

Developing Nanotechnology as if Health, Environment and Sustainability Mattered

Joel A. Tickner, ScD; Ken Geiser, PhD;
Steffen Hansen, MSc

Lowell Center for Sustainable Production
University of Massachusetts Lowell

Joel_tickner@uml.edu

www.chemicalspolicy.org

Lowell Center for Sustainable Production



Overview

- **Nanotechnology has many potential benefits but there are also many unknowns as to the health, safety and environmental implications of engineered nanomaterials**
- **We've made many technology mistakes in the past – we should learn and get it right this time**
- **We can develop nanotechnology in a way brings social, environment and health benefits**
- **This takes a new way of thinking about technology development, science, and policy**



What are emerging technologies

- **“Science-based innovations that have the potential to create a new industry or transform an existing one.”**
 - **Telecommunications**
 - **Energy**
 - **Biotechnology**
 - **Lightweight materials**
 - **Bioengineering**
 - **Computational chemistry**
 - **Nanotechnology**



Characteristics of emerging technologies

- **Rapid introduction**
- **Complex materials flows/multiple sources**
- **Broad distribution**
- **Uncertainty, ignorance, and indeterminacy**
 - **Fate, distribution, exposure, toxicity, persistence and pseudo persistence**
- **Complexity and range of materials**
 - **Cumulative and interactive effects**
- **Potential effects from low level exposures**
- **Limited regulatory oversight in many cases**
- **Hard to study and characterize risks**





Two paths – Path One - Reaction

- **Develop technology without constraints and fix problems once they occur**
- **Wait until we have perfect evidence – proof – before acting.**
- **Treat uncertainty and ignorance as a controllable or deniable problem**
- **Treat lack of information, lack of evidence of harm, and uncertainty as evidence of safety**
- **Define problems as simply technical ones that can be solved by “experts”**
- **Examine only single options to solve a problem**
- **Tertiary prevention**



Two Paths – Path Two - Precaution

- **Understand the health, environmental and social implications of a new technology before it gets widely introduced using multiple disciplines.**
- **Accept uncertainty and surprise as part of dealing with complex systems where ignorance is prominent – act on accumulating knowledge**
- **Design technologies with an eye towards potential health, safety, environmental implications**
- **Define problems as social-technical ones, that must include a wide range of stakeholders.**
- **Have multiple options to achieve a particular need – focused and incremental design**



Nanotechnology as an example of an emerging technology



Definition of nanotechnology

- **The term “nanotechnology” was coined during the 1970s to define processes smaller than “microtechnologies”**
- **Nanotechnology involves precision placement, measurement, manipulation, processing and modeling at the nanoscale**



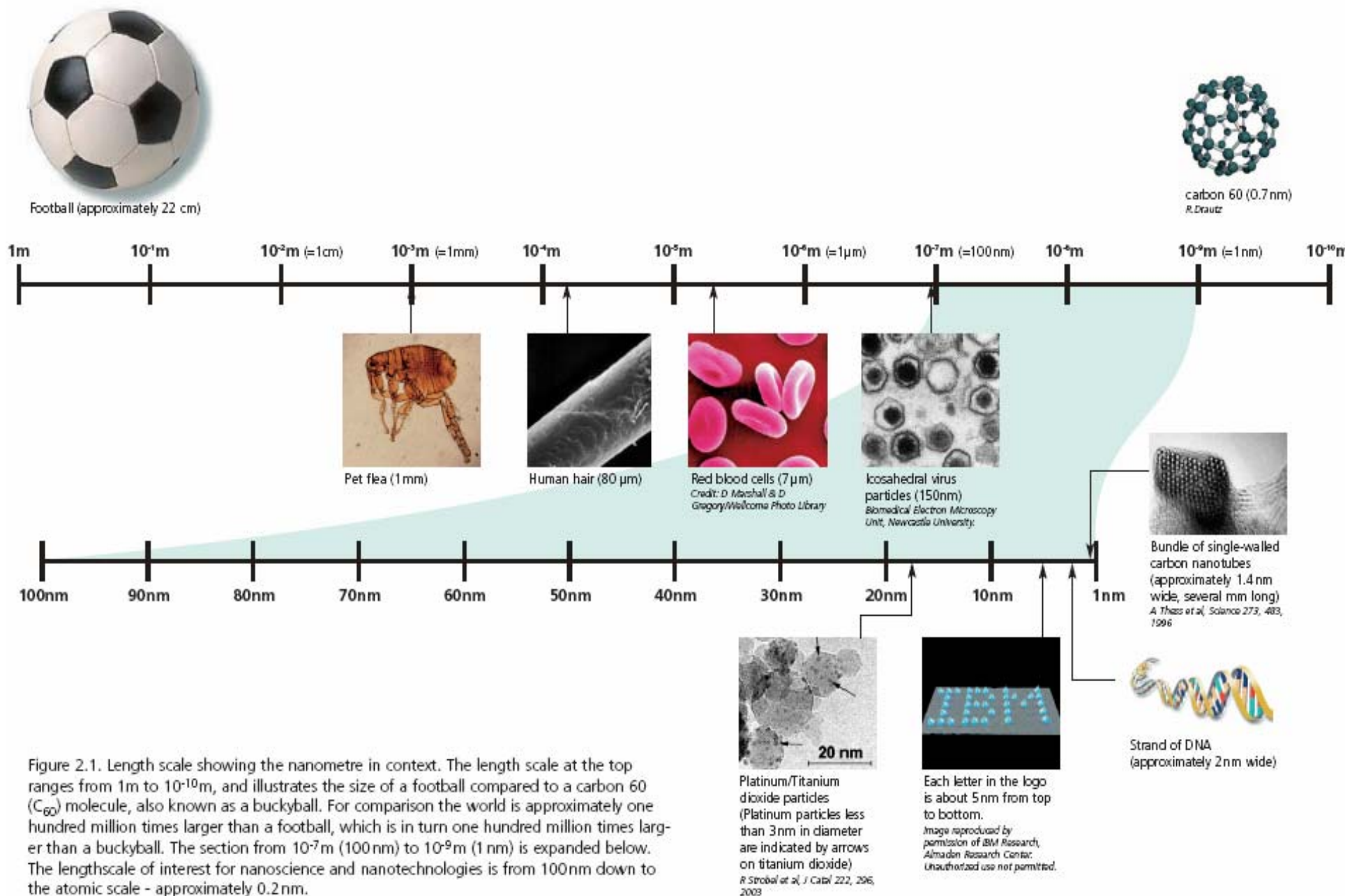


Figure 2.1. Length scale showing the nanometre in context. The length scale at the top ranges from 1m to 10^{-10} m, and illustrates the size of a football compared to a carbon 60 (C_{60}) molecule, also known as a buckyball. For comparison the world is approximately one hundred million times larger than a football, which is in turn one hundred million times larger than a buckyball. The section from 10^{-7} m (100nm) to 10^{-9} m (1 nm) is expanded below. The lengthscale of interest for nanoscience and nanotechnologies is from 100nm down to the atomic scale - approximately 0.2nm.

Nanomaterials are Not New

- **Most biological processes occur at the nanoscale**
- **Combustion processes and many chemical processes generate unintended nanoscale particles (e.g. soot particles, flour dust, welding fumes)**
- **Portions of many conventional industrial chemicals (carbon black, paint pigments, silica, etc.) are nanoscale**
- **Indeed, nanomaterials are manufactured from known chemicals such as carbon, iron, silicon, titanium**



U.S. Federal National Nanotechnology Initiative Definition

- **Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications.”**
(US National Nanotechnology Initiative 2006)
- **Researching and developing technologies that work at the atomic, molecular or macromolecular level of the scale of 1 to 100 nanometers**
- **Involving structures, devices and systems that have novel properties and functions because of their scale**
- **Controlling or manipulating materials at the atomic level**
- **Engineered nanomaterials and nanomanufacturing**



Nanomaterials are Very New

- **Nanomaterials are manufactured from known chemicals such as carbon, iron, silicon or titanium**
- **However, nanomaterials have different properties from bulk chemicals because of**
 - Scale
 - Surface area per unit of mass
 - Quantum effects
- **The physical, chemical, and biological properties of materials at the nanoscale differ in fundamental and valuable ways from bulk matter.**
- **It is our ability to measure, manipulate and process at the nanoscale that is new**



Current Investments

- **Worldwide government investment today reaches \$3 billion annually and could reach trillions within a decade.**
- **Combined worldwide government and corporate funding exceeded \$8.6 billion in 2004**
- **U.S. government nanotechnology R&D funding reached \$1.6 billion in 2004 making nanotechnology the nation's largest government funded science initiative**



U.S. National Nanotechnology Initiative

(www.nano.gov)

- **Launched in 1997 by President Clinton to**
 - **advance research**
 - **facilitate technology transfer**
 - **train a workforce**
 - **study social and environmental effects**
- **Coordinates programs in 18 federal agencies**
- **Funds programs in 11 agencies with the largest share going to the Department of Defense**
- **Funding has grown from \$116 million in 1997 to just over \$1 billion in FY 2006**



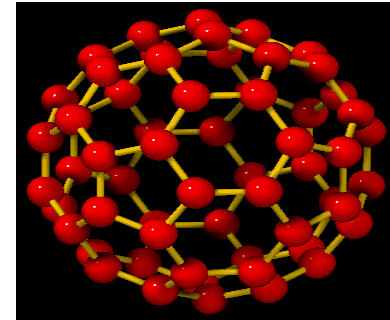
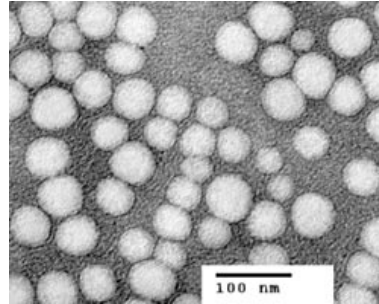
Nanotechnology Industry

- **Industry is developing around the world**
- **26 countries have nanotechnology development programs (China has a very large national program)**
- **Large firms include GE, HP, Dupont, Intel**
- **Over 500 small firms already exist in the United States**

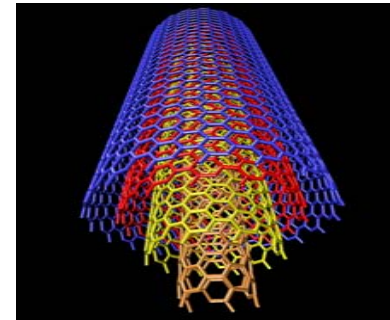
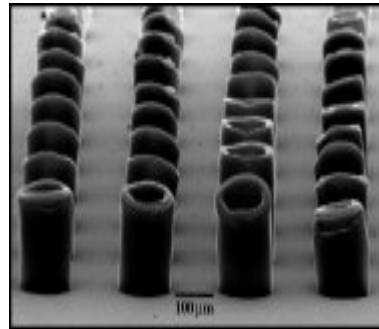


Examples of Nanomaterials

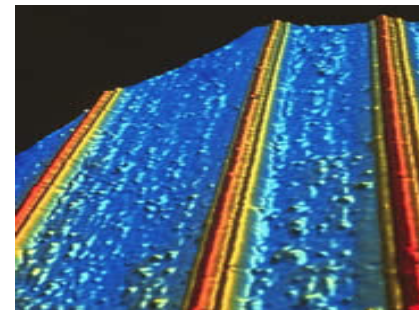
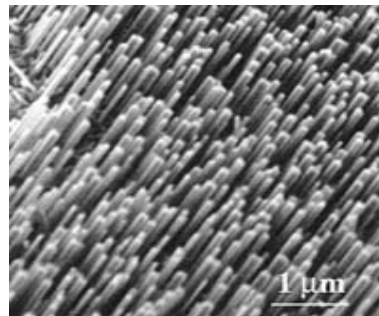
Fullerenes (C_{60})



Nanotubes



Nanowires

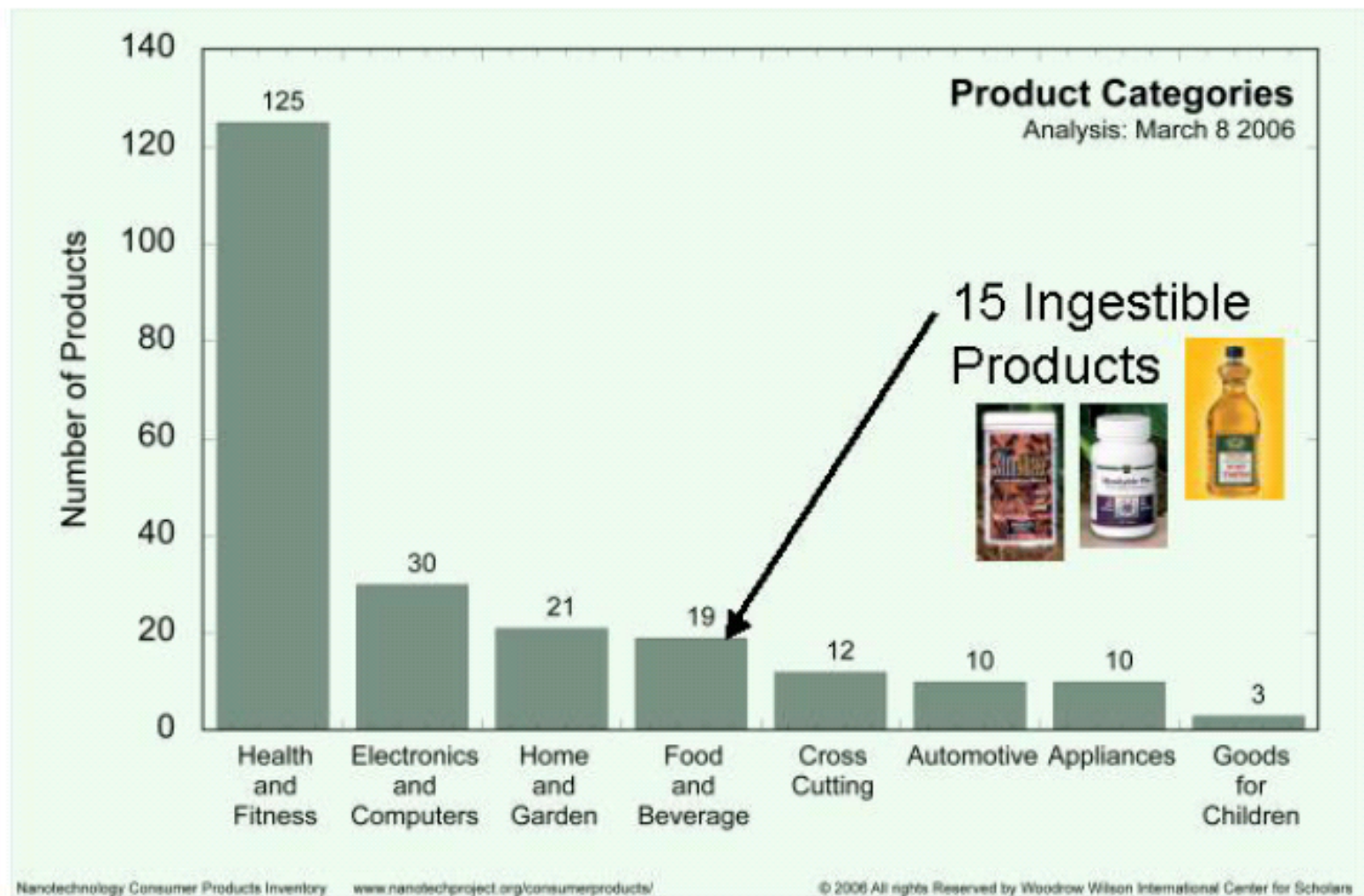


What are the potential benefits of nanomaterials?

- **Functionality**
 - Small scale leads to low weight, high strength, durable materials
 - High ratio of surface to mass leads to increased reactivity and energy transfer
 - Precision production leads to high performance, low defect applications
- **Environmental benefits**
 - Replacement for more toxic technologies
 - Less material/resource use
 - Less waste

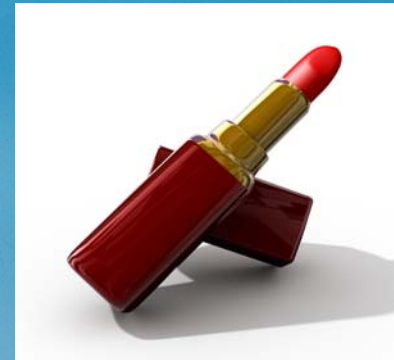


> 200 Nano-based Products in Commerce



Nanomaterials in Commerce Today

- Sunscreens and Cosmetics
 - Nanosized TiO_2 and ZnO in some suncreens
 - Nanosized Fe_2O_3 in some lipsticks
- Composites
 - Carbon nanotubes and fibers in bumpers and tennis rackets
 - Nanoclays in plastics



Nanomaterials in Commerce Today

- Coatings and Surfaces
 - Water repellency (textiles)
 - Anti-bacterial properties
 - Wear and scratch resistance
 - Stain resistance
- Harder/tougher cutting tools



Medical Applications

- **Non-invasive patient imaging**
 - **Several nanoparticle-based magnetic resonance imaging (MRI) agents have already been approved for routine clinical use,**
 - **Imaging on the cellular level is still basic research**
- **Targeted drug delivery**
 - **Smaller doses,**
 - **Can reach sites that are traditionally difficult to access (e.g. the brain)**
 - **control and direct cellular function using nanomaterials**
 - **Extend lifetime in the body – increase effectiveness, lower toxicity**



Medical diagnostic and Monitoring

- **Analytical tools**
- **Diagnostics and disease prevention**
 - **DNA and protein based Lab-on-chip using nanotubes and wires to detect HIV and cancer in individual cells**
- **Health monitoring**
 - **single molecule analysis**
- **Tissue regeneration and repair**
 - **implants**



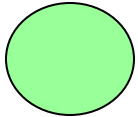
Stages of Nanotechnology Development

Technological Complexity



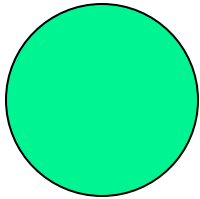
First Generation ~2001: Passive nanostructures

Nano-structured coatings, nanoparticles, nanostructured metals, polymers, ceramics, Catalysts, composites, displays



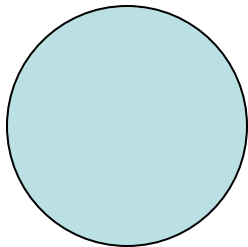
Second generation ~Now: Active nanostructures

Transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures, sensors, diagnostic assays, fuel cells, solar cells, High performance nanocomposites, ceramics, metals



Third Generation ~ 2010: 3-D nanosystems and systems of nanosystems

Various assembly techniques, networking at the nanoscale and new architectures, Biomimetic materials, novel therapeutics/targeted drug delivery



Fourth Generation ~2015 Molecular Nanosystems

Molecular devices "by design", atomic design, emerging functions



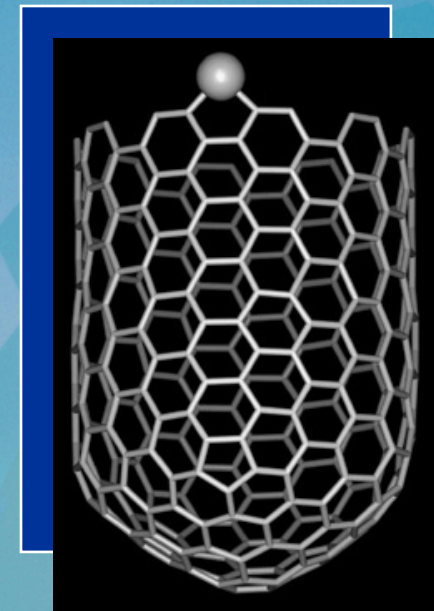
Future applications some already developed

- Medical implants
- Paints
- Fuel cells
- Integrated circuitry
- Displays
- Batteries
- Catalysts
- Fuel additives
- Lubricants
- Machinable ceramics
- Water purification and remediation
- Military battle suits
- Composites



Materials and Manufacturing

- Ability to synthesize nanoscale building blocks with precision control on size, composition etc. further assembling into larger structures with designed properties
 - Manufacturing metals, ceramics, polymers, etc. at exact shapes without machining
 - Lighter, stronger and programmable materials
 - Lower failure rates and reduced life-cycle costs
 - Bio-inspired materials
 - Multifunctional, adaptive materials
 - Self-healing materials



Energy and Environment

- Energy Production
 - Clean, less expensive sources enabled by novel nanomaterials and processes (e.g. thin-film photovoltaics)
- Energy Utilization
 - High efficiency and durable home and industrial lighting
 - Solid state electronics that reduces total electricity consumption and cuts carbon emissions
- Materials of construction sensing changing conditions and in response, altering their inner structure



Potential Exposures to Nanotechnologies

- In research labs
- In industrial production facilities
- In environmental releases
- In products in commerce
- In wastes

Workers (particularly in small companies and research labs) at greatest risk at present; some risks to consumers; unknown environmental risks



Nanotubes can become Airborne During Transfer



From review article by C-W Lam et al. 2006. Courtesy of A. Maynard (NIOSH); P. Baron et al., 2003.

Exposure to Hands



From review article by C-W Lam et al. 2006. Courtesy of A. Maynard (NIOSH); P. Baron et al., 2003.

Potential Hazards of Nanomaterials

- **Effective studies are limited and incomplete**
- **Hazards depend on**
 - **Small size**
 - **Surface area**
 - **Shape**
 - **Chemical composition (can make out of toxic things)**
 - **Purity**
 - **Aggregation**
 - **Solubility**
 - **Dissolution and degradation (during release)**
- **Size, shape, and strength create new hazards – new distribution; higher surface to mass, higher reactivity**



What We do Know

- **Greater surface areas means increased bioactivity**
- **Inhaled particles reach all areas of the respiratory tract (learning from ultrafine particles)**
- **Particles can pass the blood/brain barrier in fish and some evidence of passage of blood-testis barrier**
- **Small size and shape leads to rapid uptake into cells and more effective transport to target organs.**
- **Nanomaterials may be “carriers” for other more toxic molecules.**



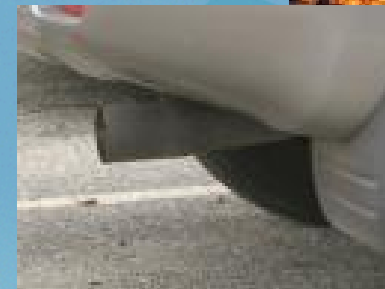
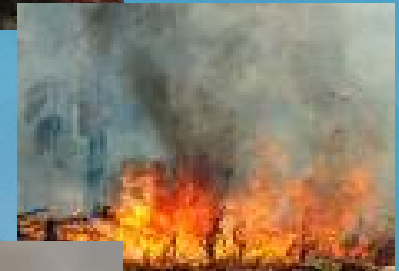
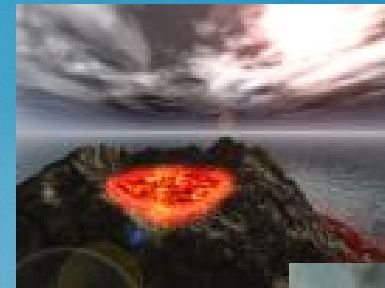
What We do Know

- **Blood and lymph transport exposes bone marrow, lymph nodes, spleen, heart and central nervous system**
- **There is evidence of inflammatory (cardiopulmonary inflammation) and anti-oxidative responses as well as mitochondrial disturbance and oxidative stress**
- **Other effects in humans are less certain**
- **Most research is focused on nanoparticles but also of potential concern are nanostructured surfaces, nanoporous materials, nanofilms.**



Ultrafine Particles vs. Nanoparticles

- **Natural sources: Volcanoes, forest fires**
- **Antropogenic sources: Cooking, combustion**
- **Traverse lungs and into systemic circulation**
- **Damage mitochondira**
- **The smaller the more dangerous**
- **Cause large numbers of deaths**
- **UFPs < 0.1 μm = 100 nm**
- **NPs < 100 nm**
- **Could engineered NPs have the same properties as UFPs?**



What We do not Know

- **Extent to which extrapolation is predictive**
- **Mechanisms of action and pharmacokinetics**
 - **Effects on target organs**
 - **Appropriate doses to assess hazards**
- **Exposure levels to workers, consumers or the environment and associated effects**
- **Uses and exposure potential**
- **Mechanisms of action and pharmacokinetics.**
- **Fate, distribution, persistence and bioaccumulation in the environment**

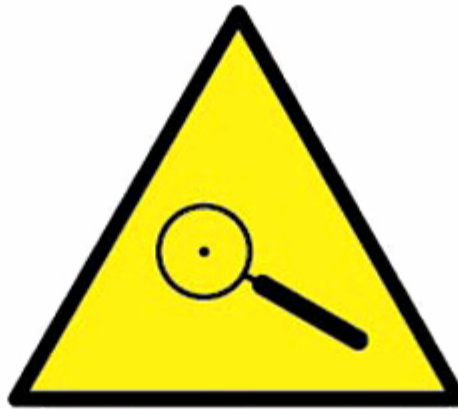


Should we be concerned??



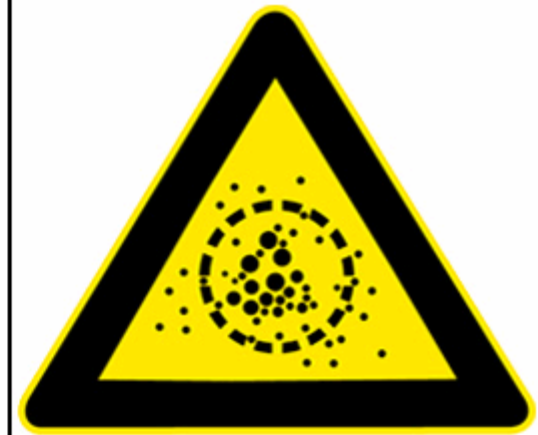
NANOHAZARD

Dimitris Deligiannis, Greece



NANO HAZARD

Shirley Gibson, Scotland



Kypros Kyprianou, England



Limited research relative to development budget

Agency	NNI-estimated risk-related annual R&D	PEN-estimated risk-related annual R&D (all relevant research)	PEN-estimated risk-related annual R&D (highly relevant research)
NSF	24.0	19.0	2.5
DOD	1.0	1.1	1.1
DOE	0.5	0.3	0
HHS (NIH)	3.0	3.0 [†]	3.0 [†]
DOC (NIST)	0.9	1.0	0
USDA	0.5	0.5	0
EPA	4.0	2.6	2.3
HHS (NIOSH)	3.1	3.1 ^{††}	1.9 ^{†††}
DOJ	1.5	0	0
Totals	38.5	30.6	10.8

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What regulations are in place to regulate nanotechnologies?

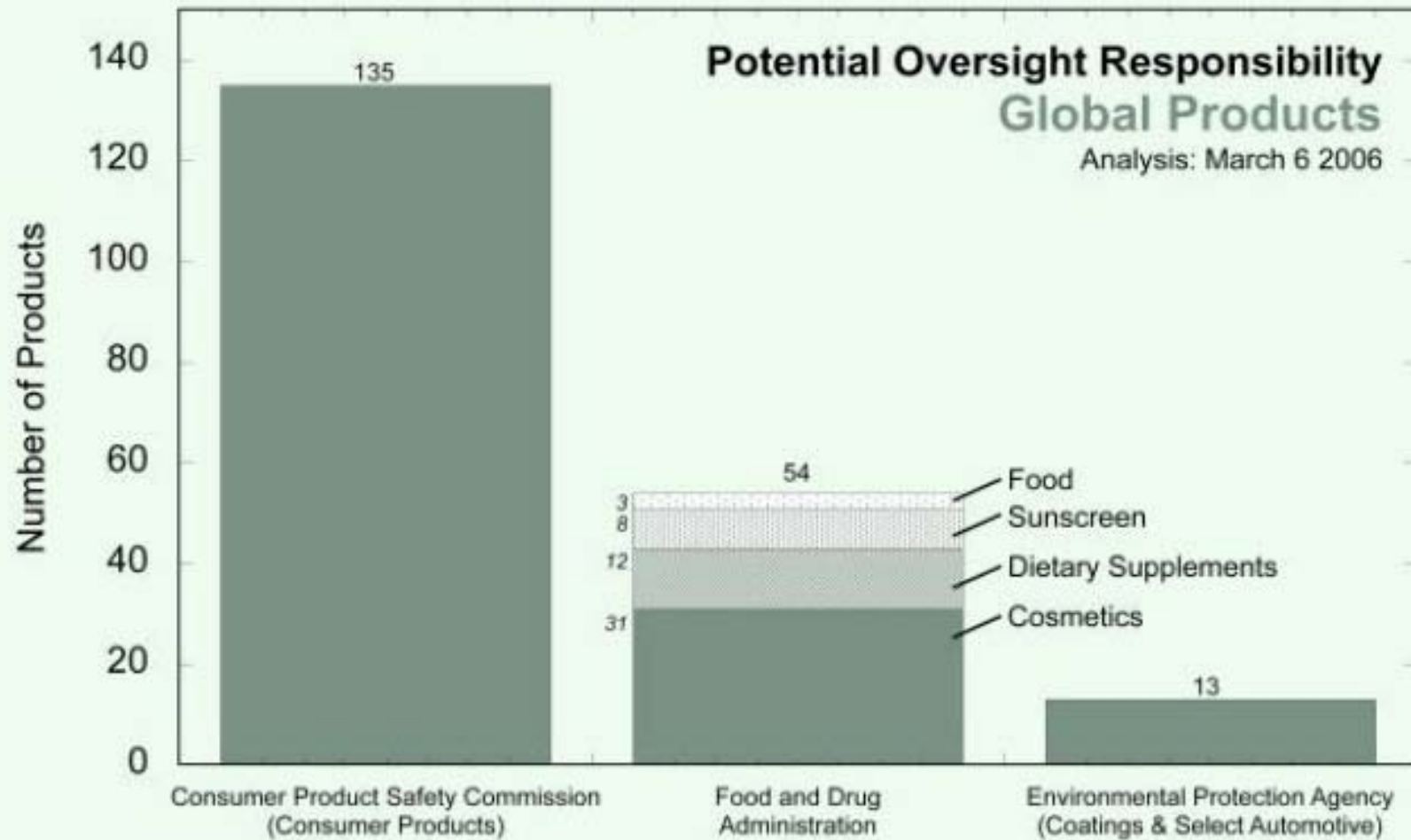


What regulations are in place to regulate nanomaterials

- **Simple answer: None**
- **More complex answer: Discussion but not much action at this point**
 - **NIOSH Safety and Health Research Program**
 - **EPA**
 - **Outlined issues and regulatory authorities under existing laws in 2005**
 - **Voluntary pilot program for nanomaterials**
 - **Specific action on nanosilver**
 - **FDA – product by product**
 - **CPSC – only when problems occur**
 - **Local governments – Berkeley and Cambridge – data collection regulations**



Where does jurisdiction lie for nanomaterials?



Precaution as a guide to emerging technologies

- Long history in public health
- Learning from late lessons and mistakes from the past
- German Vorsorgeprinzip
- European Union
- Local efforts in the US – WA, OR, MA, CA
- When there is evidence of potential harm, yet uncertainty about its nature or magnitude, take precautionary action
- Its not just about bans



Wingspread Statement on the precautionary principle

“When an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.”



Vision and principles for Precaution

- **The right to a healthy and life sustaining environment – environmental justice**
- **Acting on credible early warnings**
- **Choosing the safest feasible alternatives**
- **Responsibility on proponents**
- **Expanding the range of participants in risk decisions**
- **Rethinking the science used in policy**



Elements of a more sustainable approach to nanotechnology development

Goals:

- Precaution
- Adaptability
 - Don't get stuck in technology
 - Flexible manufacturing/institutions
- **Alternatives assessment**
- New approaches to scientific research –
Appropriate Science
- Pluralist decision-making models
- Ultimately a responsibility to integrate
sustainability concerns into the technology
development, R&D and educational process



Why Safer Alternatives Processes

- **Definition:** A flexible, holistic analysis of alternatives and opportunities to prevent impacts from potentially harmful activities.
- Focus on solutions rather than problems.
- Gets us out of never-ending discussions of “how risky”
- Allows for a greater range of information and consideration in decision-making processes
- Stimulates innovation and prevention
- Multi-risk reduction opportunities.

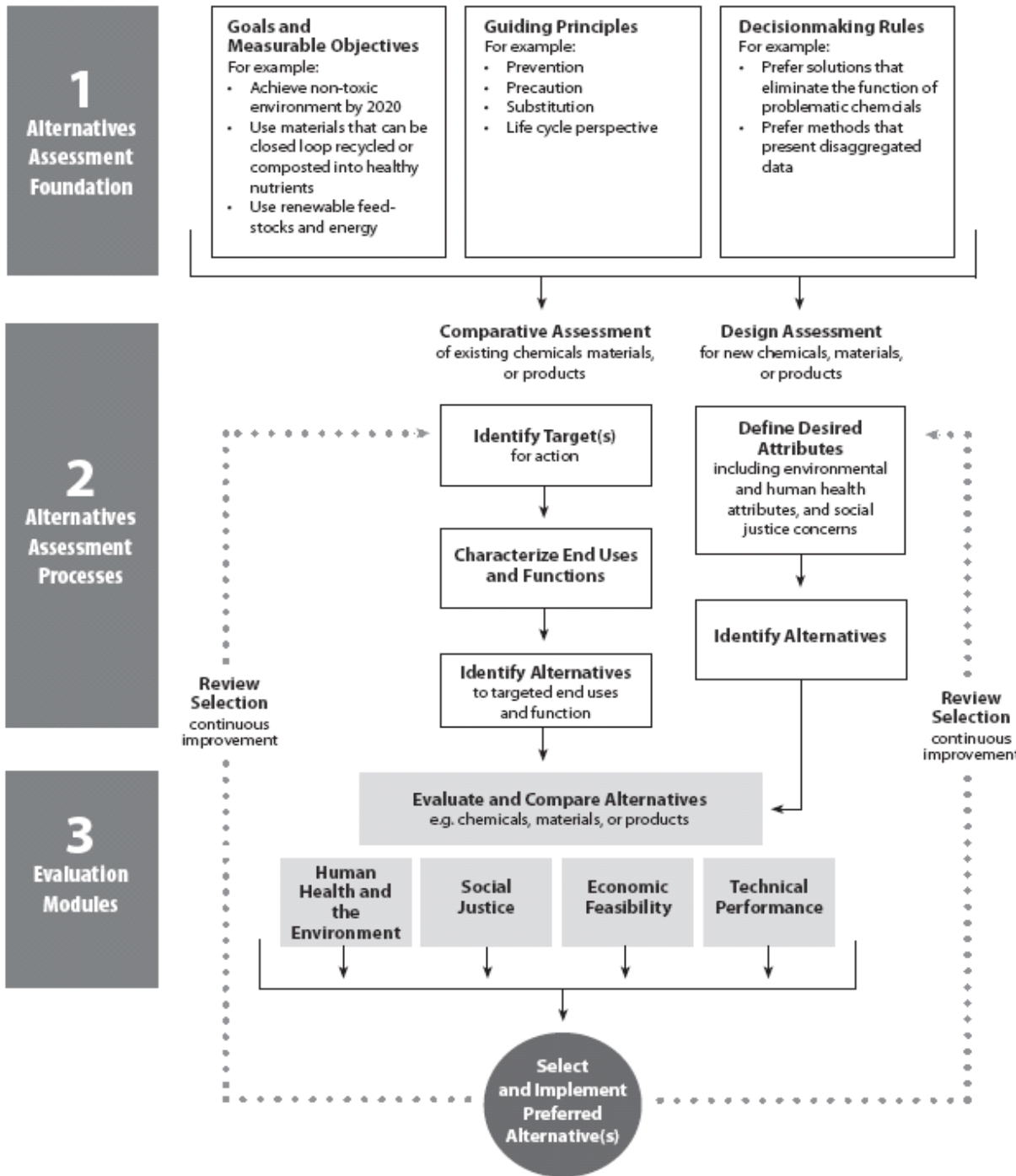


What to consider in Alternatives Assessment

- **The purpose of the activity – need, service/ functionality**
 - **Is the nanomaterial part of a product (tennis racket) that can be substituted**
 - **Or is it the product – memory units.**
 - **Are all uses the same??**
- **Understand flow of the material/characterize process and lifecycle**
- **Brainstorm a wide range of potential alternatives to meet a need or function**
- **Implement the best alternative – understanding the safety measures that need to be implemented**
- **Monitor and change course as needed – continuous improvement**



Lowell Center Alternatives Assessment Framework



Elements of a more cautious approach to nanotechnology development

- Alternatives assessment
- **New approaches to scientific research – Sustainability Science**
- Pluralist decision-making models
- Ultimately a responsibility to integrate sustainability concerns into the technology development, R&D and educational process



Sustainability Science – A new vision of science for policy

- **Methods/approaches chosen to fit the nature and complexity of the problem - flexibility**
- **Quantitative and qualitative data respected equally**
- **Risk assessment not separated from alternatives assessment (solutions)**
- **Use of interdisciplinary approaches to the extent feasible considering cumulative effects, susceptible sub-populations.**



Sustainability Science (cont)

- **More comprehensive uncertainty characterization (what we know, don't know, can know)**
- **Look at whole of evidence including accumulated knowledge and judgment**
- **Systems for continuous monitoring to avoid unintended consequences, understand health impacts, and identify early warnings**



Elements of a more sustainable approach to nanotechnology development

- New approaches to scientific research –
Appropriate Science
- Alternatives assessment
- **Pluralist decision-making models**
- Ultimately a responsibility to integrate sustainability concerns into the technology development, R&D and educational process



Expanding those involved can improve decisions under uncertainty

- **These are public decisions that involve uncertainty and contested values**
- **Helps ensure that the right questions are asked about problems**
- **Lay citizens bring a perspective and experience to the decision-making process that is not bounded by disciplinary expertise**
- **Lay judgments reflect a sensitivity to values and common sense**
- **Increases the legitimacy, quality, and accountability of decision-making processes**



Bringing new information and perspectives into decision-making

- **Experiential knowledge – ie workers**
- **Understanding of exposures**
- **Understanding limits of scientific models**
- **Critical questioning of expert claims/models**
- **Better institutionalization of regret/errors**
 - **Secretaries of experts often better than experts at predicting complex, uncertain future events**
- **Greater consideration of values and common-sense**



Potential to improve decisions

- **Broadening scope of questions asked of researchers – more interdisciplinary**
- **Incorporate observations and experience of a wider range of “experts”**
- **Expanded range of choices/options**
- **Improve legitimacy and accountability of decisions**
 - **Improved adoption of technologies/less “fear” – public from reactive to proactive**
 - **But risk communication is not just experts telling the public what to think! It’s a two way street**



Many options on how to regulate nanomaterials

- **Do Nothing – Wait and See**
- **Immediate Moratorium until further data**
- **Let the existing regulatory system deal with it**
- **Voluntary measures**
- **Develop new regulatory frameworks**
- **A hybrid**
 - **Increase research funding immediately**
 - **Immediate voluntary program (make as mandatory as possible)**
 - **Develop a regulatory scheme for nanomaterials**



Possible aspects of a new regulatory scheme

- **Develop upfront understanding NOW (continuous learning)**
 - Understand uses
 - Understand exposures
 - Understand toxicity
 - Develop ways to rapidly assess hazards and categorize uses – concern/lesser concern
- **Prioritize uses of greatest concern (immediate actions on those)**
- **Develop lists of nanomaterials of concern**



Additional aspects of a possible new approach

- **Registration of nanomaterials**
- **Regular use reporting and planning requirements**
- **Develop risk criteria – flexibility and openness to evolving information and early warnings**
- **Develop criteria for “safer” nanomaterials**
- **R&D funding on safer nanomaterials**
- **Technical support for companies to design and implement safer processes**
- **Public participation mechanisms**



Technology assessment as a necessary framework

- **Office of Technology Assessment model – social, health, environmental and political implications of technologies**
 - **Congressional research arm – created in 1972 “to provide early indications of the probable beneficial and adverse impacts of the applications of technology**
 - **200 employees, 2/3rds professional/research**
 - **Advisory panels to review work**
 - **Recommendations/policy options to resource poor Congress discussions**
- **Policy frameworks for interagency approaches to emerging technologies/contaminants**



Conclusions

- **We've made mistakes with technologies in the past**
- **We have a chance to develop a potentially beneficial technology in a more cautious and sustainable way but we haven't taken this challenge very seriously yet.**
- **Precaution isn't about stopping technology – its about using science, technology, and policy more creatively and wisely.**
- **States and localities have the opportunity to be the leaders and innovators in this area.**



Resources

- **WWI – Project on Emerging Nanotechnologies**
www.nanotechproject.org
- **National Nanotechnology Initiative -**
<http://www.nano.gov/>
- **Innovation Society Nanotech Project -**
http://www.innovationsgesellschaft.ch/nano_regulation.htm
- **Safer Nanomaterials and Nano Manufacturing Initiative -**
<http://www.greennano.org/>
- **ETC Group -** <http://www.etcgroup.org/en/>
- **UK Royal Society -** <http://www.nanotec.org.uk/>
- **European Nanoforum -** <http://www.nanoforum.org/>
- **NIOSH Nanotech Project -**
<http://www.cdc.gov/niosh/topics/nanotech/>

