Nanotechnology Long-term Impacts and Research Directions: 2000 – 2020

Chapter 4. Nanotechnology Environmental, Health, and Safety Issues

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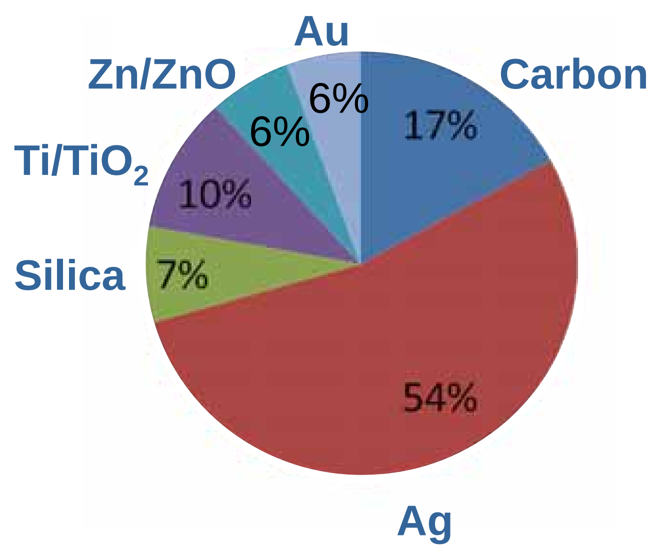
The nano EHS Challenge:

- **What is the reality?**
- **Is the glass half empty or half full?**

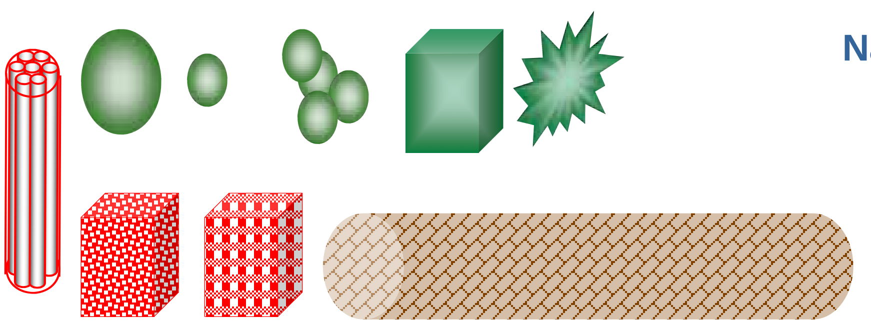
- We do not currently know of any specific human disease or serious environmental impact due to ENM
- However, there is experimental evidence of ENM hazard
- Currently, 6 base materials constitute >90% of all manufactured nano products (by number)
- Presently ~ 10^3 consumer nano products - could grow to >10^4 in the next decade, ultimately to 10^5
- Knowledge generation will take time and will be incremental
- Decision making currently proceeding on a material by material basis but regulatory awareness is gaining ground and ability to make decisions are improving

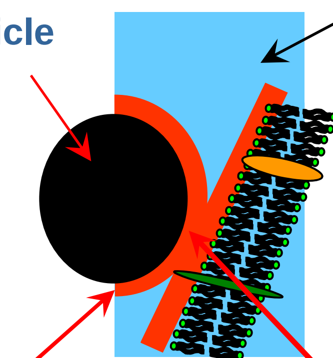
Major Materials 2009



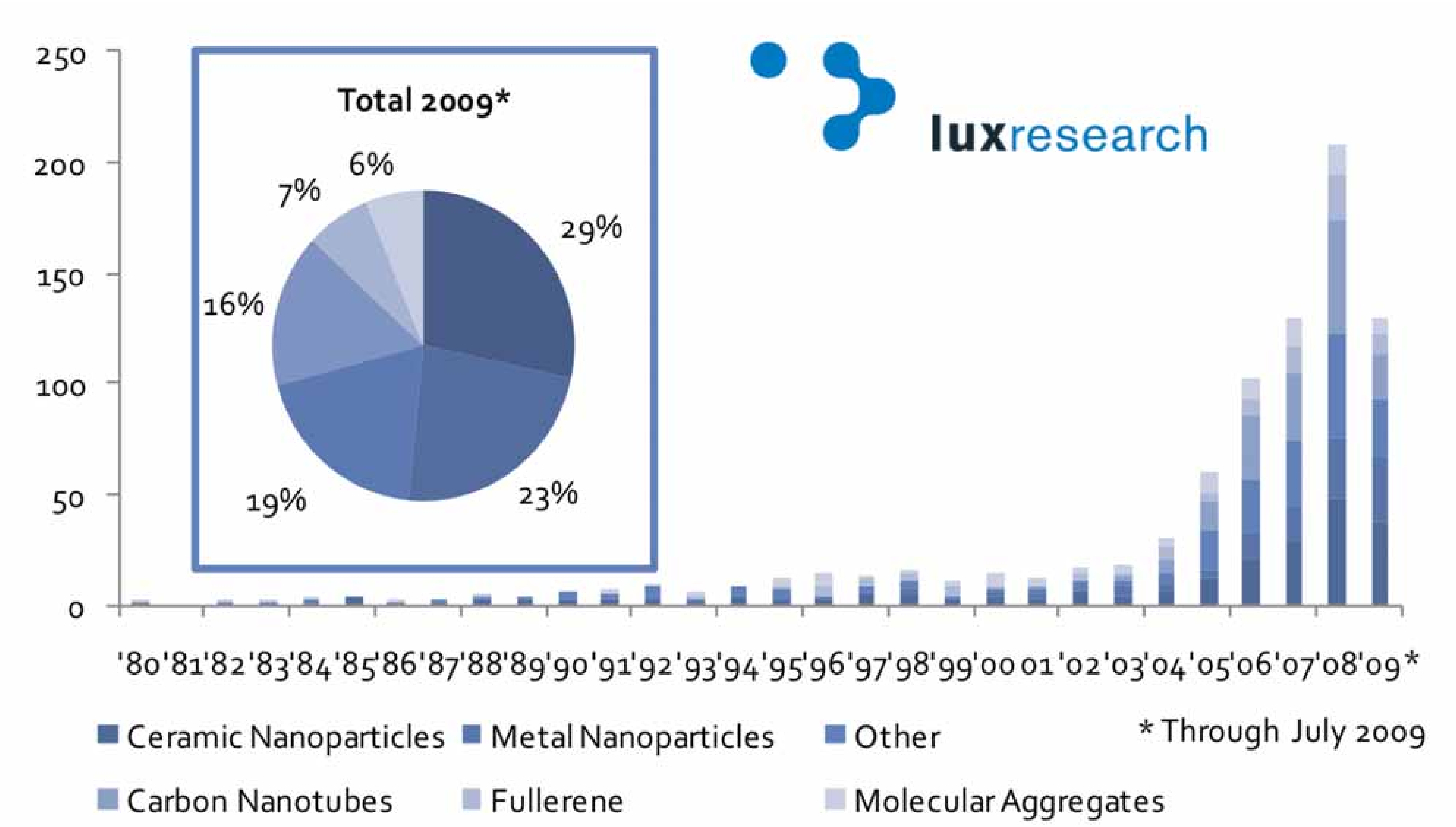
Changes of the vision in the last 10 years

- Nano EHS advanced from <u>awareness</u> level to <u>implementation</u> of the science of “nano safety” and “nanotoxicology”
- “<u>Small Is Dangerous</u>” was replaced by the recognition that the specific material <u>compositions and properties</u> determine the events at the nano-bio interface that could be responsible for toxicity





Peer-reviewed Journal Articles on nano EHS

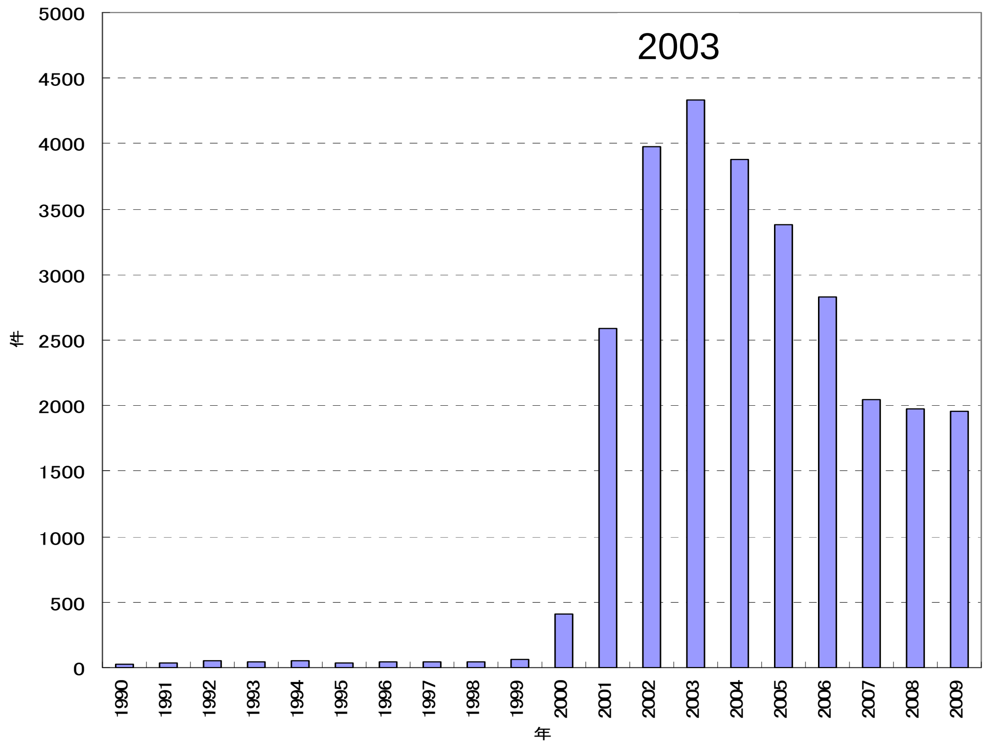


Lux Research LRNI-R-09-05

Mass Media coverage as reflection of Public Perception of Nanotechnology in Japan

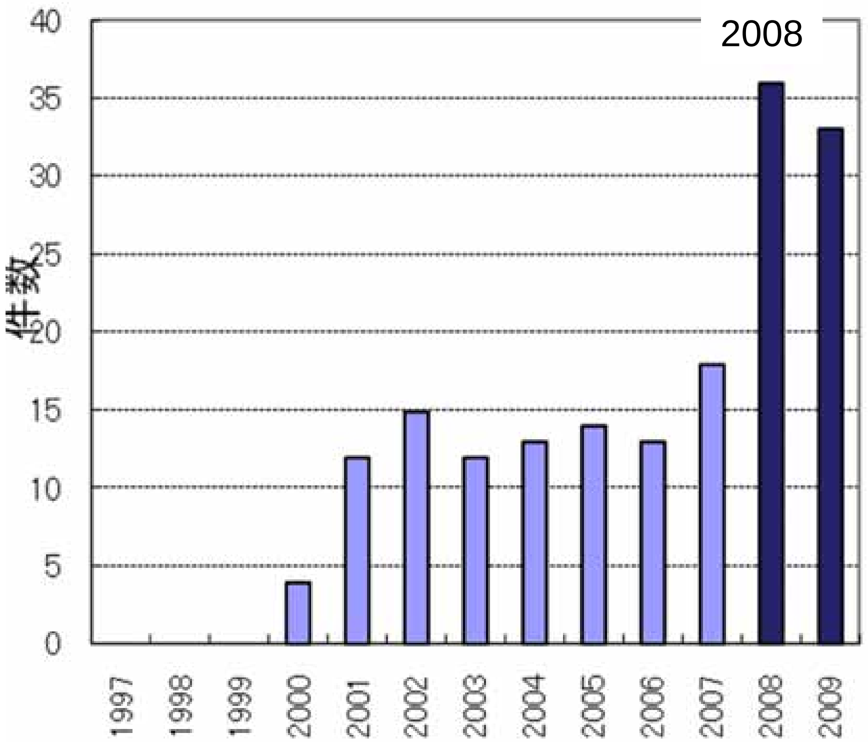
Nanotechnology

Hype is fading



Nano Risk

Increased concern and interest



Frequency of nanotechnology-related articles appeared in domestic mass media

Frequency of articles on carbon nanotube risk increased in the mass media after publication of mouse tox model

(Source Data: Nikkei-telecon, Analyzed by M. Ata)

Changes of the vision in the last ten years

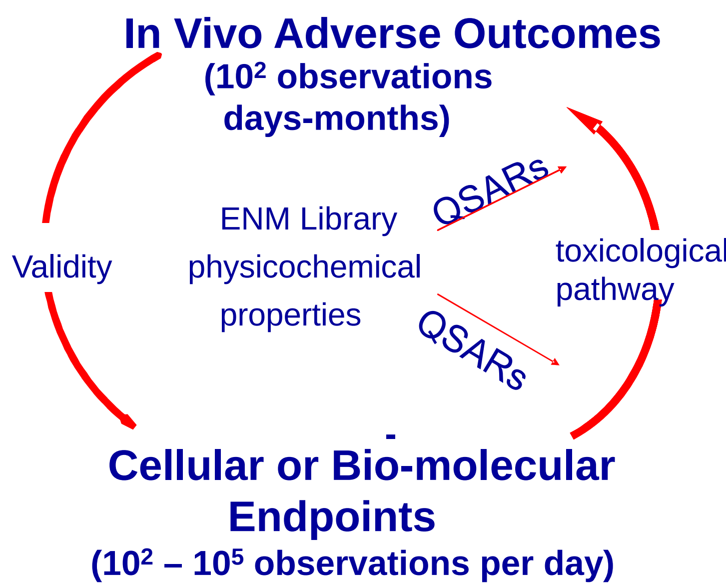
- Nanotechnology is a new science and new knowledge is required to understand how novel materials may react with bio-molecules and biological processes
- Knowledge generation will be incremental and will take time but is worthwhile because it will lead to evidence-based decision making, safe design, and sustainability
- Knowledge generation is a multidisciplinary exercise that demands a new approach to scientific integration
- Nano EHS should be an integral part of ENM design and not as a *post facto* add-on or imposed cleanup cost

Examples of the major advances over the last 10 years

- Transitioning from nano EHS awareness to action on the research and regulatory fronts
- Progress in understanding the mechanisms of hazard generation, how to perform toxicity testing on the major classes of materials but lag behind on risk profiling
- Formulation of real and perceptual risk profiling for CNT and a few high volume materials
- Acute hazard data collection for inhalable MWCNTs and SWCNTs is being used by NIOSH to implement hazard prevention in the workplace

Vision for the next 10 years

- To establish validated and robust scientific platforms for hazard, exposure and risk assessment
- Implement a predictive scientific approach that uses testing at molecular, cellular and organism level → knowledge that is instructive of more complex organisms and humans
- Replace one-material-at-a-time screening in animals → rapid throughput bio-molecular and cellular approaches



Vision for the next 10 years

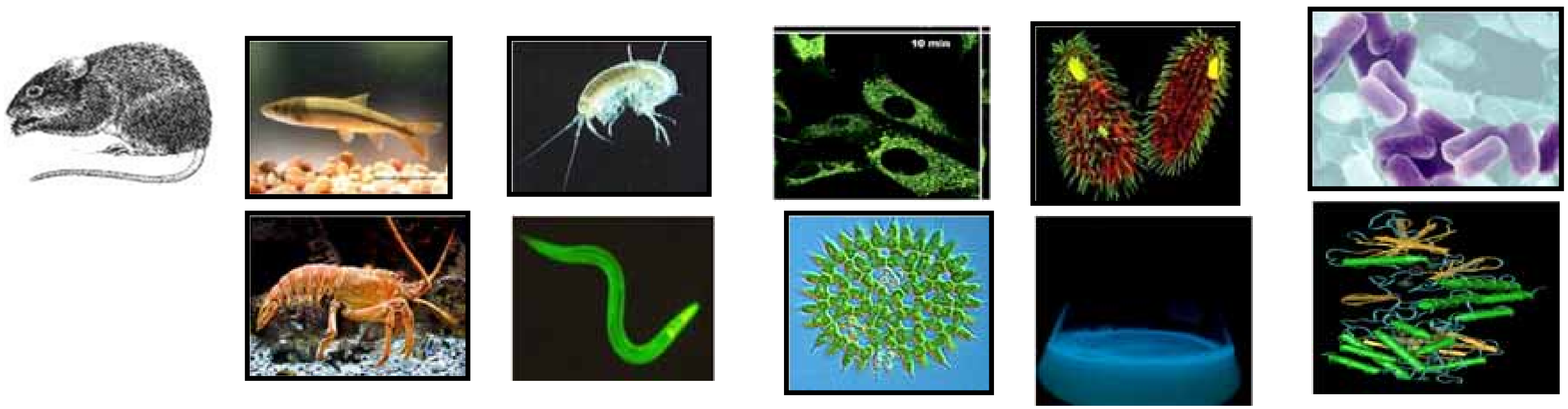
- Critical need for novel exposure, dosimetry and risk assessment methodology and approaches
- Build a nano EHS enterprise with the capacity to keep pace with the rate of growth of nanotechnology
- Develop computational methods, nano-informatics, modeling and decision-making tools to speed up nano EHS knowledge generation
- Develop safe-by-design approaches as an integral part of product development
- Industry participation in data and knowledge gathering to facilitate safe implementation of nanotechnology and active participation in nano EHS decision-making

Expected major nano EHS advances in the next 10 years

- Develop validated screening methods, harmonized protocols and risk reduction strategies

  (requires correct balance between in vitro/in vivo, appropriate dosimetry metrics, improved technology to track fate/transport & exposure)

- Develop predictive toxicological approaches that utilize the correct balance between in vitro and in vivo testing

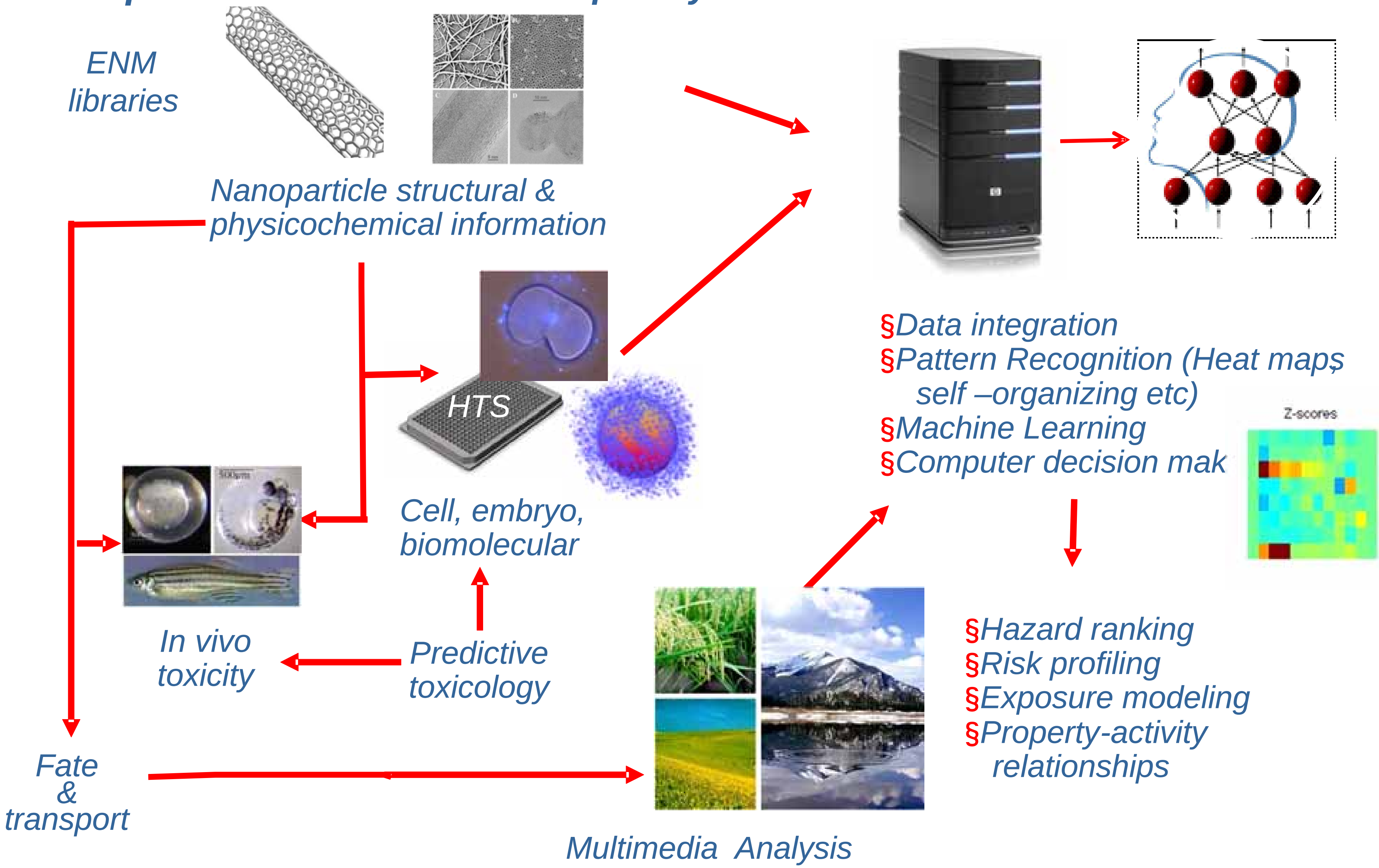


100's/year **1000's/year** **10,000's/day** **100,000's/day**

Expected major nano EHS advances in the next 10 years

- Develop a stepwise approach to nano EHS governance that takes into consideration incremental progress (see example)
- Develop computational analysis and *in silico* decision-making tools (computational biology, nano informatics, modeling)
- Develop high throughput and high content screening as a universal tool for studying ENM toxicity, hazard ranking, in vivo prioritization and designing safer materials
- Development of new approaches for exposure assessment in the environment, e.g., quantitative exposure assessment in wastewater systems and mesocosms

Example: Predictive Multi-disciplinary Science Model in the UC CEIN



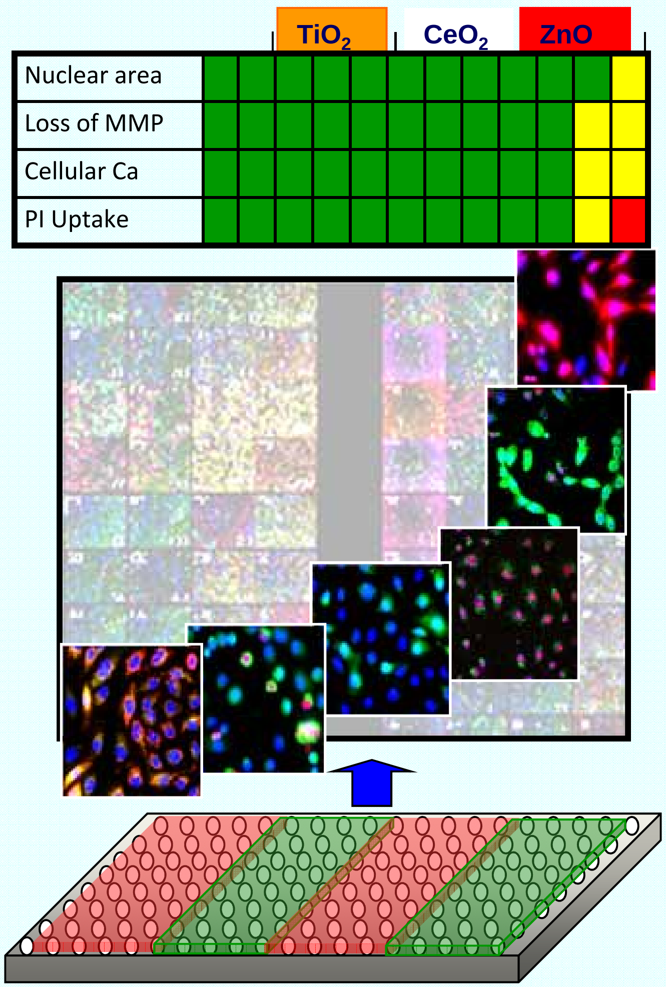
UNIVERSITY OF CALIFORNIA
UC CEIN Center for Environmental Implications of Nanotechnology

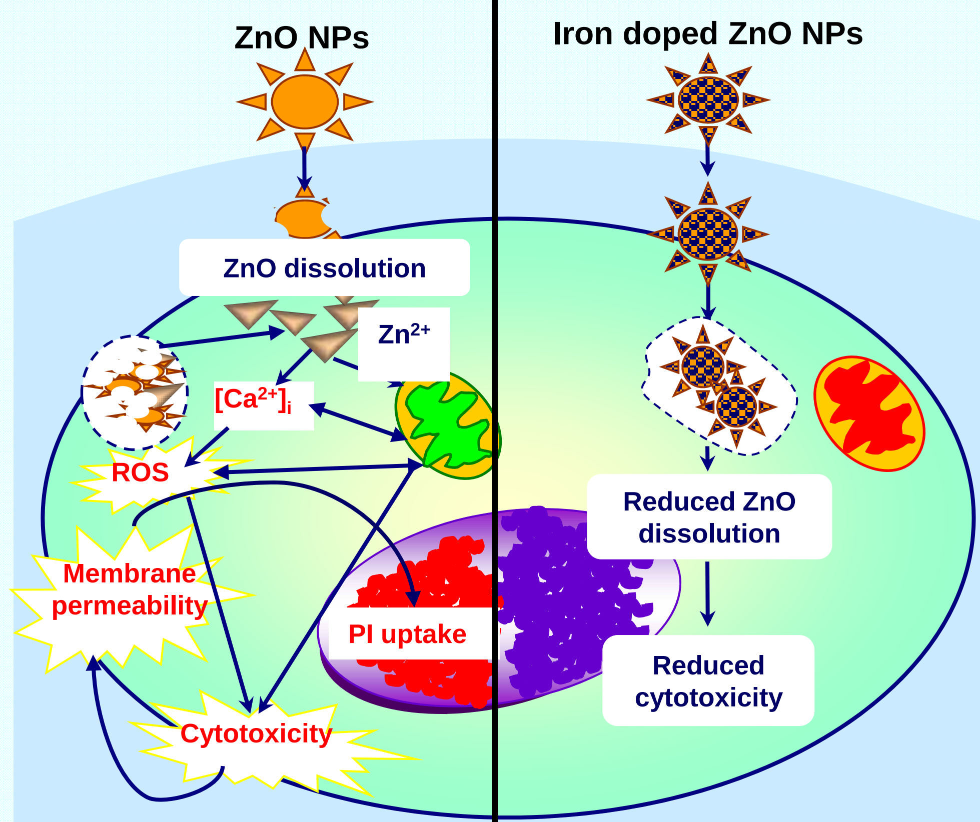
NSF: EF-0830117

Altered Dissolution ZnO by Fe-doping decreasesToxicity

High throughput toxicity screening → **Mechanism of ZnO nanoparticle toxicity** → **Proposed safe material design**

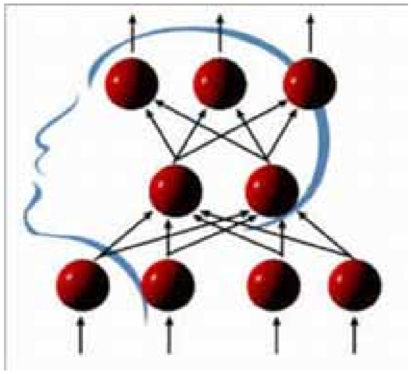
George, Pokhrel, Maedler, et al ACS Nano, 2010, 4 (1), pp 15-29.





Scientific and Technological Infrastructure Needs

- Instrumentation that will improved tracking and identification of the ENM in biological tissues and the environment
- Computational models, algorithms, decision-making tools, artificial intelligence



- Public-private partnerships to allow knowledge generation on nano safety to be incorporated by industry, including the recognition that this can lead to new intellectual property and product generation
- Need a multidisciplinary workforce that is capable of meeting the needs for safety assessment, safe implementation and development of a sustainable technology

R&D Investment and Implementation Strategies

- Increase the federal budget to improve nano safety assessment, implementation, and coordination
- Standardized nomenclature & standard reference materials
- Validated, standardized methodology for the assessment of ENM hazard
- Industry needs to play an active role in investing in nano EHS R&D

  (rewards: facilitated access to marketplace, safely designed and improved materials, new intellectual property and applications)
- Regional nano EHS user facilities to assess and design safer materials by product category

Emerging Topics and Priorities

- The important role of nanotechnology in environmental remediation
- Green manufacturing and green nanotechnology
- Safe-by design approaches to develop safer and improved products
- Nanotechnology as a pervasive technology with a great promise of helping to develop sustainable technologies
- Key role of nano for providing clean water, renewable energy and improved food supply

Broad Societal Implications

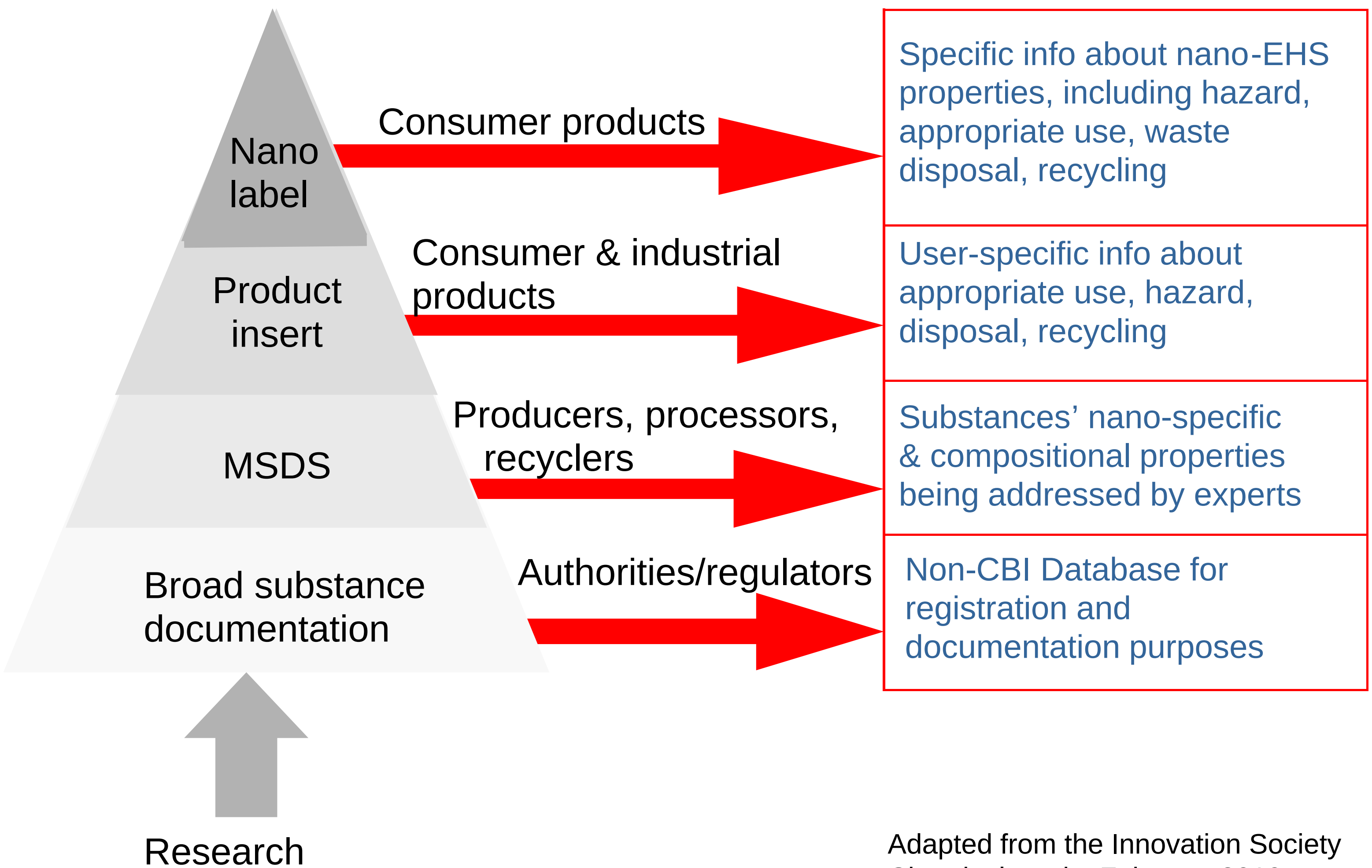
- The public stands to benefit from nanotechnology providing better consumer products, medicines, and stimulation of the economy

- Important contributions of nanotechnology to sustainability

- The safety and potential hazard of nanomaterials needs to be conveyed to the public in a balanced and responsible manner

- Where potential hazards are identified it is important to consider responsible product safety disclosure, e.g., the nano-pyramid

Example: Proposed Nano-pyramid for Product Information Disclosure



Adapted from the Innovation Society
Chemicalwatch . February 2010

Major positions amongst stakeholders regarding nano-regulatory philosophy

- The existing regulatory situation is adequate. If scientific evidence indicates the need for modification, the regulatory framework will be adapted

- Specific guidance and standards must be developed to support existing regulations but the existing regulatory situation is generally adequate

- Regulation should be amended (on a case by case basis) for specific ENM and their applications. When a high potential risk is identified, a precautionary approach should be chosen

- The existing regulatory situation is not adequate. Nanomaterials should be subject to mandatory, nano-specific regulation

Example: Stepwise approach to the formulation of Nano-regulatory Policy

Stage 1: Short-term Approach

Changes we could implement with existing information and statutes through coordination:

- Data collection (e.g., commerce chain, life cycle)
- Safe management practices (e.g., occupational exposures)
- Best practices
- Hazard assessment
- Exposure assessment
- Streamlined risk reduction practices

Stage 2: Longer term approaches

Shift to risk prevention paradigm

- Proof of hazard, exposure reduction
- Effective control measures
- Continuously improving best practices
- Restrict specific ENM if risk is compelling
- Safe-by-design and green nanotechnology
- Statuary reform to promote data collection
- Active role for industry

Future Stages

Evidence-Based Decision Making

Sustainability Decision Making

Example: Streamlined Risk Reduction Approach for setting Exposure Limits and Effective Exposure Control by NIOSH

Prioritize CNT

- Widespread use
- High volume of production

Animal hazard studies

- Acute exposures
- Multiple study review
- No single study yields sufficient risk assessment
- Coherence of data revealing lung fibrosis and granulomas

New Technology

Facilitates airborne CNT detection

Assess occupational exposure potential

- Workplace surveys/measurement
- Significant airborne levels
- Limits of detection
- Exposure events: weighing, mixing, vortexing, transfer, etc.

Calculated

Potential human exposure levels & dose based on

- Animal lung burden assessment
- Animal to human comparisons based on alveolar epithelium surface area ratios

Establish Exposure Limit

Effective control measures (HEPA filters, ventilation, respirators) ↓ human exposure below LOD

Achieves risk prevention without:

Complete risk characterization
Chronic inhalation data
Complete exposure data