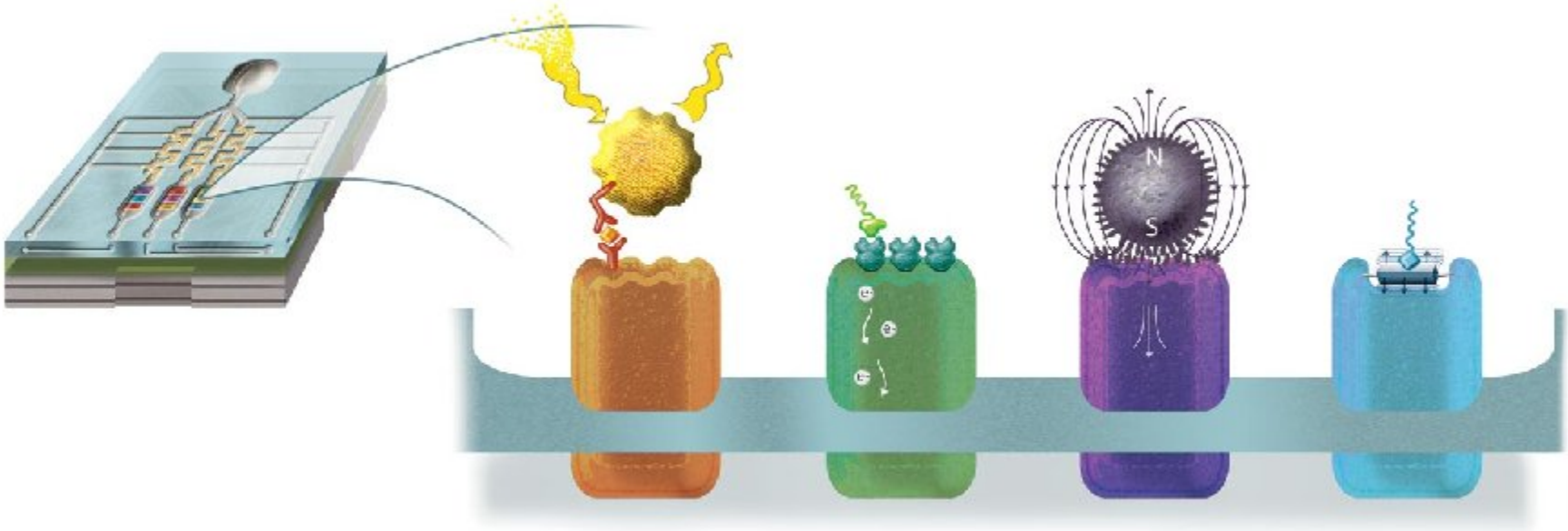
- Targeted Transducers
- Multiplexing
- Multiparameter, orthogonal transducers
- Built on silicon fabrication technology

Ongoing Challenges

- Drift & Fouling
- Preconcentration
- Signal processing
- Integration/materials processing
- Modeling

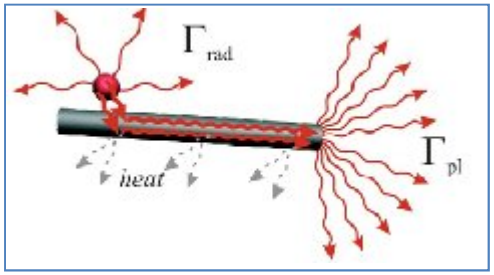


Transducers

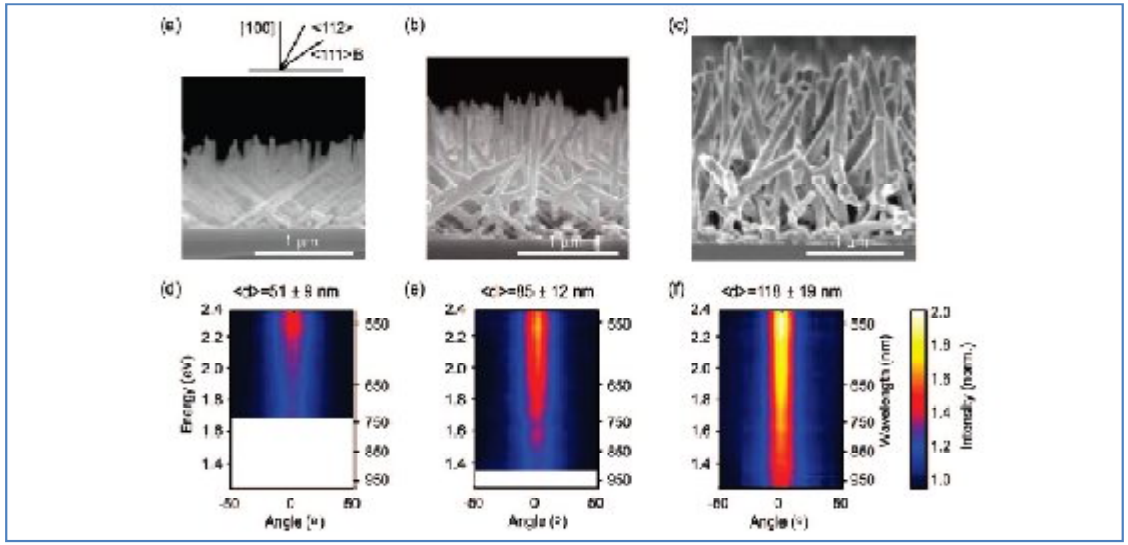


- Electro/Chemical
- Electromagnetic
- Spectroscopic
- Magnetic
- Mechanical

Electromagnetic Transduction



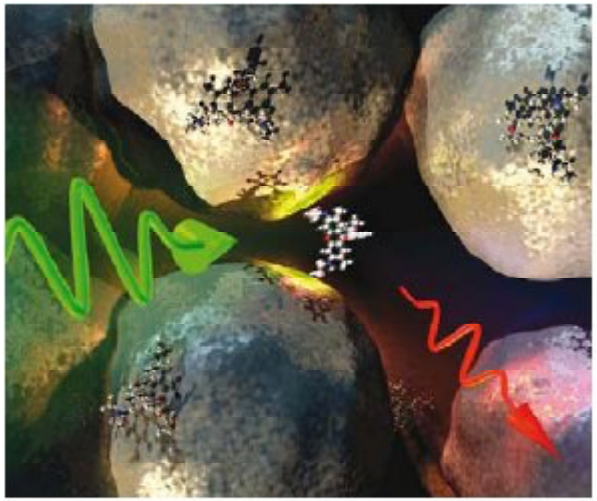
Akimov et al., Nature, **450**, 402



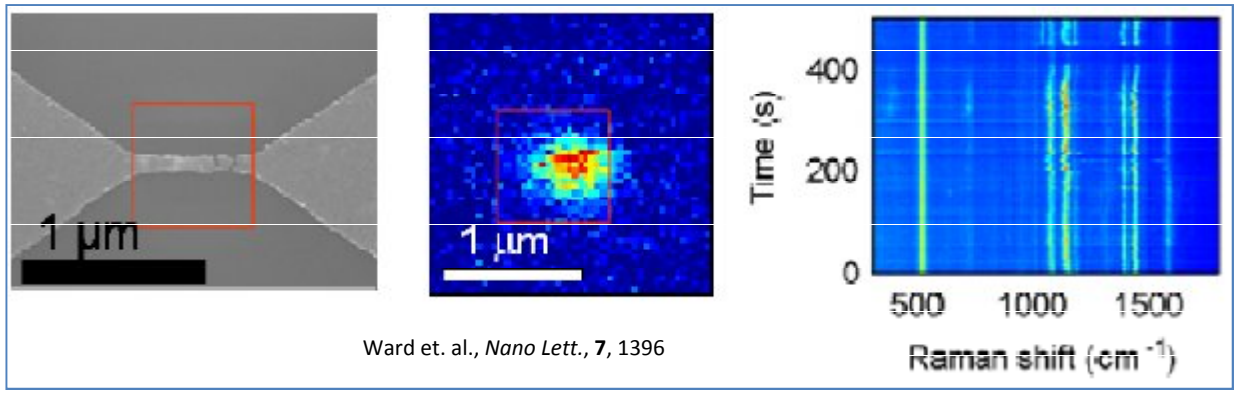
Mumskens et al., *Nano Lett*, **9**, 930

- **Research Needs**
  - Multifunctional materials
  - Impedance matching
  - Thermal control
  - Fabrication
- **Directions**
  - Chip-scale fabrication
  - Integration of silicon with III-V compounds

Spectroscopic Transduction



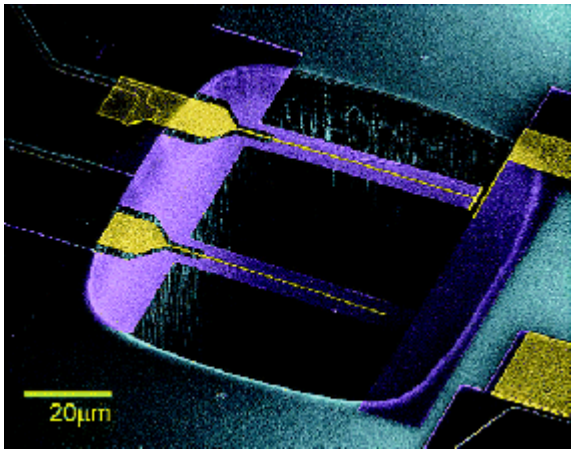
Etchegoin, *Phys. Chem. Chem. Phys*, **10**, 6079



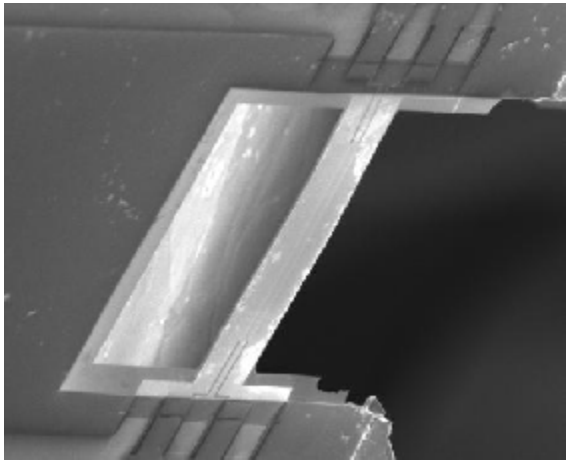
Ward et. al., *Nano Lett.*, **7**, 1396

- **Research Needs**
  - Metamaterials
  - Dispersion
  - Light delivery
  - Fabrication
- **Directions**
  - Stable SERS & SEIRA substrates
  - Multiplexed sensing

Mechanical Transduction



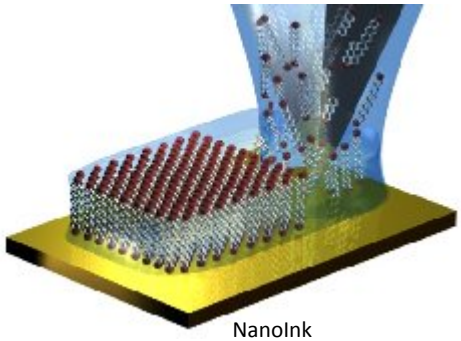
Arlett et. al., *Nano Lett.*, **6**, 1000



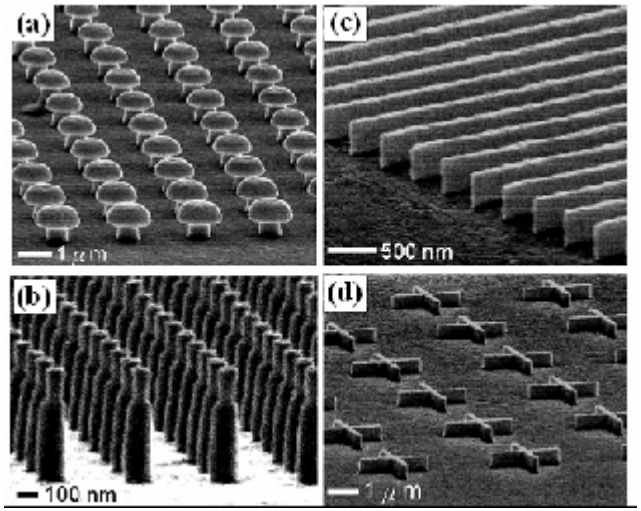
http://ornl.gov/adm/partnerships/factsheets/2066.pdf

- **Directions**
  - Orthogonal detection
  - Photothermal detection
- **Research Needs**
  - Fabrication
  - Coupling with other methods (e.g. spectroscopic)

Fabrication

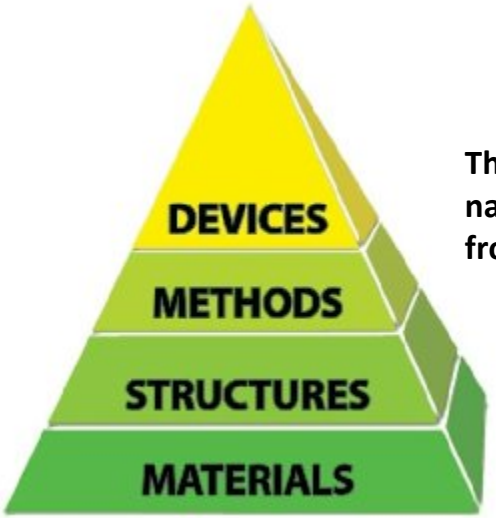


NanoInk



Advanced Materials, **15**, 49

Fabrications Issues

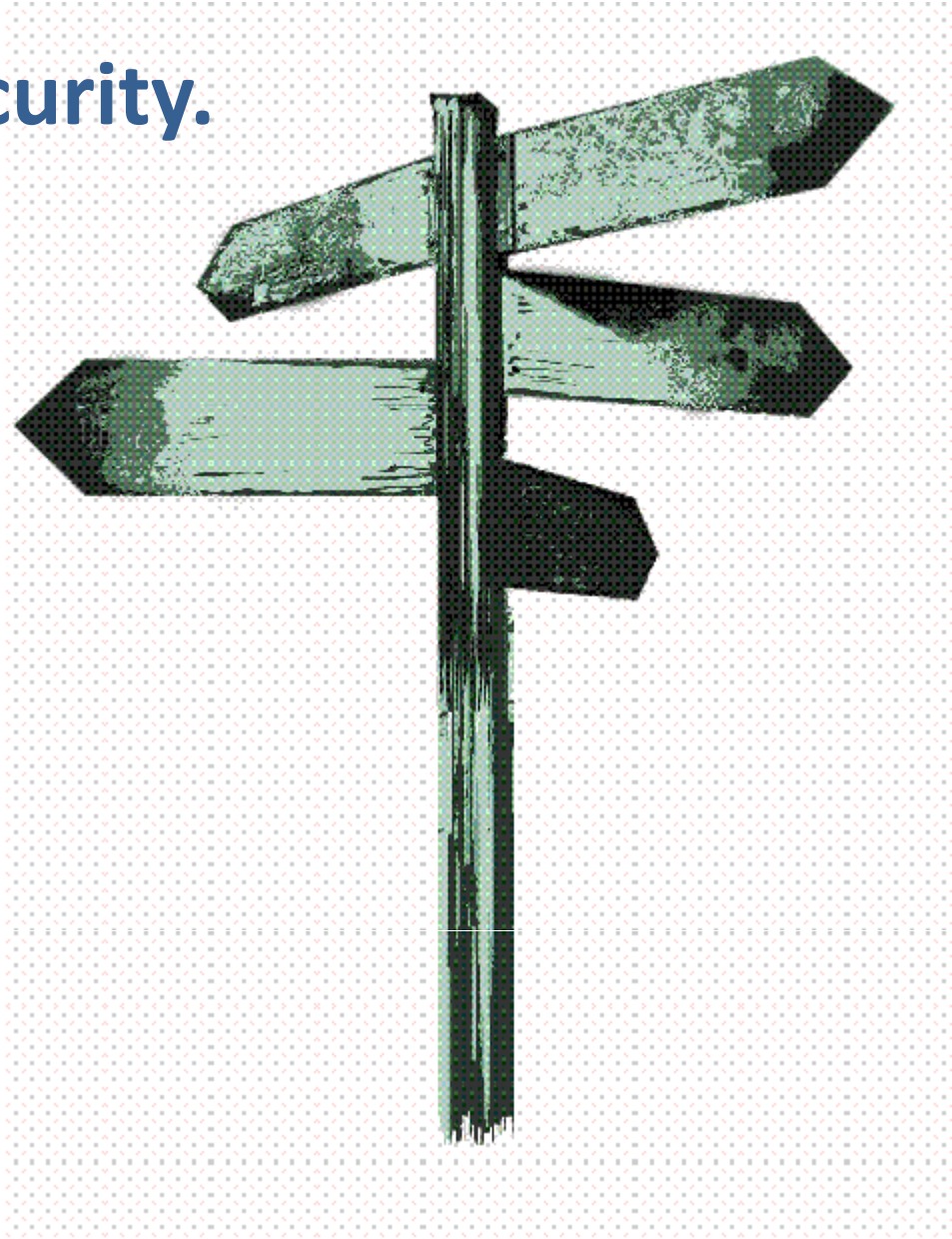


The hierarchical development of nanotechnology-enabled sensors, from materials to sensing systems.

- **Enabling Capabilities**
  - Modeling
  - Foundries
  - Standardized/shared platforms
  - Packaging & Integration
- **Ongoing Challenges**
  - Electrical connections
  - In-situ characterization
  - Hybrid structures

Ethical & Societal Issues

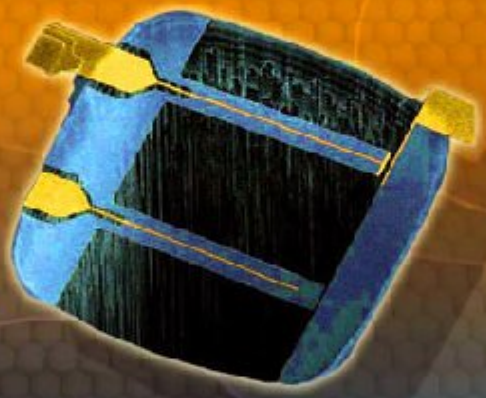
- Personal information security.
- Safety.
- Education
- Learning from the past.



NANOTECHONOLOGY-ENABLED SENSING

REPORT OF THE NATIONAL NANOTECHNOLOGY INITIATIVE WORKSHOP

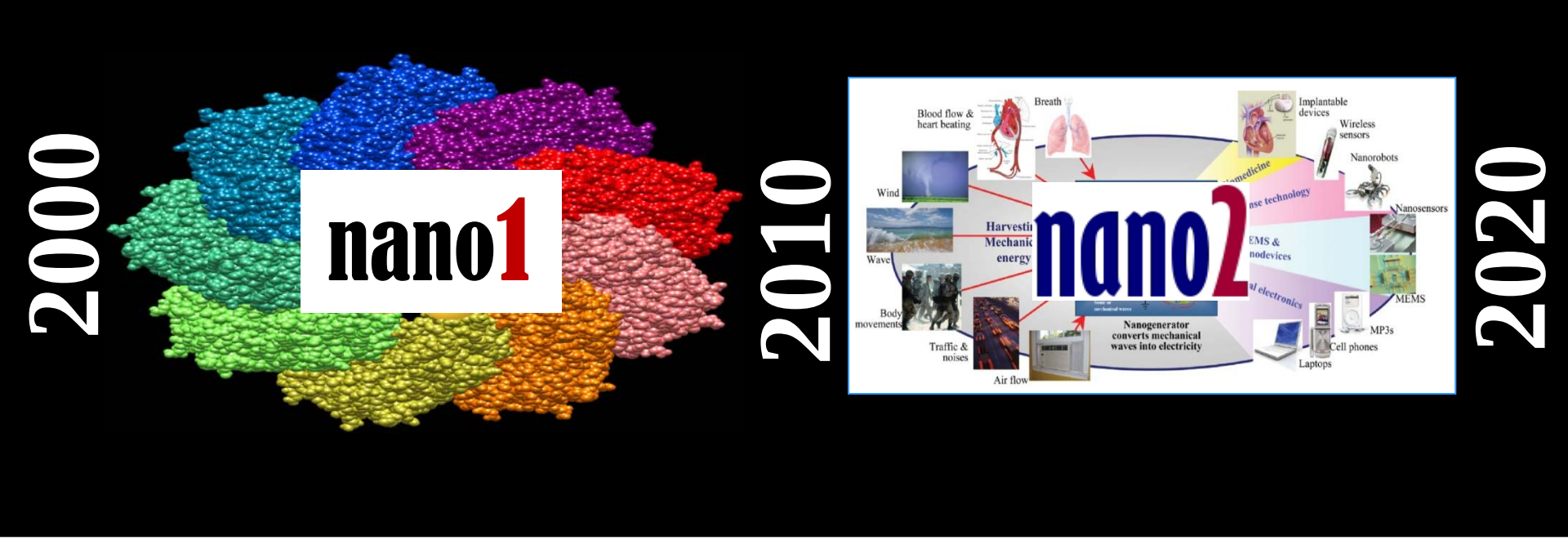
May 5-7, 2009



www.nano.gov

Prepared by
Subcommittee on Nanoscale Science, Engineering, and Technology
Committee on Technology
National Science and Technology Council

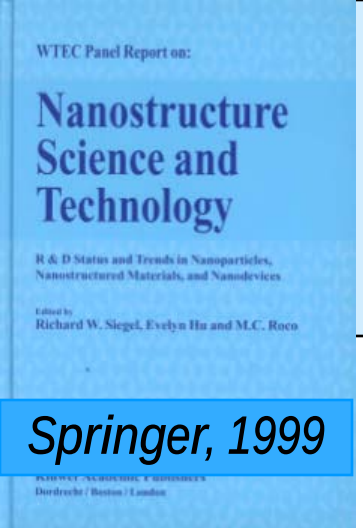
Thank-you



Nanotechnology Research Directions for Societal Needs in 2020

Mike Roco
NSF and NNI

USDA, December 10, 2010



Benchmark with experts in over 20 countries in 1997-1999

"Nanostructure Science and Technology"

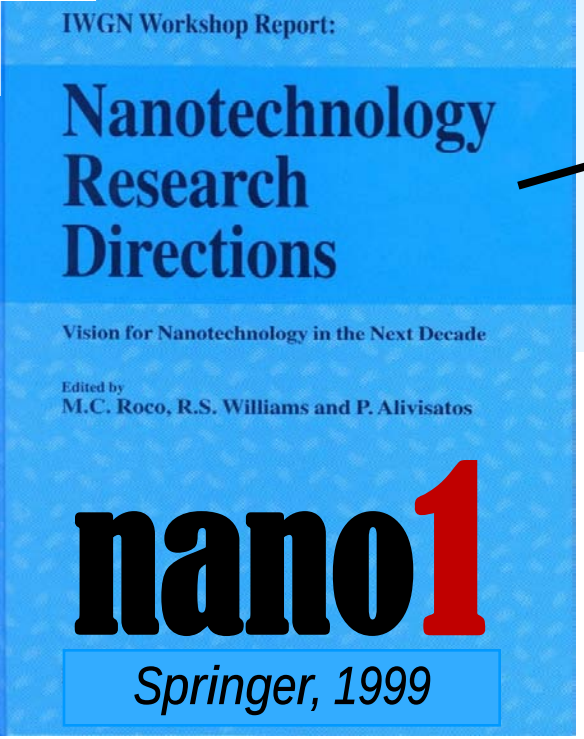
NNI preparatory Report, Springer, 1999

Nanotechnology Definition for the R&D program

Working at the atomic, molecular and supramolecular levels, in the length scale of ~ 1 nm (a small molecule) to ~ 100 nm range, in order to understand, create and use materials, devices and systems with specific, fundamentally new properties and functions because of their small structure

NNI definition encourages new R&D that were not possible before:

- ***the ability to control and restructure matter at nanoscale***
- ***collective effects → new phenomena → novel applications***
- ***integration along length scales, systems and applications***



"Vision for nanotechnology in the next decade", 2001-2010

http://www.wtec.org/loyola/nano/IWGN.Research.Directions/IWGN_rd.pdf

Systematic control of matter on the nanoscale will lead to a revolution in technology and industry

- *Change the foundations from micro to nano*
- *Create a general purpose technology (similar IT)*

More important than miniaturization itself:

Novel properties/ phenomena/ processes/ natural threshold

Unity and generality of principles

Most efficient length scale for manufacturing, biomedicine

Show transition from basic phenomena and components to system applications in 10 areas and 10 scientific targets

NSF-led report in 2010

Panel of US experts

Input from 250 leading nanotechnologists from 35 countries

5 brainstorming workshops

Peer review

Public comment

Open source “Nano2 Report”

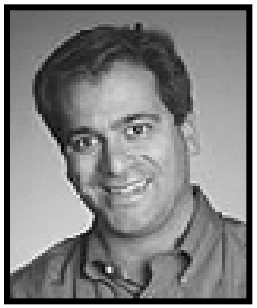
Nanotechnology Research Directions for Societal Needs in 2020

Goals

- Global progress made in the last ten years 2000 - 2010
- Vision and research directions by 2020?
- Re-focus nanotechnology goals as a S&E megatrend
- Institutionalize nanotechnology development

Moderators and Contributors

Mike Roco
(NSF Coordinator)



Chad Mirkin, Co-Chair
(Northwestern)

Mark Hersam, Co-Chair
(Northwestern)

Dawn
Bonnell
(Penn)

C. Jeffrey
Brinker
(Sandia)

Evelyn
Hu
(Harvard)

Mark
Lundstrom
(Purdue)

André
Nel
(UCLA)

Jeffrey
Welser
(IBM)

Topical

Mark
Tuominen
(U Mass)

Mamadou
Diallo
(Caltech)

Jim
Murday
(USC)

Stuart
Wolf
(U Va)

Main topics of the study

- Fundamental scientific and engineering Issues for nanotechnology
- Investigative tools: Theory, modeling, and simulation
  Measure, instrumentation and metrology
- Synthesis, processing and manufacturing
- Nanotechnology environmental, health and safety (EHS) issues
- Sustainability: Environment, Water, Food and Climate
  Energy conversion, storage and conservation
- Applications: Nanobiosystems, medical and health
  Nanoelectronics and nanomagnetics
  Photonics and plasmonics
  Nanostructured catalysts and other chemicals
  High performance materials, systems, emerging areas
- Governance: Preparation of people and physical infrastructure
  Innovative and responsible governance

Mass Application of Nanotechnology after ~ 2020

New areas

MATERIALS | ELECTRONICS | HEALTH CARE | ENVIRONMENT | ENERGY | TRANSPORT | MANUFACTURING | SECURITY | INSTRUMENTS

CREATING A NEW FIELD AND COMMUNITY IN 2 FOUNDATIONAL STEPS (2000~2020) with 4 generations of nanotechnology products

2020

NS&E integration for general purpose technology

~ 2011 ← **nano2** → **~ 2020**

Direct measurements; Science-based design and processes; Collective effects; Create nanosystems by technology integration

New disciplines

New industries

Societal impact

Foundational interdisciplinary research at nanoscale

~ 2001 ← **nano1** → **~ 2010**

Indirect measurements, Empirical correlations; Single principles, phenomena, tools; Create nanocomponents by empirical design

Infrastructure

Workforce

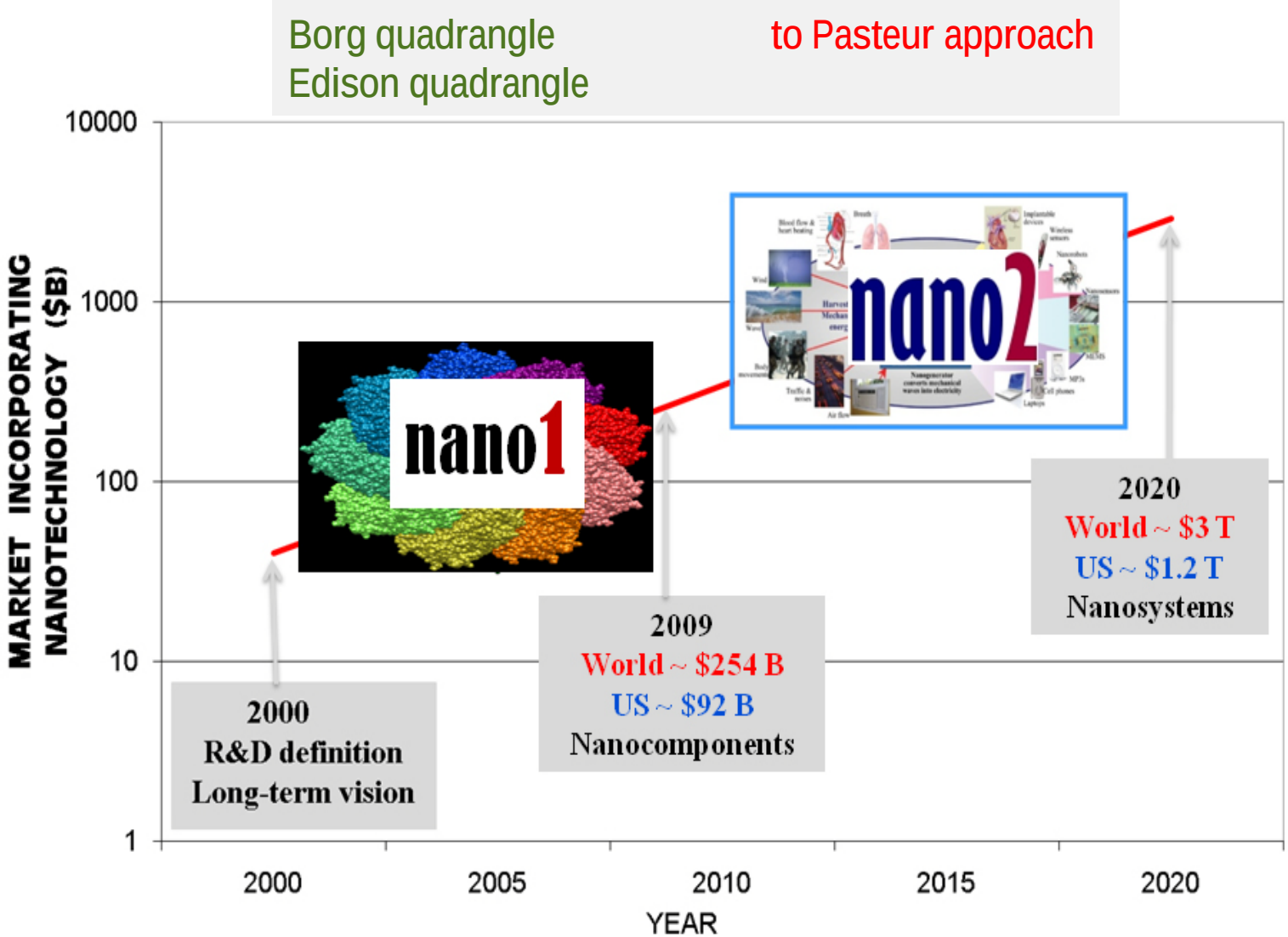
Partnerships

2000

Market of final products incorporating nanotechnology

Nano1: R&D focus on fundamental discoveries and empirical processing (2000-2010)

Nano2: focus on applications-driven fundamental and system research (2010-2020)



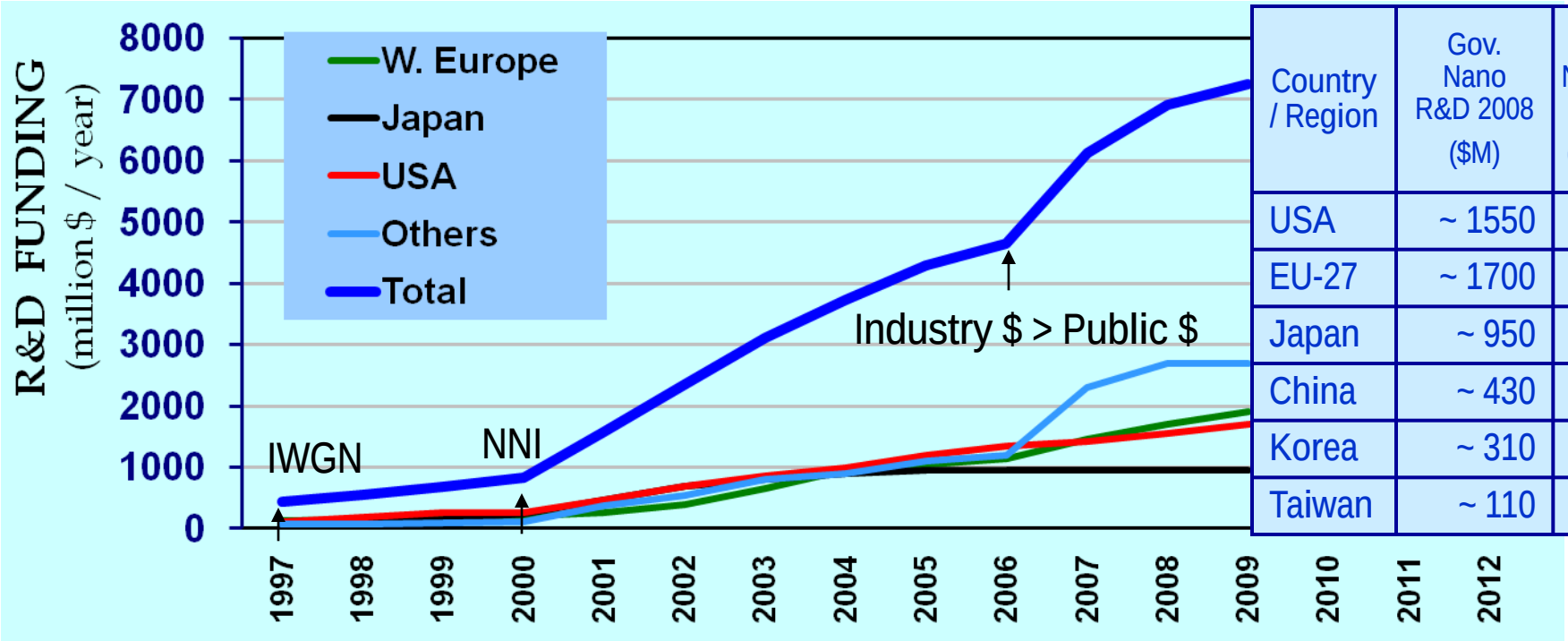
Nano2 Report, 2010, p. X

2000-2008
Estimates show an average growth rate of key nanotechnology indicators of 23 - 35%

World /US/	People -primary workforce	SCI papers	Patents applicat-ions	Final Products Market	R&D Funding public + private	Venture Capital
2000 *(actual)*	~ 60,000 /25,000/	18,085 /5,342/	1,197 /405/	~ $30 B /$13 B/	~ $1.2 B /$0.37 B/	~ $0.21 B /$0.17 B/
2008 *(actual)*	~ 400,000 /150,000/	65,000 /15,000/	12,776 /3,729/	~ $200 B /$80 B/	~ $14 B /$3.7 B/	~ $1.4 B /$1.17 B/
2000 - 2008 average growth	~ 25%	~ 23%	~ 35%	~ 25%	~ 35%	~ 30%
2015 *(estimation in 2000)*	~ 2,000,000 /800,000/			~ $1,000B /$400B/		
2020 *(extrapolation)*	~ 6,000,000 /2,000,000/			~ $3,000B /$1,000B/		
Evolving Topics	*Research frontiers change from passive nanostructures in 2000-2005, to active nanostructures after 2006, and to nanosystems after 2010*					

Nano2 Report, 2010, p. XXXIII

2000-2009
Changing international context:
federal/national government R&D funding (NNI definition)



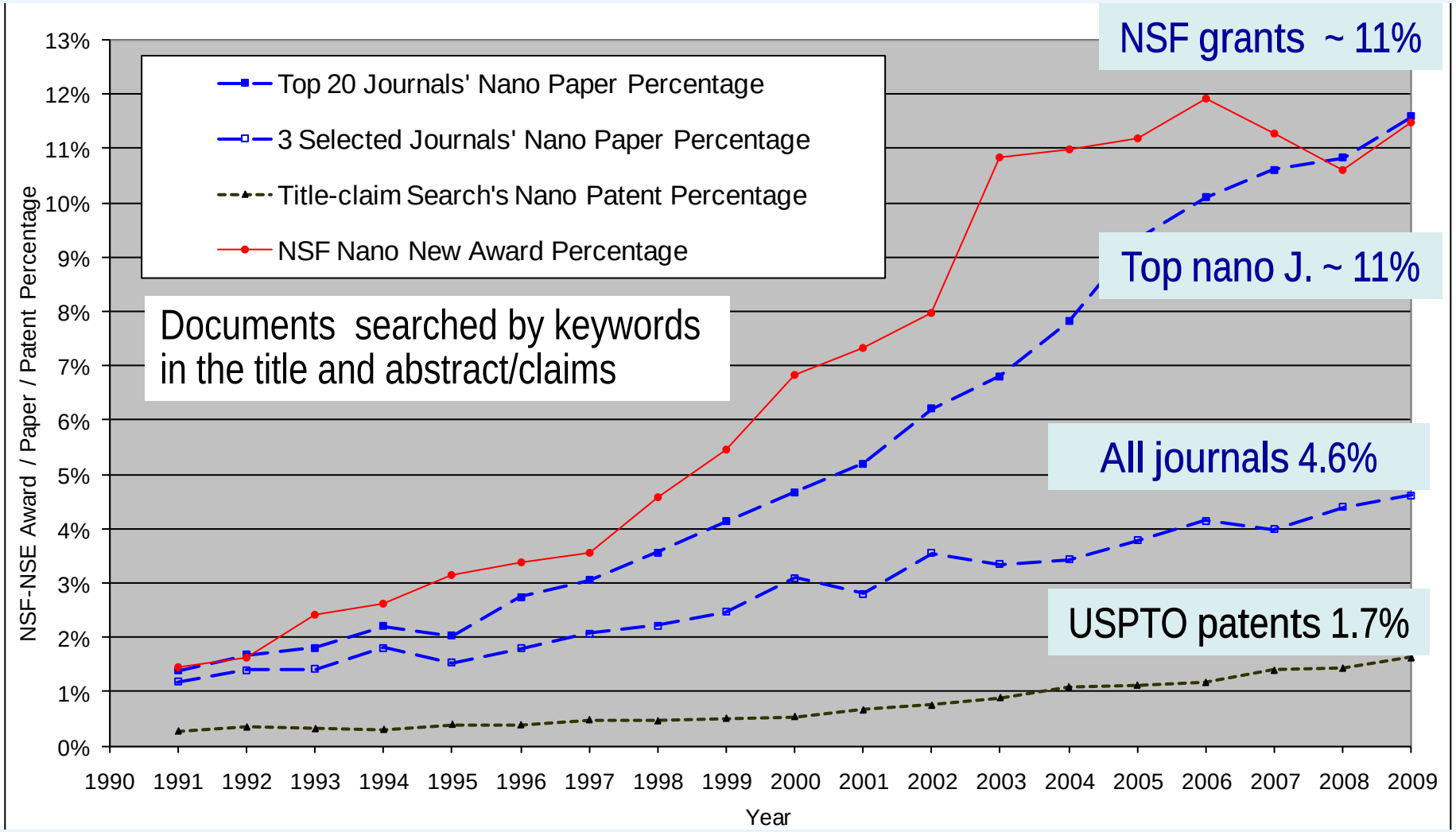
Country / Region	Gov. Nano R&D 2008 ($M)	Specific Nano R&D 2008 ($/Capita)
USA	~ 1550	~ 5.1
EU-27	~ 1700	~ 4.6
Japan	~ 950	~ 7.3
China	~ 430	~ 0.4
Korea	~ 310	~ 6.0
Taiwan	~ 110	~ 4.5

Seed funding 1991 - 1997 | NNI Preparation vision/benchmark | 1st Generation products passive nanostructures | 2nd Generation active nanostructures | 3rd Generation nanosystems

Rapid, uneven growth per countries

Percentage of nanotechnology content in NSF awards, ISO papers and USPTO patents (1991-2009)

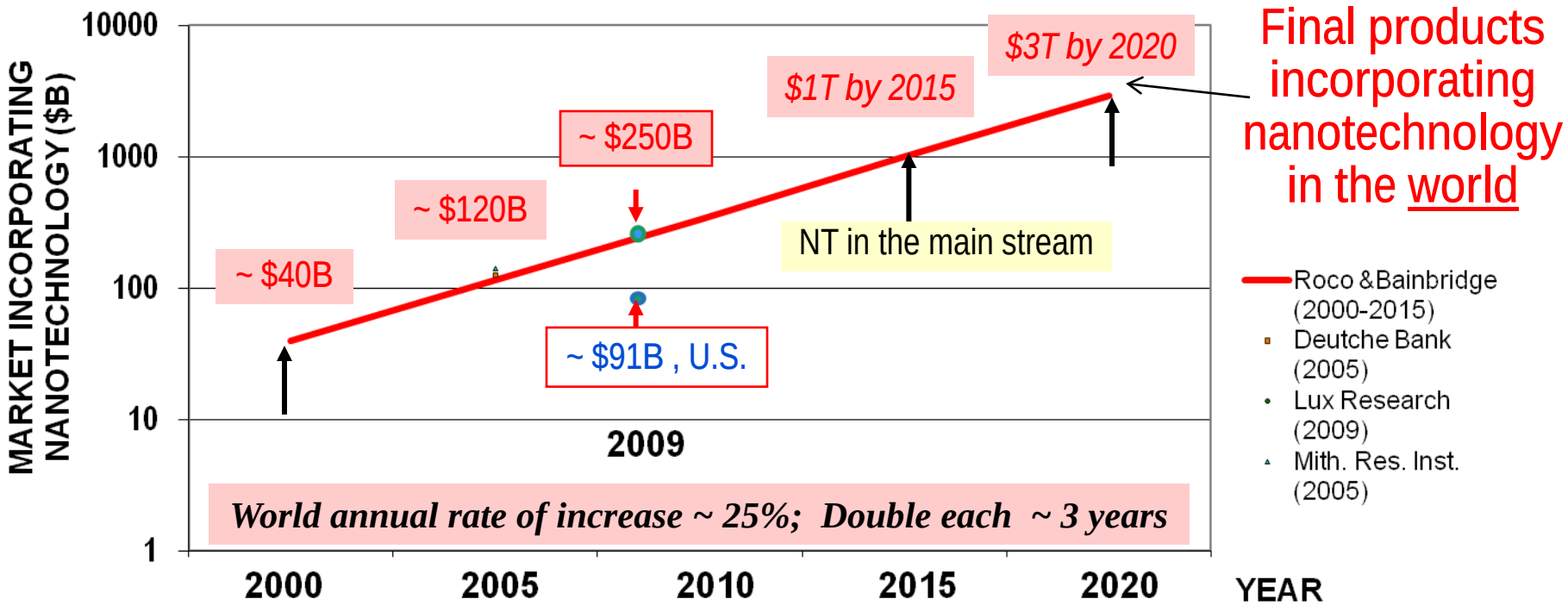
(update after Encyclopedia Nanoscience, Roco, 2008)

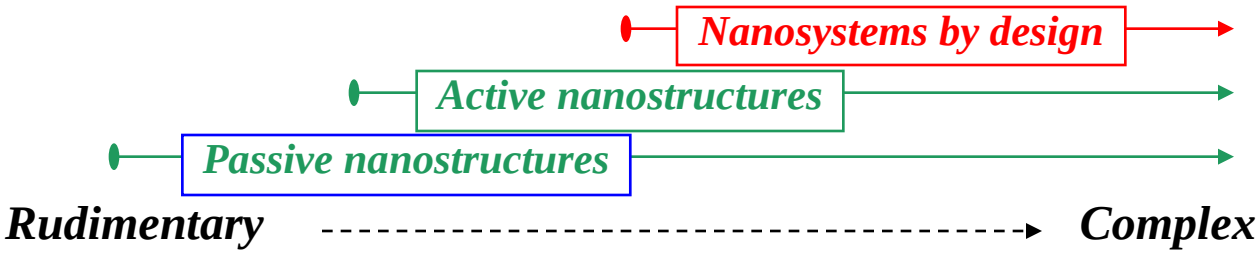


Similar, delayed penetration curves: for funding/papers/patents/products

WORLDWIDE MARKET INCORPORATING NANOTECNOLOGY

(Estimation made in 2000 after international study in > 20 countries)





From: Nano2 Report, 2010, p. XXXV

2000-2010 Outcomes

- **Remarkable scientific discoveries** than span better understanding of the smallest living structures, uncovering the behaviors and functions of matter at the nanoscale, and creating a library of 1D - 4D nanostructured **building blocks for devices and systems**

- **New S&E fields have emerged** such as: spintronics, plasmonics, metamaterials, carbon nanoelectronics, molecules by design, nanobiomedicine, branches of nanomanufacturing, and nanosystems

- **Technological breakthroughs** in advanced materials, biomedicine, catalysis, electronics, and pharmaceuticals; **expansion into** energy resources and water filtration, agriculture and forestry; and **integration of nanotechnology with other emerging areas** such as quantum information systems, neuromorphic engineering, and synthetic and system nanobiology

2000-2010: Methods and Tools

- **Femtosecond measurements** with atomic precision in domains of biological and engineering relevance
- **Sub-nanometer measurements** of molecular electron densities
- **Single-atom and single-molecule** characterization methods
- **Simulation** from basic principles has expanded to **assemblies of atoms 100 times larger** than in 2000
- **Measure**: negative index of refraction in IR/visible wavelength radiation, Casimir forces, quantum confinement, nanofluidics, nanopatterning, teleportation of information between atoms, and biointeractions at the nanoscale. Each has become the foundation for new domains in science and engineering

2000-2010: Safe Development

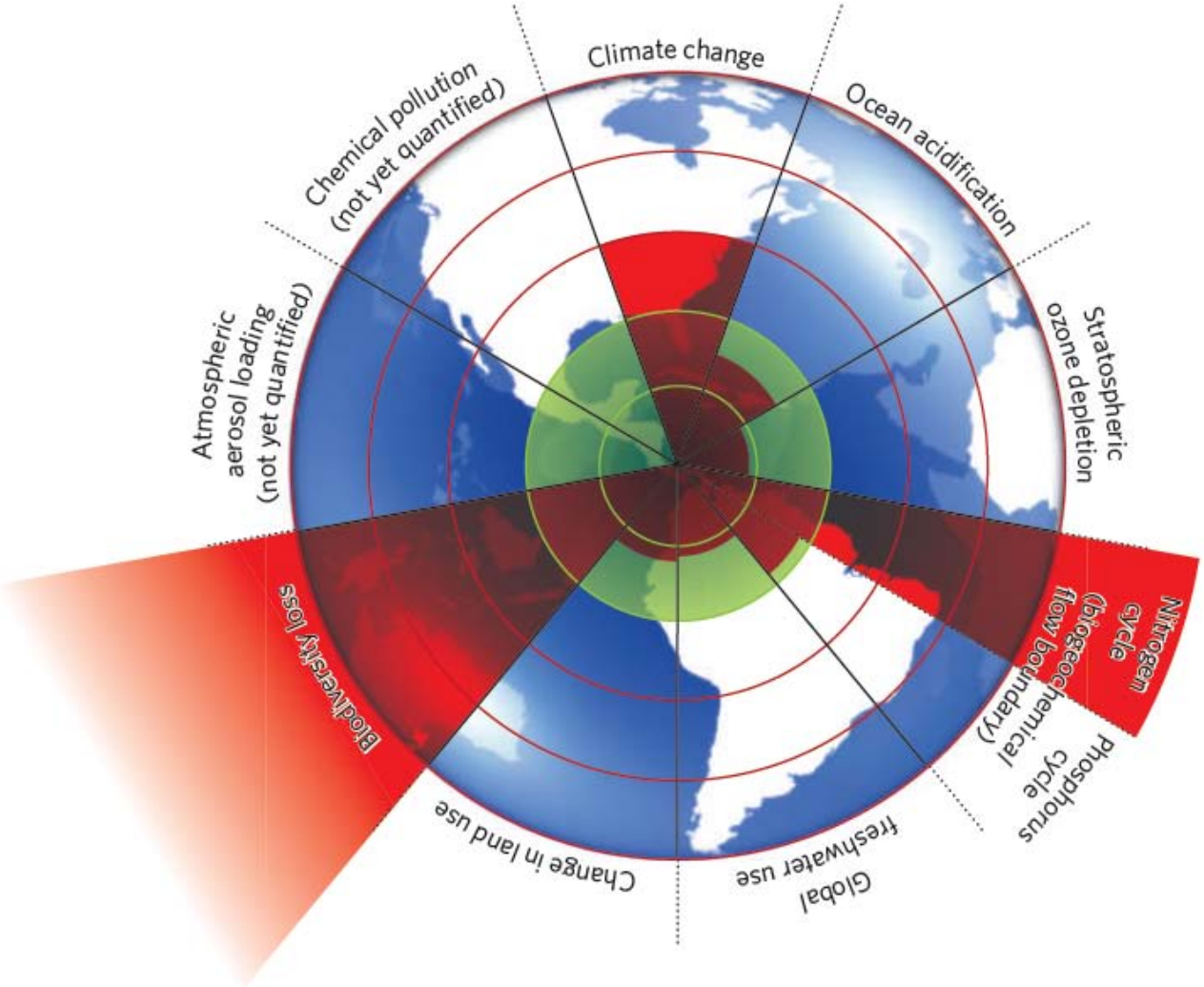
There is greater recognition of the **essential areas** of nanotechnology-related EHS and ELSI issues

- Building physico-chemical-biological **understanding**
- Regulatory challenges for **specific nanomaterials**
- **Experiment governance methods** under conditions of uncertainty and knowledge gaps
  - risk assessment frameworks
  - life cycle analysis based on expert judgment
  - use of voluntary codes, and
  - incorporation of safety considerations into the design and production stages of new nano-enabled products

2000-2010: Sustainable Development

- **Nanotechnology has provided solutions for about half of the new projects** on energy conversion, energy storage, and carbon encapsulation in the last decade
- **Entirely new families have been discovered of nanostructured and porous materials** with very high surface areas, including metal organic frameworks, covalent organic frameworks, and zeolite imidazolate frameworks, for improved hydrogen storage and CO_2 separations
- **A broad range of polymeric and inorganic nanofibers** for environmental separations (membrane for water and air filtration) and catalytic treatment have been synthesized
- **Testing the promise of nanomanufacturing** for sustainability

Sustainable nanotechnology solutions for clean environment; energy, water, food, mineral resources supplies; green manufacturing, habitat, transportation, climate change, biodiversity



Current critical planetary boundaries are biodiversity, nitrogen cycle, climate change

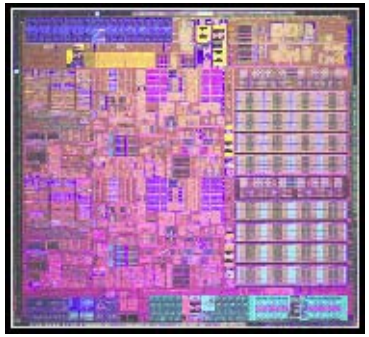
(Rockström et al. 2009)

Nano2 Report, 2010, p. 147

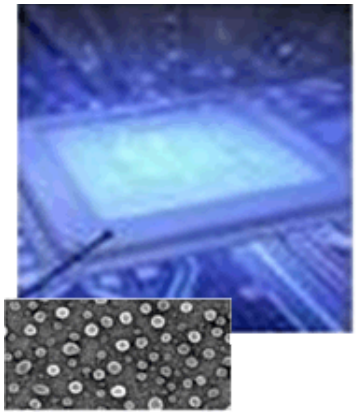
2000-2010: Towards nanotechnology applications

- Current applications are based upon relatively simple "passive" (steady function) nanostructures used as components to improve products (e.g., nanoparticle-reinforced polymers). However, since 2005, more sophisticated products with "active" nanostructures and devices have been introduced (e.g., point-of-care molecular diagnostic tools and life-saving targeted drug therapeutics).
- Entirely new classes of materials have been discovered and developed: from one-dimensional nanowires and quantum dots of various compositions to polyvalent noble metal nanostructures, graphene, metamaterials, nanowire superlattices, and many other nanocomposites. A periodic table of nanostructures is emerging

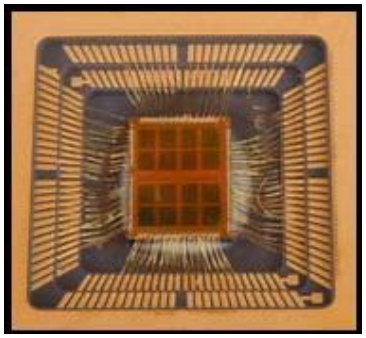
Nanoelectronic and nanomagnetic components incorporated into common computing and communication devices, in production in 2010



32 nm CMOS processor technology by Intel (2009)

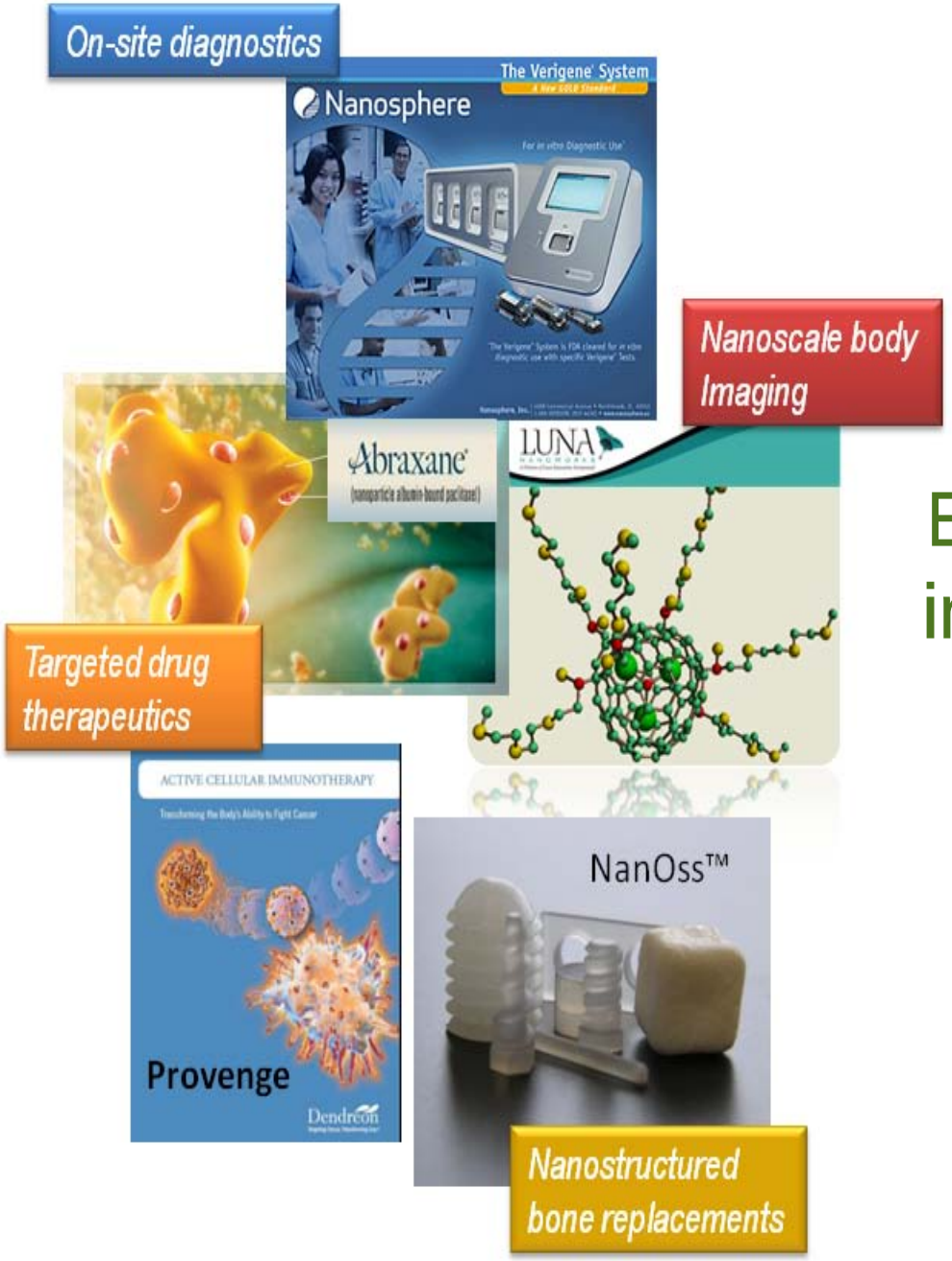


90 nm thin-film storage (TFS) flash flexmemory by Freescale (2010)



16 megabit magnetic random access memory (MRAM) by Everspin (2010)

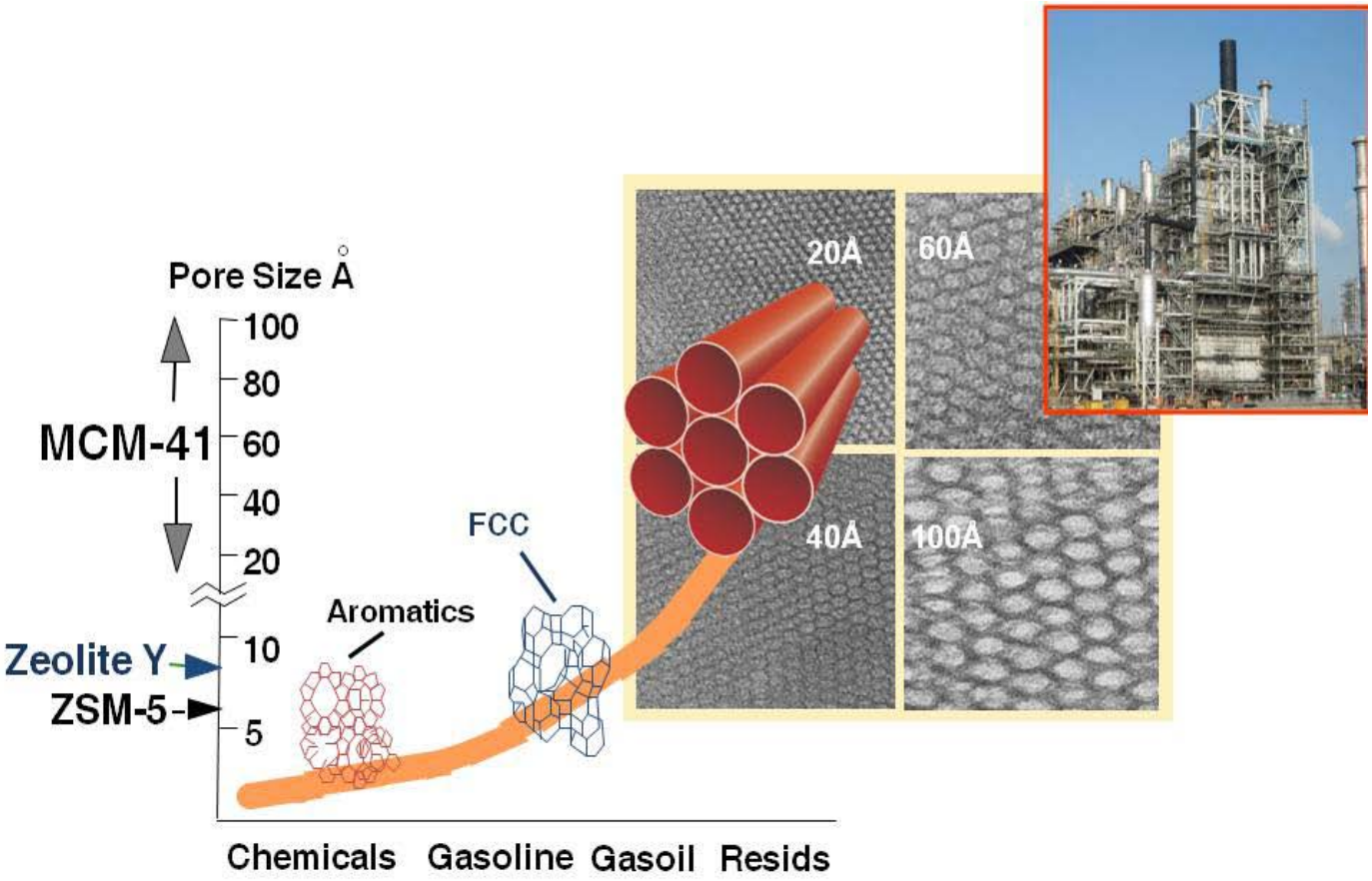
"Nanotechnology Research Directions for .. 2020" , 2010, p. XII



Examples of nanotechnology incorporated into commercial healthcare products, in production in 2010

"Nanotechnology Research Directions for ..2020", 2010, p. XIV

Examples of nanotechnology in commercial catalysis products for applications in oil refining, in production in 2010

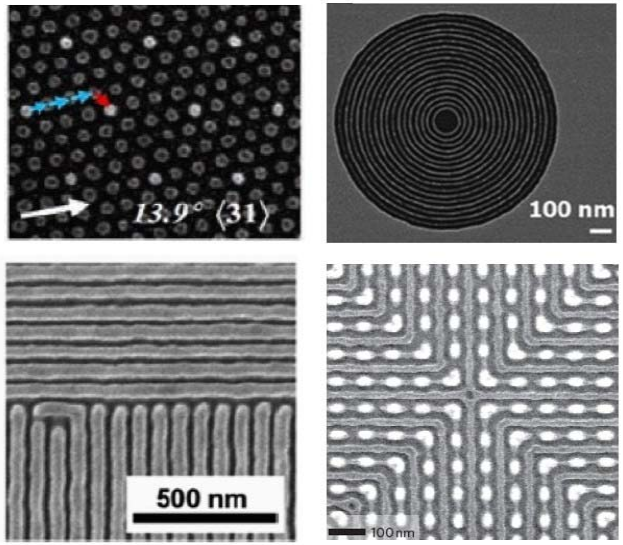


Redesigned since 2000 mesoporous silica materials, like MCM-41, along with improved zeolites, are used in a variety of processes such as fluid catalytic cracking (FCC) for producing gasoline from heavy gas oils, and for producing polyesters. Nano-engineered materials now constitute 30–40% of the global catalyst market

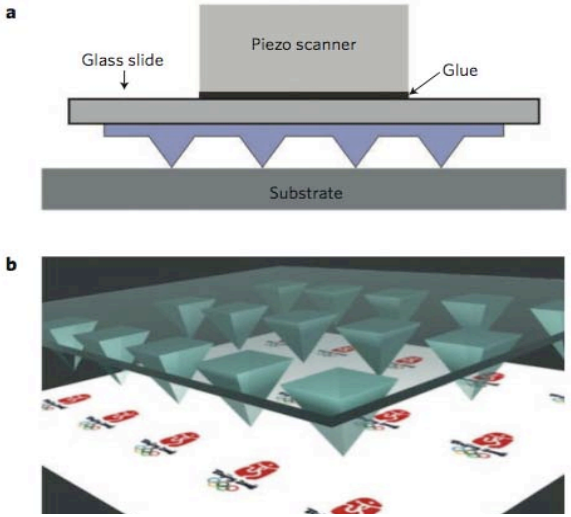
"Nanotechnology Research Directions for ..2020" , 2010, p. XVII

2000-2010: Towards nanotechnology applications - examples -

- **Patterning on surfaces:** a versatile library has been invented of surface patterning methods including directed selfassembling, optical and “dip-pen” nanolithography, nanoimprint lithography, and roll-to-roll processes for manufacturing graphene and other nanosheets

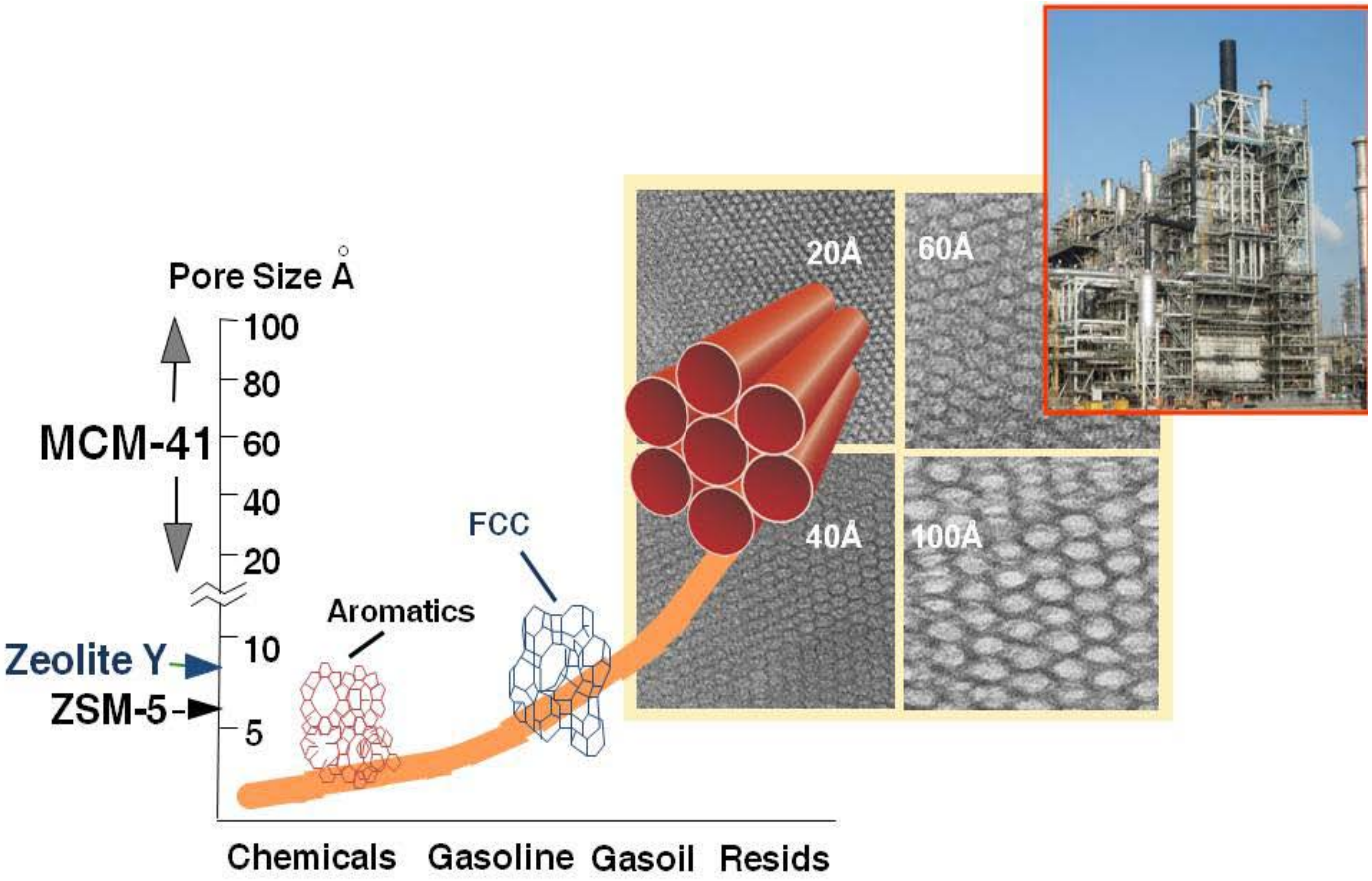


Diblock copymer directed selfassembling



Polymer-pen array lithography

Examples of nanotechnology in commercial catalysis products for applications in oil refining, in production in 2010



Redesigned since 2000 mesoporous silica materials, like MCM-41, along with improved zeolites, are used in a variety of processes such as fluid catalytic cracking (FCC) for producing gasoline from heavy gas oils, and for producing polyesters. Nano-engineered materials now constitute 30–40% of the global catalyst market

Nano2 Report, 2010, p. XVII

Examples of Penetration of Nanotechnology in Several Industrial Sectors

The market percentage and its absolute value affected by nanotechnology are shown for 2010

U.S.	2000	2010	Est. in 2020
Semiconductor industry	0 (with features < 100 nm) 0 (new nanoscale behavior)	60% (~$90B) 30% (~$45B)	100% 100%
New nanostructured catalysts	0	~ 35% (~35B impact)	~ 50%
Pharmaceutics (therapeutics and diagnostics)	0	~ 15% (~$70B)	~ 50%
Wood	0	0	~ 20%

Nano2 Report, 2010, p. XXXVI

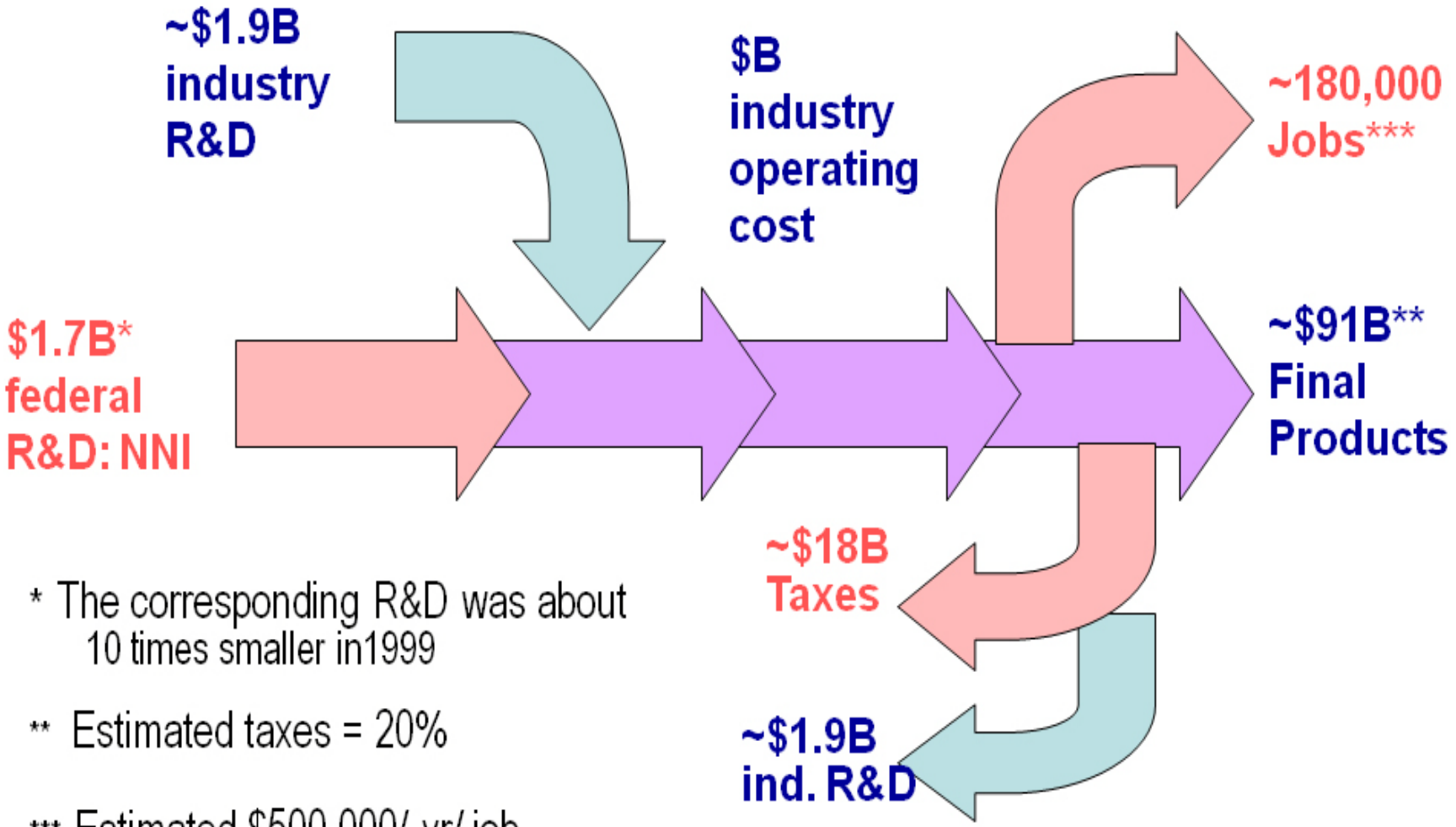
Ten highly promising products incorporating nanotechnology in 2010

- Catalysts
- Transistors and memory devices
- Structural applications (coatings, hard materials, cmp)
- Biomedical applications (detection, implants,.)
- Treating cancer and chronic diseases
- Energy storage (batteries), conversion and utilization
- Water filtration
- Video displays
- Optical lithography and other nanopatterning methods
- Environmental applications

With safety concerns: cosmetics, food, disinfectants,..

2010 nanosystems: nano-radio, tissue eng., fluidics, etc

Estimation of Annual Implications of U.S. Federal Investment in Nanotechnology R&D (2009)



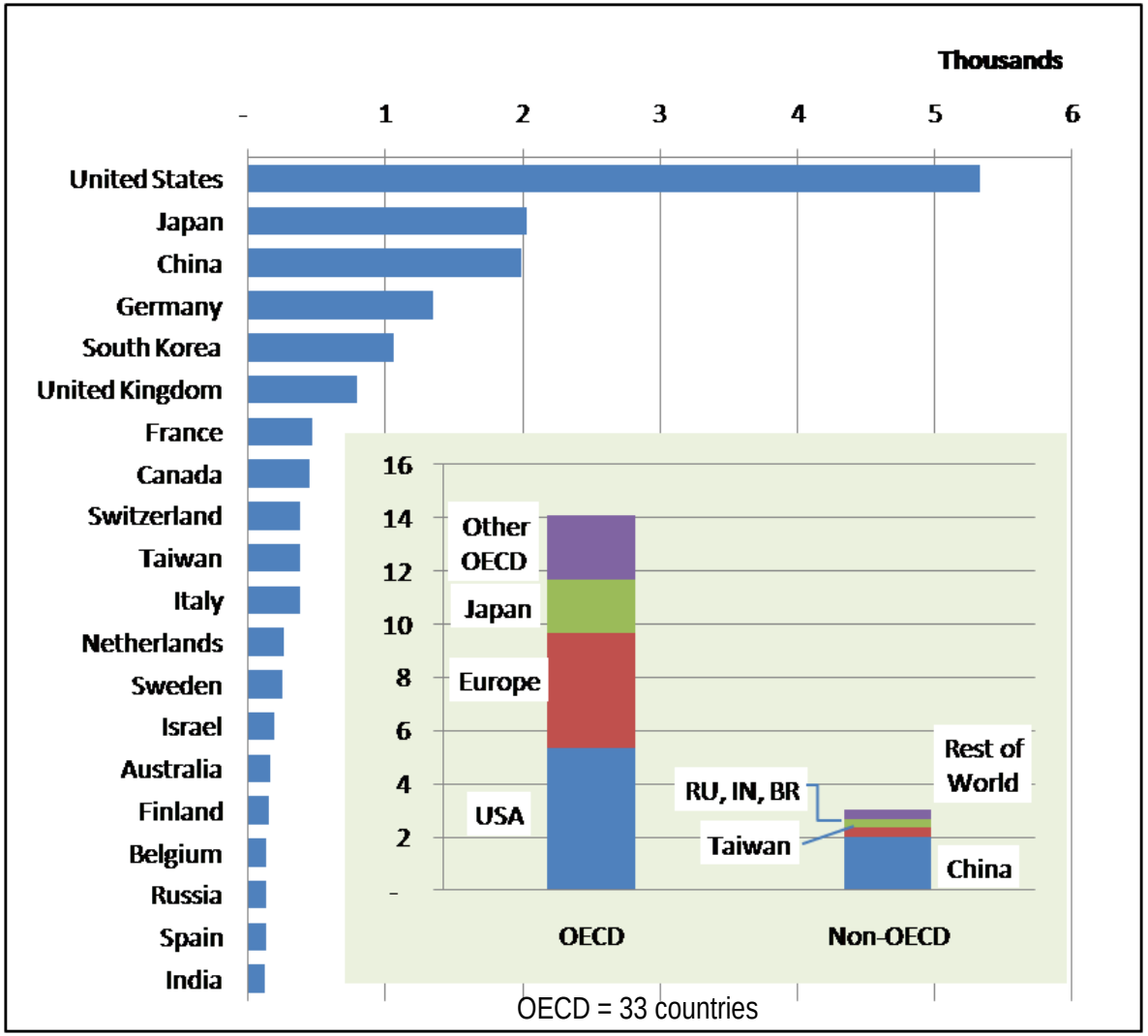
* The corresponding R&D was about 10 times smaller in1999

** Estimated taxes = 20%

*** Estimated $500,000/ yr/ job

Transformative governance

Ex.: Corporate Entry in leading countries (has products, articles and/or patents), 1990-2009



Nano2 Report, 2010, p. 411

Courtesy Phil Shapira, Jan Youtie and Luciano Kay

NSF investment in nanoscale science and engineering education, moving over time to broader and earlier education and training

2000	Graduate Education Programs (curriculum development)
2002	Undergraduate Education Program
2003	High School Education Programs
2004-2005	K-12 and Informal (museum)
2006	Technological Education Network

Nano2 Report, 2010, p. 360

Changes of the vision in the last ten years

Nanotechnology governance *has evolved considerably* :

- The viability and societal importance of nanotechnology has been confirmed, while extreme predictions have receded
- An international community has been established
- Greater recognition to nanotechnology EHS and ELSI after 2004
- The 2001 vision of international collaboration – reality after the first International Dialogue on Responsible Development of Nanotechnology (Arlington, 2004)
- Nanotechnology has become a model for governance issues (transformative/responsible/inclusive/visionary) of other emerging technologies. Increasing role of innovation

Not fully realized objectives after ten years

- General methods for **“materials by design”** and composite materials (because the direct TMS and measuring techniques methods were not ready)

- **Sustainable development projects:** energy received momentum only after 5 years, nanotechnology for water filtration and desalination only limited; delay on nanotechnology for climate research (because of insufficient support from beneficiary stakeholders?)

- **Public awareness remains low**, at about 30%. Challenge for public participation

On target in 2010, even if doubted in 2000

- **The growth rates of papers and inventions** (23-35%) is quasi exponential at rates higher than the average in all fields (about 5-10%)
- **Nanotechnology stimulated interdisciplinary research and education**, creating a multidisciplinary projects, organizations, and communities
- Estimation that **nanotechnology R&D investment in US will grow by about 30% annual growth rate** (government and private sector, vertical and horizontal development) in 2000-2008; **International coordination and collaboration**

Better than expected after ten years

- Major industry involvement after 2002-2003
  Ex: >5,400 companies with papers/patents or products (US, 2008); NBA in 2002; Keeping the Moore law continue 10 years after serious doubt raised din 2000

- Discoveries in several S&E fields
  plasmonics, metamaterials, spintronics, graphene, cancer detection and treatment, drug delivery, synthetic biology, neuromorphic engineering, quantum information system

- The formation / strength of the international community, including in nanotechnology EHS and ELSI; governance studies

Main lessons learned after ten years

- Need continued, focused investment on **theory, direct measuring and simulation** at the nanoscale. Nanotechnology still in the formative phase
- Besides nanostructured metals, polymers and ceramics, **classical industries can provide excellent opportunities**, such as in: textiles, wood and paper, plastics, agricultural and food systems. Improved mechanisms for public-private partnerships to establish consortia or platforms are needed
- Need to increase **multi-stakeholder and public participation** in nanotechnology governance

Nanotechnology in 2010 - still in an earlier formative phase of development

- Characterization of nanomodules is using micro parameters and not internal structure
- Measurements and simulations of a domain of biological or engineering relevance cannot be done with atomic precision and time resolution of chemical reactions
- Manufacturing Processes – empirical, synthesis by trial and error, some control only for one chemical component and in steady state
- Nanotechnology products are using only rudimentary nanostructures (dispersions in catalysts, layers in electronics) incorporated in existing products or systems
- Knowledge for risk governance – in formation

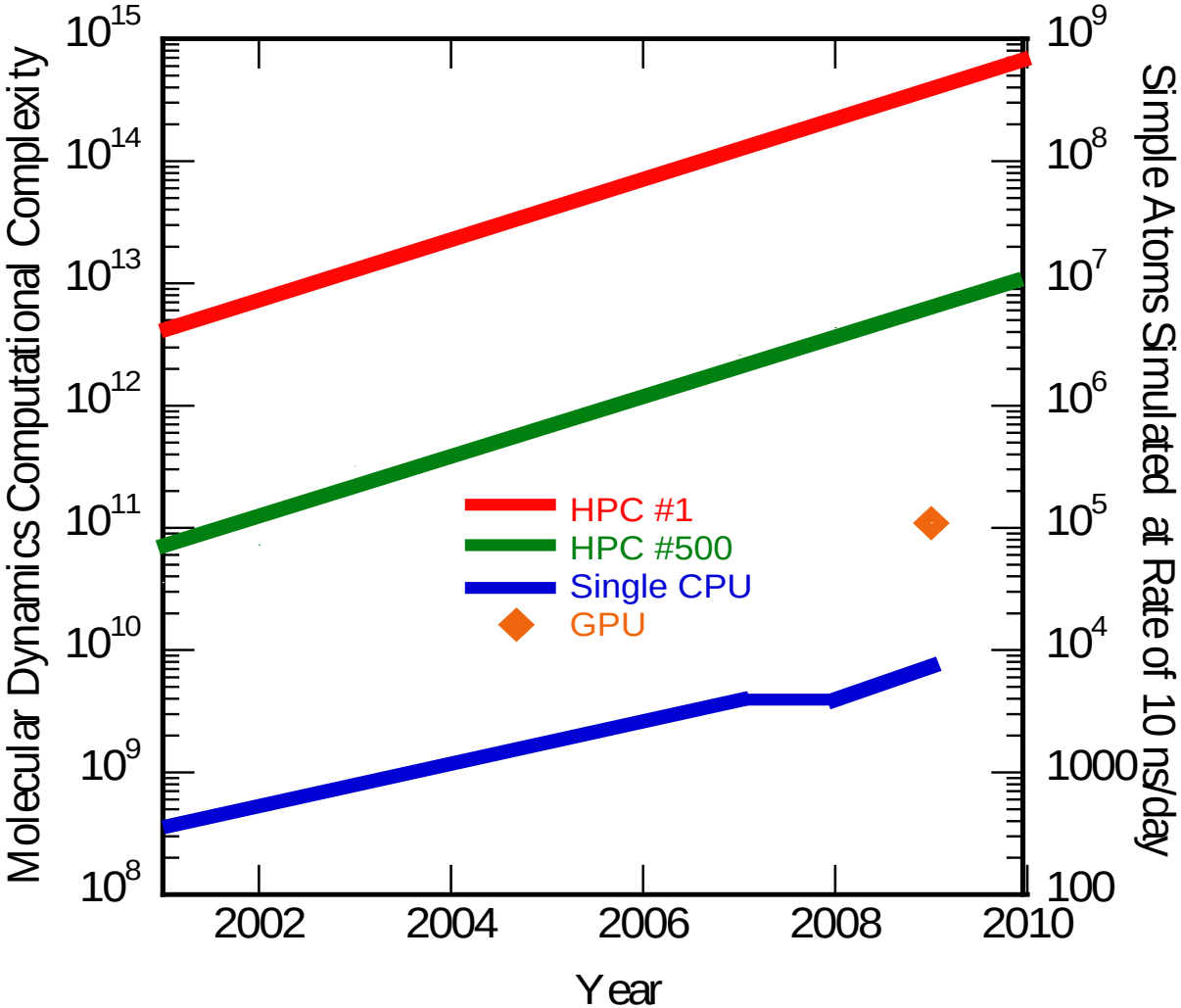
Twelve trends to 2020

www.wtec.org/nano2/

- Theory, modeling & simulation: x1000 faster, essential design
- "Direct" measurements – x6000 brighter, accelerate R&D & use
- A shift from "passive" to "active" nanostructures/nanosystems
- Nanosystems, some self powered, self repairing, dynamic
- Penetration of nanotechnology in industry - toward mass use; catalysts, electronics; innovation– platforms, consortia
- Nano-EHS – more predictive, integrated with nanobio & env.
- Personalized nanomedicine - from monitoring to treatment
- Photonics, electronics, magnetics – new capabilities, integrated
- Energy photosynthesis, storage use – solar economic by 2015
- Enabling and integrating with new areas – bio, info, cognition
- Earlier preparing nanotechnology workers – system integration
- Governance of nano for societal benefit - institutionalization

1. Theory, modeling and simulation - faster, more useful in design

Ex: Growth of computing power on classical molecular dynamics (CMD), 2000-2010



Left axis:
CMD computational complexity

Right axis:
For monatomic fluid, # of atoms that can be simulated for 10 ns in one day

To improvement factor of simulated nano-structure size ~ <u>1000 times in next decade</u>

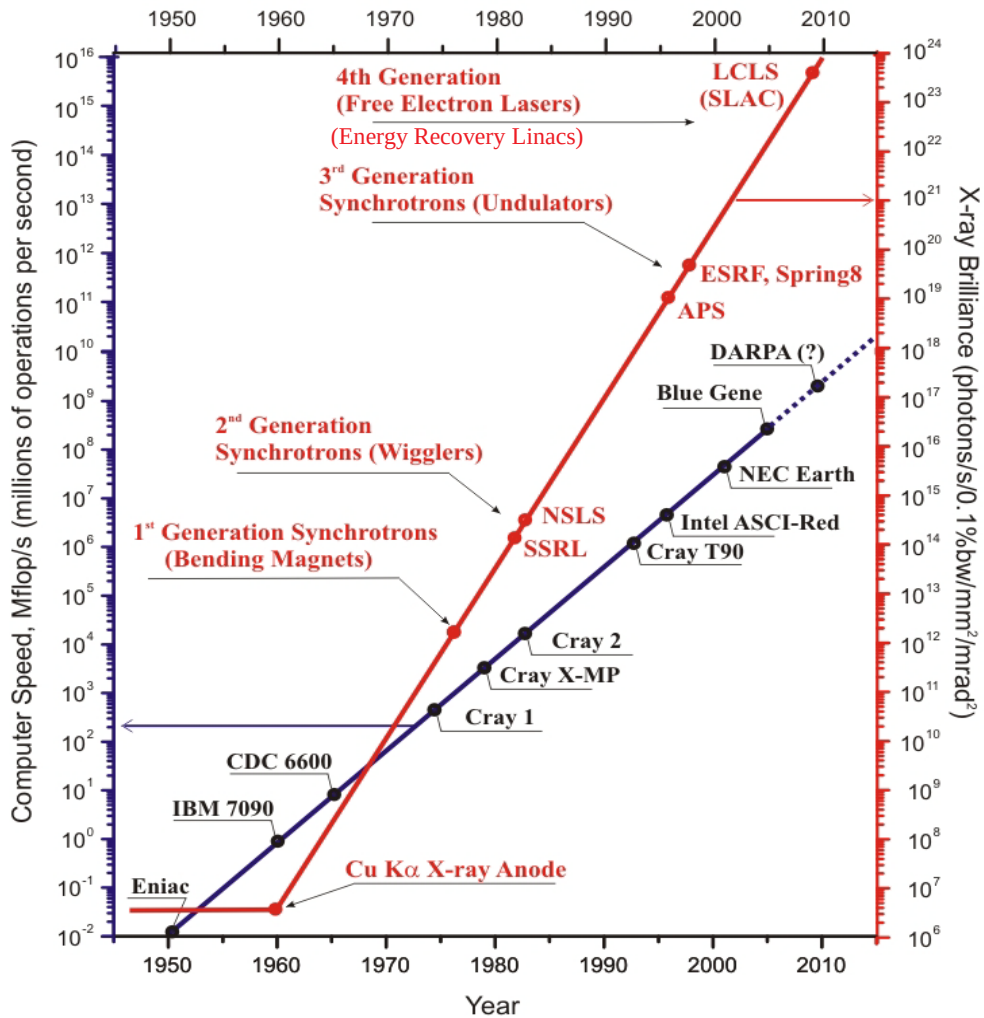
Nano2 Report, 2010, p.5

2. "Direct" measurements and metrology

EX: Exponential law for X-ray Sources: Coherence for 3 D dynamic (~ femtosecond) imaging of structures with atomic precision

Semiconductor Moore's law (black):

2 orders of magnitude in last decade



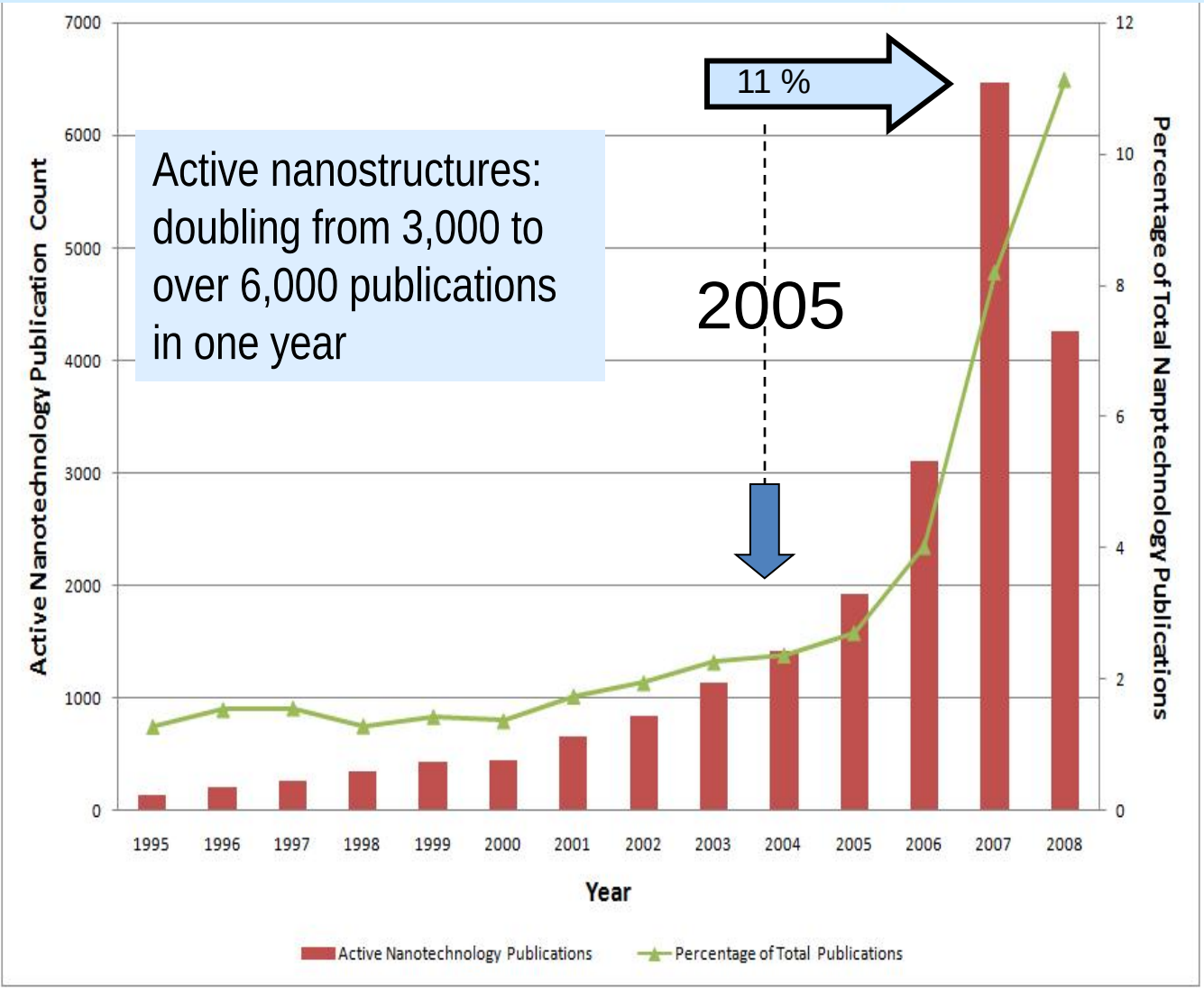
X-ray source brilliance (red):

estimated 3.6 orders of magnitude

To increase ~ 5,000 times in next decade

Nano2 Report, 2010, p. 41

3. Shift from "passive " to "active" nanostructures (>2005) and systems (>2010)



Ex.:

Targeted drugs and chemicals

NEMS

Self-healing materials

Remote actuated (e.g., magnetic, electrical, light and wireless tagged nanotech)

Environmentally responsive

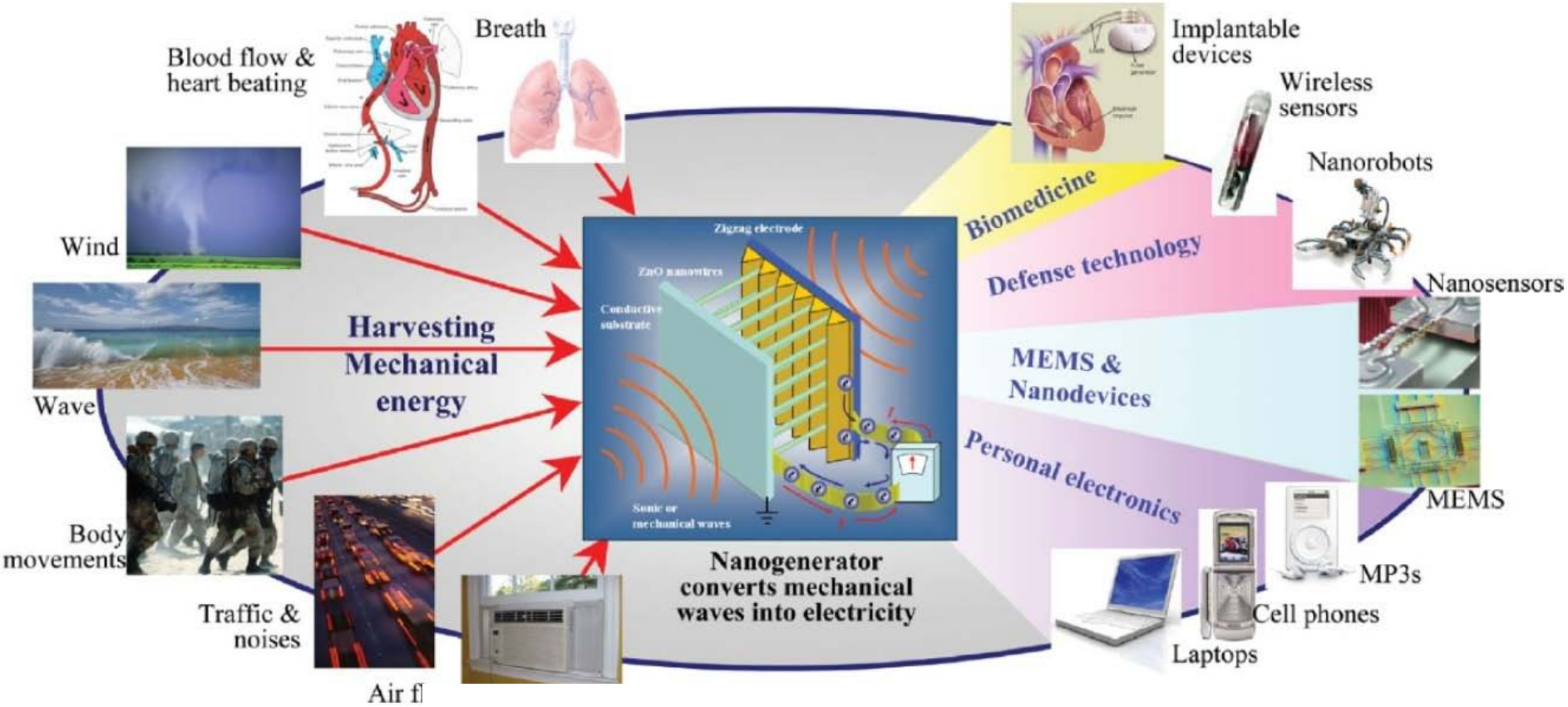
Energy storage devices

Semiconductors, molecular electronics

Nano2 Report, 2010, based on V. Subramanian et al., J. Nanoparticle Research, 2010

4. Ex: Self-powered nanosystems

Multifunctional, self-powered nanosystems (using fluid motion, temperature gradient, mechanical energy..) in wireless devices, biomedical systems...



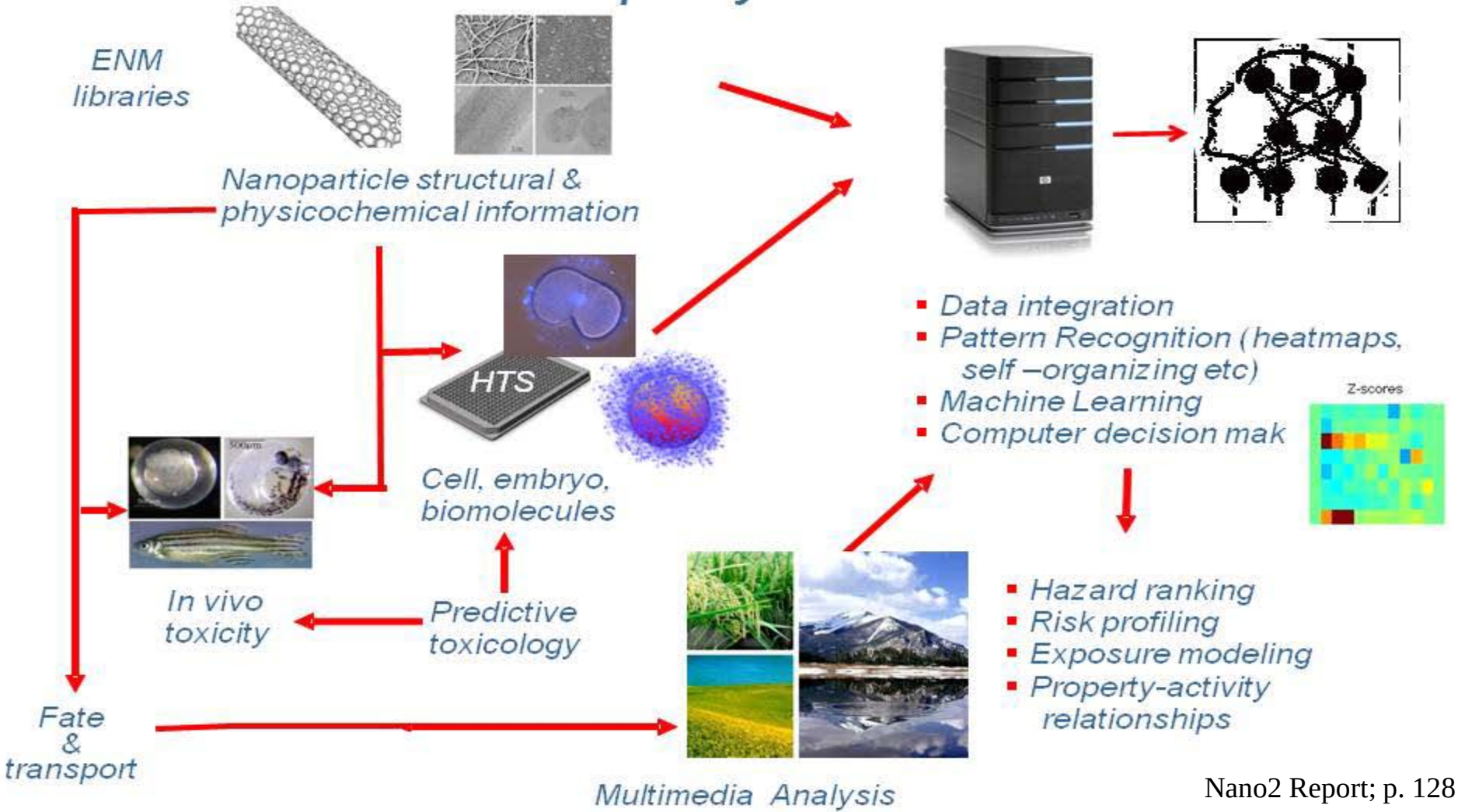
Reference: Z. L. Wang, Adv. Funct. Mater., 2008

UC CEIN predictive model for hazard ranking and risk profiling

UNIVERSITY OF CALIFORNIA
UC CEIN Center for Environmental Implications of Nanotechnology

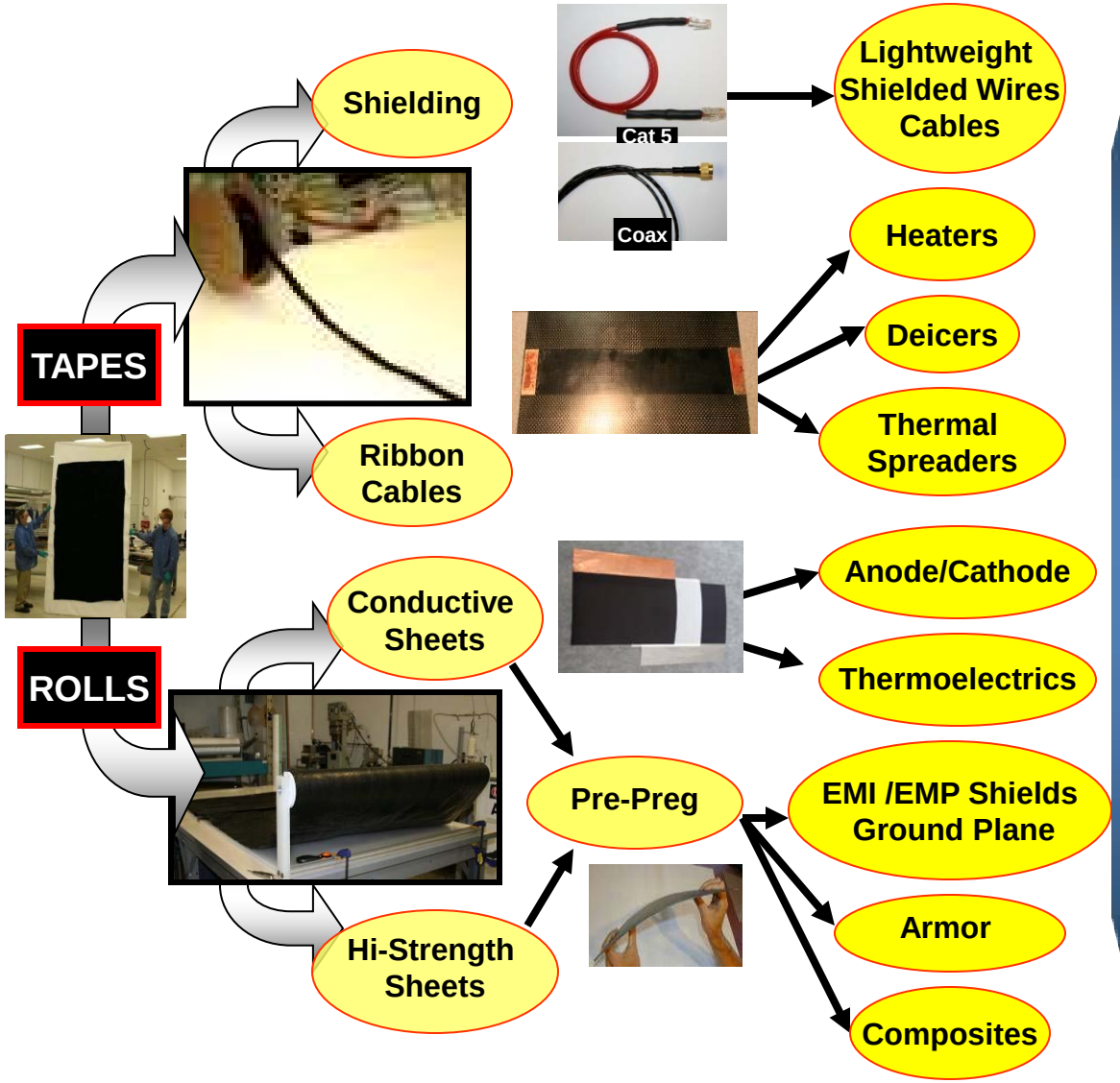
NSF: EF-0830117

UC CEIN Predictive Multi-disciplinary Science Model



Nano2 Report; p. 128

Expanded CNT sheet production with broad impact



Commercial and Defense Impact
Multi-Industry Use

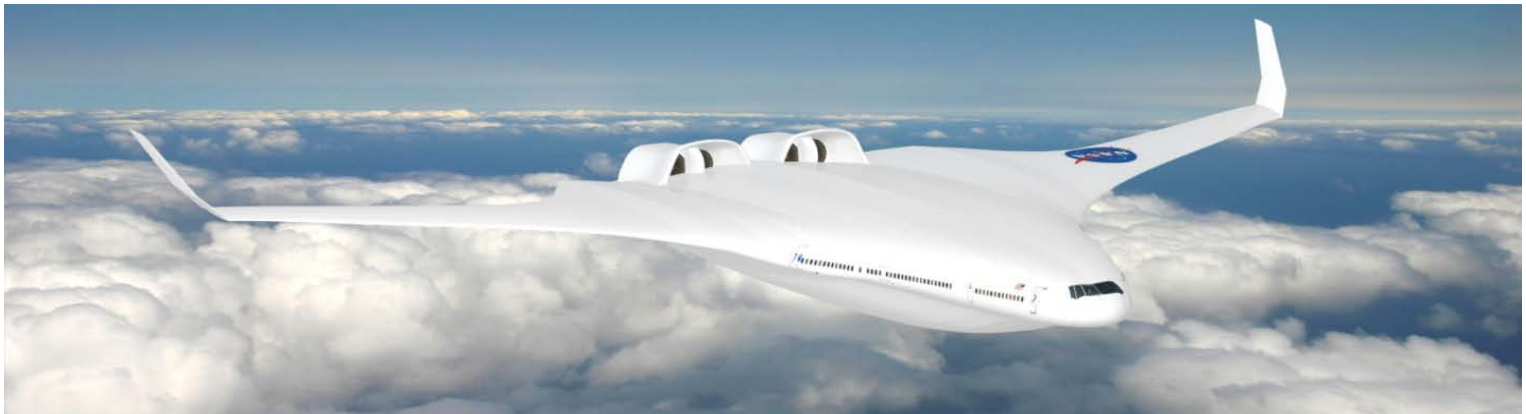
Nano2 Report, 2010, p. XLVI. Courtesy R. Ridgley

Nanotechnology for Aerospace

Future aircraft designs include nanocomposite materials for ultra-lightweight multifunctional airframes; “morphing” airframe and propulsion structures in wing-body that can change their shape; resistance to ice accretion; with carbon nanotube wires; networks of nanotechnology based sensors for reduced emissions and noise and improved safety

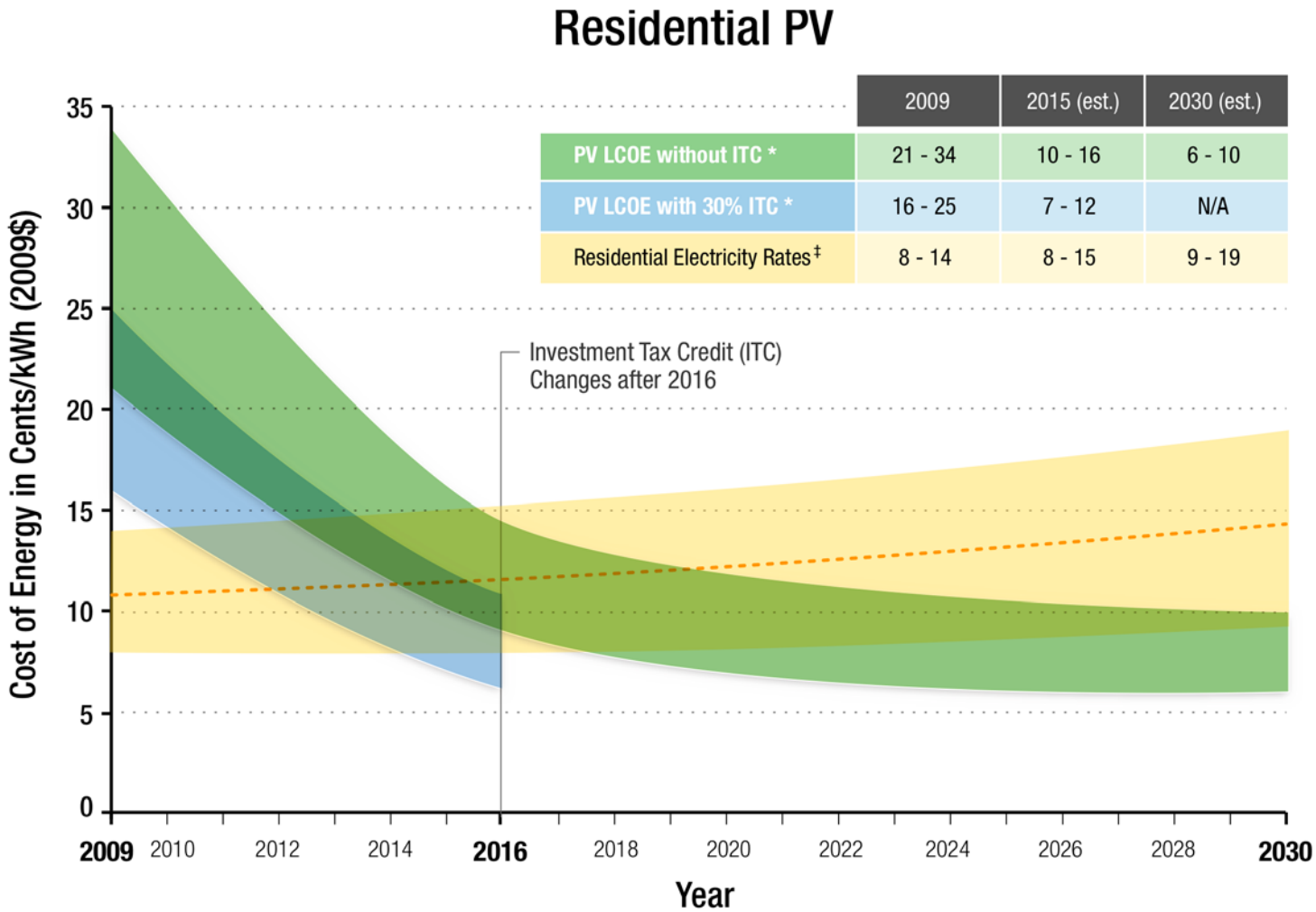
Design by NASA and MIT for a 354 passenger commercial aircraft that would be available for commercial use in 2030-2035 and would enable a reduction in aircraft fuel consumption by 54% over a Boeing 777 baseline aircraft

Nano2 Report, 2010, cover page. Courtesy of NASA and MIT



Goal: U.S. grid parity by 2015 for photovoltaic technologies

Levelized cost of energy (LCOE)



	2009	2015 (est.)	2030 (est.)
PV LCOE without ITC *	21 - 34	10 - 16	6 - 10
PV LCOE with 30% ITC *	16 - 25	7 - 12	N/A
Residential Electricity Rates ‡	8 - 14	8 - 15	9 - 19

Courtesy DOE, 2010

2010-2020: Key areas of emphasis

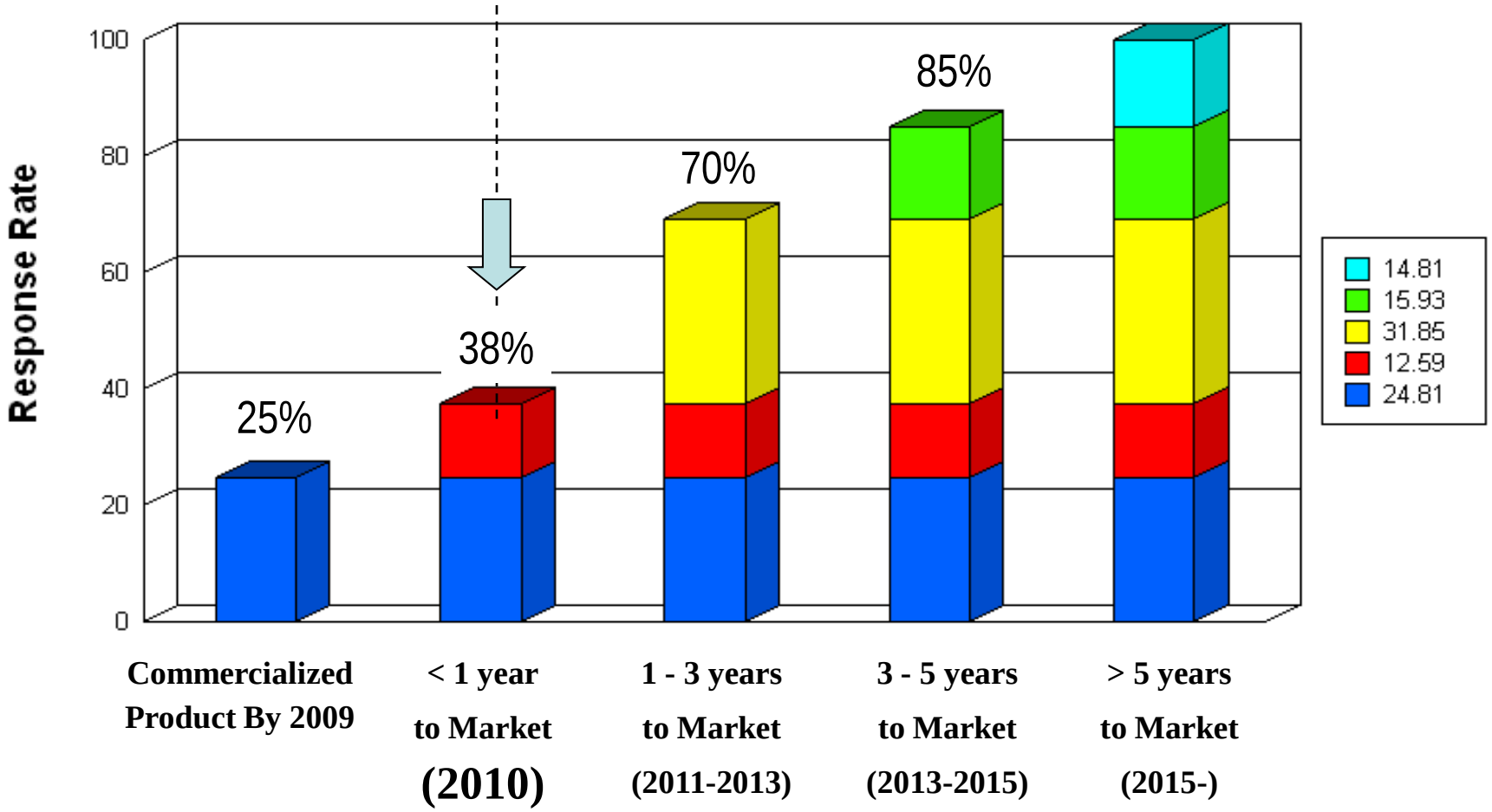
- Integration of knowledge at the nanoscale and of nanocomponents in nanosystems, aiming toward creating fundamentally new products
- Better experimental and simulation control of molecular self-assembly, quantum behavior, creation of new molecules, and interaction of nanostructures with external fields to create products
- Understanding of biological processes and of nano-bio interfaces with abiotic materials, and their biomedical applications
- Nanotechnology solutions for sustainable development
- Governance to increase innovation and public-private partnerships; oversight of nanotechnology EHS, ELSI, multi stakeholder, public and international participation. Sustained support for education, workforce preparation, and infrastructure all remain pressing needs

2010-2020: Increasing R&D intensity and return

- Research into the systematic control of matter at the nanoscale will **accelerate in the first part of the next decade** (2011-2015)
- Nanotechnology by 2020 seamlessly integrated with most technologies and applications, **driven by economics** and by the strong potential for achieving **previously unavailable solutions**
- Support for **fundamental research** and infrastructure - essential
- Support **focused R&D programs** for frontiers and bottlenecks
- **Realize nanomaterials and nanosystems by design**
- High potential of nanotechnology to support **sustainable development** in water, energy, minerals, and other resources

A shift to new nano enabled commercial products after 2010

Survey of 270 manufacturing companies

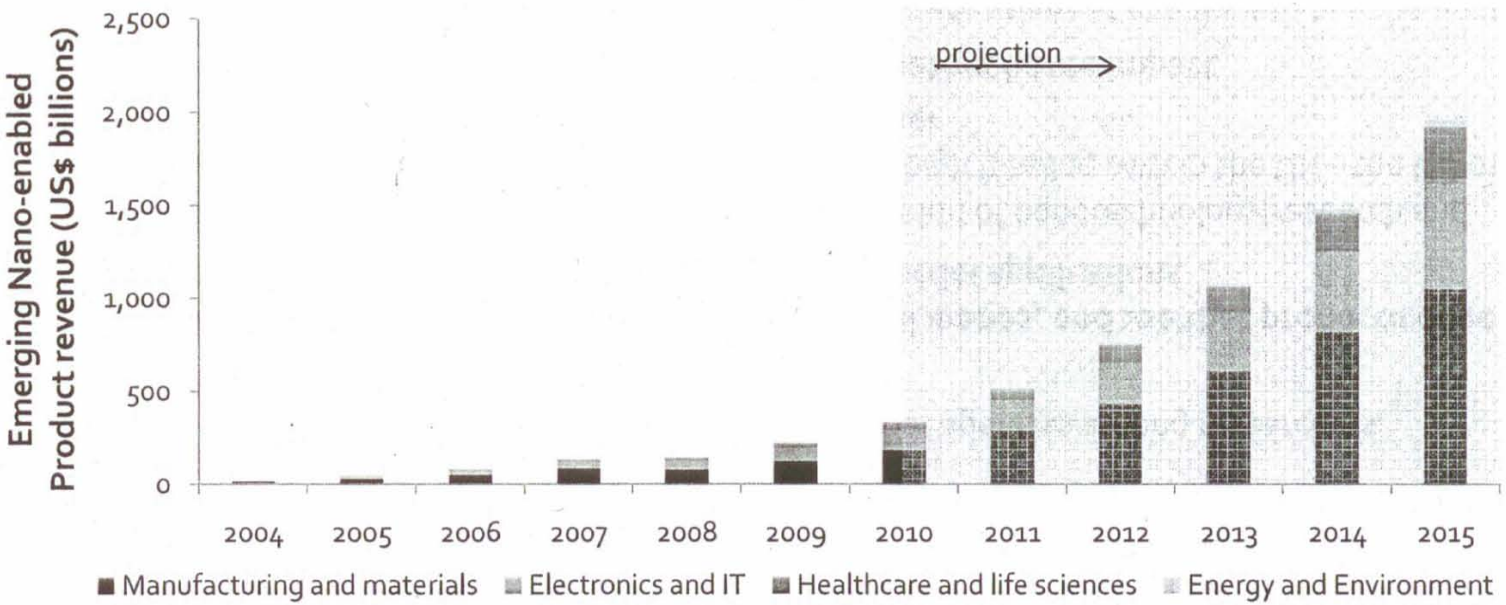


Nano2 Report, 2010, p. XXXIX. *Courtesy National Center for Manufacturing Sciences (NCMS, 2010)*

NDUSTRY STUDY (Lux Research, 2010) - THE NEXT 5 YEA

Emerging nanotechnology products will introduce modifications to today's products

- The overall growth of nano-enabled products to 2015 will consist largely of emerging applications in materials and manufacturing as well as electronics. Healthcare and life sciences will grow as these fields overcome safety, testing, and consumer acceptance barriers not faced by other applications.



Source: Lux Research

2010-2020: OTHER PRIORITIES

- Advance **partnerships** between industry, academia, NGOs, multiple agencies, and international organizations
- Support precompetitive R&D and system application **platforms**
- Promote **global coordination**; Create an international co-funding mechanism for databases, nomenclature, standards, and patents
- Support horizontal, vertical, and system **integration in nanotechnology education; and personalized learning**
- Use **nanoinformatics** and computational science prediction tools
- **New strategies** for mass dissemination, public participation
- **Institutionalize**—create standing organizations and programs to fund and guide nanotechnology

It will be imperative over the next decade to focus on higher purpose goals of nanotechnology development

- How nanoscale science and engineering can improve understanding of nature, generate breakthrough discoveries and innovation, and build materials and systems by nanoscale design – "**knowledge progress**"
- How nanotechnology can generate economic and medical value —"**material progress**"
- How nanotechnology can address sustainable development, safety, and international collaboration —"**global progress**"
- How nanotechnology governance can enhance quality-of-life and social equity —"**moral progress**"

National Institute of Standards and Technology – Physical Measurement Laboratory

Metrology for Nanomaterials and Collaboration Opportunities at NIST

Michael T. Postek, Ph.D.

Chief, Mechanical Metrology Division
Physical Measurement Laboratory
National Institute of Standards and Technology

USDA Nanotechnology Grantees' Meeting
December 10, 2010

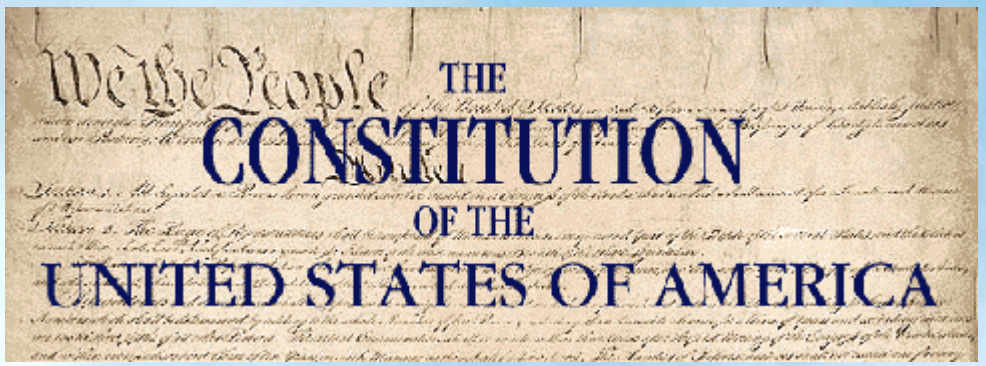
NIST/Department of Commerce

Gary F. Locke
Secretary of Commerce

- National Oceanic and Atmospheric Administration
- International Trade Administration
- US Patent and Trademark Office
- **National Institute of Standards & Technology**
- Economics and Statistics Administration
- other agencies...

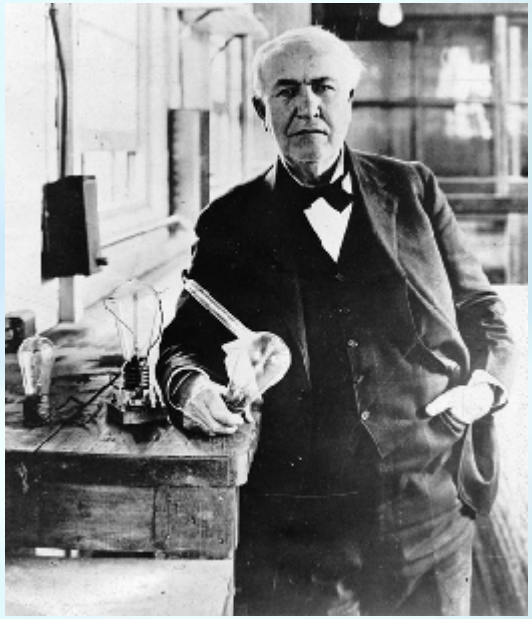
The historic mission of the Department is "to foster, promote, and develop the foreign and domestic commerce" of the United States. This has evolved, as a result of legislative and administrative additions, to encompass broadly the responsibility to foster, serve, and promote the Nation's economic development and technological advancement.

The Importance of Standards



Article I, Section 8: The Congress shall have the power to…*fix the standard of weights and measures*

- National Bureau of Standards established by Congress in 1901
  - Eight different "authoritative" values for the gallon
  - Electrical industry needed standards
  - American instruments sent abroad for calibration
  - Consumer products and construction materials uneven in quality and unreliable



National Archives

Estimated that 80% of global merchandise trade is influenced by testing and other measurement-related requirements of regulations and standards

NIST Mission and Programs

"To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life"

NIST Laboratories

- Create critical measurement solutions and promote equitable standards to stimulate innovation, foster industrial competitiveness, and improve the quality of life.

Hollings Manufacturing Extension Partnership

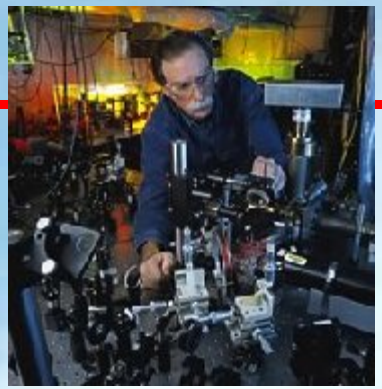
- Nationwide network of resources helping smaller manufacturers compete globally

Baldrige Performance Excellence Program

- Promoting and recognizing performance excellence via information and Presidential awards in manufacturing, service, small business, education, health care, and the nonprofit sector

Technology Innovation Program

- Supports development of cutting edge technologies by the private sector and universities to address critical national needs and key societal challenges



© Geoffrey Wheeler

Courtesy Stoner Inc.

Courtesy Steuben

NIST Products and Services

Collaborations

- 2600 Associates and Facility Users

Measurement Research

- 2,200 publications per year
- 8,000 attendees at 69 technical conferences

Standard Reference Data

- 100 different types
- 6,000 units sold per year
- 130 million data downloads per year

Standard Reference Materials

- 1,300 products available
- 30,000 units sold per year

Patents and Inventions

- 60 in FY 08

Baldrige National Quality Program

- 67 Award recipients (71 Awards)
- 1,139 Baldrige Award applications

Manufacturing Extension Partnership

- 28,000 Clients

Calibration Tests

- 18,000 tests per year

Laboratory Accreditation

- 800 accreditations of testing and calibrations laboratories per year

Standards Committees

- 400 NIST staff serving on 1,000 national and international standards committees

Other Agency R&D

- > 300 Agreements with 80 Fed. Agencies
- $125M received in FY 2009

NIST has……four joint institutes

JILA
NIST + University of Colorado

Center for Advanced Research in Biotechnology
NIST + University of Maryland
Biotechnology Institute

Joint Quantum Institute
NIST + University of Maryland + NSA

Hollings Marine Laboratory
NIST + NOAA + South Carolina
+ College of Charleston
+ Medical University of South Carolina

NIST has…… unique facilities

Advanced Measurement Laboratory

Courtesy HDR Architecture, Inc./Steve Hall ©Hedrich Blessing

Center for Nanoscale Science & Technology

©Robert Rathe

NIST Center for Neutron Research

Advanced Chemical Sciences Laboratory

NIST Has.....Strong Partnerships

Industry

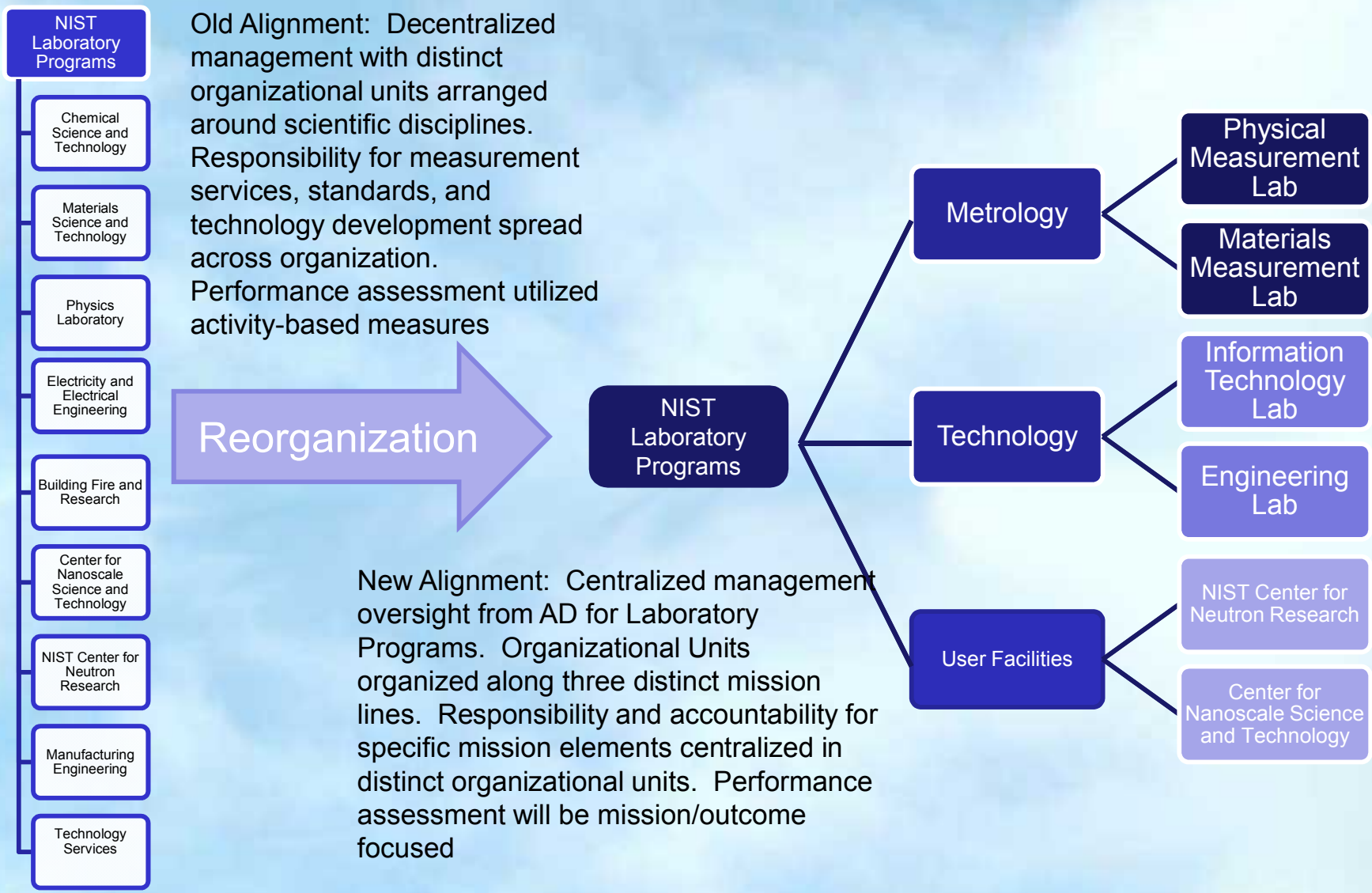
Universities

Nonprofits

Government

NIST Reorganization

Major shift in how NIST manages its programs – from an activity/discipline oriented organization to one focused on mission and outcomes



Old Alignment: Decentralized management with distinct organizational units arranged around scientific disciplines. Responsibility for measurement services, standards, and technology development spread across organization. Performance assessment utilized activity-based measures

New Alignment: Centralized management oversight from AD for Laboratory Programs. Organizational Units organized along three distinct mission lines. Responsibility and accountability for specific mission elements centralized in distinct organizational units. Performance assessment will be mission/outcome focused

NIST Reorganization

Director
Patrick Gallagher

Executive Officer for Administration
Management Organization
Administrative Support

Chief of Staff
Program Coordination
Public and Business Affairs
Congressional and Legislative Affairs
International and Academic Affairs

Associate Director for Laboratory Programs/ Principal Deputy
vacant

Staff Offices
Standards Coordination
Special Programs

Physical Measurement Laboratory

Laboratory
Cita Furlani

Center for Nanoscale Science and Technology
Robert Celotta

NIST Center for Neutron Research
Robert Dimeo

Associate Director for Innovation & Industry Services
vacant

Staff Offices
Technology Partnerships
Economic Analysis
Grants Management

Baldrige Performance Excellence Program
Harry Hertz

Hollings Manufacturing Extension Partnership
Roger Kilmer

Technology Innovation Program
vacant

Associate Director for Management Resources
David Robinson

Staff Offices
Boulder Site Management
Civil Rights and Diversity
Research Support Services
Strategic Resources

Office of Facilities and Property Management
Stella Fiotes

Office of Financial Resource Management
vacant

Office of Workforce Management
Michael Culpepper

Office of Information Systems Management
Delwin Brockert

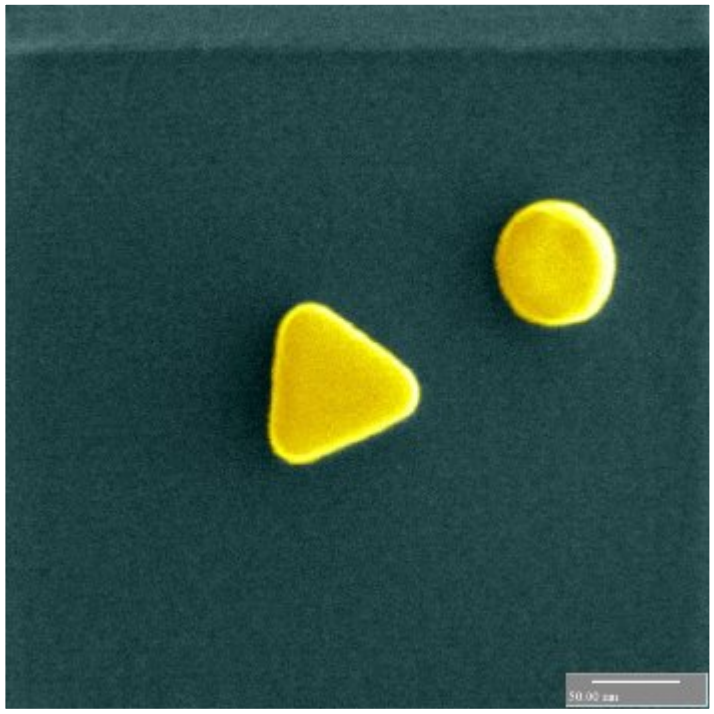
Office of Safety, Health and Environment
Richard Kayser

Mechanical Metrology Division (MMD)

- **Responsible for the realization and dissemination of the SI units of:**
  - **Length from:**
    - **kilometers to nanometers (12 orders of magnitude);**
  - **The mass scale from:**
    - **0.5 mg to 27 300 kg (12 orders of magnitude);**

and the Derived Units:

  - **The force scale from:**
    - **10 pN to 53 MN (18 orders of magnitude);**
  - **Acoustic pressure from:**
    - **1 micropascal to 200 pascals (9 orders of magnitude of sound pressure) over a frequency range of 50 Hz to 20 kHz;**
  - **Vibration from:**
    - **0.5 m/s^2 to 100 km/s^2 (6 orders of magnitude) over a frequency range of 2 Hz to 20 kHz.**



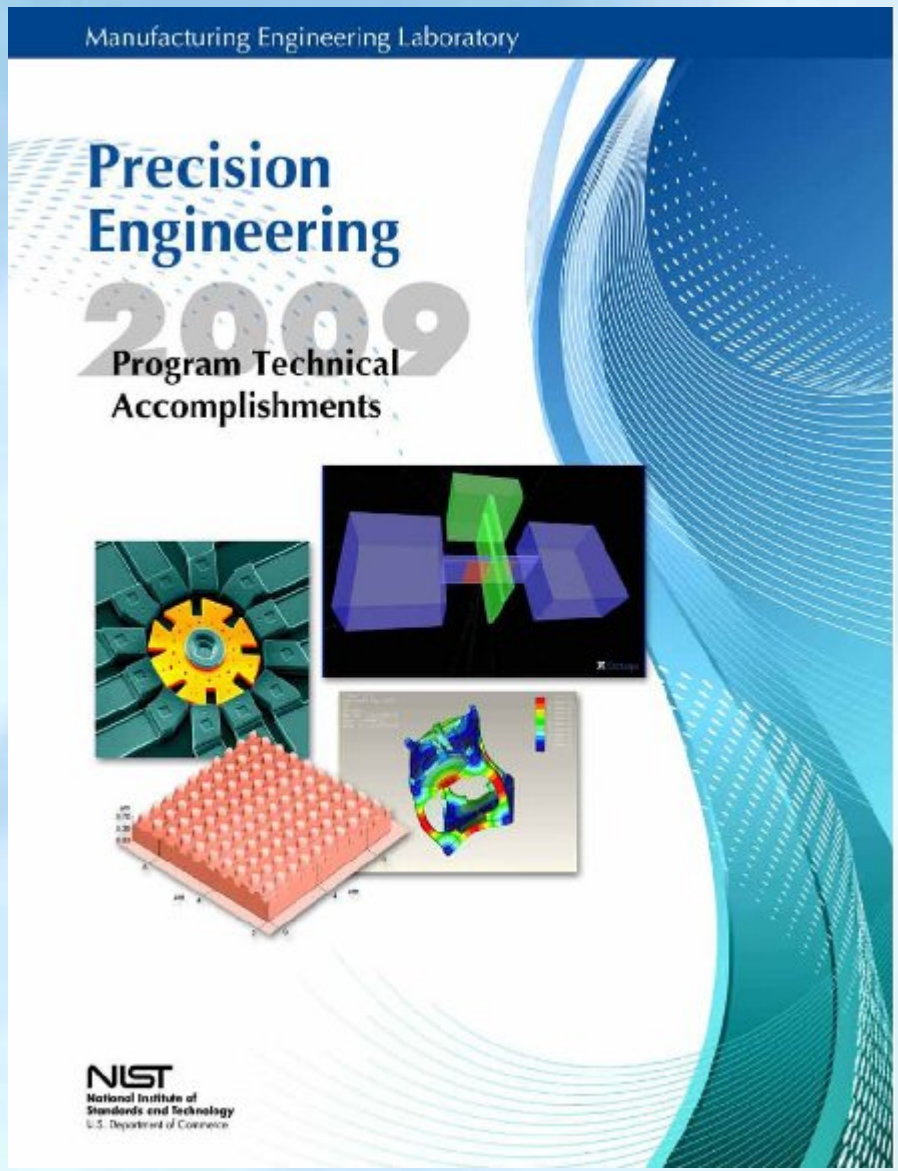
Mechanical Metrology Division (MMD)

- **MMD achieves that goal by:**
  - Conducting research in dimensional and mass measurements;
  - Developing new measurement methods;
  - Providing measurement services;
  - Developing National and International artifact and documentary standards;
  - Disseminating the resulting technology and length-based standards.
- **Provides the delivery of those measurements, standards and infrastructural technology services that promote U.S. innovation and industrial competitiveness.**
  - Infrastructural metrology

Precision Engineering Division

Length component of MMD

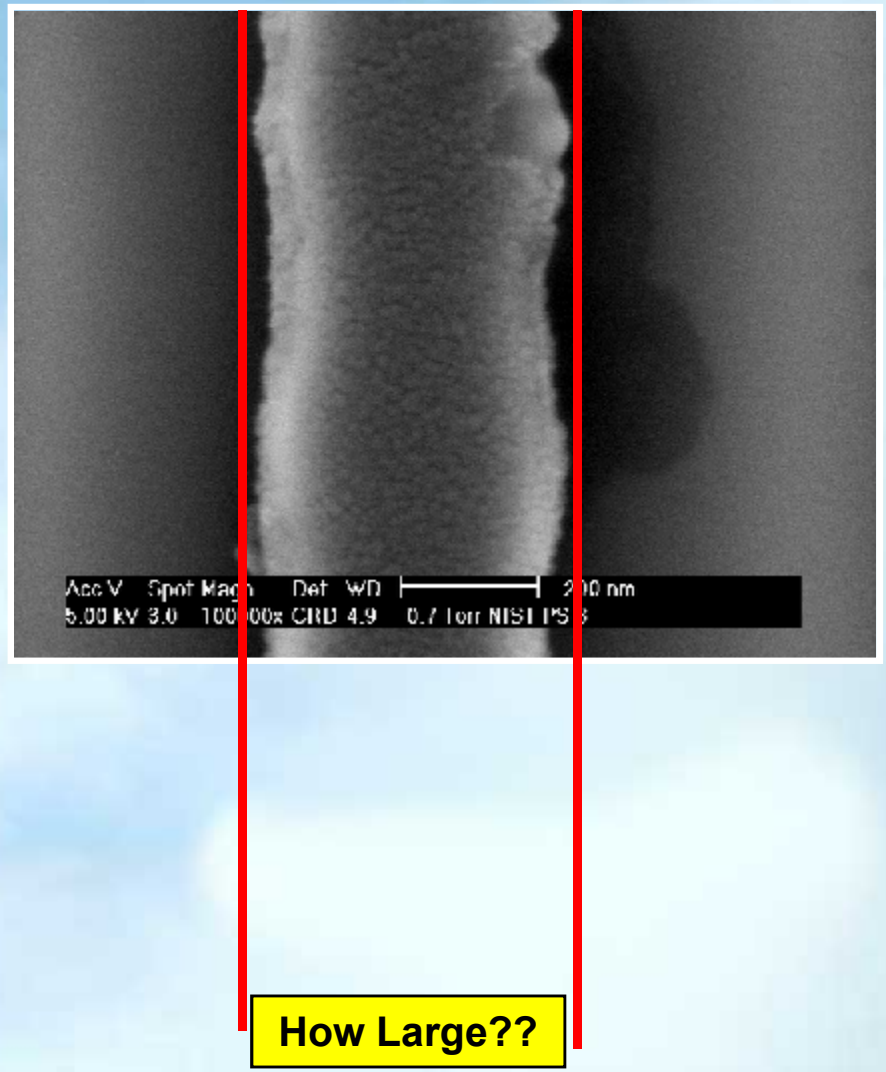
2009 PED Accomplishments
(in Length Metrology)



http://www.nist.gov/pml/div681/upload/ped2009pta.pdf

NIST's Technical Role

- **Works with the other Agencies, industry & academia to develop needed measurement technology**
  - What is measured
  - How it is measured
  - Determination of the limitations of the measurement process
- **Development of new standards**
- **Development of uncertainty statement**
  - Provides a means of comparison of strengths and weaknesses of metrology techniques
  - Quality of a measurement
- **Value of metrology**
  - Economics of the measurements



Dimensional Measurement

- Example:
  - Critical Dimension (CD) measurement for the semiconductor industry
    - Needed to maintain tight process control
  - Infrastructural
    - Since essentially 1-D particle metrology (3-D)
  - Very interesting and complicated scientific and industrial problem
- How hard can that be?

Dimensional Measurement

- Three major instruments used:
  - Optical Microscopy
    - Resolution limited by wavelenght of the illumination source
    - Effects of diffraction
  - Scanning Particle Beam Microscopy (electron, and ion)
    - Resolution limited by accelerating voltage
    - Specimen/beam interaction
  - Scanned Probe Microscopy
    - Resolution limited by probe size and geometry
    - Probe specimen interactions

Accurate Measurement

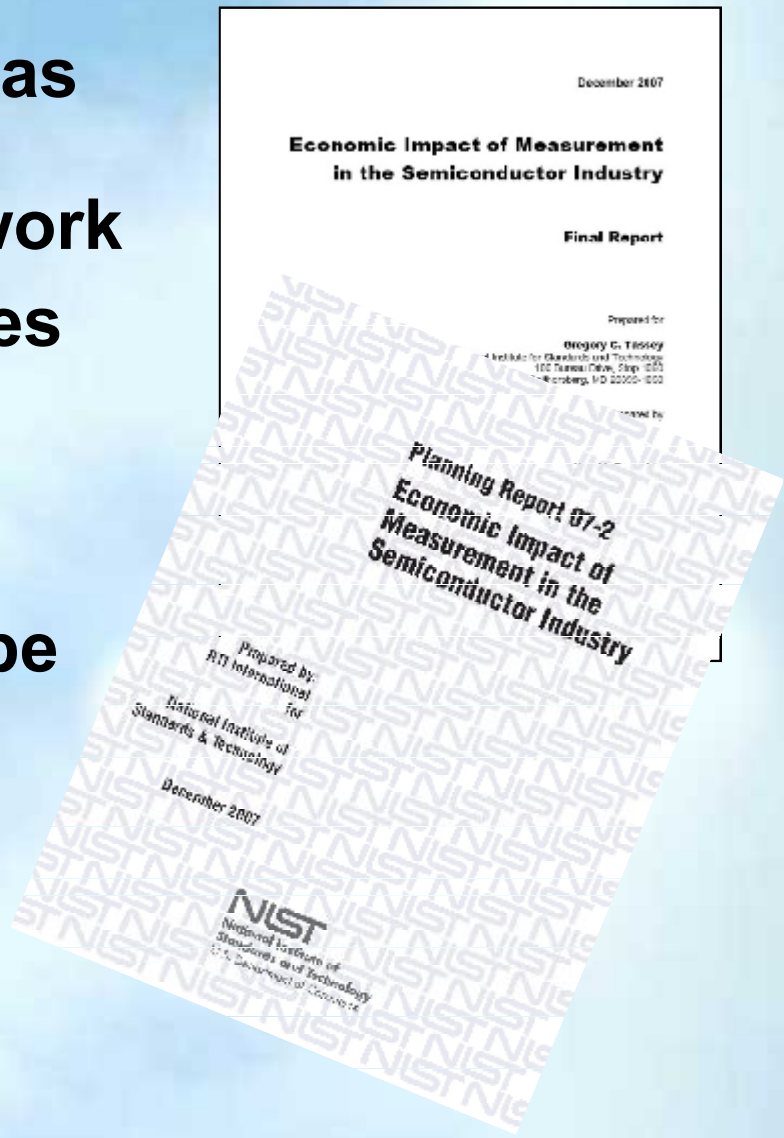
- All three require:
  - An intimate understanding of the entire measurement process and the measurand
  - Physics-based model to deconvolute the instrument signal response recorded and measured, from the actual structure to obtain accurate dimensional information
  - Understanding of the uncertainty associated with that entire process
- Very interesting and complicated scientific, academic and industrial problem - to do accurately

Dimensional Measurements at the Nanoscale = Nanometrology

- Why is this important?
  - Consistent measurements worldwide
    - Flat-world
  - Tight process control of small structures has immense economic worth.
    - Small increases in yield reaps huge profits.
- What do measurements mean to an industry overall?

RTI International report: Economic Impact of Measurement in the Semiconductor Industry

- Semiconductor manufacturing has clearly benefitted and has demonstrated the value of this work
- RTI International Report estimates that **for every $1 spent on measurement, the industry as a whole saw a $3.30 return**.
- Metrology is and has proven to be value added and will be for any nanomanufacturing process.



Semiconductor Industry

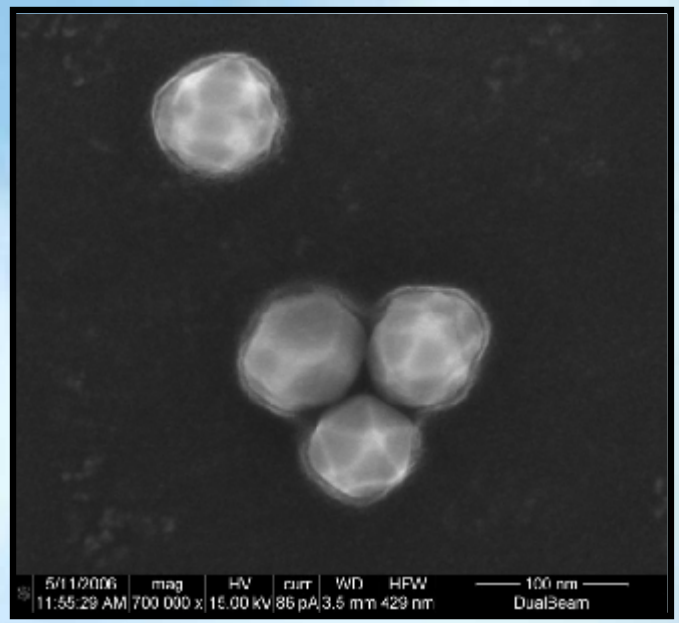
- Early 1990s:
  - "Metrology is not value added"
- Today
  - "If you cannot measure it you cannot manufacture it"
- Measurement is even more important for Nanotechnology and Nanomanufacturing
  - The error budget at the nano-level is basically non-existent

Transition "Nanotechnology" – to- Nanomanufacturing

- From the largest airplane to the smallest transistor gate on a microprocessor, nanotechnology and "nanomanufacturing" will become a greater and greater component of the U. S. manufacturing base.
  - Aerospace – next generation airplanes with carbon nanotube or nanocellulose reinforced composites
  - Automotive – sensors, lighter parts
  - Electronics – carbon nanotube and nanowire circuitry
  - Molecular electronics – bottom up self assembly
- The number of possibilities is enormous and the U. S. must be there - and be there first

Effective Nanomanufacturing

- For nanotech products to achieve the broad impacts envisioned they must be manufactured:
  - In market-appropriate quantities to take advantage of the economy of scale
  - In a reliable, repeatable, economical and commercially viable manner
    - Currently, Intel produces ~10^{18} transistors/yr
    - @ about 3B transistors/computer
  - ALSO with environmental and human health concerns met, worker safety issues appropriately assessed and handled, and liability issues addressed



"Prior to the introduction of new materials and technologies, we should not only consider cost, effectiveness, and efficacy but also social, cultural, and ethical appropriateness."

Nora Savage, PhD, EPA

Moores Law and Lessons for Nano

Moores Law depends upon a synergy between performance and cost:

"Silicon is cheap" - Noyce

Postek's corollary for Nanotechnology:

Carbon is also cheap

Cellulose nanocrystals are even cheaper…and sustainable

parts

- **Not just smaller must be cheaper and better**
- **Ultimately,must create an innovative engine making stuff people will buy**

Concept credit: George Thompson, Intel

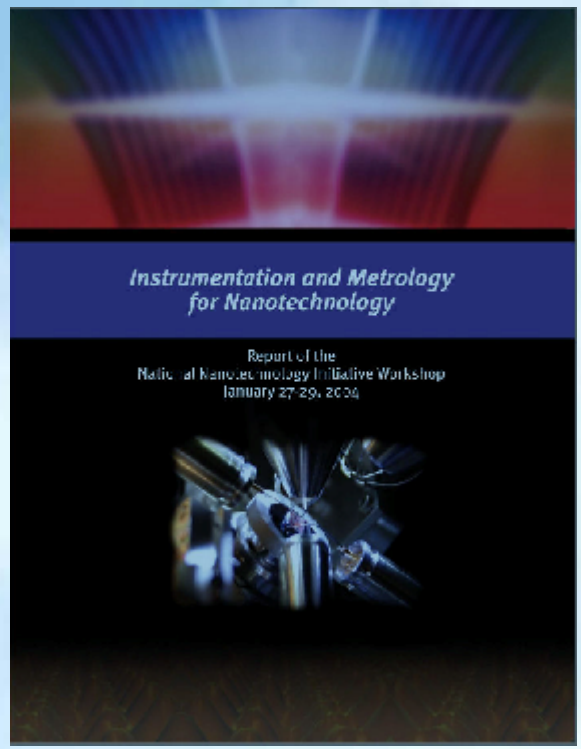
Nanotechnology benefitted from Semiconductor Manufacturing

- Semiconductor industry push
  - Demanded better and better imaging, measurement and characterization of fine structures
  - Resulted in better instruments for all industrial applications
- PML/MMD properly positioned for nanotechnology and the development of nanometrology
  - Working more than a decade in nanometrology and nanomanufacturing*
  - Hosted three major major workshops which are of relevance to this group

* Lyons, K., and Postek, M. T. 2009. Historic commitment of the NIST Manufacturing Engineering Laboratory to nanomanufacturing and nanometrology. SPIE Proceedings. Proc. SPIE 7405 740503-1 – 740503-18.

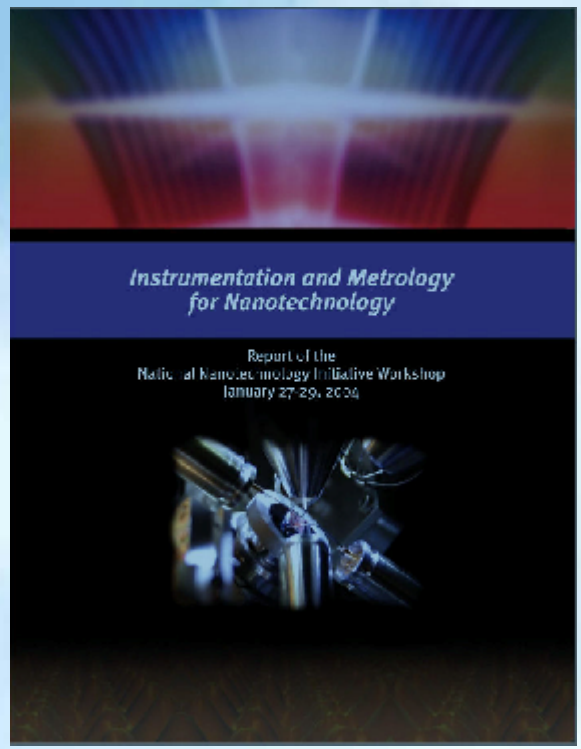
Workshop 1: Instrumentation and Metrology for Nanotechnology

- **Much of the measurement infrastructure currently available for materials characterization is only evolutionary**
  - Optics
  - Transmission Electron Microscope
  - Scanning Electron Microscope
  - Scanning Probe Microscope

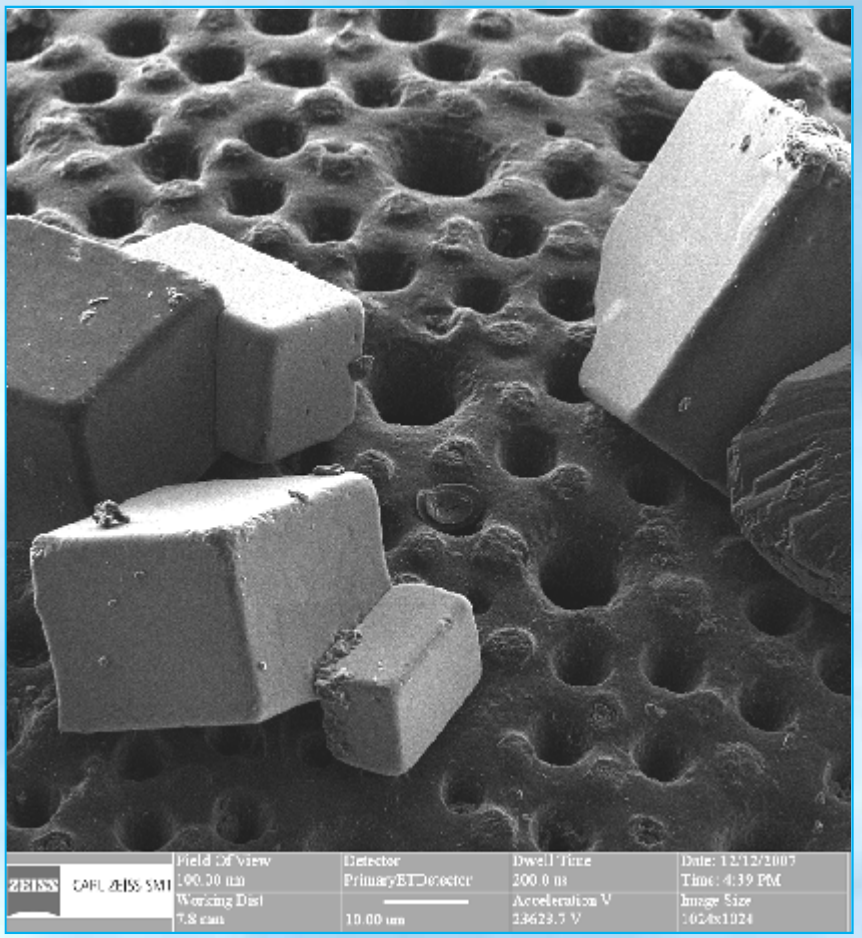


Workshop 1: Instrumentation and Metrology for Nanotechnology

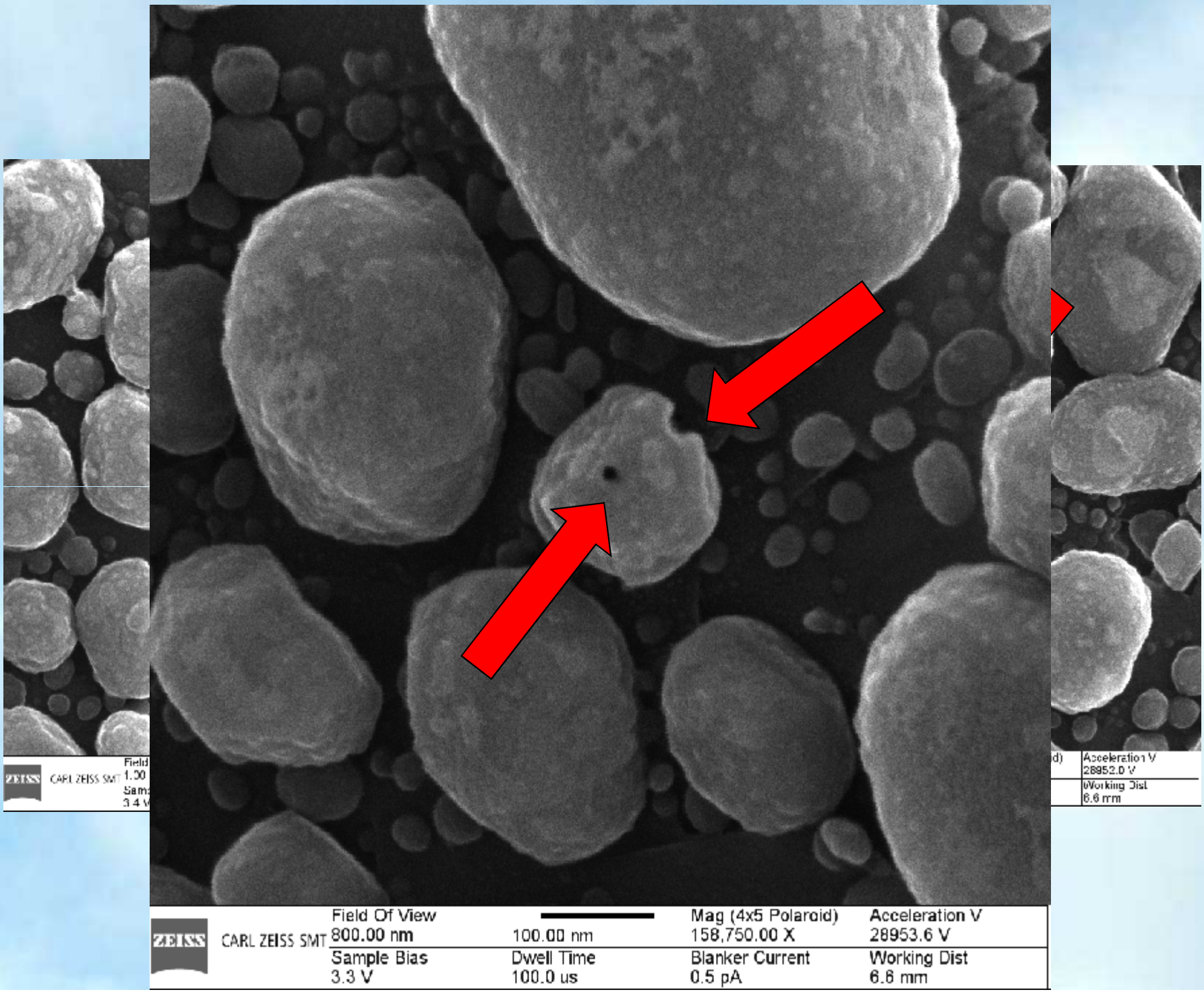
- **Materials characterization at the nanoscale requires that automated, operator-independent instrumentation must be developed**
  - Instrument operators are the largest source of measurement error
  - This has been well documented by the semiconductor industry
- **New, potentially revolutionary characterization tools are needed for many applications**



Helium Ion Microscope



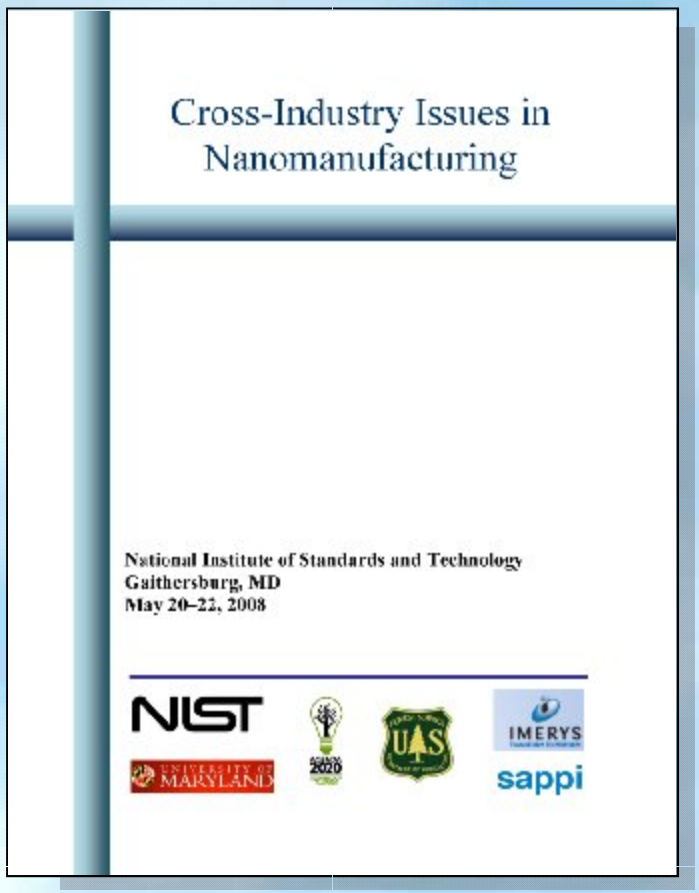
- **Application of NIST (and others) microscopy, metrology, and materials characterization expertise to the study of the physics of this instrument will greatly advance scientific discovery**
  - **Current ongoing collaborations with Chemical and Material Science Laboratories**


ZEISS
CARL ZEISS SMT
Field Of View
800.00 nm
100.00 nm
Mag (4x5 Polaroid)
158,750.00 X
Acceleration V
28953.6 V
Sample Bias
3.3 V
Dwell Time
100.0 us
Blanker Current
0.5 pA
Working Dist
6.6 mm

Workshop 2: Instrumentation, Metrology and Standards for Nanomanufacturing

- NNI-Sponsored Interagency Working Group on Manufacturing R&D
- A coordinating consortium-type organization (or organizations) could make huge strides in the development of needed materials characterization instrumentation
  - Reduce duplication of effort
  - Focus resources
  - Guide the instrument manufacturers
  - Assure the needed tools are available
- Requires nanotechnological commonalities of need in instrumentation, metrology and standards to be identified across the field and a focus must be developed
  - Act as the focal point for any road mapping exercises.

Workshop 3: Cross Industry Issues in Nanomanufacturing



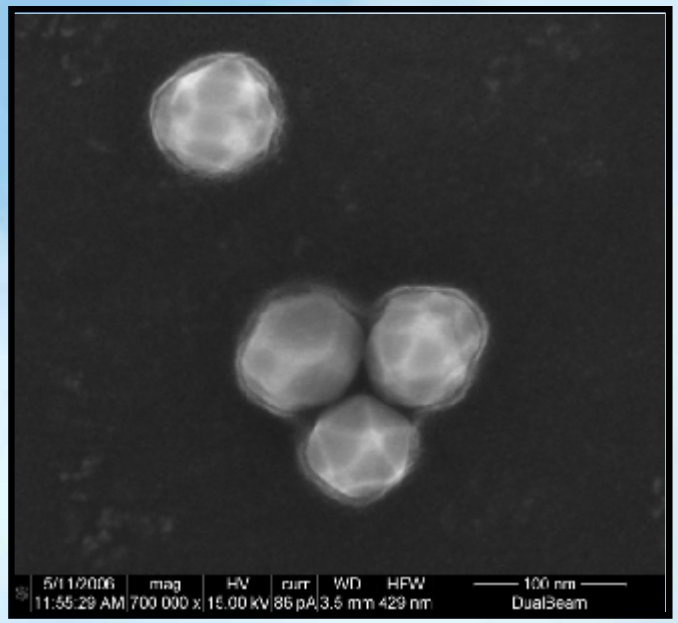
Supported by a loose consortium of 10-12 industrial partners including:

- Forest Products
- Semiconductor Industry
- Auto Industry
- Aeronautics

- Accurate databases need to be developed of nanomaterial properties to enable materials and processes by design and reduce trial and error
- The development of validated modeling capability to predict multiple properties of nanomaterials in complex matrices to reduce the time and cost to develop new products and processes
  - Development of Predictive Modeling
    - Huge basic scientific and materials challenge
- The characterization of scale-up challenges for both process control and high-throughput manufacturing and measurement capabilities

Accuracy and Precision

- Nanomanufacturing will rely on highly precise process control in order to obtain economy of scale once "accuracy" is established
  - Accuracy is telling the truth (within some measurement uncertainty)
  - But, if accuracy is not assured precision is telling the same lie over and over again.
- Why is this so important now?
  - Worldwide database development for nanomaterials and nanoparticles



Material Databases

- Databases are only as good as the contained information
  - If these data are not accurate these databases will be rendered useless
- What is the degree of correlation between databases?
- Accurate data is needed so that science-based decisions, not hype, can be made

Strategic Alliances Imperative

- Developing effective instrumentation, nanometrology, and nanostandards is not a simple problem to solve.
- Success requires strategic alliances between: Governments, University, Industry and Professional Societies
- Nanotech strong fit for strategic alliances
  - Multi-disciplinary nature
  - Enabling technology
  - Broad industry implications
  - Federal funding opportunities
  - Commercialization challenges
- Cannot be done alone which leads to the multidimensional nature of nanotechnology…

Conclusion

- If a product cannot be measured it cannot be manufactured.
- If a product cannot be made safely it should not be manufactured.
- If a product cannot be measured how would you even know?

NanoScience +Engineering
SPIE Optics+Photonics

21 - 25 August 2011
San Diego Convention Center
San Diego, California United States

Instrumentation, Metrology, and Standards for Nanomanufacturing, Optics, and Semiconductors V

Conference OP114

Part of program track on **NanoEngineering**

This conference has an open call for papers:

See submission guidelines for Authors & Presenters

Submit an abstract

Conference Chair

Michael T. Postek, National Institute of Standards and Technology

Conference Co-Chairs

Victoria A. Coleman, National Measurement Institute of Australia (Australia); **Zu-Han Gu**, Surface Optics Corp.

Program Committee

John A. Allgair, GLOBALFOUNDRIES Inc. (Germany); **Russell A. Chipman**, College of Optical Sciences, The Univ. of Arizona; **Khershed P. Cooper**, U.S. Naval Research Lab.; **Thomas A. Germer**, National Institute of Standards and Technology; **Daniel J. C. Herr**, Semiconductor Research Corp.; **Mark D. Hoover**, The National Institute for Occupational Safety and Health; **Alexei A. Maradudin**, Univ. of California, Irvine; **Ndubuisi G. Orji**, National Institute of Standards and Technology; **Nora Savage**, U.S. Environmental Protection Agency; **John Small**, National Institute of Standards and Technology; **Shouhong Tang**, KLA-Tencor Corp.; **John F. Valley**, Raytex USA Corp.; **Xianfan Xu**, Purdue Univ.

SPECIAL "GREEN" MATERIALS AND METROLOGY SESSION

Dr. Nora Savage, Environmental Protection Agency (United States)

The optics and photonics industries are poised to be instrumental factors in
alization of environmental sustainability. Starting with the employment of
ign materials in the research and production of novel devices enabled by th
re to the development of innovative reclaim and recycling options for
als and devices that have reached the end of the product life cycle, optics
tonics have the potential to impact the way we devise, employ and
/recycle products. As a result of the size and inter-disciplinary nature of
tries, efforts and activities by the members thereof toward protection
ith and the ecosystem can usher in an environmental consciousness
ety. In addition, the application of technological advances in these
form conventional components and devices. The resultant novel
ve a more environmentally friendly design.

nde information concerning novel photonic and optical devices
are processed using benign materials. The processes and
inform the audience about potential methodologies and
products. This session will also feature presentations
n the field which result in the replacement of more toxic
ith other "greener" constituents and products, such
that use less energy, require less water, and
devices and products would have increased
ipated benefits to public health and the

Thank you

Contact Information

Michael T. Postek, Ph.D.
Chief, Mechanical Metrology Division
National Institute of Standards and Technology
100 Bureau Drive, Stop 8210
Gaithersburg, MD 20899-8210
postek@nist.gov
Ph: 301-975-2299

Research Outcome, Impacts and Directions of Nanoscience and Nanotechnology for Medical Applications at NIH and Current Hot Topics

Albert Lee, Ph.D.

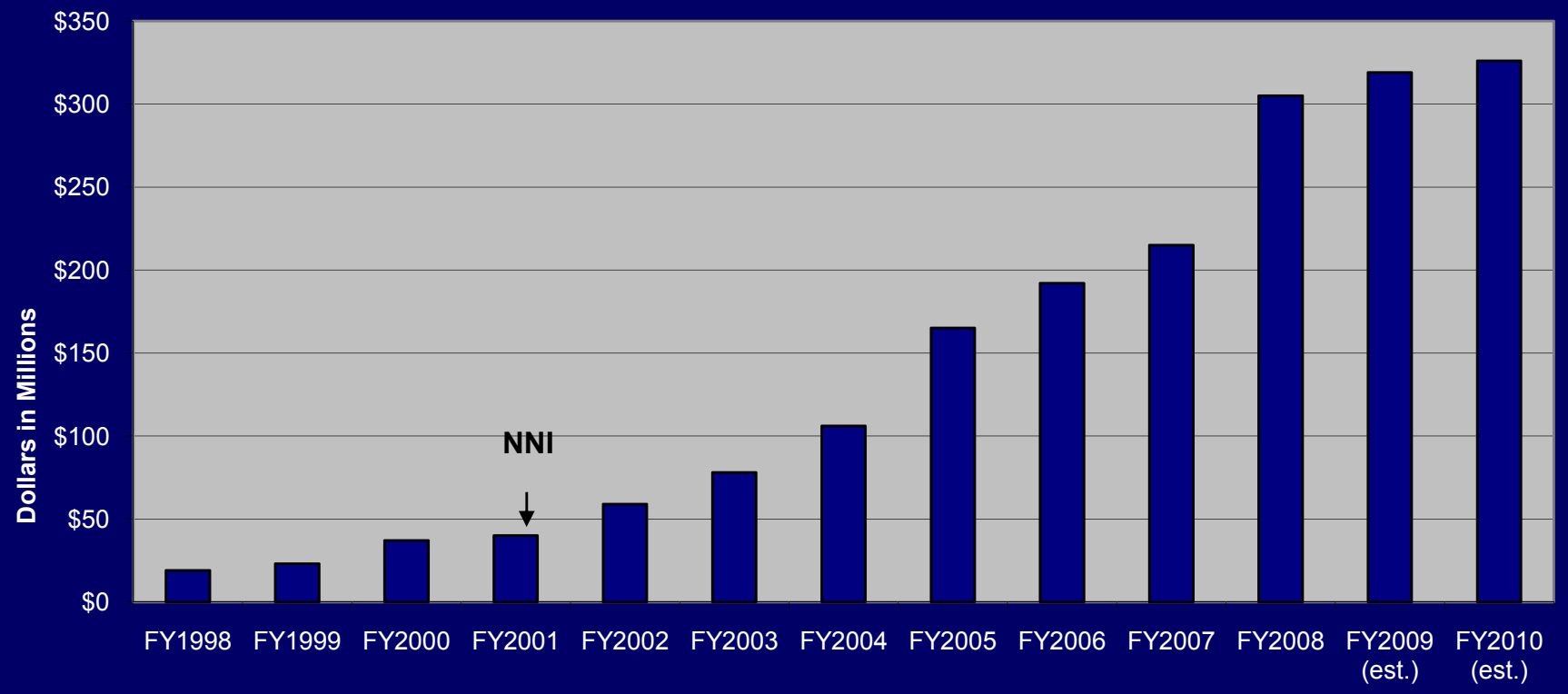
Program Director

National Institute of Biomedical Imaging and Bioengineering

NATIONAL INSTITUTES OF HEALTH

NIBIB

NIH Funding in Nanotechnology (NT) (1998 – 2010)



Estimated FY2009 $311.3 M

Phenomena & Processes:	48.4	Metrology & Standards:	5.5
Nanomaterials:	44.5	Nanomanufacturing:	0.7
Devices & Systems:	164.3	Education/Societal Dimensions:	0.6
Research Facilities & Acquisitions:	37.1	Environmental Health & Safety	10.2

American Recovery & Reinvestment Act

ARRA Investments in NT based on the new Research, Condition, and Disease Categorization system (RCDC): $73.3 M

Summary of ARRA-specific Funding Opportunities

- **Challenge Grants: Priority Research in 15 Broad Areas**
- **Grand Opportunities (GO) Grants: Large-scale, High impact Research**
- **Summer Research Experiences for Students & Educators**

Visit the NIH's Research Portfolio online reporting tool (RePORT) for NT project listing . See http://grants.nih.gov/recovery for all ARRA projects

Nanotechnology (NT) at NIH: 2009 - 2010

"National Nanotechnology Initiative: A future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society"

I. Subcommittee on Nanoscale Science, Engineering and Technology (NSET): Four goals within Presidential 2008 Plan

- Advance a world-class R&D program
- Foster tech-transfer for commercial & public benefit
- Develop & Sustain educational resources and skilled workforce
- Support responsible development of NT

"Continue to support a wide range of basic and clinical research to achieve an understanding of biological processes and novel approaches to engineer NT solutions"

NIH Infrastructure and Ongoing Strategies

II. Trans-NIH Nanotechnology Task Force:

- Science Vision: – Identify the role NIH can play in guiding and facilitating the development of NT via portfolio analysis and thinking out of the box
- Health Implications: Develop and assist in coordinating a plan to determine fundamental interactions of engineered nanomaterials with biological systems (NanoHealth Enterprise Initiative)
- Ethical, Legal & Societal Implications: Identify ethical, legal, and societal implications of NT research as it relates to the NIH mission
- Communications & Public Trust: Develop training, communication, education and outreach activities about NIH-related NT activities

Strategies:

- Focus is on Health implications of engineered nanomaterials
- Collaborative Research to advance Nano Discovery & Translational R&D
- Informatics for the Integration of NT data

NIH - NT Research Programs continue

- NIH NANOMEDICINE ROADMAP INITIATIVE: Characterize quantitatively the physical and chemical properties of molecules and nanomachinery in cells to gain an understanding of the engineering principles used in living cells in which to "build" molecules, molecular complexes, organelles, cells, and tissues

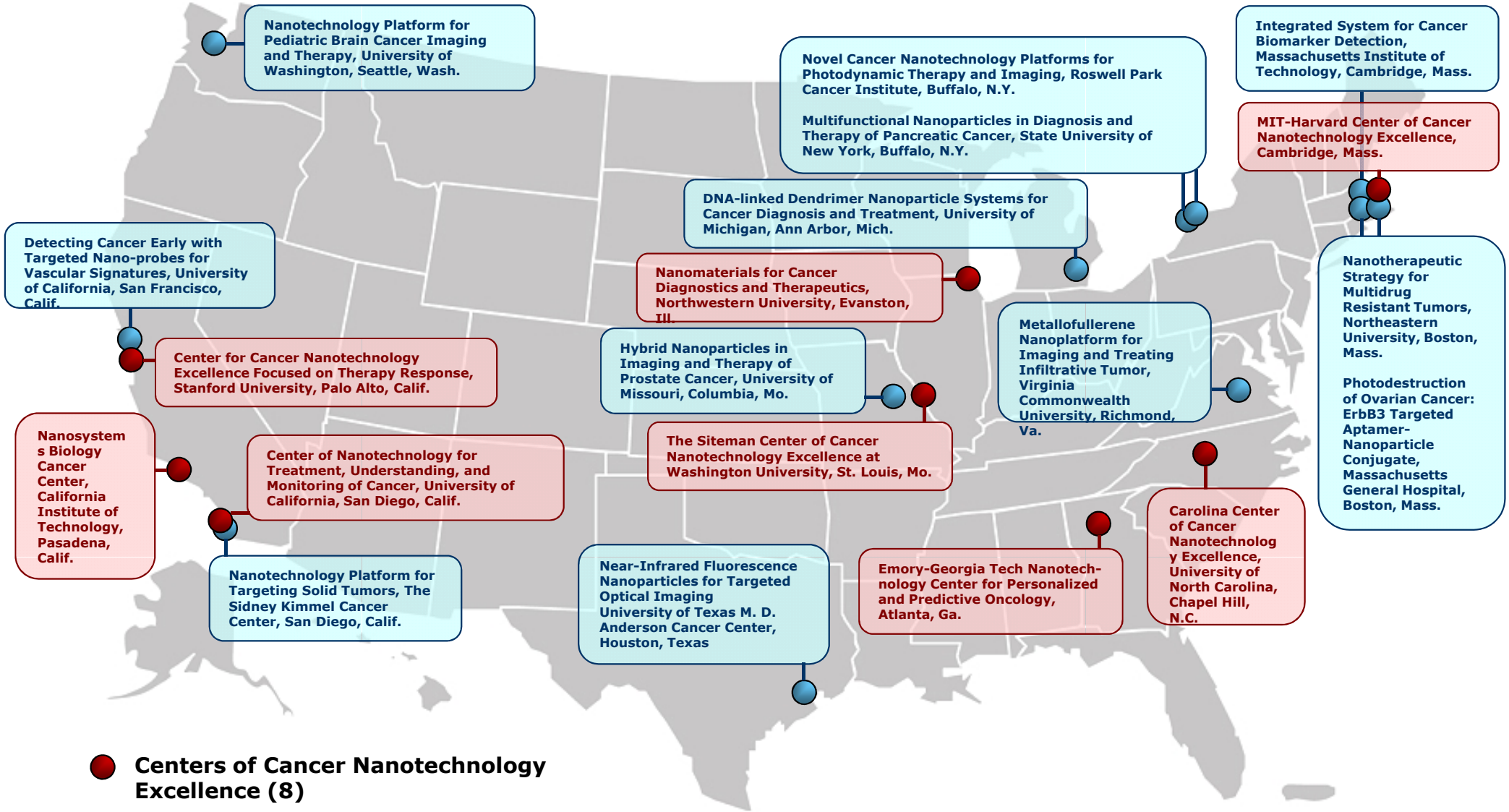
- NCI ALLIANCE FOR NANOTECHNOLOGY IN CANCER: Establish of centers and platform technologies that enable new solutions to treat Cancer

- NHLBI'S PROGRAM OF EXCELLENCE IN NANOTECHNOLOGY: Develop and apply NT solutions to the diagnosis and treatment of heart, lung, blood, and sleep disorders. 4 PENS funded - Detection, diagnosis, and therapeutic treatment of plaque using integrated Nanosystems

- NIEHS NANOHEALTH ENTERPRISE INITIATIVE: A partnership between NIH Institutes, federal agencies, and public-private institutions to employing state-of-the-art technologies in research to examine the fundamental physicochemical interaction of engineered nanomaterials with biological systems at the molecular, cellular and organ level

- NIGMS SINGLE MOLECULE BIOPHYSICS AND NANOSCIENCE: Development of new and improved instruments, methods and technologies for nanoscience, and for the analysis of single protein and nucleic acid molecules and their complexes *in-vivo* and *in-vitro*

NCI Nanotechnology Alliance - Awards

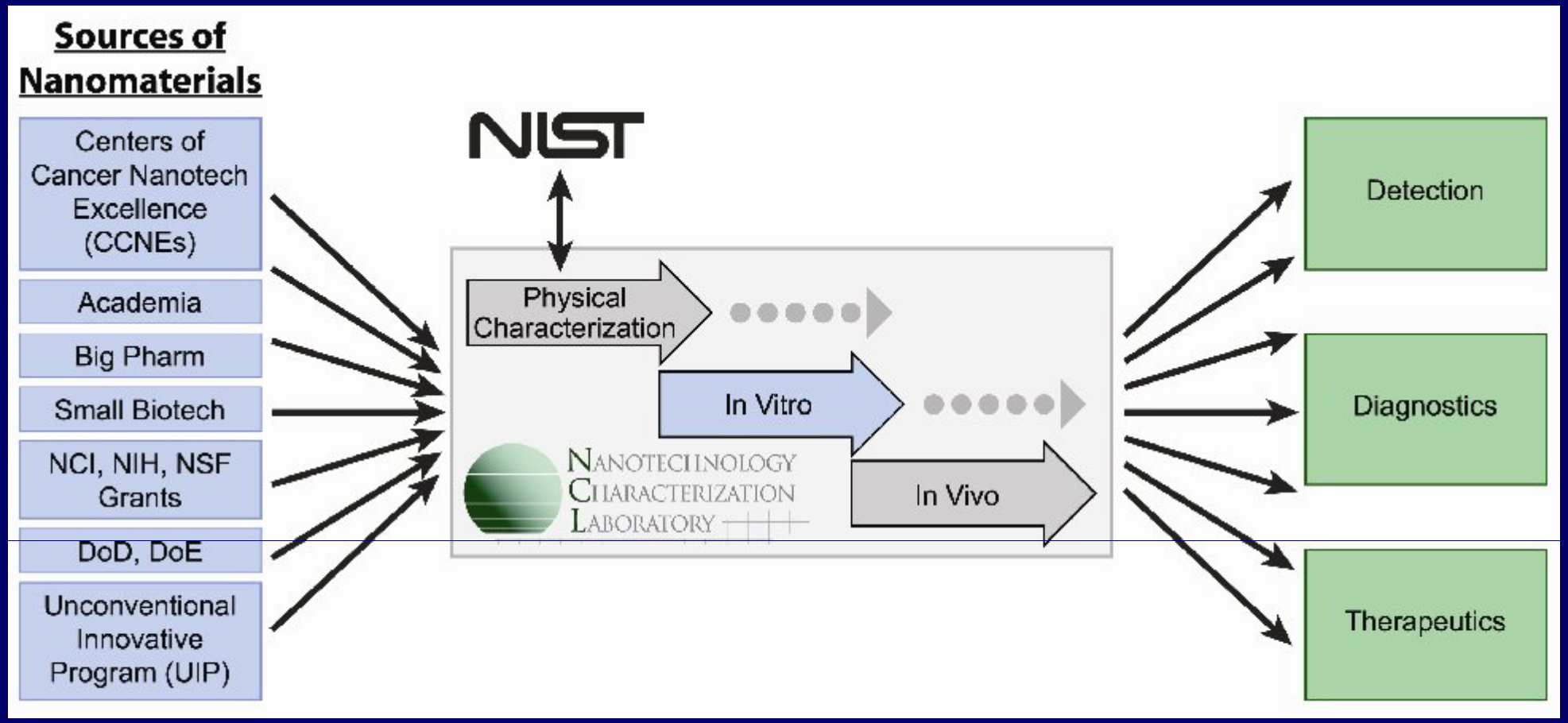


- **Centers of Cancer Nanotechnology Excellence (8)**
- **Cancer Nanotechnology Platform Partnerships (12)**

http://nano.cancer.gov/

Nanotechnology Characterization Laboratory

Established Nanotech Characterization Lab (NCL) as a major hub for nanomaterials characterization



NHLBI's Program of Excellence

NHLBI funded 4 multidisciplinary PENs in 2005 committing $54 M over 5 years

1. Ralph Weissleder (Mass General/Harvard/MIT) - Nanoparticle based probes for in vivo imaging and for cardiac cell differentiation
2. Gang Bao (Emory University/Georgia Tech) -Detection and Analysis of Plaque Formation
3. Karen Wooley (WashU/UCSF/UCSB) – Nanoscale agents for diagnosis & therapeutics
4. Jeffrey Smith(Burnham Institute/UCSB) – Delivery vehicles to image and treat vulnerable plaque

NIH Nanomedicine Roadmap -
http://nihroadmap.nih.gov/nanomedicine/index.asp

NIH Roadmap: Nanomedicine Centers

1. Nanomedicine Center for Nucleoprotein Machines - characterize the assembly of DSB repair complexes using molecular imaging approaches

2. Center for Cell Control - characterize and quantify nano-molecular components of cells and to precisely control and manipulate these molecules and supramolecular assemblies to improve human health

3. NDC for the Optical Control of Biological Function - develop methods for rapidly turning select proteins in cells on and off with light

4. Center for Protein Folding Machinery - use chaperones as important targets for therapeutic interventions or diagnostic analyses in several human diseases related to protein misfolding

5. Engineering Cellular Control :Synthetic Signaling and Motility Systems - engineer cells and artificial cell-like devices that can be flexibly programmed to carry out a wide range of specific diagnostic and therapeutic tasks

6. Nanomedicine Center for Mechanobiology - Direct immune cell behavior by manipulating the mechanical environment in which chemical signals are delivered

Nanomaterial Registry Project

- Establish an authoritative nanomaterial registry
  - Provides curated information on the biological and environmental interactions of nanomaterials
  - Provides efficient data searching, querying, and reporting and links to publications, modeling, and manufacturing procedures
  - Facilitates data validation and data quality improvement
  - Enhances the development of new models, assays, standards, and manufacturing methods
  - Accelerates the translation of new nanomaterials for biomedical and environmental applications
  - Promotes standards and identifies reliable information that can be used in regulatory decision-making
- This 3-yr project is co-funded by NIBIB, NIEHS, and NCI with NIBIB taking the lead

NIBIB Investments

"NT for Medicine and Healthcare"

Selected Programs

Drug and Gene Delivery Systems

Nanoparticles

- Controlled Release
- Targeted Delivery
- Imaging & Monitoring Activity

Medical Devices and Sensors

Nano Devices, Arrays, and Switches

- Biochemical detection
- Sensing biomolecules
- Cell-based Assays

Imaging Modalities

Contrast Agents & Probes

- Image cell signaling processes
- Cell tracking & monitoring intracellular events
- Microscopic detection
- Nanoscale chemical Imaging
- Intra-operative surgery

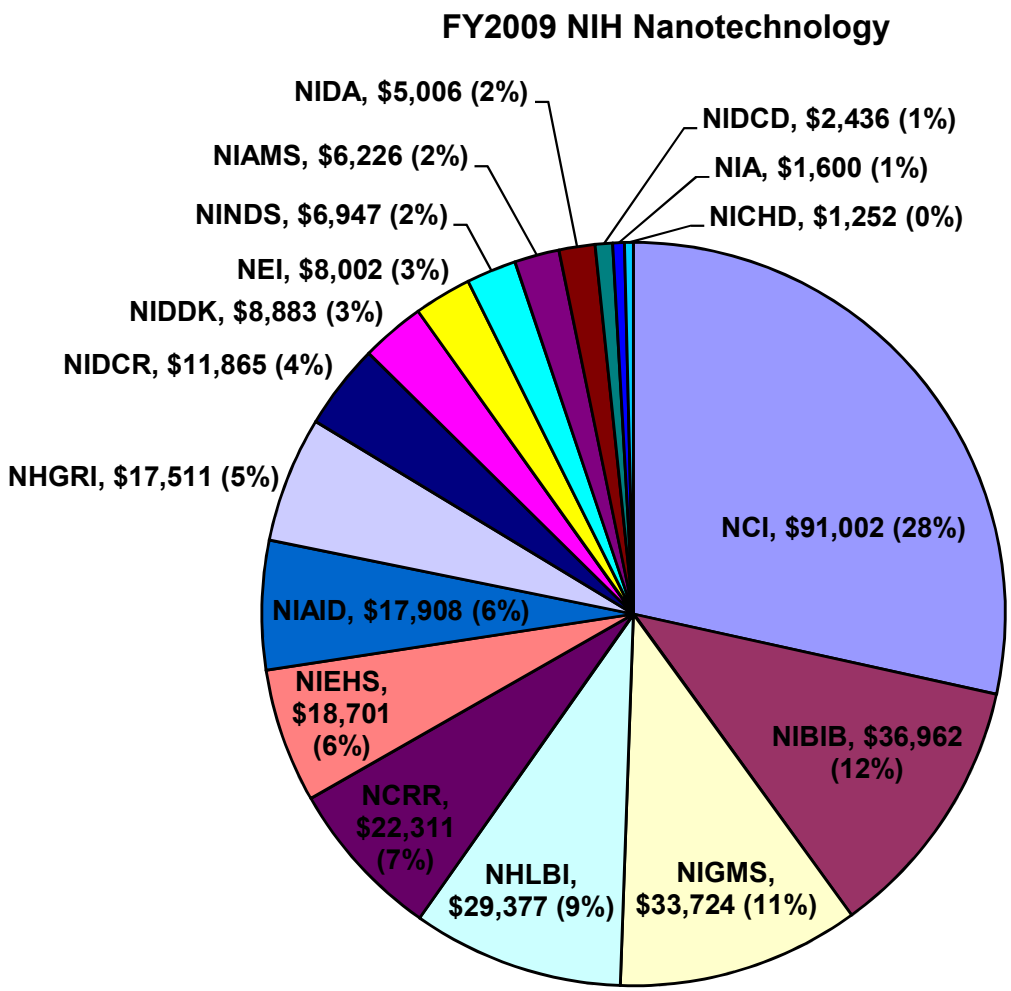
Tissue Engineering

Nanostructures

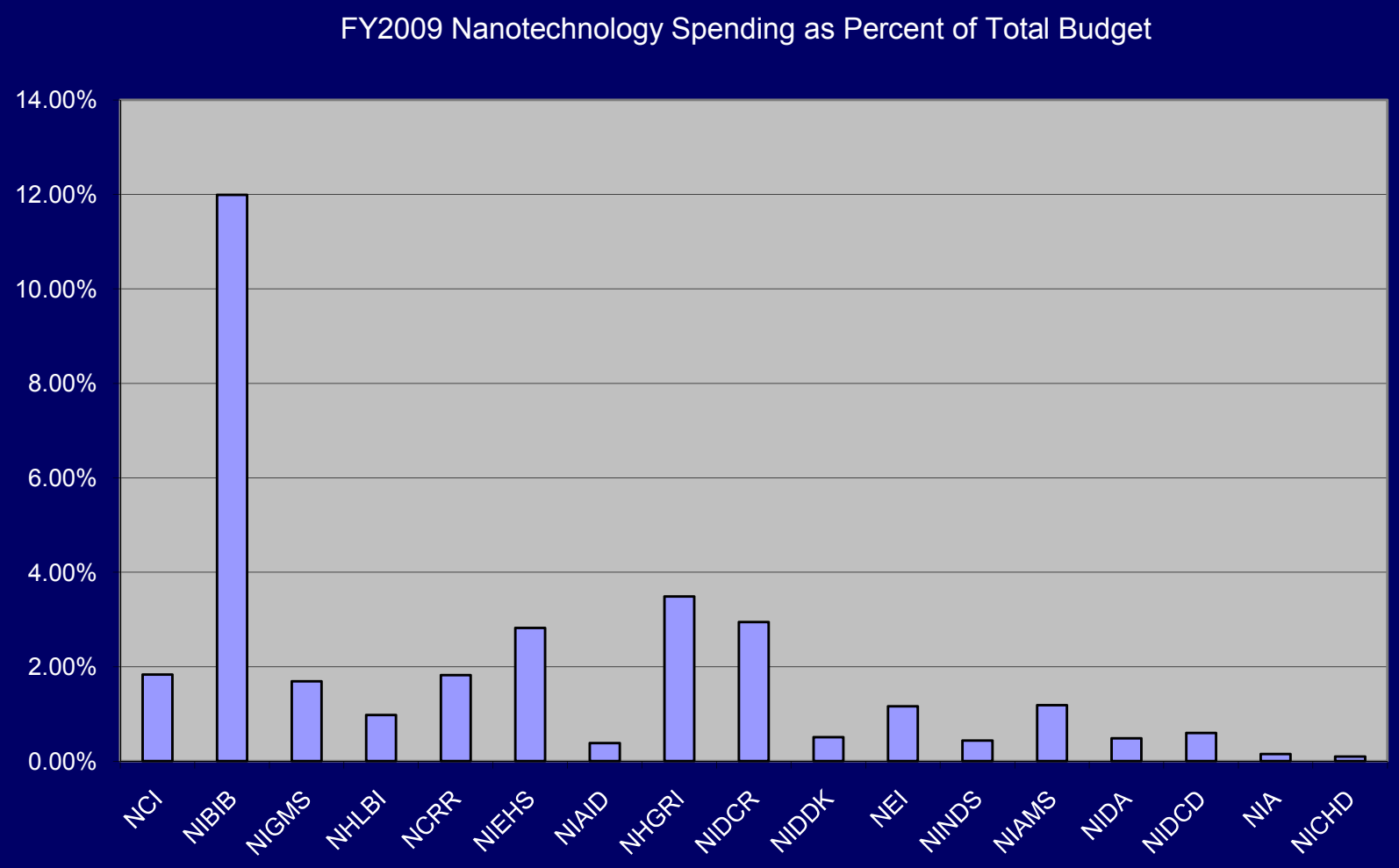
- Physical cues for cell signaling & mechanics
- Nanopatterned surfaces to control cell response & fate
- Nanoengineered surfaces to control topography & presentation of ligands

- Detecting Disease *Before* Health has deteriorated
- Repair or replace damaged body parts
- Improve diagnostic and therapeutic approaches

NIBIB Investments Relative to Other ICs



Investments as a Percentage of Total IC Budget

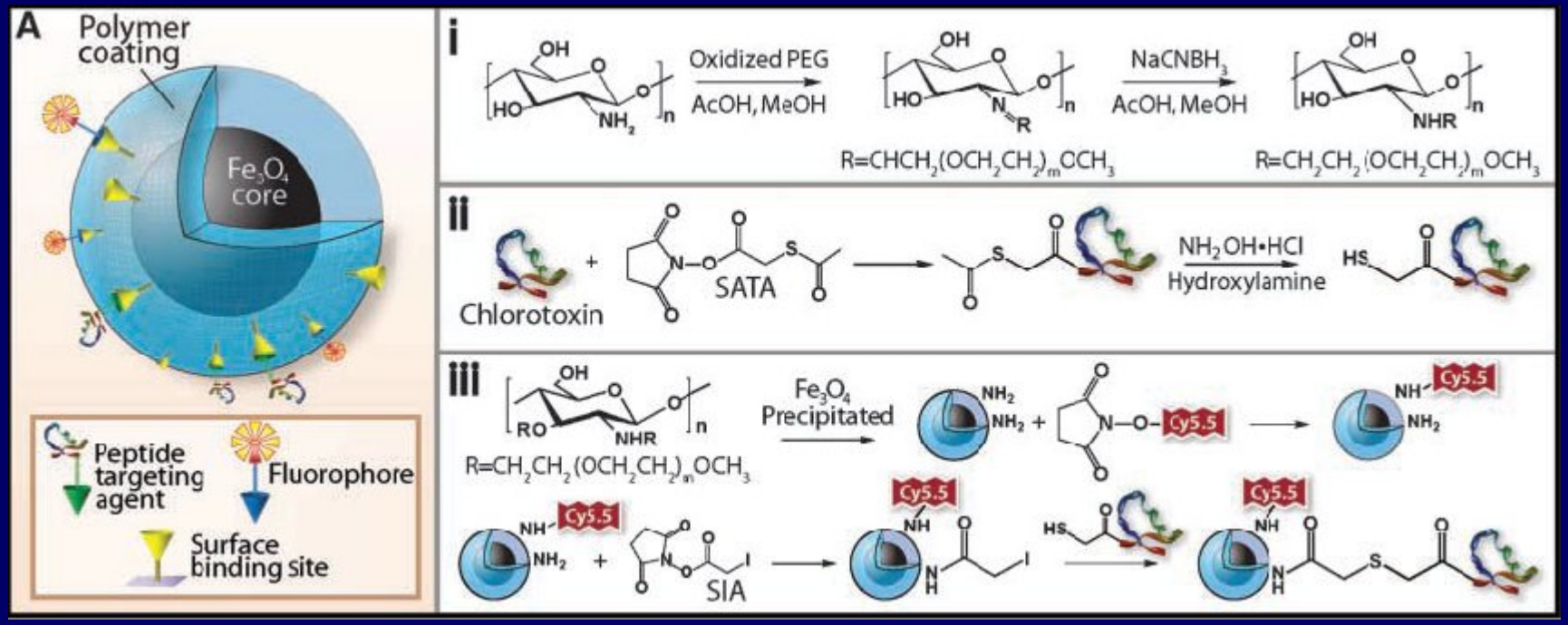


Novel Magneto-fluorescent Nanoprobes that cross the Blood-Brain-Barrier

Miqin Zhang, Ph.D.; Dept. of Material Science and Engineering, University of Washington

Goal: To develop theranostic nanoprobes for non-invasive diagnosis and treatment of pediatric brain tumors

Probe Design: Magnetite (Fe3O4) crystalline core and a small peptide targeting agent isolated from scorpion venom

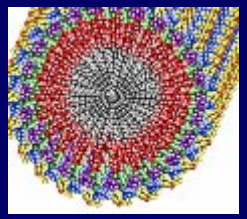


Bioactive Nanostructures for Regenerating Axons

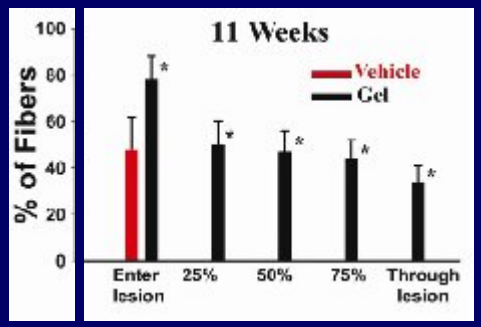
Sam Stupp, Ph. D., Northwestern University, EB3806

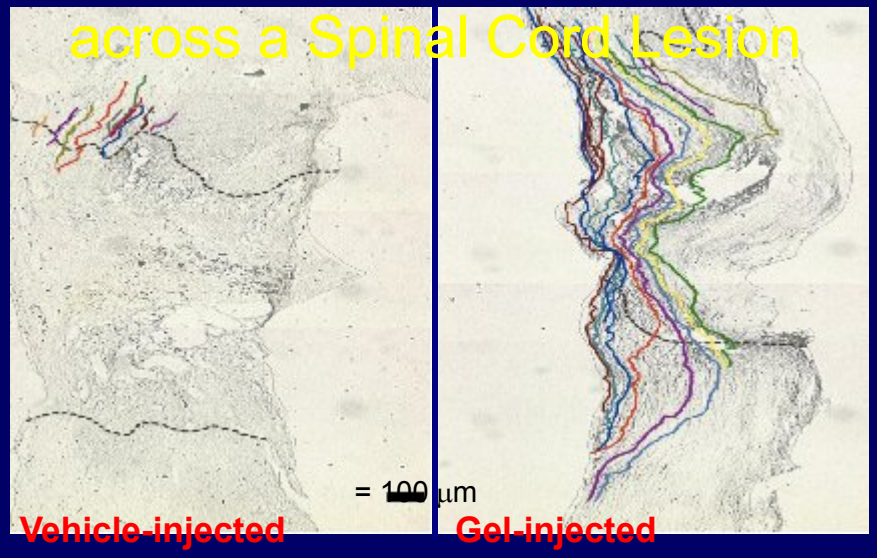
Goal: Develop technologies for neural regeneration and pancreatic tissue replacement

- *scaffolds with programmable delivery of growth factors*
- *engineer stem cells*
- *novel implantation strategies*



Self-assembling nanofibers display 10^{15} neurite sprouting IKVAV signals per cm^2





Tracings of BDA-labeled descending motor fibers in vehicle-injected and IKVAV peptide amphiphile gel-injected rats**

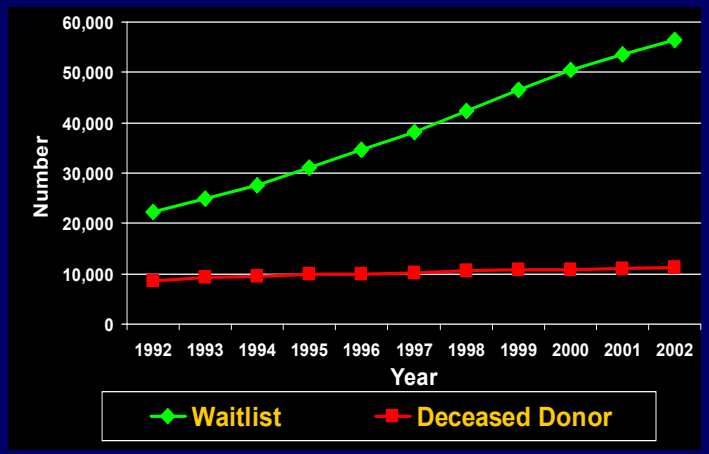
All descending fibers in the vehicle-injected group stopped at or near the edge of the lesion, whereas 40% of the axons in the gel-injected group grew through the injured area.

**Dotted grey lines - borders of the spinal cord crush injury lesion

Nanoporous Membranes for An Implantable Bioartificial Kidney

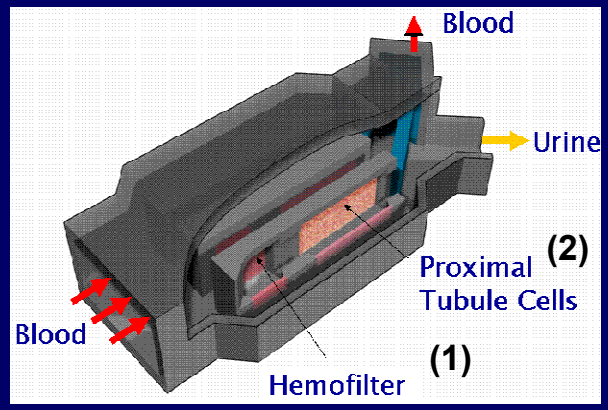
Shuvo Roy, Ph.D., Biomedical Engineering, Cleveland Clinic EB8049

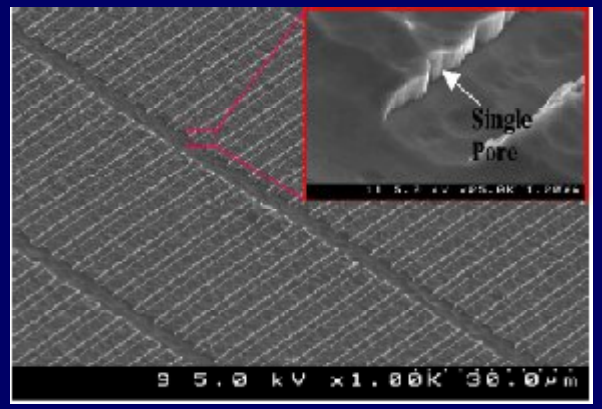
Goal: Develop a miniature, implantable bioartifical kidney to potentially eliminate the majority of dialysis procedures performed in the US

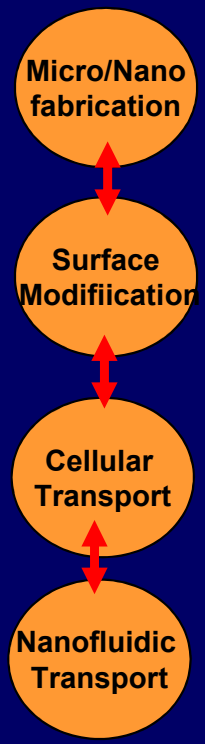


Transplant Shortage

Alternative : 2 Component Renal Assist Device



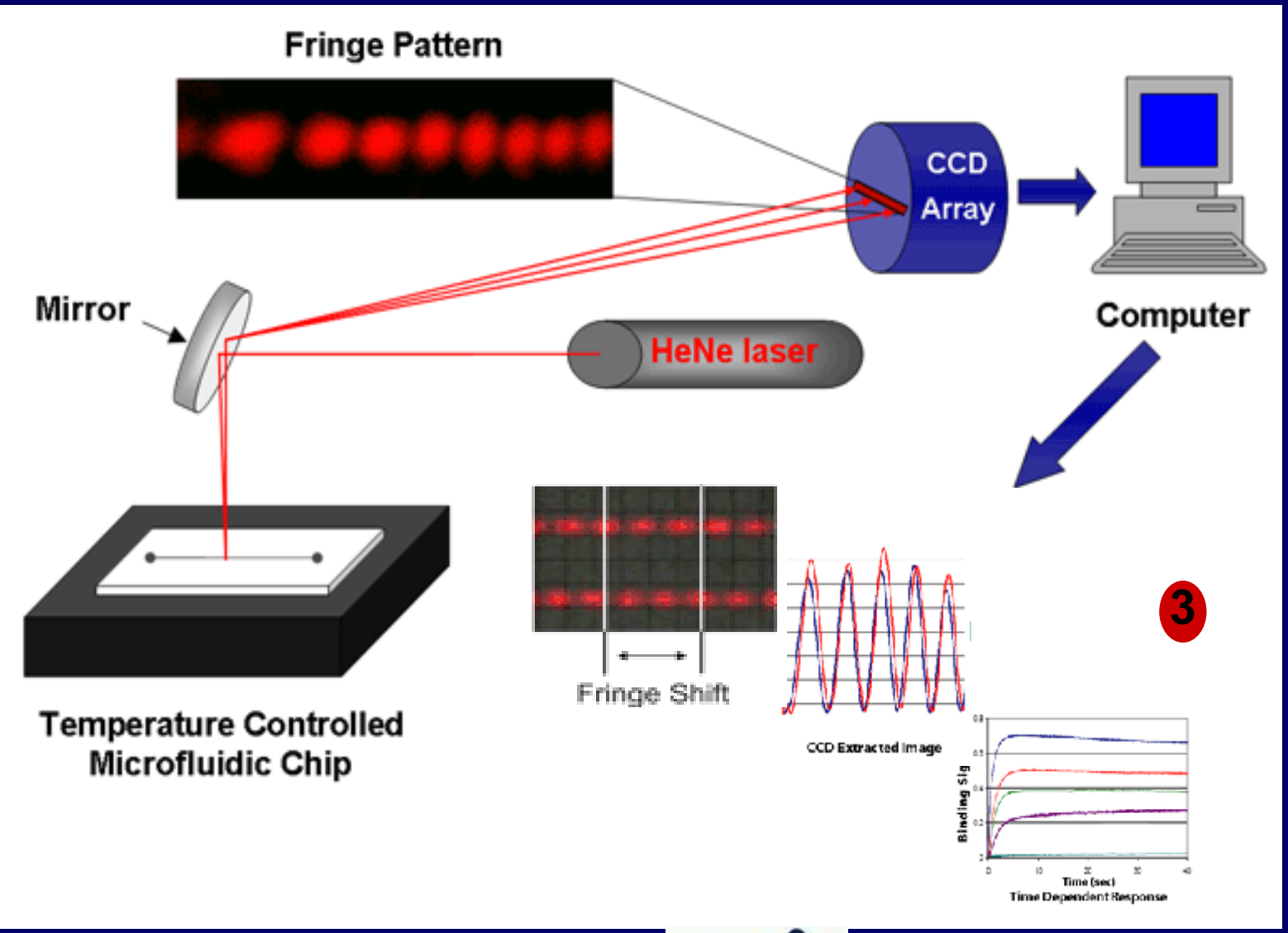




Phase 1: Nanoporous membrane for the Hemofilter

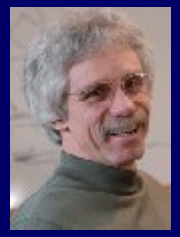
Back-Scattering Interferometry (BSI) Measures Native-State Protein Binding

R01-EB 3537 (PI: Bornhop, Vanderbilt)



BSI system

(1) Samples mixed in a microfluidic chip, illuminated with HeNe laser
(2) Resulting BSI fringe pattern is directed to a CCD array
(3) Image is extracted and the positional shift provides a binding signal

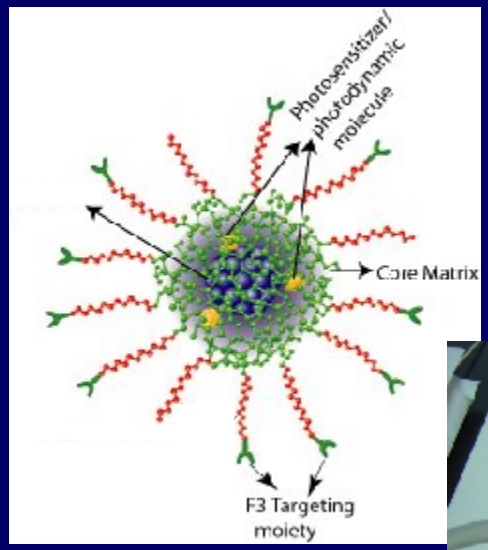


Molecular Sensing

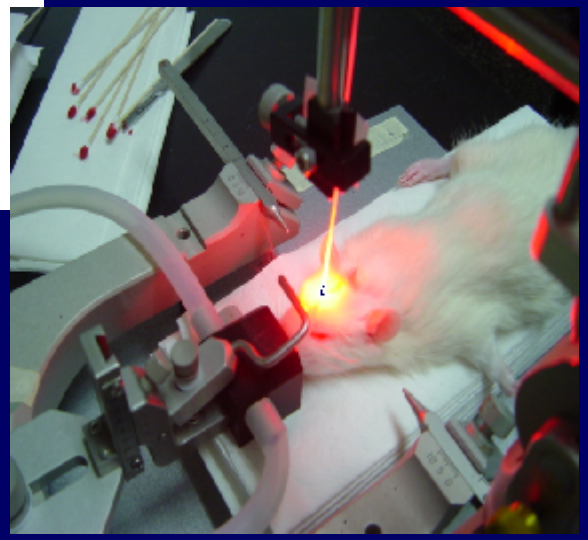
Science *317*: 1732 (2007)

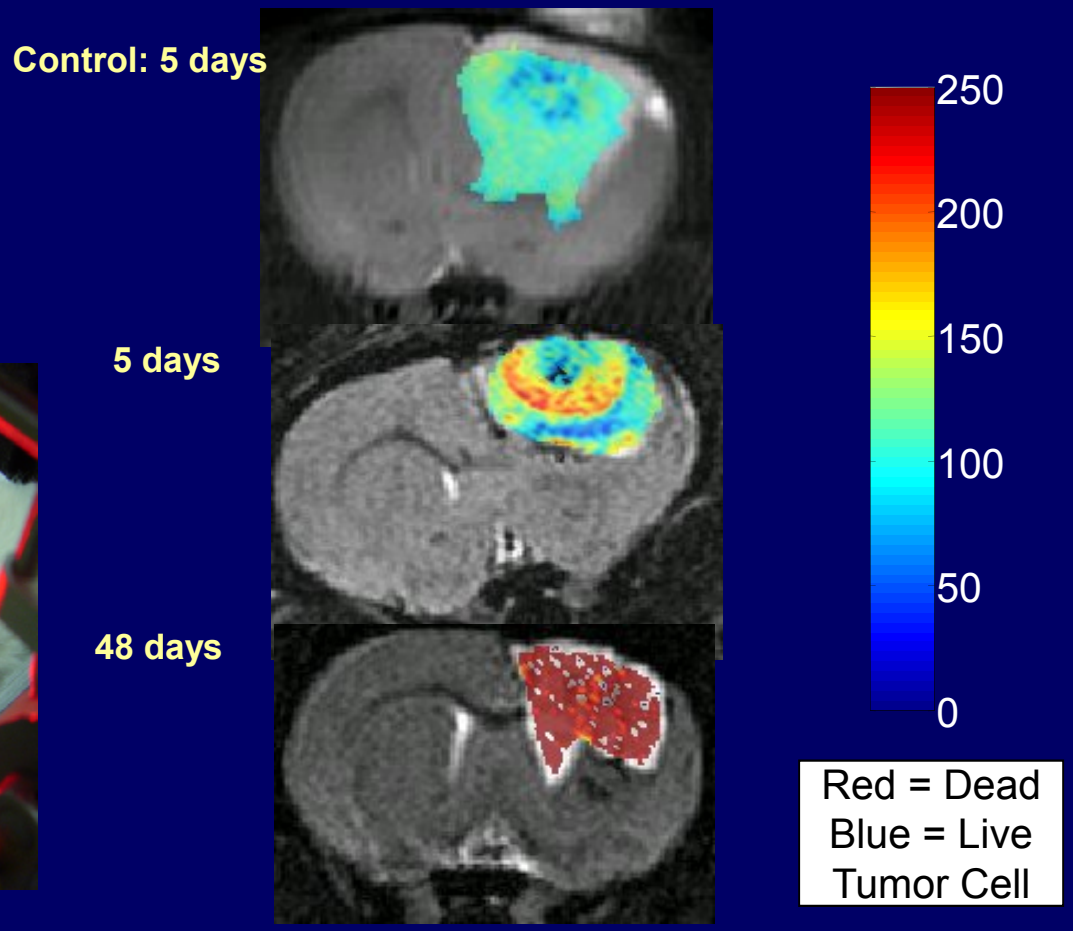
Nanoparticle-enabled Intraoperative Imaging & Therapy for Brain Tumors

Raoul Kopelman, Ph.D.; University of Michigan, EB7977



30nm





Goal: Develop targeted, multifunctional nanoparticles that provide optical contrast for tumor margination and photodynamic therapy treatment of residual cells to improve the survival of brain tumor patients

Funding Opportunities at NIH

- NIH Nanoscience and Nanotechnology in Biology and Medicine (R21 PA-08-053: R01 PA-08-052) - The purpose is to stimulate nanoscience and nanotechnology research approaches that have the potential to make valuable contributions to biology and medicine.
- NIH Bioengineering Nanotechnology Initiative for Small Business Innovation Research (PA-09-267) on October 2, 2009. The purpose is to stimulate Small Business Innovation Research that employs nanotechnology to enable the development of diagnostics and interventions for treating diseases.
- NIH Bioengineering Nanotechnology Initiative for Small Business Technology Transfer grant applications (PA-09-266) was re-issued in parallel with the SBIR and has a similar objective.

"Nanoscience and nanotechnology refers to the understanding and control of matter at the atomic, molecular or macromolecular levels, at the length scale of approximately 1 - 100 nanometers."

Institute Specific Program Announcements

- NIBIB & NHLBI: Development of Multifunctional Drug & Gene Delivery Systems (R01: PAR 10-048) - engineer novel, multifunctional drug and gene delivery systems that can target therapies to particular cells and intracellular compartments and can monitor delivery and determine therapeutic efficacy

- NIBIB: Innovation in Molecular Imaging Probes (PAR-09-016) - engineer nanoprobes or develop nano-enabled tools to detect and image specific molecular activities in vivo for clinical applications

http://grants.nih.gov/grants/guide/index.html

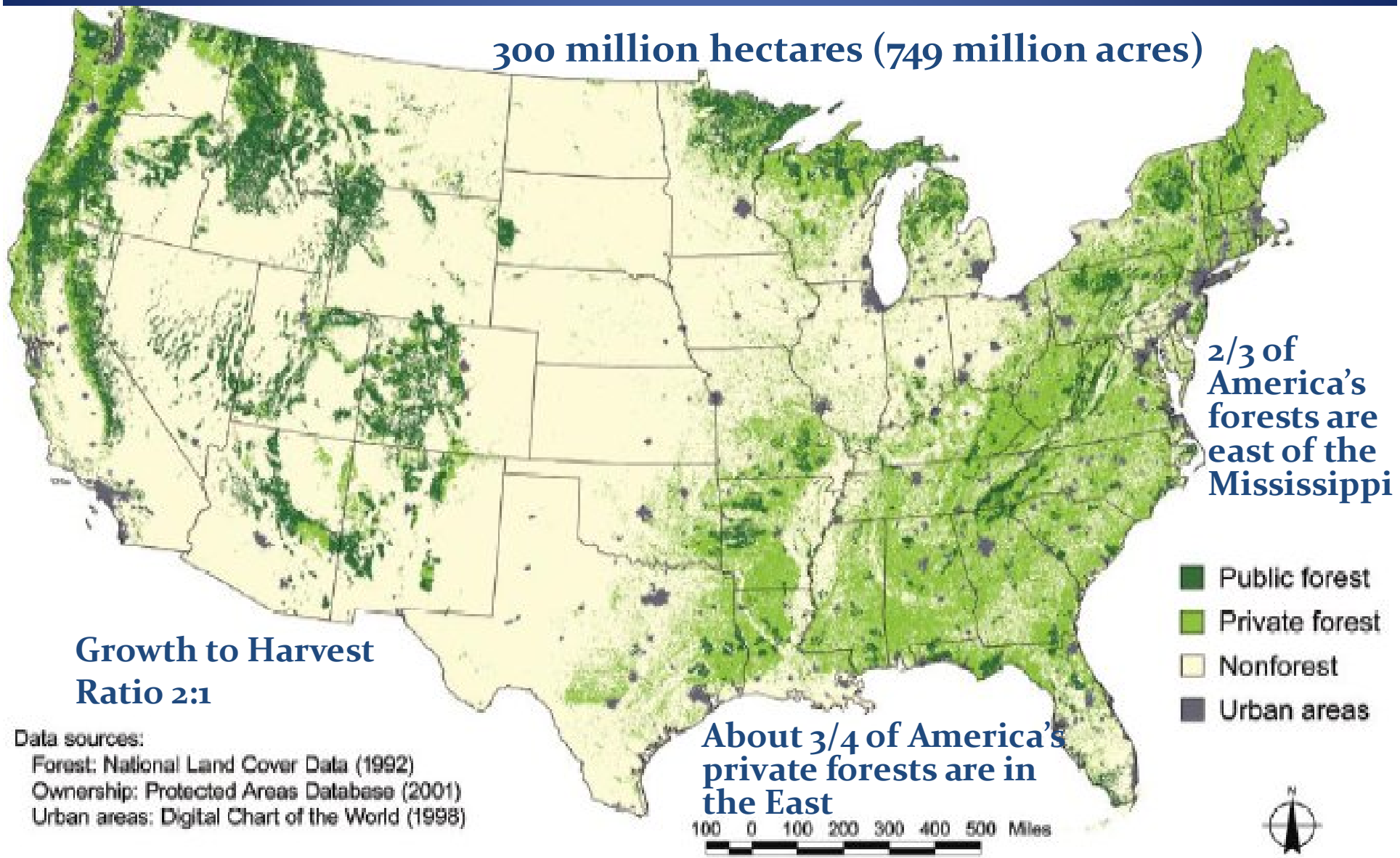
Nanotechnology in the Forest Products Industry and Packaging

Theodore H. Wegner, PhD
World L-S Nieh, PhD
USDA Forest Service

Presentation Overview

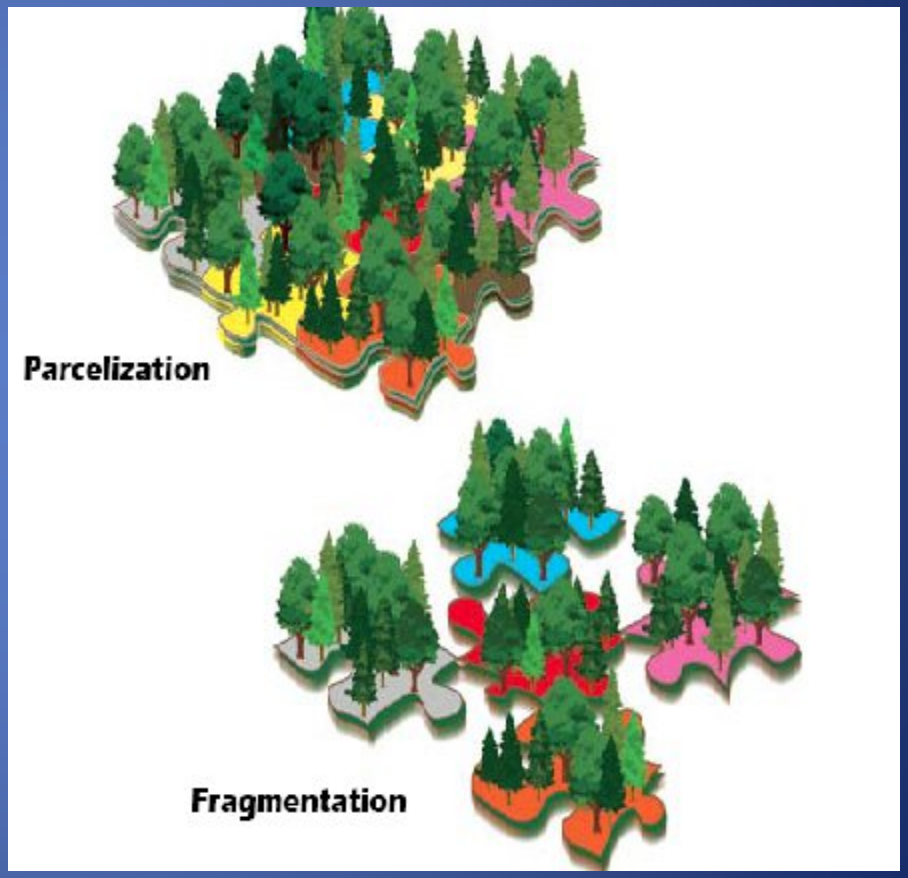
- Wood is a Sustainable & Renewable Material
- Cellulosic Nanomaterials From Wood
- Cellulosic Nanomaterials and Packaging
- Public-Private Partnership for Commercialization of:
  - Cellulosic Nanomaterials
  - Nano-enabled Products

America's Forest Resource



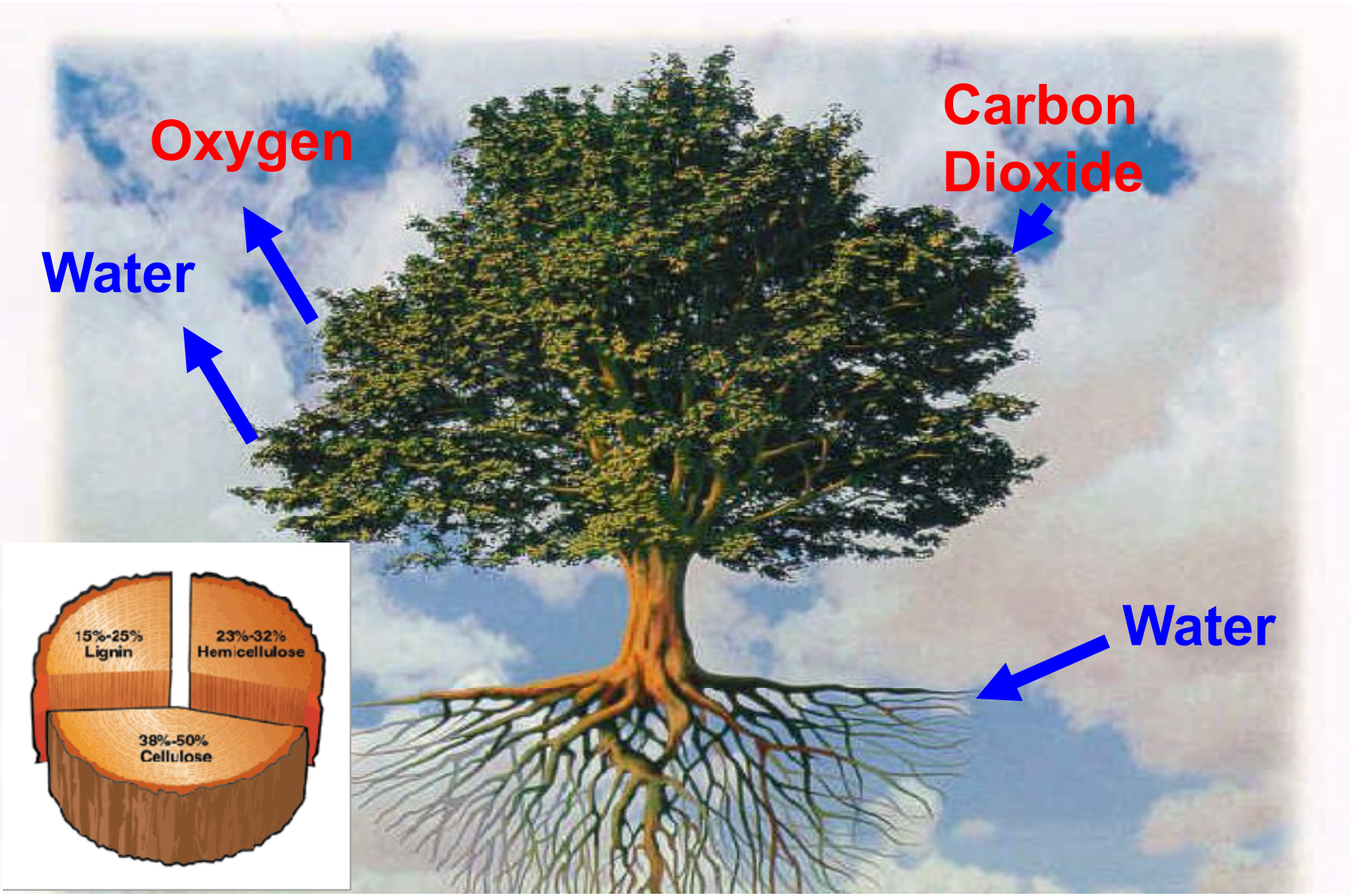
Forests in the U.S.

- America's forests are a major strategic asset and cover over 740 million acres
- Annual U.S. harvest of timber for industrial use is less than 1 percent of the standing volume and growth to harvest ratio is about 2 to 1.
- U.S. forest inventory has been growing for almost a century and the greatest threats to America's forests come not from forest products production but from fragmentation, parcelization, and conversion of forestland to non-forest uses.
- Forest products production offsets the cost of forest management and helps prevent the conversion of forestlands to non-forest uses by providing return on investment to forestland owners.



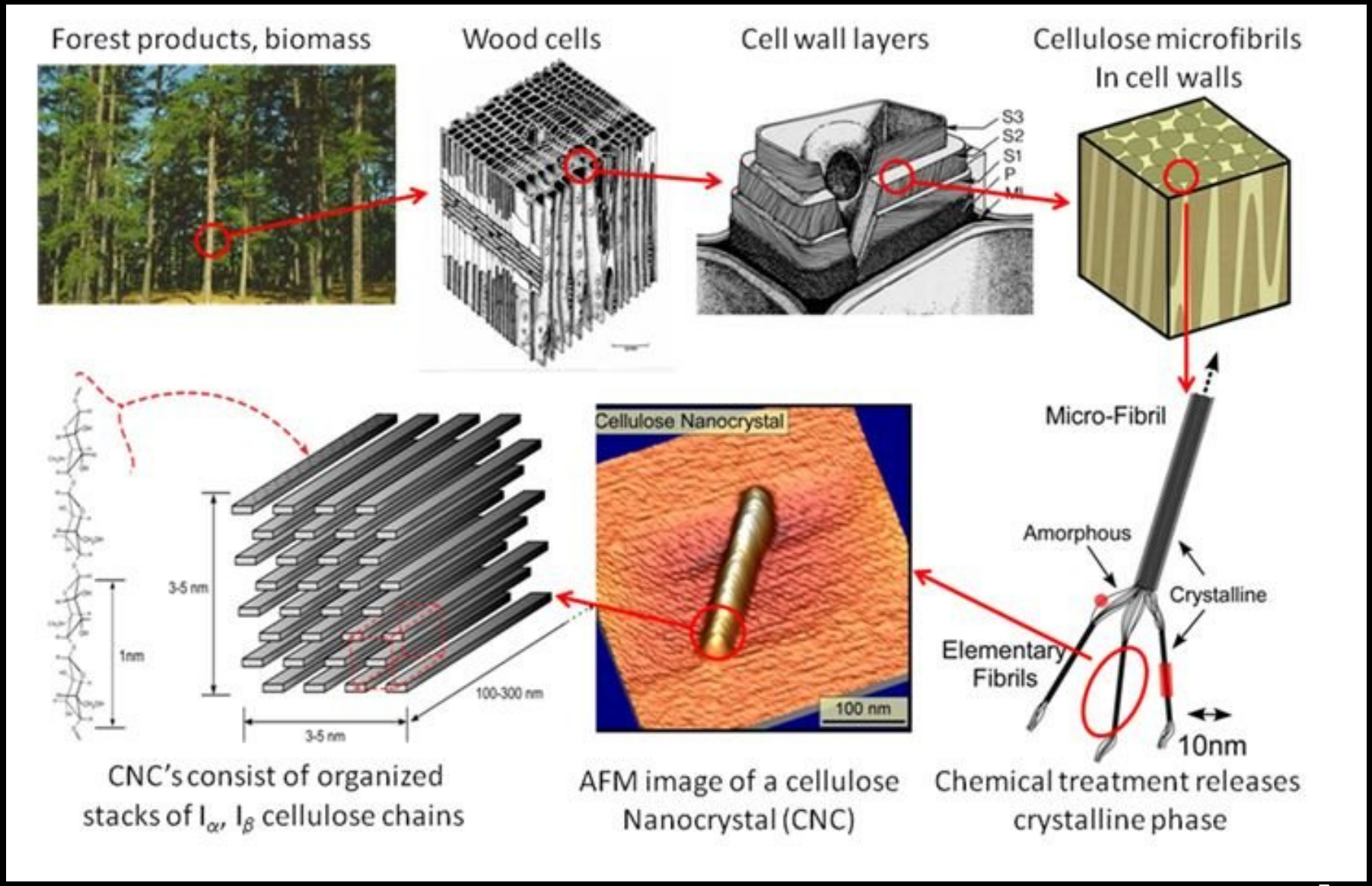
The U.S. Forest Products Industry

- America's forest products industry is the largest in the world and is based upon using America's abundant, renewable and sustainable forest resources--most forest products are produced from smaller diameter plantation grown trees.
- The U.S. forest and paper industry represents approximately 6% of U.S. manufacturing base.
- The industry ranks among the top ten in manufacturing in 48 states with an average employee salary of approximately $50,000 per year.
- The U.S. forest and paper industry is comprised of 5250 Wood Products and Converting Facilities and 418 Pulp and Paper Manufacturing Facilities--employing over 1million people.
- In 2006, total sales were $282 billion--with $112 billion for the Wood Industry and $170 billion for Paper Manufacturing. The majority of these products served global commodity-based markets.

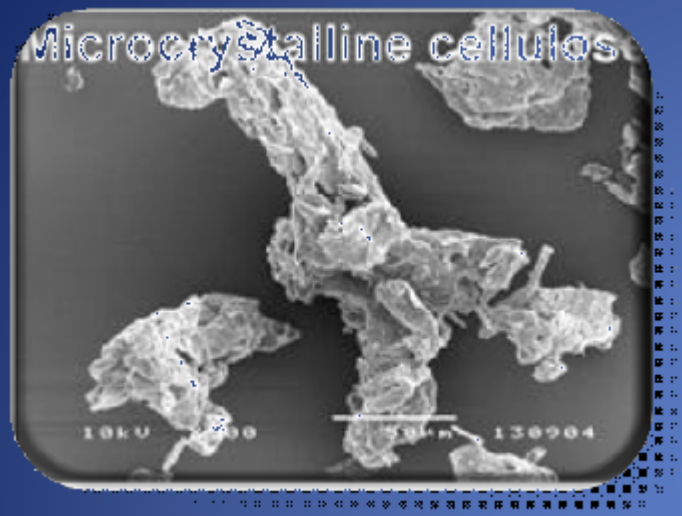


Trees synthesize biomass with GHG's (CO_2, water), and solar energy (photosynthesis). Carbon is stored in trees and bio-based products.

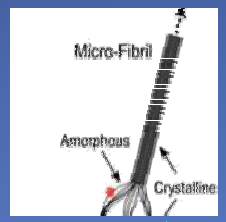
Size Scale of Lignocellulosics

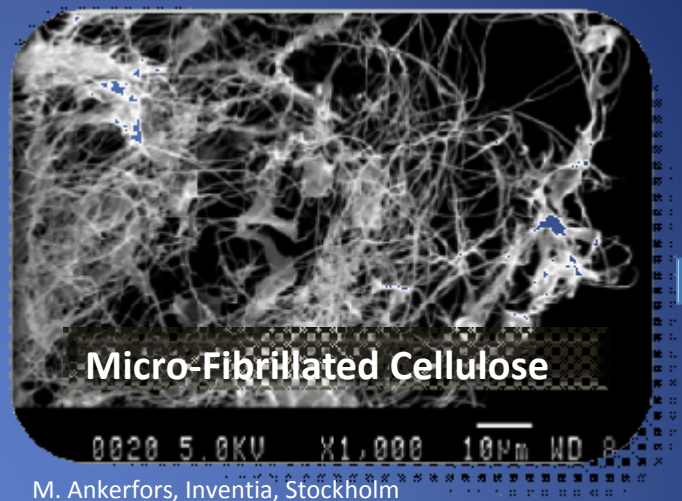


Hierarchical Cellulose Structure

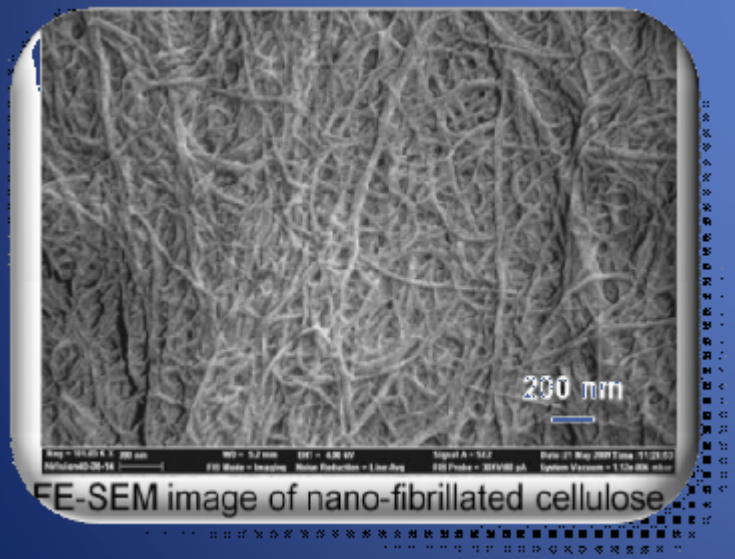


AAPS: www.aapspharmscitech.org/view.asp?art=pt070489

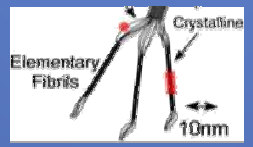


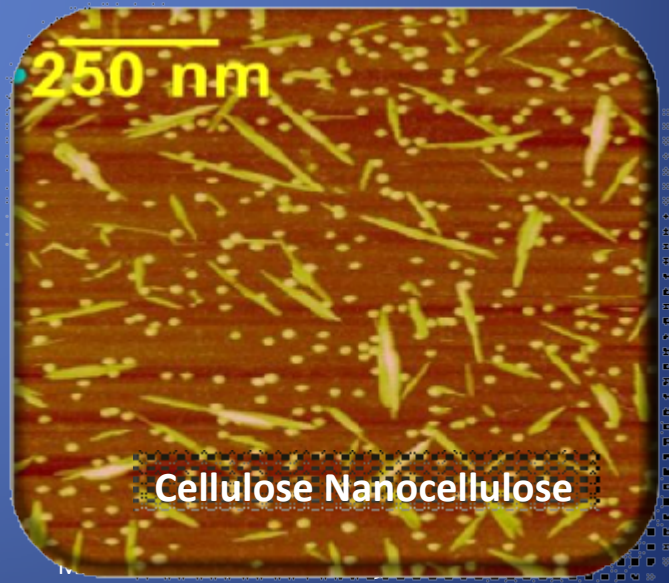


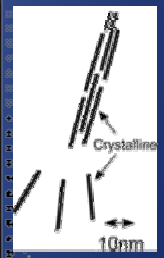
M. Ankerfors, Inventia, Stockholm



G. Gagnon et. al. U Maine, Orono







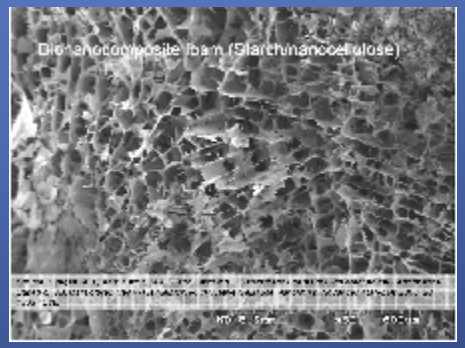
Micro Crystalline Cellulose (MCC)

- Manufactured by acid hydrolysis of α-cellulose.
- Particle size in the range of 50 – 180 µm.
- Use: filling, binding and blasting material for direct tableting and dry & wet granulation, filling material for hard gelatine capsules.
- Other use: emulsion stabilizer, rheology stabilizer, absorbents in cosmetics.

Cellulose Nanomaterials

- Opportunities for renewable nanomaterials from wood

- Batteries
- Super-Capacitors
- Bio Plastics
- Nano Coatings
- Reinforced Polymers
- Sensors
- Flexible Displays
- High Efficiency Filters
- Light Weight Nano Composites
- Nano Membranes
- Photonic Devices
- Multifunctional Packaging

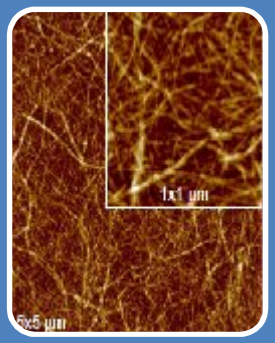


Cellulose Nanomaterials can be produced in tens of millions of ton quantities

Environment, Health and Safety of Cellulose Nanomaterials

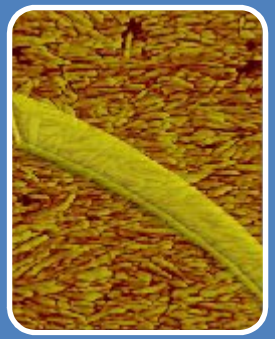
- Cellulose nanomaterial has been part of several EHS studies and there are ongoing environmental and human safety tests (U.S., Canada, EU).
- The Finnish Institute of Occupational Health is studying cellulose nanomaterials. Results are still very preliminary.

Cellulose Nanomaterials Manufacturing



Nanofibrillar Cellulose (NFC)

- Manufactured by milling or grinding of pulp
- Manufactured by beating pulp



Nanocrystal Cellulose (CNC)

- Manufactured by acid hydrolysis of pulp

NFC Production

Pretreatment

- Chemical pretreatment
- Biological pretreatment

Mechanical Treatment

- Homogenizer
- Masuko Grinder
- Extruder

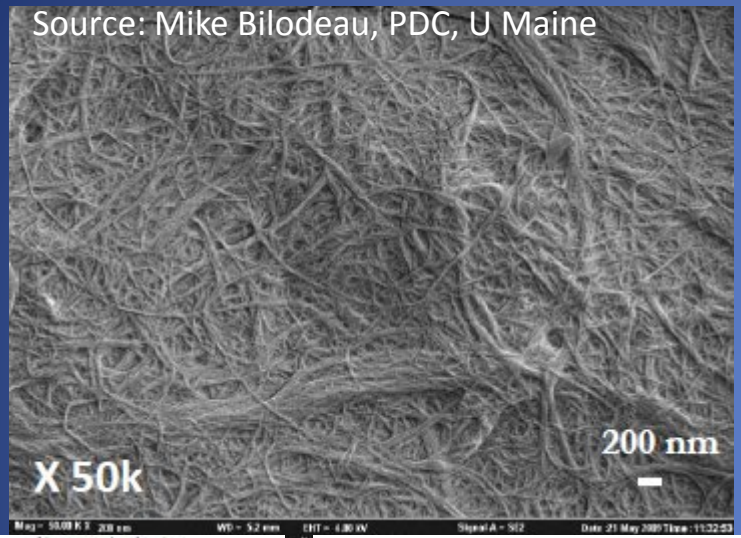
Characterization

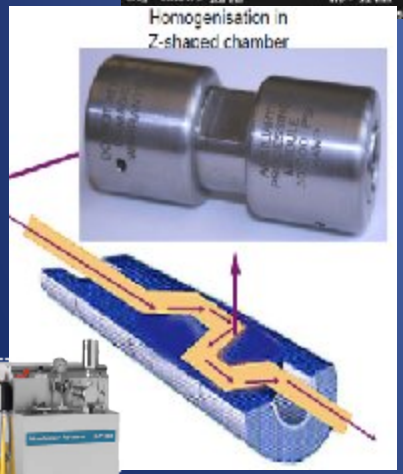
- Physical, Optical, mechanical, size, rheology
- SEM, dynamic contact angel, vapor transmission

Products

- Improve existing products
- Green Products: to displace petroleum based products

NFC Applications





- Typically 10-30 nm wide, >100 nm long.
- Potential application
  - Coatings, films, aerogels, composites, foams
  - Non-caloric food thickening, flavor carrier, cosmetics, medicine carrier, rheology modifier

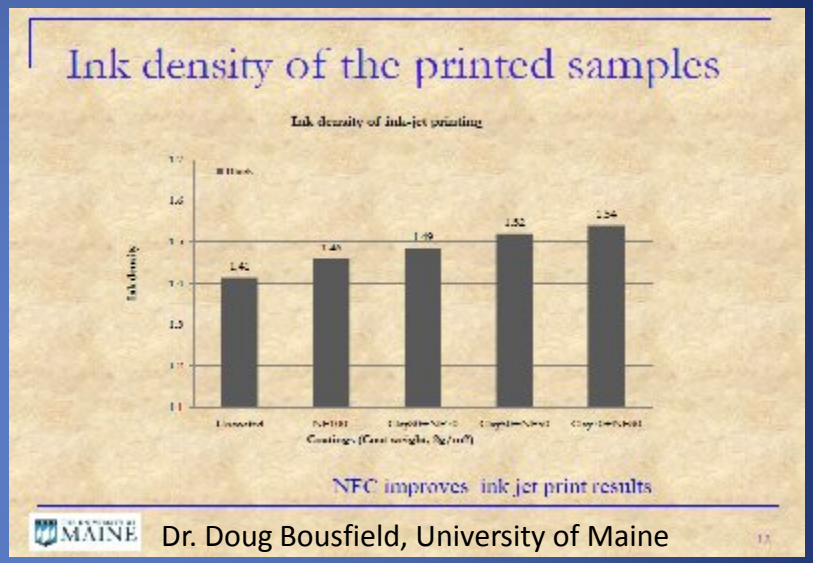
Coatings - Paper

Coatings on Pulp

- Bond Strength
- Water Interaction
- Chemical & Nanoparticles

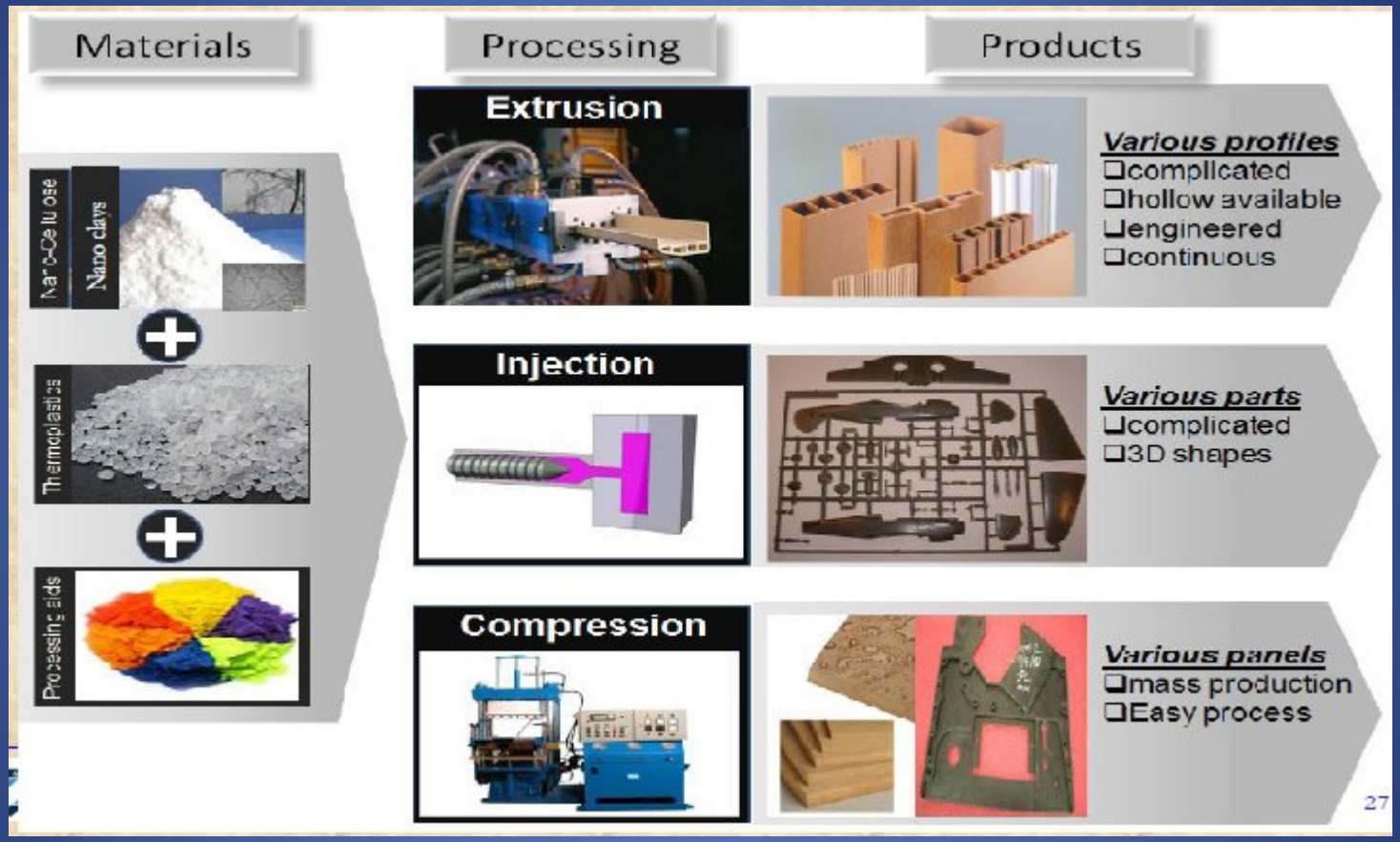
Coatings on Paper

- Brighter & Sharper Colors
- Improved coating hold out
- Improved print quality



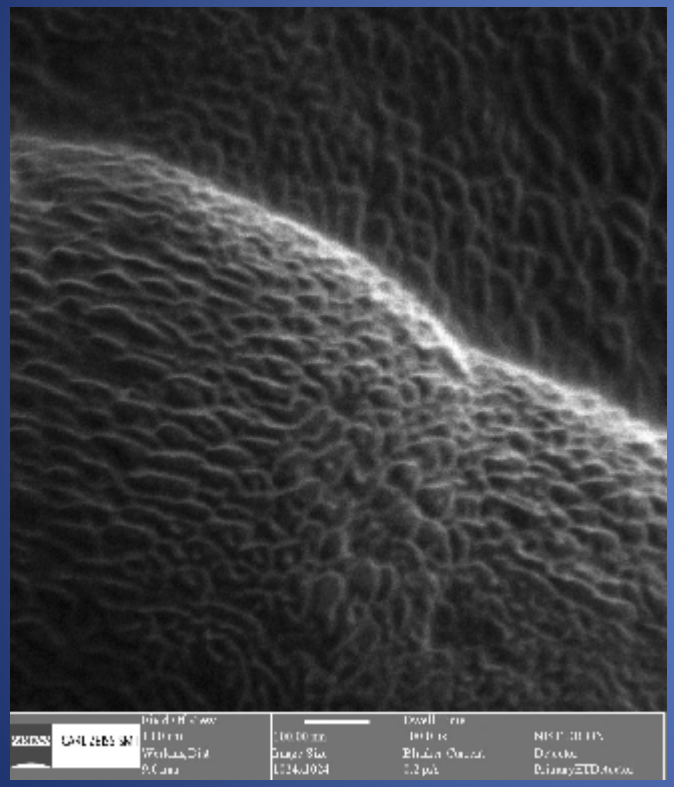
EKA Chemicals Inc.

Nanocellulose in Plastics



- Source: University of Maine Process Development Center (PDC), Michael Bilodeau (mbilodeau@maine.edu).
- Source: University of Maine Advanced Engineered Wood Composite (AEWC) Center, Doug Gardner (douglas.gardner@umit.maine.edu).

Cellulose Nanocrystals - A High Value Product



Source: Mike Postek, NIST

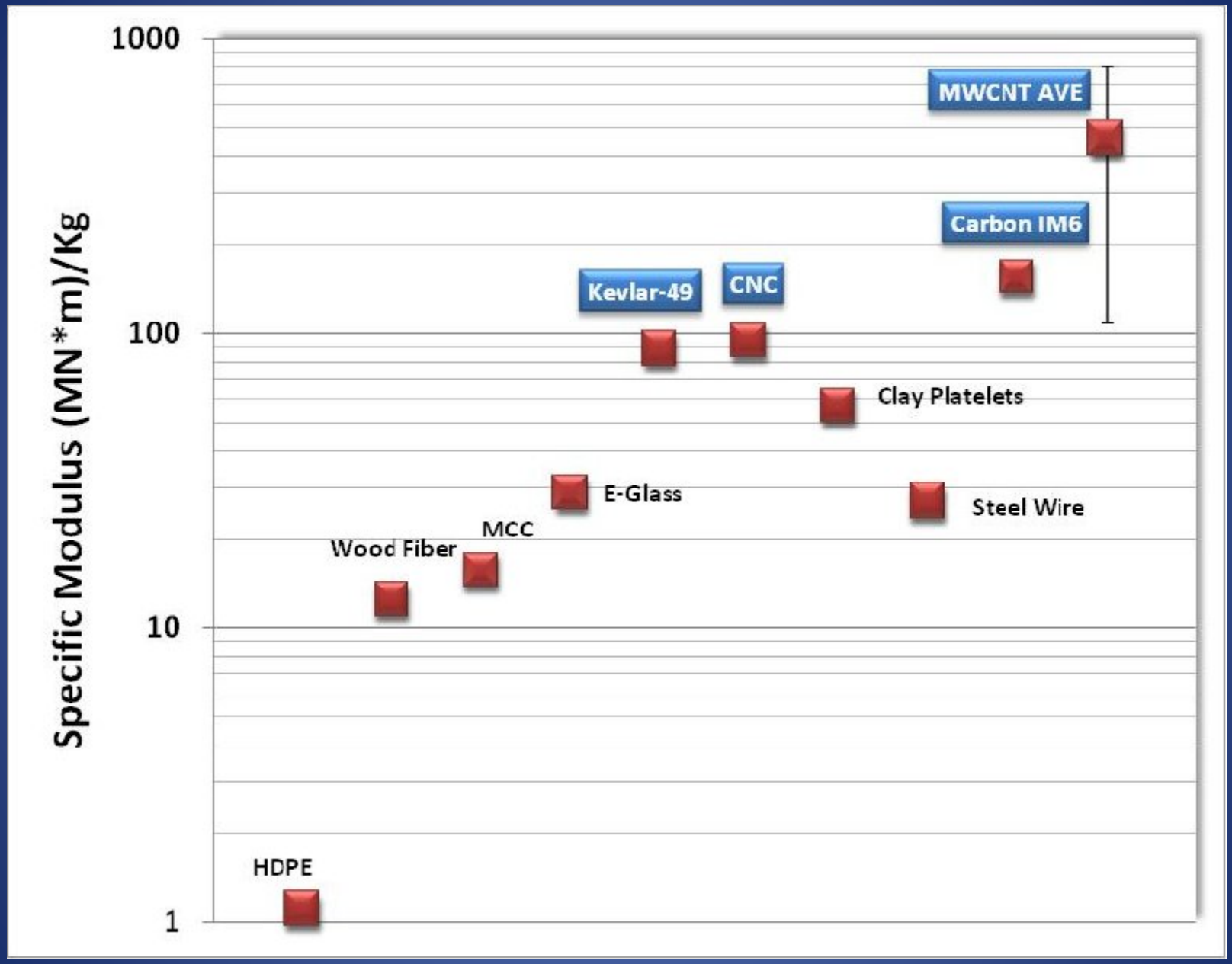
CNC Source	Length	Cross-Section
Algal	>1000nm	10-20nm
Bacterial	100 to >1000nm	5-10nm by 30-50nm
Cotton	200-350nm	5nm
Tunicate	100 to >1000nm	10-20nm
Wood	100-300nm	3-5nm

Beck-Candanedo et al., Biomacromolecules, 2005, 6, 1048

Material	Tensile Strength (GPa)	Modulus (GPa)
Cellulose Nanocrystals	**7.5**	**145**
Glass fiber	4.8	86
Steel wire	4.1	207
Kevlar	3.8	130
Graphite whisker	21	410
Carbon nanotubes	11–73	270–970

http://woodscience.oregonstate.edu/faculty/simonsen.

- **Photonic Properties**
- **Piezoelectric Properties Equivalent to Quartz**


1000
100
10
1
Specific Modulus (MN*m)/Kg
MWCNT AVE
Carbon IM6
Kevlar-49
CNC
Clay Platelets
E-Glass
Steel Wire
MCC
Wood Fiber
HDPE

FS-FPL CNC Pilot Plant

100 gal reaction tank, 1000 gal quench tank, 200” filter, 1500 gal receiving tank

HVAC, spill control, soft and DI water, filters

20 kg/batch, operational in 2011

Modify or Create New Paper Characteristics to Increase Capabilities: Optical

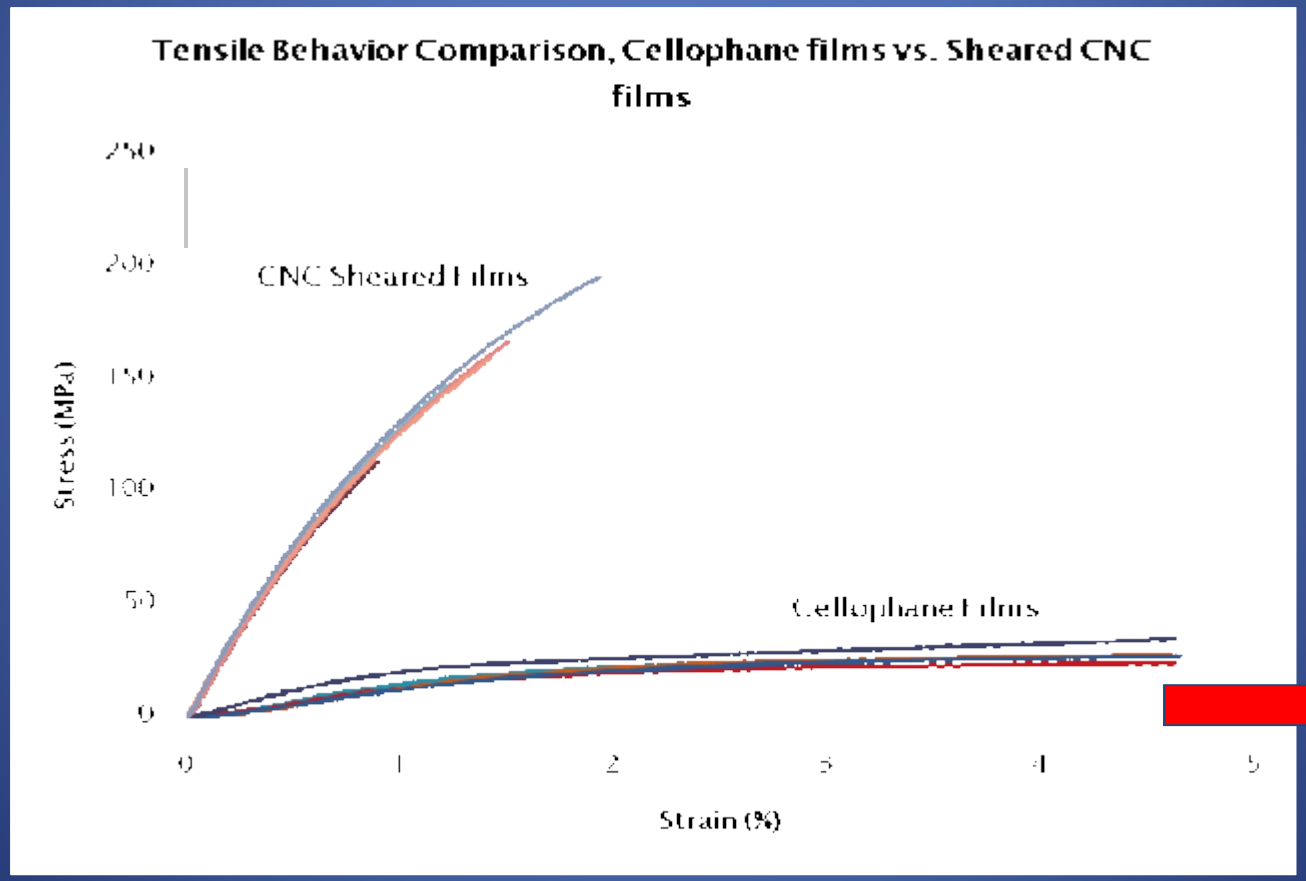
Optically Transparent

Masaya Nogi,* Shinichiro Iwamoto, Antonio Norio Nakagaito, and Hiroyuki Yano
Kyoto University, Kyoto, Japan

- Nanofiber paper folds like traditional paper and scatters more light
- Translucent- powder generating plant, can be used in generate unseen UAV (embedded with sensors that can generate it power), self powered materials, airborne sensing platforms, chemical sensors, new armor material in terms of self power and self sensing

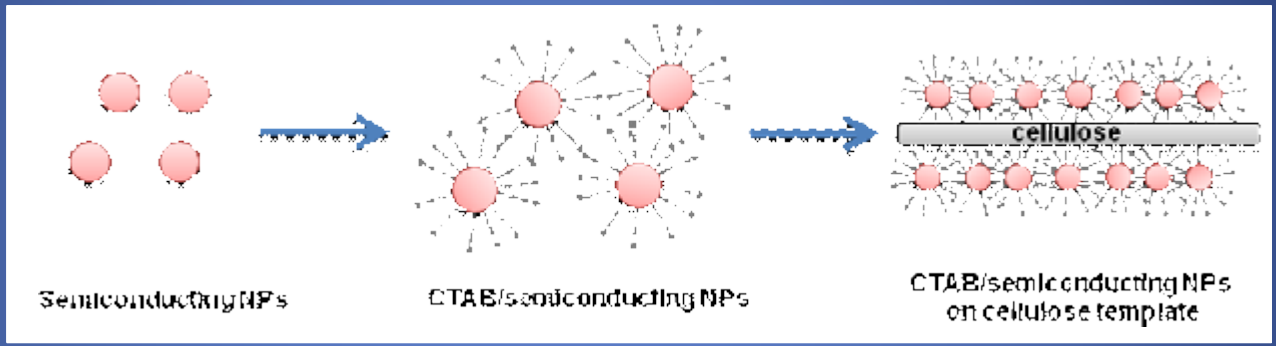
DMA Tensile Testing

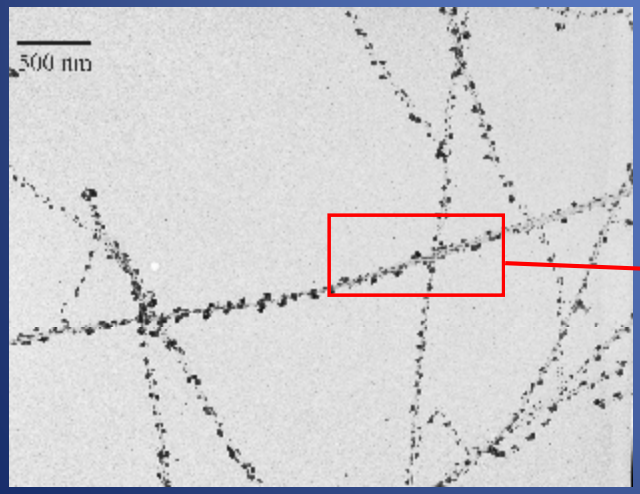
- Modulus of CNC films is higher than cellophane or wood
  - Cellophane ~ 1.7 GPa, Oak ~ 10 GPa, Sheared CNC films ~ 16 GPa
  - Still significantly lower than seen in individual crystals (145 GPa)

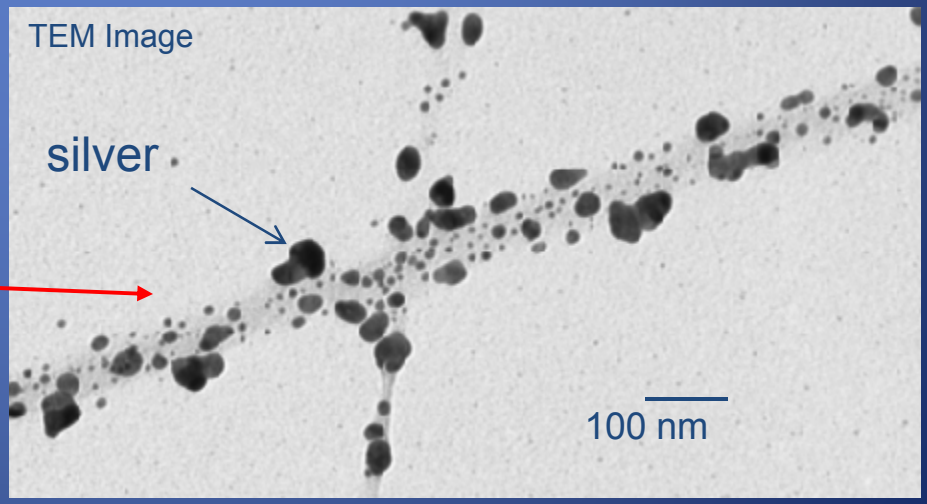


Nanoparticle Precipitation on CNCs

- Ag, Au, Cu, Pt, CdS, PdS, ZnS
- New Properties to CNCs & CNC composites (Electrical….)
- Antimicrobial







Padalkar et al., Langmuir, 2010, 26(11),8497-8502

Cellulose Nanomaterials & Packaging

- Can use NFCs and CNCs based upon cost/performance
- Barrier films with tunable properties
- Sensors
- Lightweight/high strength Packaging
- Flexible electronic displays
- Flexible batteries
- Food Coating & Encapsulating
- Food Additives
  - Viscosity modifiers
  - Fiber
  - nutrient release

Sensor Technology

Sensing:

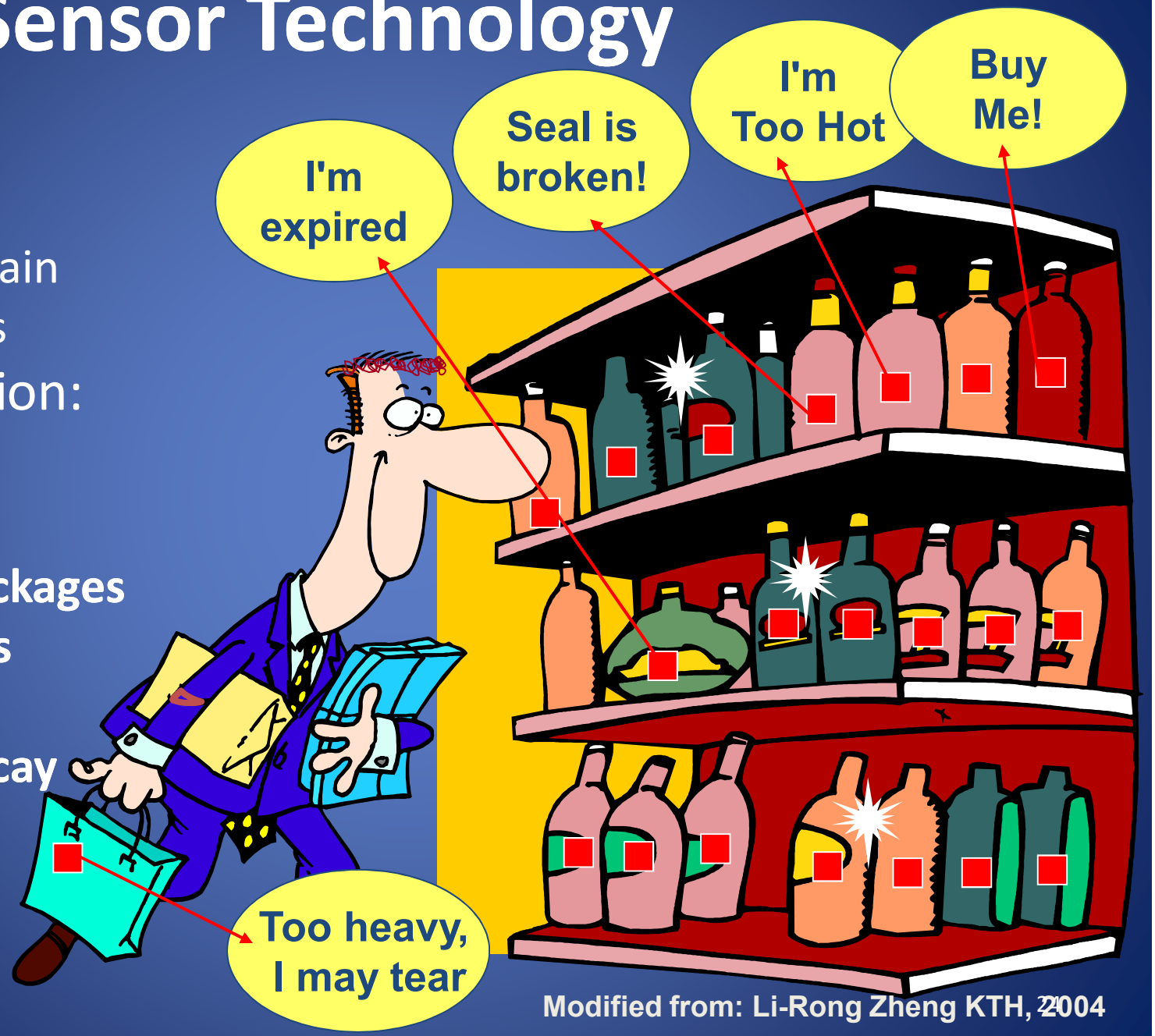
- Moisture
- Stress/Strain
- Chemicals

Communication:

Respond:

Examples

- **Smart Packages**
- **Adhesives**
- **Coatings**
- **Wood decay**
- **Biological**
- **Soils**

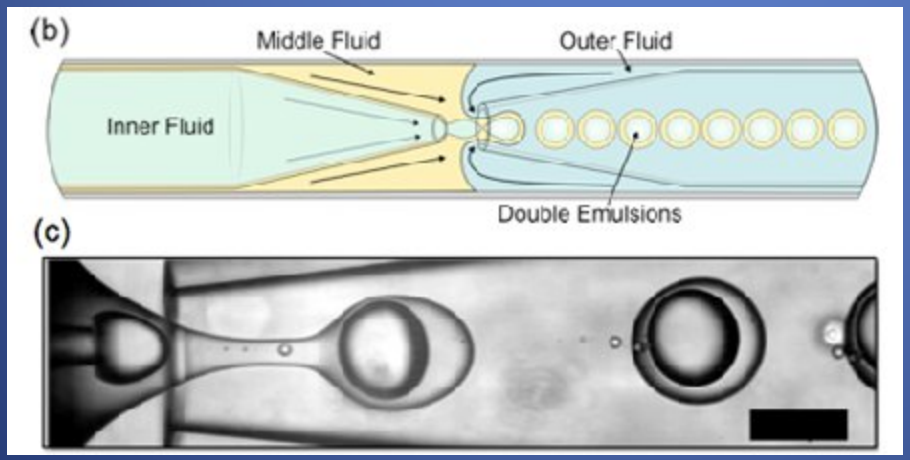


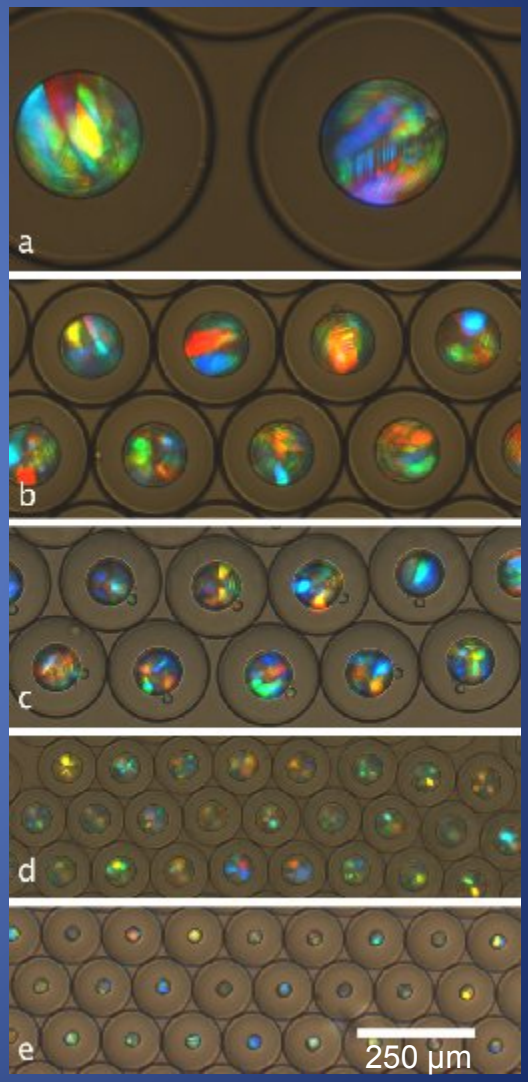
Modified from: Li-Rong Zheng KTH, 2004

Sensor Technology

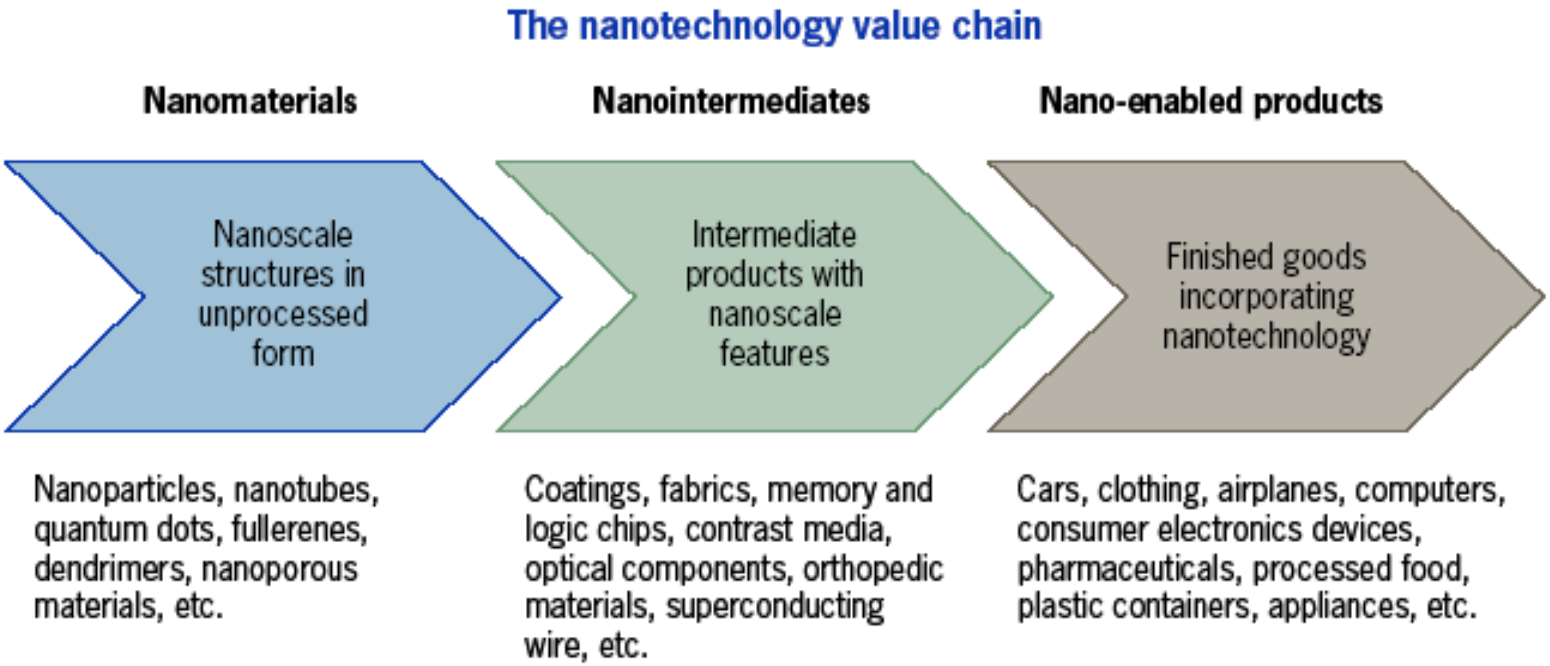
Program Objectives:

- Multifunctional Sensor Development
- Microcapsule Development
- Nano-Micro Sensor Development
    - Incorporate in polymer matrix
    - Incorporate in existing products
- Reversible & Continuous Measurements
- Food Packaging Applications





Commercialization Value Chain



Source: October 2004 Lux Research report "Sizing Nanotechnology's Value Chain"

Federal Forest Products Nanotechnology R&D

- USDA Forest Service lead Federal Agency
  - Collaborating Federal Entities—NIST, USDA-NIFA, NSF, DOD, EPA, NIH
- Public-Private Partnership
  - Forest Products industry, Forest Service, Academia, Cellulose Nanomaterials Users
  - Develop a common vision and priorities for nanotechnology
  - Focus on research, development & deployment
  - Define roles and expectations
  - Strategies
    - Produce nanomaterials from wood
    - Incorporate a variety of nanomaterials into forest products to improve performance and multifunctionality
  - Develop a program implementation plan

R&D COMPETENCIES

NANOTECHNOLOGY

TECH TRANSFER, INTELLECTUAL PROPERTY

FEDERAL (FS and …)

ACADEMIA (Purdue, PSU, GT, Maine, NCSU, UTK, OSU)

INDUSTRY (IMERYS, Verso, MWV, Agenda 2020)

CONVENTIONAL FOREST PRODUCTS

LIGHTER AND/OR STORNGER PAPER & BUILDING MATERIALS, PRODUCTS WITH HIGHER RECYCLE CONTENT, DURABLE WOOD PRODUCTS, SMART PACKAGING

NON-CONVENTIONAL PRODUCTS

TRANSPARANT ARMOR, AUTOMOBILE, AIRCRAFT, ELECTRONICS, SMART PACKAGING, BIOMEDICAL, SENSORS, POLYMERS & PLASTICS

ECONOMIC (replace 300,000 jobs lost in forest products industry)

IMPROVE INTERNATIONAL COMPETITIVENESS

GREENING OF OUR NATION

INTERNATIONAL STANDARDS

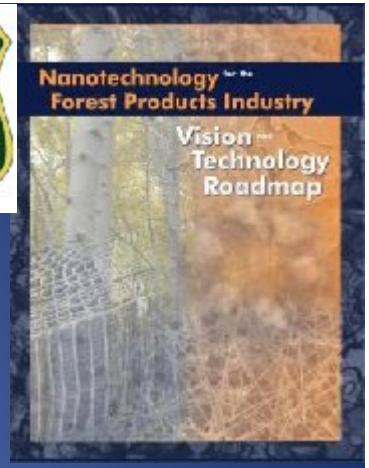
POLICY

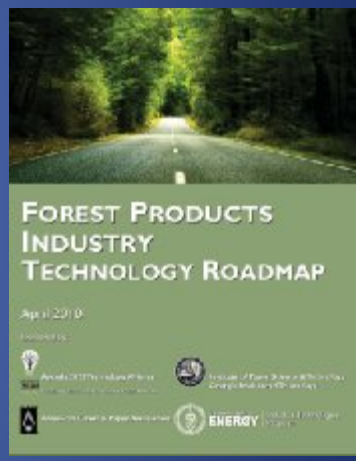
Material and Application Science

- Viscoelasticity of cellulose nano materials
- Surface chemistry and surface modification
- Biomedical applications
- Stimuli responsive material
- Electrospinning, yarn and weaving machines – airplane wings, automobile body
- Resins, plastics & Bio-plastics (e.g. PLA), coating, barrier for extreme environments
- Photonic effects
- Nanomanufacturing

Public-Private Industry Cooperation

- 2005 FPI Nanotechnology Roadmap
- 2006 & 2010 American Forest & Paper Association (AF&PA) Agenda 2020 FPI Technology Roadmaps
- 2007-2010 NNI Forest Products Industry Liaison
  - Conversion of industry goals using industry jargon to underlying fundamental science needs
  - Link with other industry sectors to explore commonalities in fundamental science needed and applications
  - Develop an implementation plan based upon annual plans of work with a focus on commercialization





Nanotechnology to Enable New Products and New Product Features – Forest Products Industry Technology Roadmap 2010

Table 9.4: Technology Objectives for Product Features	
Create New Bio-Based Composites and Nanomaterials	Develop bio-based composites and nanomaterials that leverage the unique properties of biomass and provide features desired by customers
Achieve a 20–50% Improvement in Performance/Weight Ratio of Paper and Packaging Products without Compromising Performance Properties	Increase the performance-to-weight ratio of paper and packaging products by 20–50% through the development of new technologies and techniques
Develop New Paper Features—Optical, Electronic, Barrier, Sensing, Thermal, Surface Texture—that Take Advantage of Advances in Nanotechnology	Modify existing and/or create new paper characteristics to increase product capabilities and value, and develop commercial applications of promising advances in nanotechnology
Develop New Forms of Biomass-Based Packaging	Develop sustainable biomass-based packaging competitive with existing packaging technologies
Separate Biomass Into Basic Components, Preserving Nanoscale Properties of the Components	Investigate and develop technologies and methods to deconstruct biomass into fundamental components for commercial use, without disrupting nanoscale properties
Develop New Printed Functionalities to Make "Smart" Surfaces on Paper, Paperboard, and Wood Products	Develop technologies to add "smart" functions via printing to surfaces of paper and paperboard and wood products

http://www.agenda2020.org/PDF/Forest_Products_Industry_Tech_RM-043010.pdf

A Wide Range of Industries are Interested in Cellulose Nanomaterials

- Plastics, coatings, case for electronic devices.
- Water harvesting, filtration, barrier materials.
- Biomedical applications.
- Stimuli responsive material.
- Electrospinning, yarn and weaving – airplane wings, automobile body, helicopter windows.
- Defense armor.
- Major companies are conducting R&D with cellulose nanomaterials.

Partnering — Looking for Applications Opportunities

Ted Wegner
Tel: 608 231 9434
twegner@fs.fed.us

John G. Cowie
Tel: 202 463 2749
John_cowie@afandpa.org

World L-S Nieh
Tel: 703 605 4197
wnieh@fs.fed.us

Phil Jones
Tel: 770 331 0325
pjones@imerys.com

IMERYS

Sean Ireland
Tel: 207-469-4253
sean.ireland@versopaper.com

2011 TAPPI International Conference on Nanotechnology for Renewable Materials

Washington, D.C.

June 6-8, 2011

United States Environmental Protection Agency

Nanotechnology Research Program

Overview of EPA Nano Program: Applications & Implications

USDA/NIFA-AFMNet Joint Nanotechnology Grantees Conference

Nora Savage, PhD

US EPA,

Office of Research & Development

National Center for Environmental Research

Technology and Engineering Division

OUTLINE

- Sustainable Approach
- EPA & Nano
- EPA STAR Research
- Path Forward

EPA's Interest in Nanotechnology

Nanotechnology Research Program

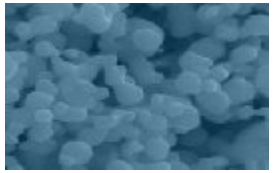
- **Fulfill mission**
  - Develop appropriate risk assessment & risk management approaches
- **Provide leadership**
  - U.S. and global communities - environmental appls and impls
- **Support research**
  - Enhance collaborations, increase knowledge base
- **Address statutory requirements**
  - CAA, CWA, FIFRA, RCRA, SDWA, TSCA, etc.
- **Encourage proactive approach**
  - Predictive tools (comp tox), P2, green nano)

Nanotechnology Research Program

Anthropogenic

Engineered

- Carbon-based NTs, Fullerenes
- Metal Oxides
- Quantum Dots
- Nanotubes
- Nanowires
- Dendrimers



Incidental

Particles from:

- Combustion
- Industrial Processes
- Vehicles
- Construction

Natural

Particles from:

- Plants, Trees
- Oceans, other water bodies
- Erosion
- Dust

Core - Sustainable Design

SHINING “STAR” Examples

Science To Achieve Results

Research at NCER

Applications – use nano to improve monitoring/detection and remediation techniques, pollution prevention

(Approx. $12.2 M to date)

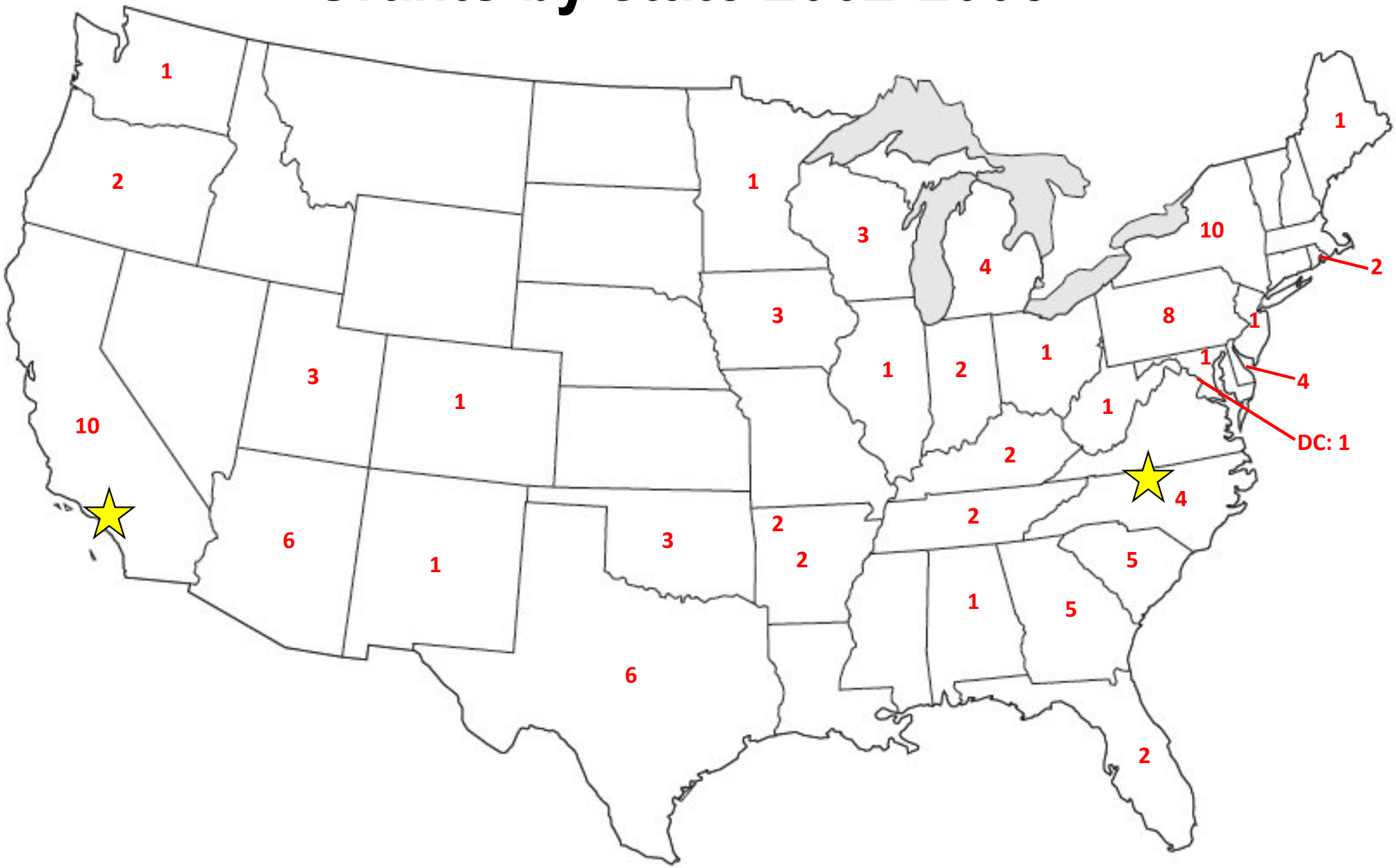
Implications – assess the interactions of enms (human & env), exposure, and possible risks that may arise

(Approx. $17.8 million to date, excluding ultrafine)

United States Environmental Protection Agency

Nanotechnology Research Program

Grants by state 2002-2008



Paul Westerhoff
Arizona State University

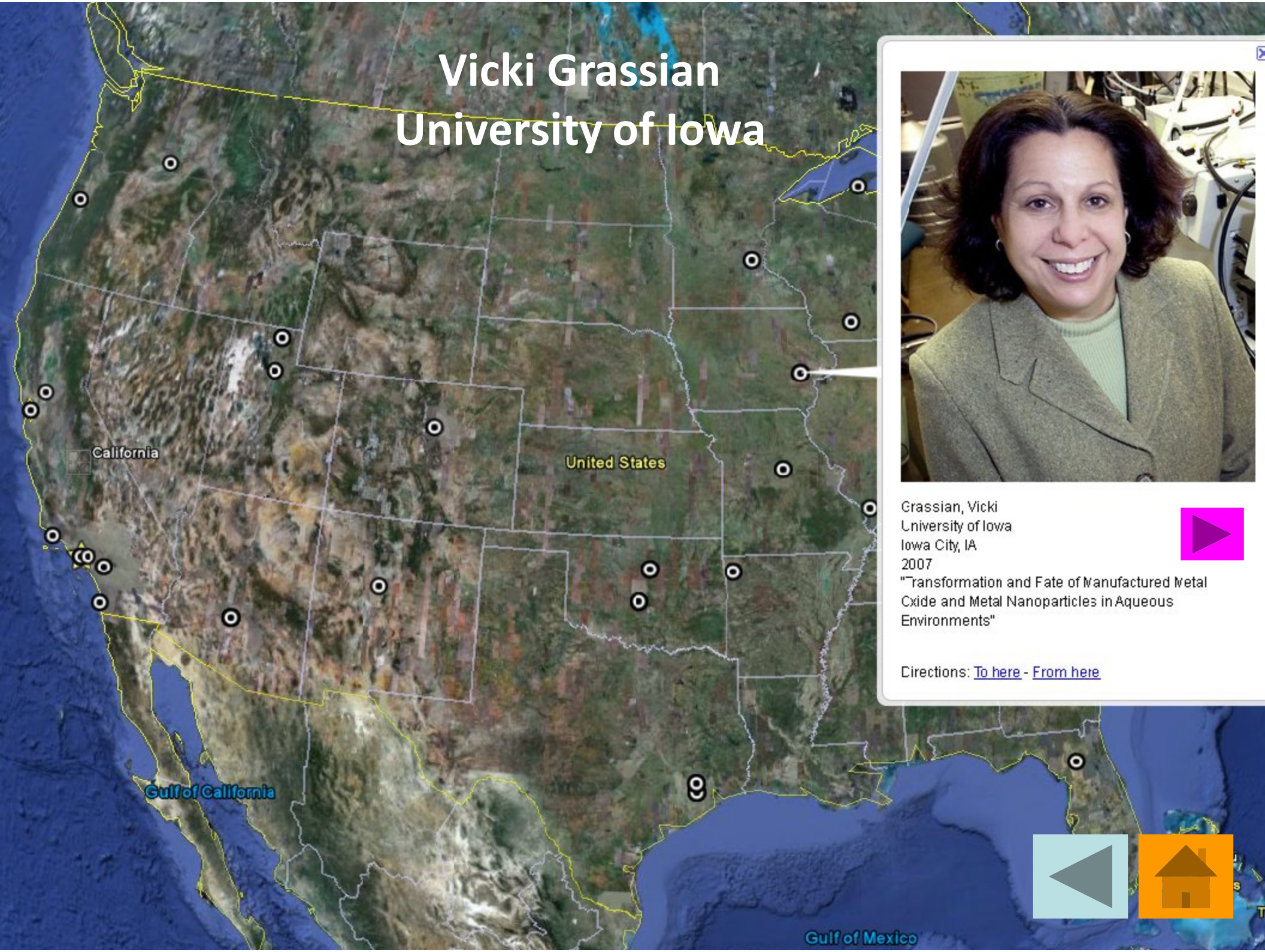
Westerhoff, Paul
Arizona State University
Tempe, AZ
2006
"Biological Fate and Electron Microscopy Detection of Nanoparticles During Wastewater Treatment"

Directions: To here - From here

Nanoparticles Leach from Commercial Products into Sewage, but Can be Removed during Wastewater Treatment

In 2008, Professor Paul Westerhoff and his graduate student published a paper that showed how nano silver particles can leach from commercially available clothing into wash water. Experiments were conducted using socks that contain nano silver to inhibit bacterial growth which contribute to foot odor. Nano silver is now among the most widely used nanoparticles in clothing and many other products used around the house today. We confirmed the presence of nano silver particles both in the initial sock fabric and in water used to wash the sock, which could mimic the release of silver in a washing machine which would then end up as sewage leaving your house.

Vicki Grassian
University of Iowa

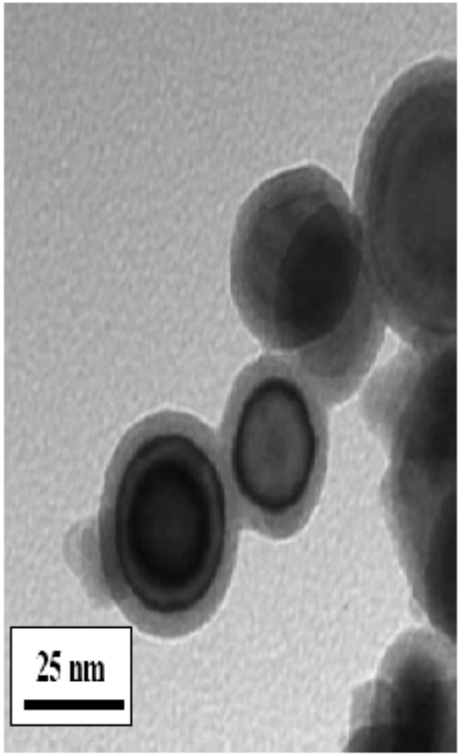


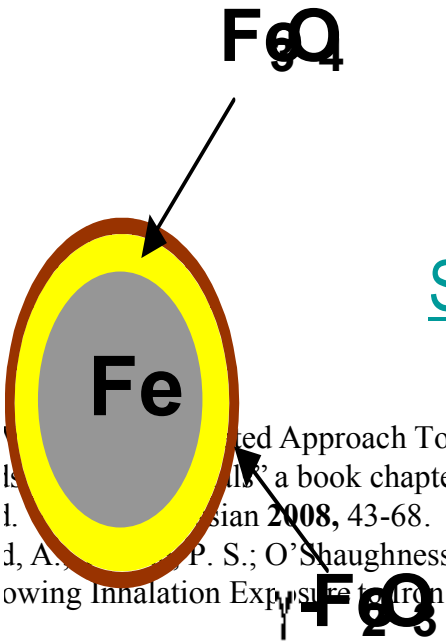
Grassian, Vicki
University of Iowa
Iowa City, IA
2007
"Transformation and Fate of Manufactured Metal Oxide and Metal Nanoparticles in Aqueous Environments"

Directions: To here - From here

Nanotechnology Research Program

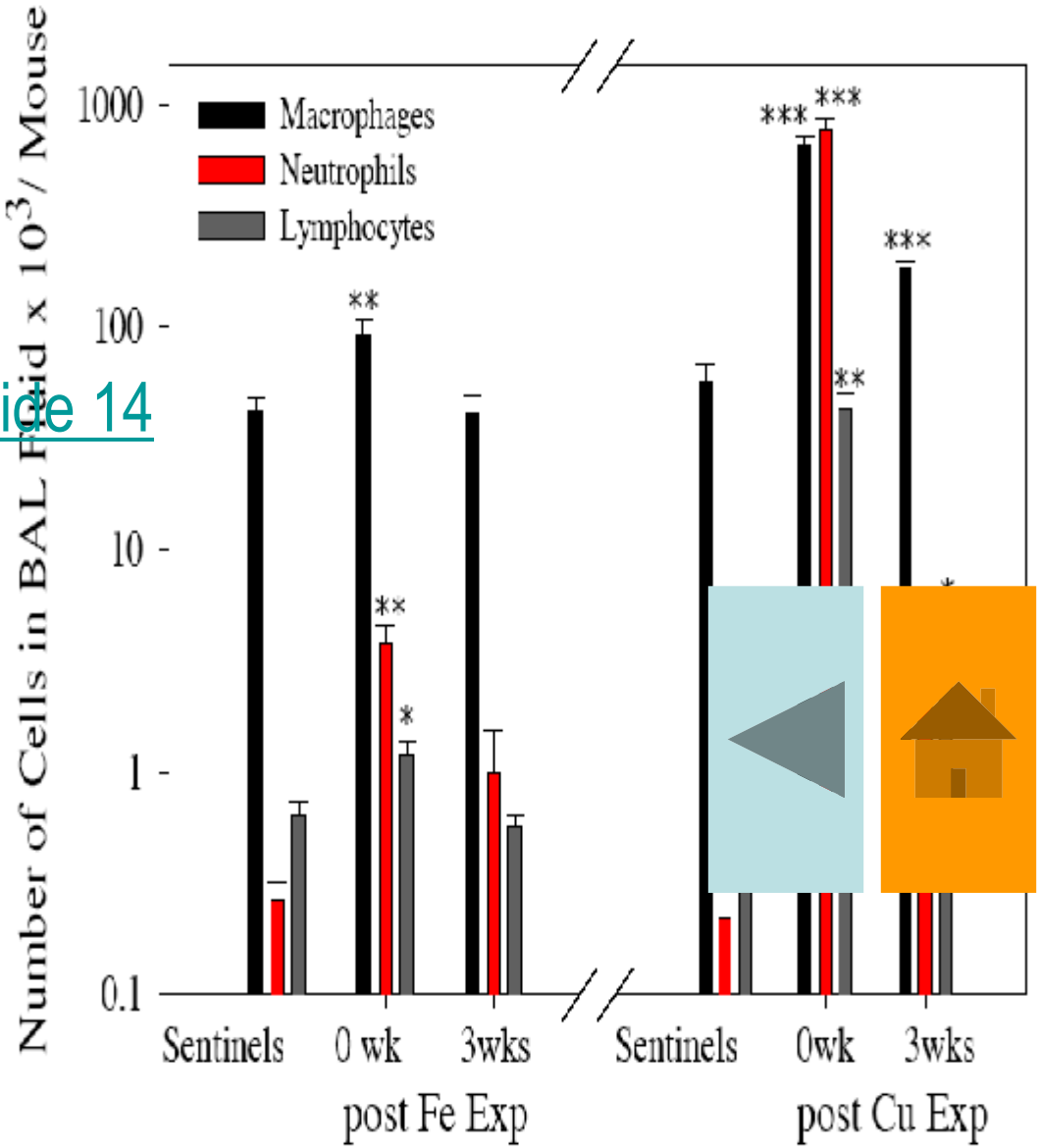
An Integrated Approach Toward Understanding the Toxicity of Inhaled Nanomaterials





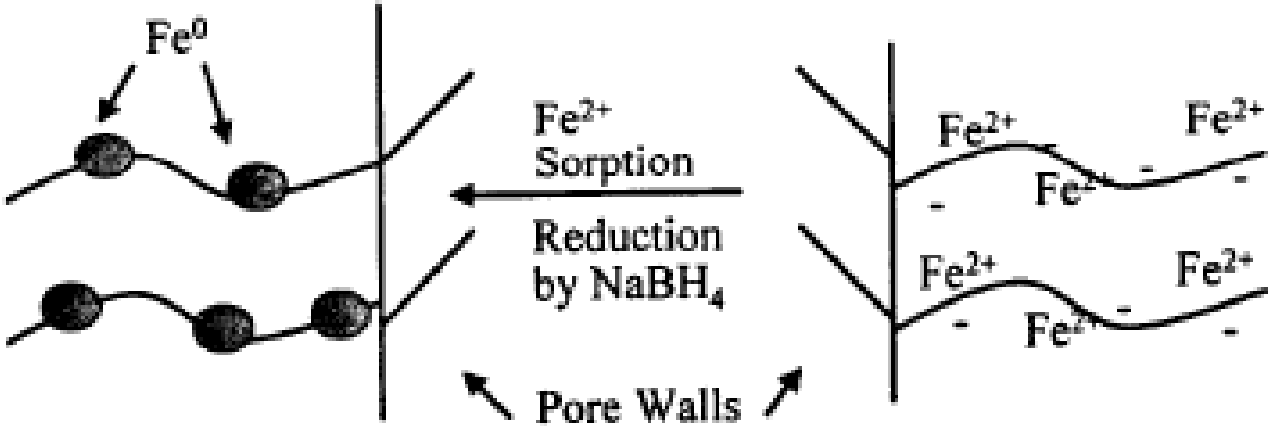
1.
T
E
2.
"
1
ted Approach Tov
ls ll" a book chapter
l. sian **2008,** 43-68.
d, A. P. S.; O'Shaughnessy
owing Inhalation Exposure to Iron a

Slide 14



Membrane-Based Nanostructures

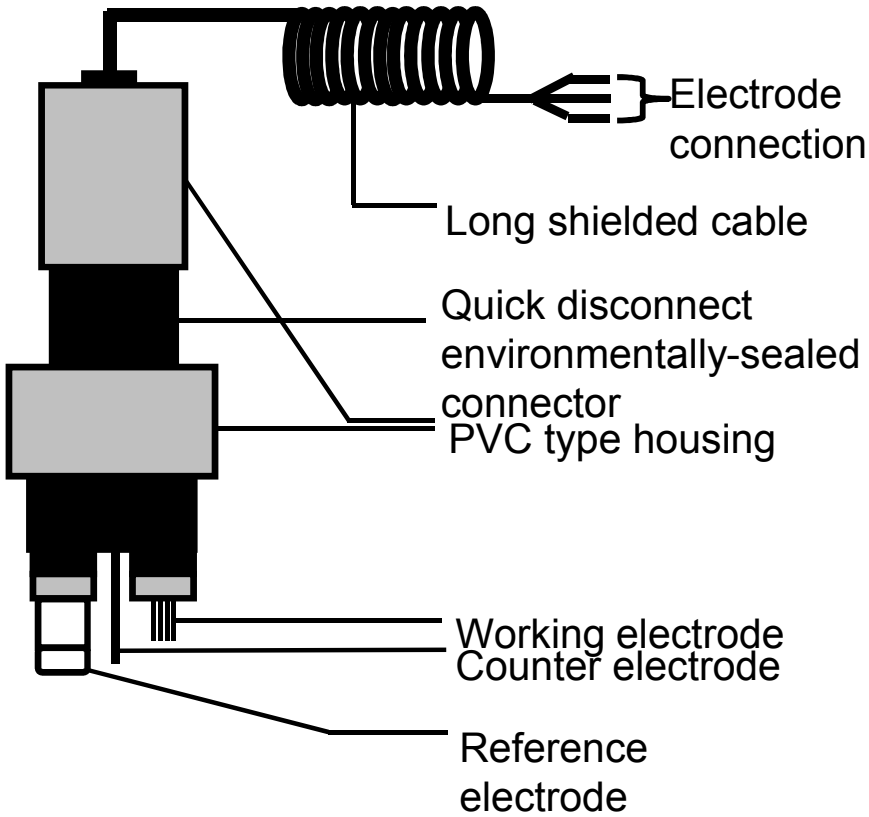
Immobilization

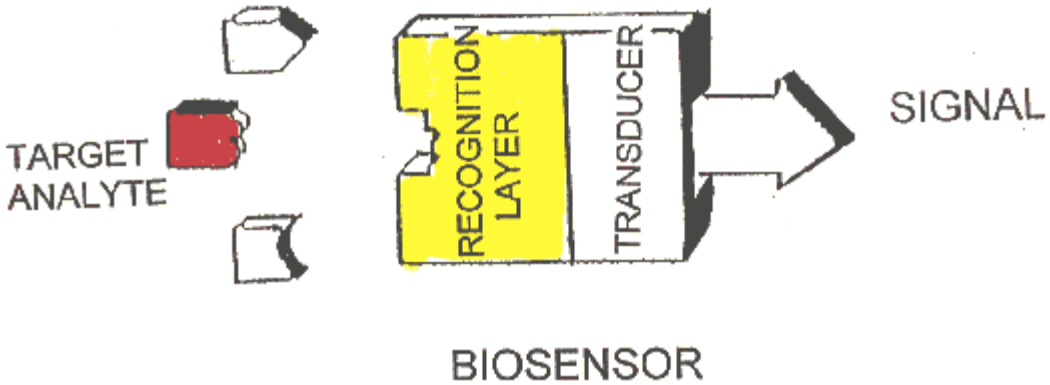


Nanoparticles immobilized in membrane for treatment of hazardous organics in water. Use may lead to miniaturization of dechlorination reactor systems.

Dibakar Bhattacharyya, University of Kentucky

Monitoring and Detection



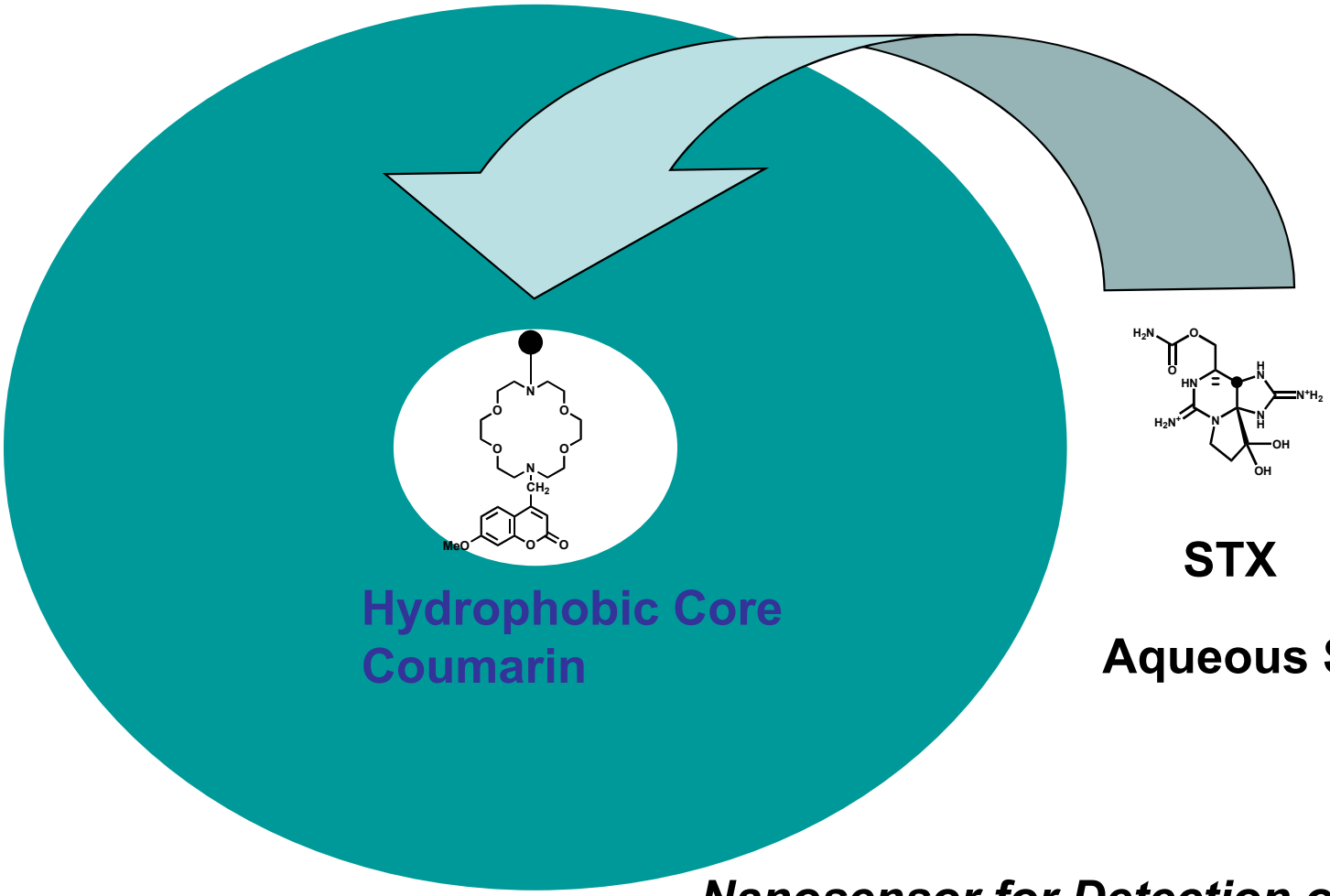


Remote electrochemical and bio-sensors

J. Wang, Arizona State University

Nanotechnology Research Program

Coumarin Sensor Anchored in Dendrimer



Nanosensor for Detection of Saxitoxin

Robert Gawley, University of Arkansas

CEINs

- 2007 Solicitation through NSF
  - 2 Awards – UCLA and Duke
- $1M/year from EPA, ~$7M/year from NSF for initial 5 year period
- International Partners
- Enabling holistic approach – introduction of novel compounds/materials

2008 Solicitation

Environmental Effects of Nanomaterials

- Joint with United Kingdom
- Investigating Environmental Effects of Manufactured Nanomaterials
  - fate/transport & exposure
- ~ $4 million (US, UK), $2 million each, 4 years
- Consortia teams
- Closed August 2009
- 13 proposals received
- 3 awards (CPSC)

United States Environmental Protection Agency

Nanotechnology Research Program

2009 Solicitation

Increasing Scientific Data on the Fate, Transport and Behavior of Engineered Nanomaterials in Selected Environmental and Biological Matrices

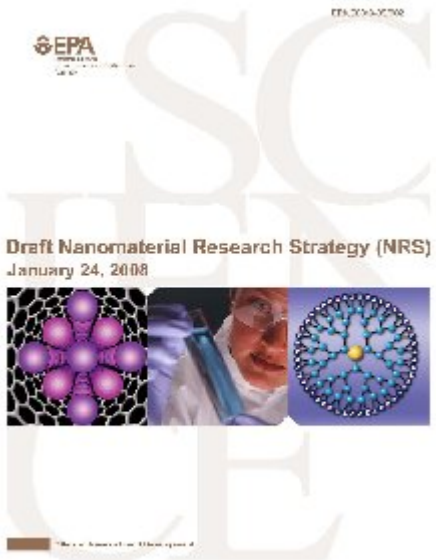
- Collaboration with EC
- ~ Additional consideration" on US side (EC partnership)
- Opened November 2. 2009, Closed February 2, 2010
- ~100 Proposals received
- 14 awards EPA, NSF, USDA

Nanomaterial Research Strategy (NRS)

EPA Research Needs

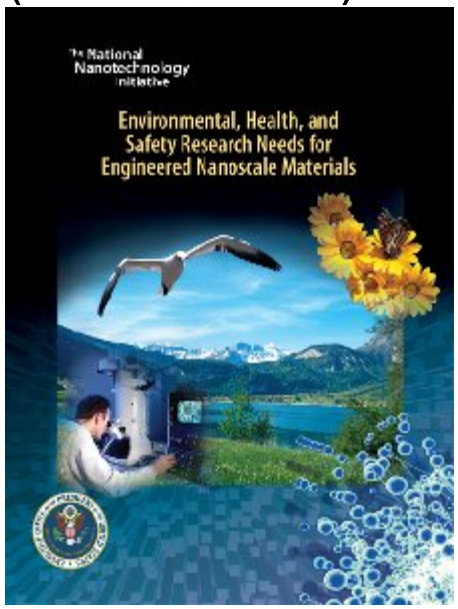
EPA initial focus on the following high priority areas.

- Environmental fate, transport, transformation
- Exposure
- Monitoring and detection methods
- Effects assessment methods



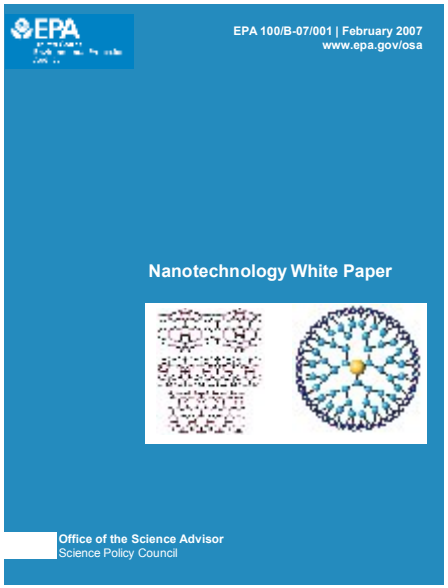
ORD Nanomaterial Research Strategy

Nanotechnology Environmental and Health Implications (NEHI) Interagency Working Group of NSET, (NSTC, 2006)



http://www.nano.gov/NNI_EHS_research_needs.pdf

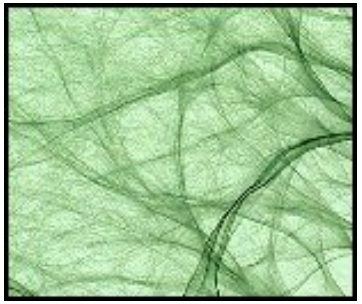
EPA White Paper on Nanotechnology (EPA, 2007)



http://www.epa.gov/OSA/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf

NCER's Nano Web Page

Nanotechnology Home



Nanotechnology

Factsheet

Solicitations

Newsroom

Research Projects

Publications & Proceedings

Nanotechnology has both applications and implications for the environment. EPA is supporting research in this technology while evaluating its regulatory responsibility to protect the environment and human health. This site highlights EPA's research in nanotechnology and provides useful information on related research at EPA and in other organizations.

http://www.epa.gov/ncer/nano

EPA's Nano Web Page

Types of Nanomaterials

Exposure

Ecological Effects

Health Effects

Green Manufacturing

Risk Assessments

Pollution Management

Fate and Transport

Research Centers Research Grants

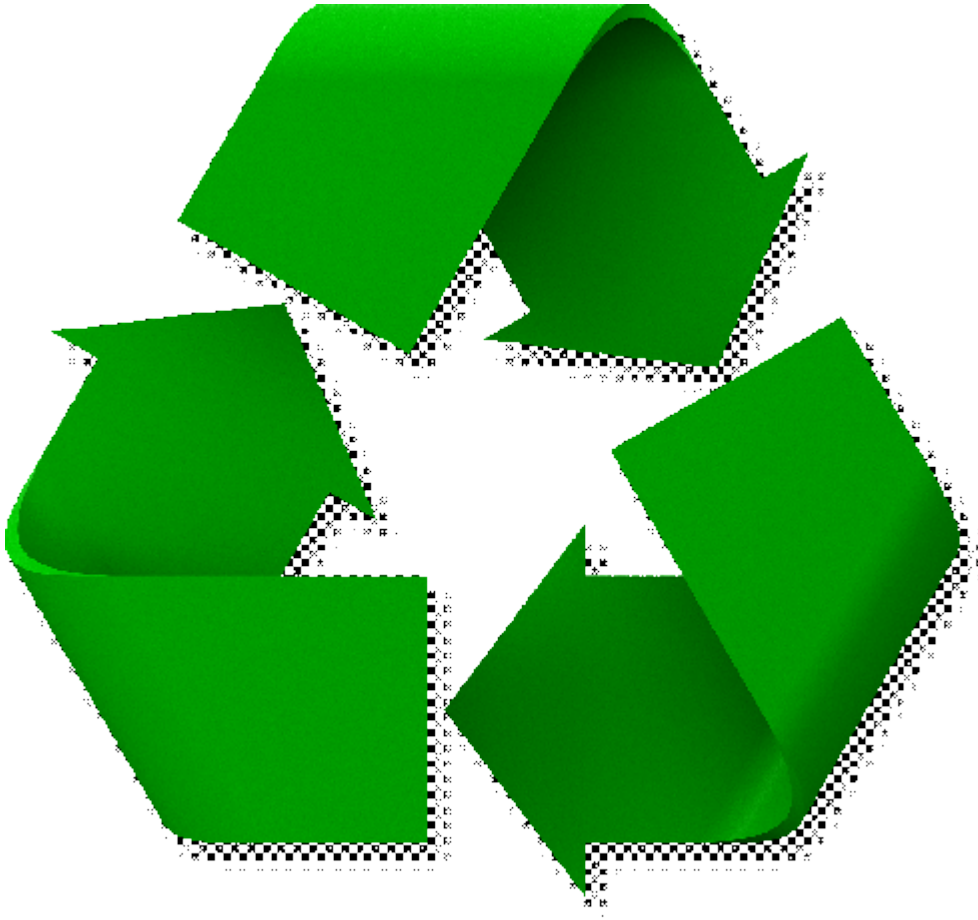
Life Cycle Research

http://www.epa.gov/nanoscience

Nanotechnology Research Program

Nano Research
Research

Idea



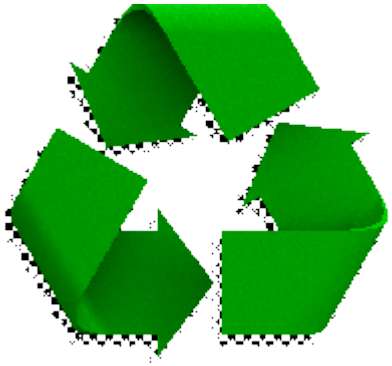
Application

Project

Idea

CONSIDER:

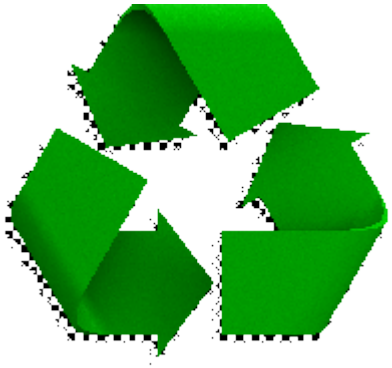
- Starting materials
- Environmental Use
- Material end



Project

CONSIDER:

- Processes
- Unintended Use
- Material Recovery



Application

CONSIDER:

- Material toxicity
- Wastes
- Multiple Use

Direction & Goals - STAR

- Continued focus on understanding fate/transport
- Understanding behavior of enms
  - Interactions w/ other compounds & materials
  - Interactions within biological and environmental media
  - Transport between environmental media

Move from “compound x compound” approach ➔

Moving Towards…..

Holistic assessment and management of environment

Collaborations (ALL sciences)

Result in

Improved public health and environmental ptotection

Application of beneficial technologies for QoLI

Understanding of complex mixtures – real exposures

=➔ emerging materials

United States Environmental Protection Agency

Nanotechnology Research Program

2011 Gordon Research Conference

Environmental Nanotechnology GRC

May 29 – June 3

Waterville Valley Resort, NH

Contact Information

Dr. Nora Savage

Savage.nora@epa.gov

Environmental Engineer, Nano Team Lead

National Center for Environmental Research

http://www.epa.gov/ncer/nano

Office of Research & Development, U.S. EPA

1200 Pennsylvania Avenue, N.W.

Mail Code: 8722F (8722P

Washington, DC 20460

703-347-8194