Nanotechnology: What is it; where are we; what should we think about?

Barbara Karn, PhD
US EPA/Office of Research and Development detailed to Woodrow Wilson International Center for Scholars/ Emerging Nanotechnologies Project

Environmental Law Institute

Nashville, TN May 19, 2006

OUTLINE

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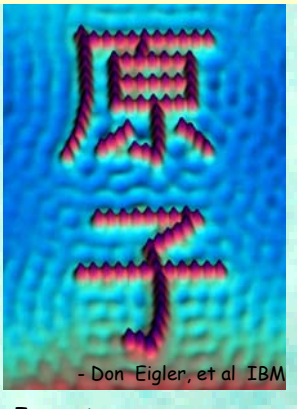
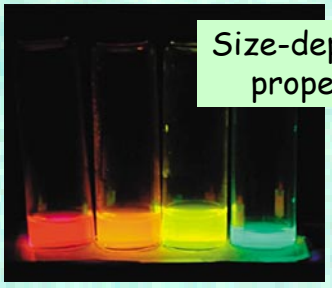
What is Nanotechnology?

Atomic-level manipulation



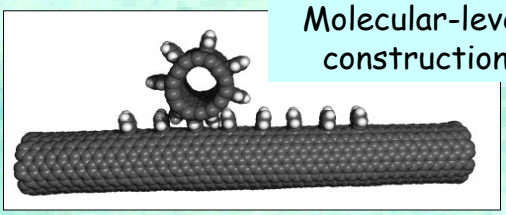
Iron atoms on a copper surface

Size-dependent properties



Different sizes of cadmium selenide nanoparticles

Molecular-level construction



Carbon nanotube gears

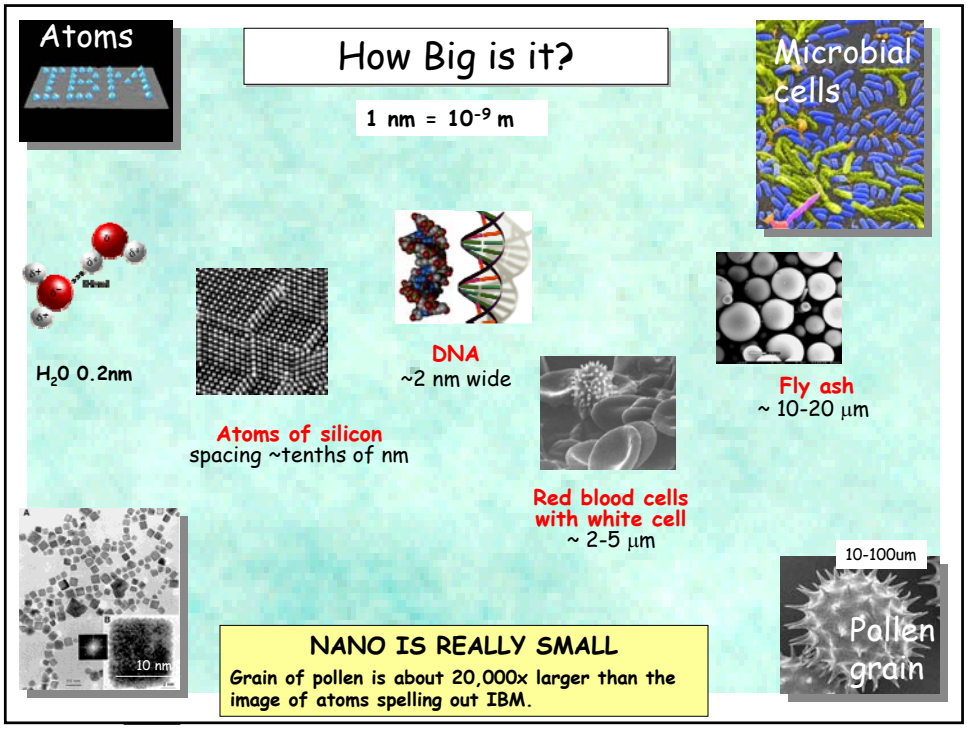
What is Nanotechnology?

While many definitions for nanotechnology exist, the NNI calls it "nanotechnology" only if it involves all of the following:

1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.

2. Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

3. Ability to control or manipulate on the atomic scale.



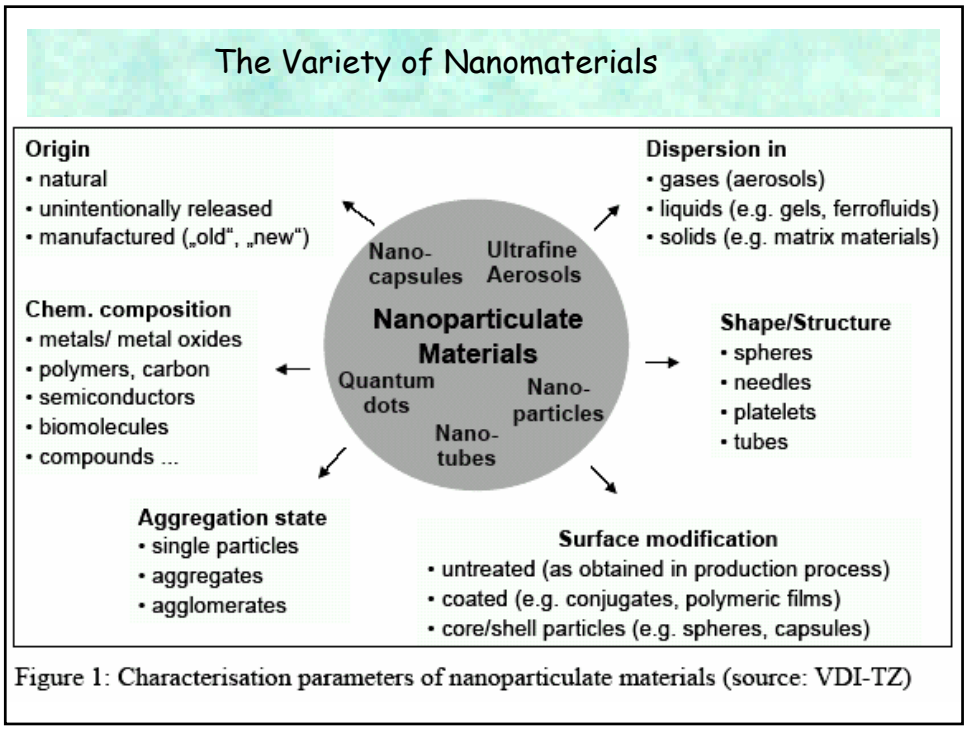
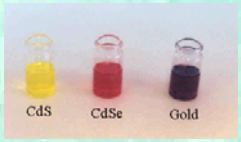
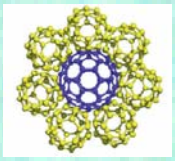


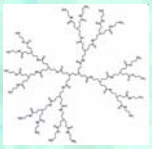
Figure 1: Characterisation parameters of nanoparticulate materials (source: VDI-TZ)

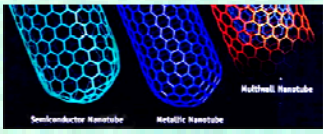
Keep in mind

Nanotechnology does not include just a single material or class of materials









Nanotechnology does not include just a single industry or industrial sector

Nanotechnology converges with other technologies: biotechnology, information technology and cognitive science

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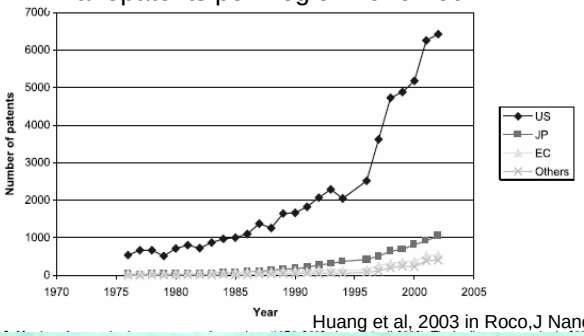
It's all about properties.

Surface Properties	Application examples
• Mechanical properties (e.g. tribology, hardness, scratch-resistance)	Wear protection of machinery and equipment, mechanical protection of soft materials (polymers, wood, textiles, etc.)
• Wetting properties (e.g. antiadhesive, hydrophobic, hydrophilic)	Antigraffiti, antifouling, Lotus-effect, self-cleaning surface for textiles and ceramics, etc.
• Thermal and chemical properties (e.g. heat resistance and insulation, corrosion resistance)	Corrosion protection for machinery and equipment, heat resistance for turbines and engines, thermal insulation equipment and building materials, etc.
• Biological properties (biocompatibility, anti-infective)	Biocompatible implants, abacterial medical tools and wound dressings, etc.
• Electronical and magnetic properties (e.g. magneto-resistance, dielectric)	Ultrathin dielectrics for field-effect transistors, magnetoresistive sensors and data memory, etc.
• Optical properties (e.g. anti-reflection, photo- and electrochromatic)	Photo- and electrochromic windows, antireflective screens and solar cells, etc.

Table 2: Tunable properties by nanoscale surface design and their application potentials

Nanopatents per Region 1976-2002

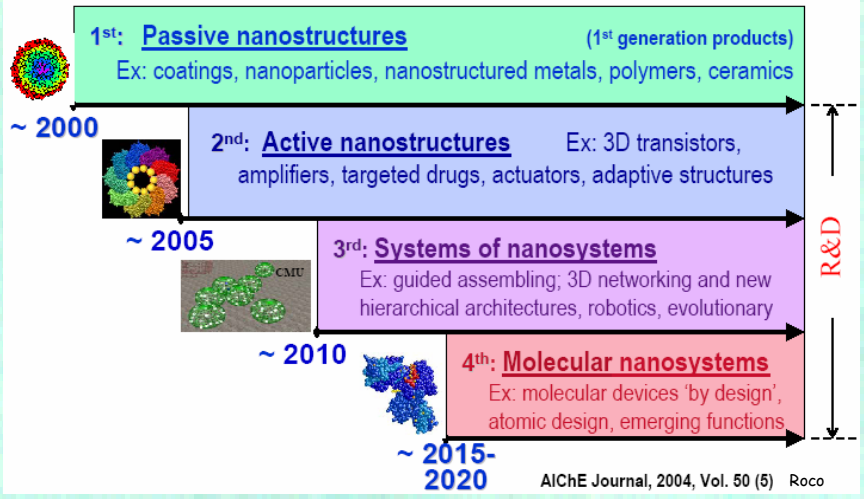


Huang et al, 2003 in Roco,J Nanopart Res

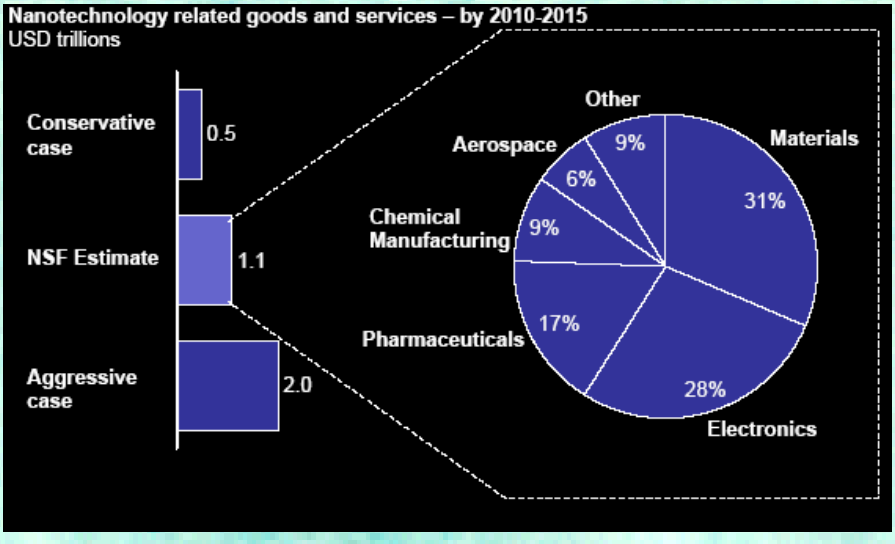
Research leads to patents

King Features Syndicate, September 22, 2004

Timeline for Nanotechnology



The magnitude of nanotechnology



Source: NSF data, Sean Murdock presentation

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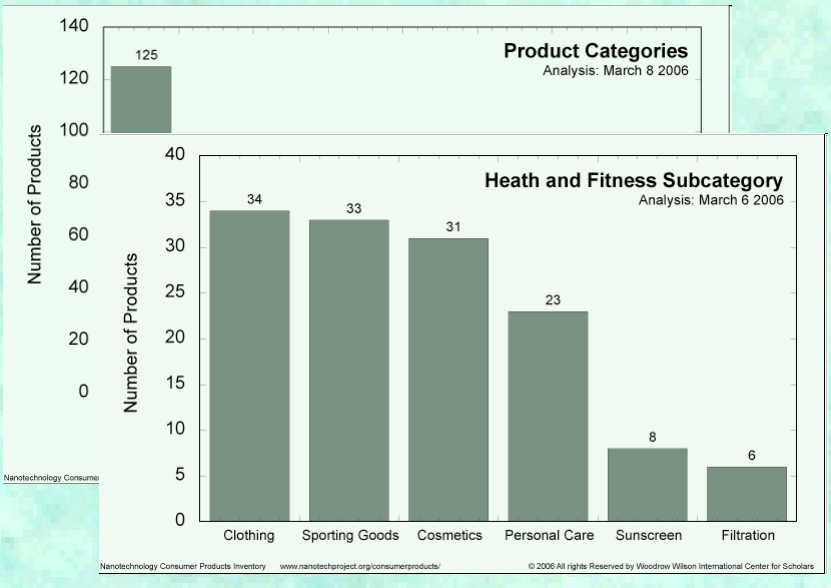
Nanotechnology is Here

- Many nanoparticle manufacturers are listed on the NASDAQ.
- Almost all major corporations in the world are involved: Intel, IBM, Dupont, Procter & Gamble, L'Oreal, Kodak, GM, Ford, HP, Dow, etc.

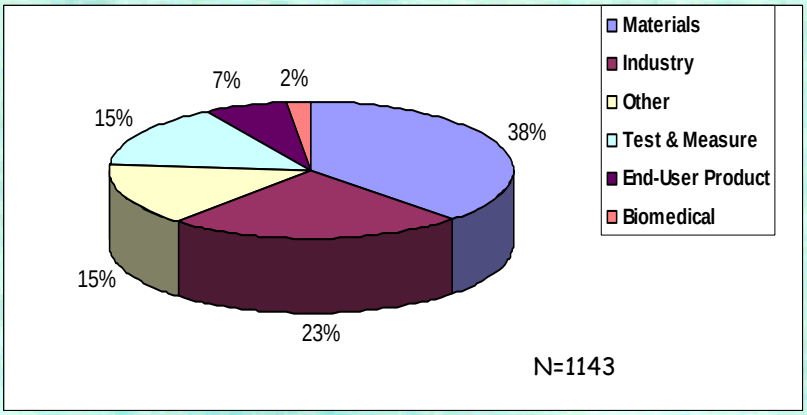
Nano Consumer Products: Wilson Center Database of 200+

Consumer Products Categories



Nano Consumer Products—Order Now!

Nanoproducts (Sept. 2005)



Products of Nanotechnology:

End User Applications (9%):

Tennis Balls, Rackets
Clothing
Cameras
Respirators
Razor Blades
Cosmetics
Beer Bottles
Sunscreens

Industrial Imaging (8%):

TEM
STEM
SEM
AFM
E-Beams
X-Ray, Confocal Microscopes

Capital Equipment (15%):

Positioners
Cantilevers
Coaters
Probes/Manipulators
Lithography:Masks, Resists
AFM's

Software (4%):

Modeling
AFM software
Controllers for Microscopes
CAD navigation

Components (8%):

Transistors
Fillers
Catalytic Converters
Fenders
Mirror Housings
Fuel Cells
Step Assists
Polarizers/Wave Plates
Displays-OLED
Surgical Fusions

Test & Measurement (9%):

Strain
Film Thickness
Surface Topography

Materials (44%):

Nanotubes
Fullerenes
Quantum Dots
Metal oxides
Dendrimers
Nanoclays
Nano metals - Gold, Silver
Nanocomposites

Therapeutic System (3%)

Women's cream designed for short-term use (Estrasorb)
Drug for chemotherapy-induced nausea (Emend)
An antibacterial protocol available to doctors and researchers (NanobacTX)
Nanoparticle-based nutraceutical spray to deliver nutritional supplements through the cheek lining
Automating equipment for biomedical sample preparation process
Immunosuppressive drug (Rapamune)
Ultrasmall silver nanocrystals (Acticoat Burn Dressing)

(August, 2004)

Electronics is out in front

Small Times Magazine

Electronics takes the lead

Other industries may lose out as semiconductor trade groups gear up for a future with nano

By David Forman

from the March 2005 issue of Small Times magazine

Photo courtesy of International Sematech

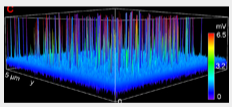
Electronics research moving to new products

Thursday, April 27, 2006

Free Electricity from Nano Generators

Throw away your batteries. Tiny nanowires could power medical implants, even your iPod.

By Kevin Bullis



A graph showing spikes of electrical discharge as the nanowires are scanned. (Courtesy of Zhong Lin Wang, Georgia Tech.)

Today's portable electronics (except for self-winding watches and crank radios) depend on batteries for power. Now researchers have demonstrated that easy-to-make, inexpensive nanowires can harvest mechanical energy, possibly leading to such advances as medical implants that run on electricity generated from pulsing blood vessels and cell phones powered by nanowires in the soles of shoes.

"When you walk, you generate 67 watts. Your finger movement is 0.1 watt. Your breathing is one watt. If you can convert a fraction of that, you can power a device. From the concept we've demonstrated, we can convert 17-30 percent of that," says Zhong Lin Wang, professor of materials science at Georgia Tech and one of the researchers of the work, published in the journal *Science*.

Technology Review AN MIT ENTERPRISE

Infotech | Biotech | Nanotech | Biztech | Magazine | Blogs | MIT News

[1]

Monday, February 13, 2006

The Ultra Battery

A new type of ultracapacitor could eventually have you throwing out your conventional batteries.

By Kevin Bullis

A breakthrough technology is holding forth the promise of charging electronic gadgets in minutes, never having to replace a battery again, and dropping the cost of hybrid cars. Indeed, the technology has the potential to provide an energy storage device ten times more powerful than even the latest batteries in hybrid cars -- while outliving the vehicle itself.

Technology Review AN MIT ENTERPRISE

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[1] 2 Next »

Tuesday, March 07, 2006

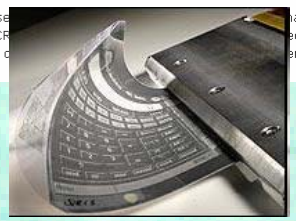
Flexible CRT Displays

A new method of patterning nanotubes could lead to flexible, flat-screen displays with many of the advantages of bulky CRTs.

By Kevin Bullis

The unique electronic properties of carbon nanotubes make them promising for a range of applications, including use as ultra-efficient "electron emitters" in bright, low-power displays. Now researchers have found a way to pattern carbon nanotubes in plastic sheets that could lead to flexible versions of these displays -- and electronics that you could roll up and put in your pocket.

Several companies, such as Samsung and Motorola, are developing carbon nanotube-base hat nanotubes can emit electrons extremely efficiently. Like familiar bulky cathode ray tube (CR ectrons to excite phosphors on a screen to produce an image. But unlike standard CRTs, nanotubes c energy that other flat-panel technologies.



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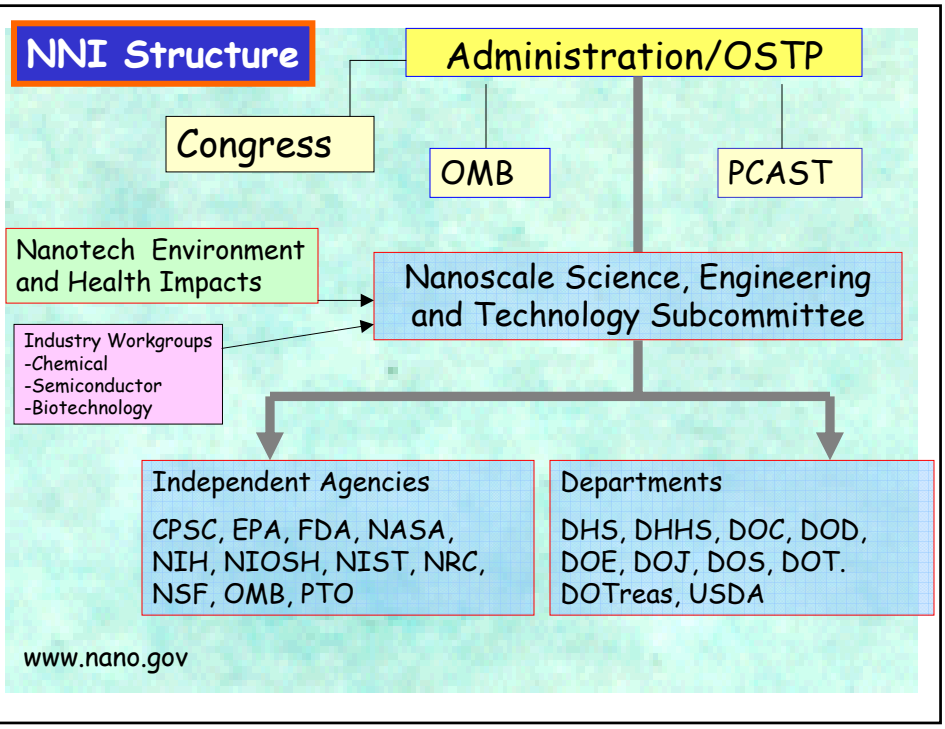


National Nanotechnology Initiative

Vision: a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry. www.nano.gov

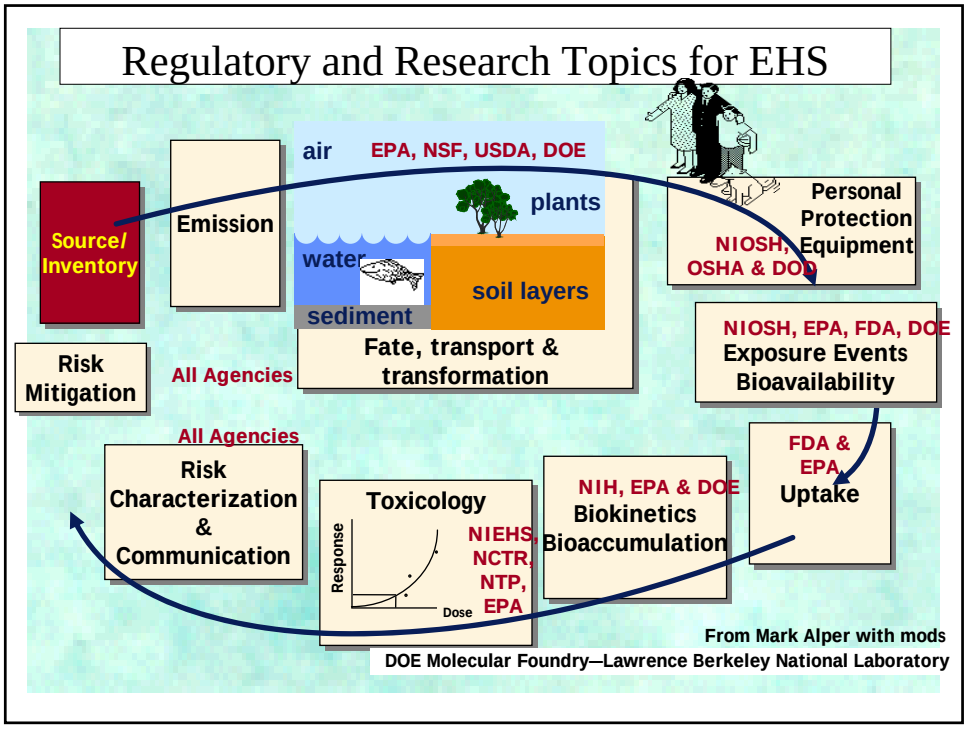
Goals: 1. **Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology**
2. **Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit**
3. **Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology**
4. **Support responsible development of nanotechnology**

2005 budget for R& D: $1,200M

$38.5M spent on EHS in 2005, approx. 3% of the NNI total

Efforts of NNI on Nanotechnology – Environment and Human Health

- EPA(since 2000), NIOSH (2004), NSF(2004) plus NIEHS (2005) Research Grants on Environmental Applications ($14 M) and Implications ($21M)
- NIH Research on Effects of Nanoscale Materials in Body-Adjunct to Cancer and Drug Research
- NIOSH Research on Nanomaterials
- National Toxicology Program (NIEHS)
  - C nanotubes, quantum dots, titanium dioxide, fullerenes
- NSF, DOE, DOD Research Centers



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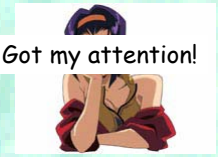
WHY DON'T WE THINK AHEAD?



Big Problem

Interesting

Passionate

Exciting

Prevention

Apathetic

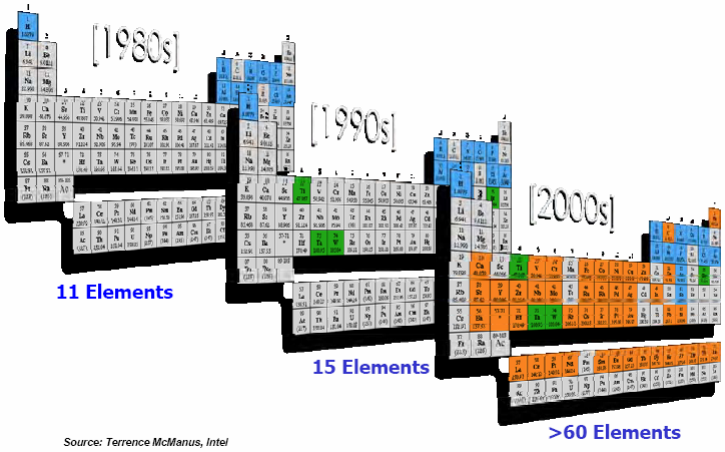
Boring

Dull

Human Nature

Prevention Issues: other "stuff"

Growing Use of Elements in Semiconductor Industry



Different elements, unknown environmental impacts

Green Nanotechnology

1. Production of nanomaterials and products does not harm the environment

Making NanoX "greenly"

e.g., Green chemistry, Green engineering, DfE, Smart business practices

Using NanoX to "green" production

e.g., Nanomembranes, nanoscaled catalysts

Pollution Prevention Emphasis

2. Products of nano help the environment

Direct Environmental Applications e.g., environmental remediation, sensors

Indirect Environmental Applications e.g., saved energy, reduced waste,

Addressing a full systems approach to nanomaterials and nanoproducts

NEXT STEPS: Policies that offer incentives for developing green nanoproducts and manufacturing techniques

Issues in Governance

1. Defining and measuring nanotechnology

Does size matter? How do we name nanomaterials?

CAS names

Standards: ASTM, ANSI, ISO, Chinese Academy

2. Keeping up with rapid development – institutional constraints

Who does what?

What is new?

Timeframe of legal system

3. How to characterize the risk – research and monitoring

Instrumentation

Research in toxicity and exposure

Standards Development
ANSI, ASTM, ISO

ANSI Nanotechnology Standards Panel

including, but not limited to, nomenclature/terminology; materials properties; and testing, measurement and characterization procedures

ASTM Committee E56

1) The development of standards and guidance for nanotechnology & nanomaterials
2) the coordination existing ASTM standardization related to nanotechnology needs.

ISO/TC 229

Tasks include developing standards for:
terminology and nomenclature; metrology and instrumentation, including specifications for reference materials;
test methodologies; modeling and simulation;
science-based health, safety, and environmental practices

ISO 14001

Environmental Management System

develop a systematic management approach to the environmental concerns of an organization

Goal: Continual improvement in environmental management.

"In Case of" Plans

Inventory of types of materials (e.g., elements, molecules)

Personal protective equipment

Accidents/spills

Emissions

Worker Health Surveillance

Protecting the protectors

Updates

3 issues to watch

Magic Nano

Call for FDA ban on nano cosmetics

Call for EPA to regulate nano silver in washing machines

Nanotechnology risk governance issues

EHS, ELSI, Education Gap, Human Development, Political & Security

- Investment policies (R&D, infrastructure) for best and equitable results
- Occupational safety
- Consumer safety
- Environmental safety
- Legal framework (ex: science testimony; national / international levels); its impact on international trade
- Individual rights to information and knowledge
- Social implications: human integrity and dignity; new opportunities and losses; societal structure; etc.)
- International relationships: IP, North-South divide, equity between haves and have-nots
- Long-term human development – need for anticipatory measures
- Political and economical stability, security risks (national /transnational)
- Need for principles to be converted to defined and planned actions

M.C. Roco, 04/28/06

International Risk Governance Council

Parting thoughts

Nanotechnology will change existing technologies

We are thinking ahead about impacts and how to manage them

We must plan for full life cycle of products

We need rational governance of this new technology

Nanotechnology offers the opportunity to do it right in the first place.
It's an opportunity we don't want to miss!

Questions??

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Come forth into the light of things, Let nature be your teacher

William Wordsworth