

# Trends And Skill Needs in the Field of Nanotechnology -

## The State of Affairs in the Czech Republic in the European Context

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# OUTLINE

Introduction

Nanotechnology Trends

nanomaterials, nano-biotechnology,  
nanoelectronics

Nanotechnology Impacts

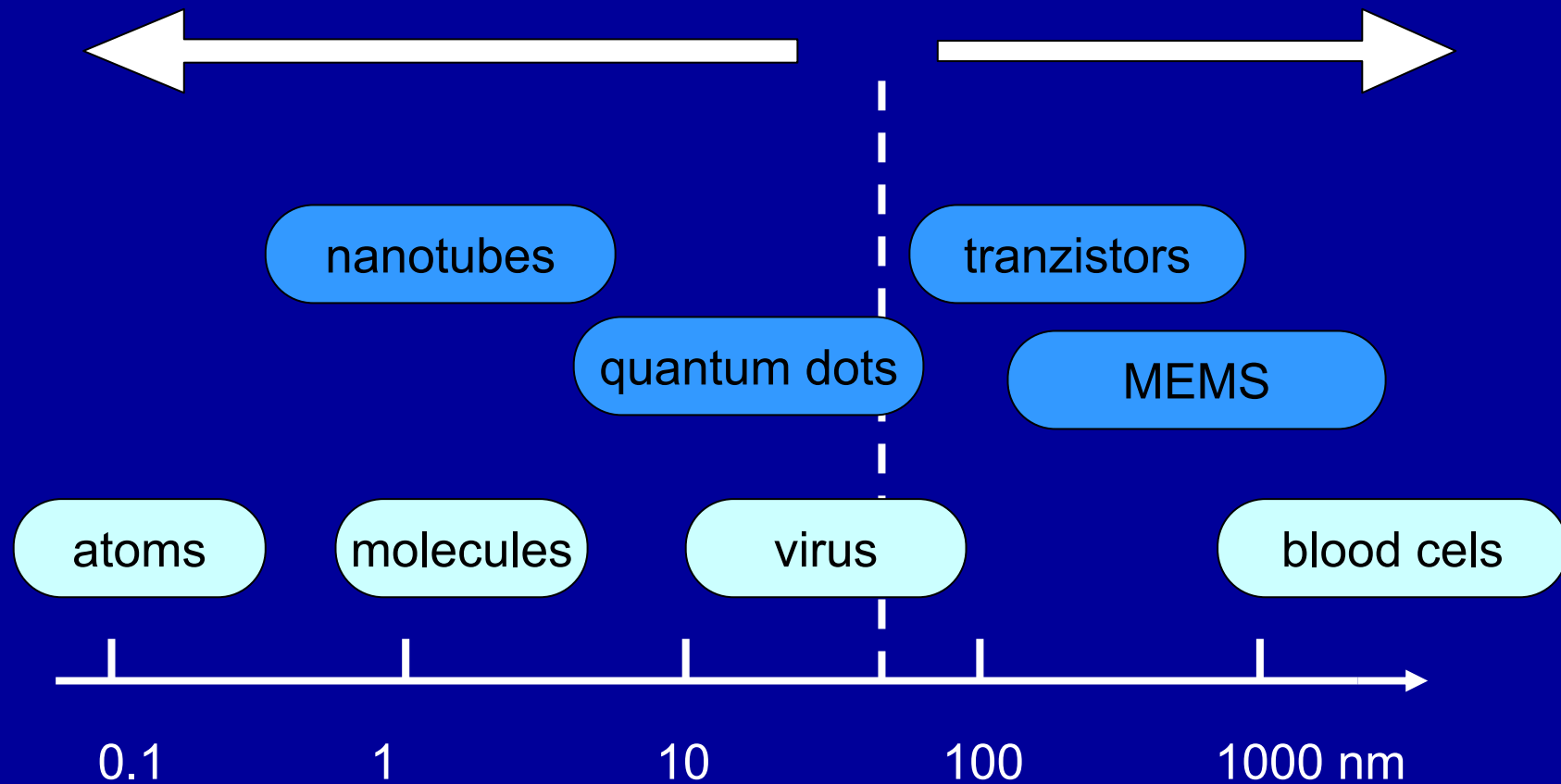
health, ethical aspects  
jobs, education, training

European and Czech Nano-Infrastructure

poles of excellence, education, institutes

Conclusion

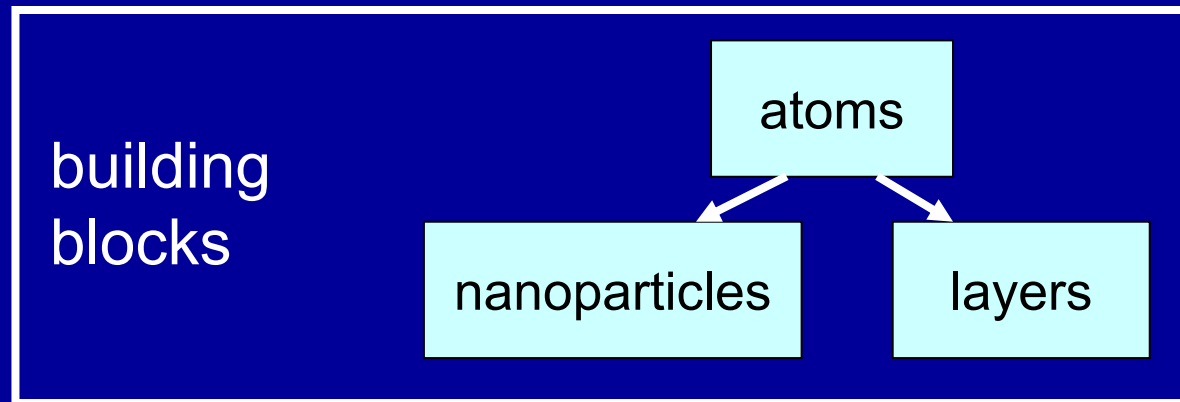
# Nanoscale - Microscale



# Nanotechnology Trends

- nanoelectronics
- nanomaterials
- nano-biotechnology

# Nanotechnology



SYNTHESIS

ASSEMBLY

Nano-structures

Nano-materials

Nano-biotechnology

Nano-electronics

dispersions  
and coatings

high surface  
area materials

consolidated  
materials

functional  
nanodevices

# Nanoelectronics

electron wavelength:

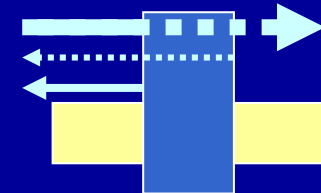
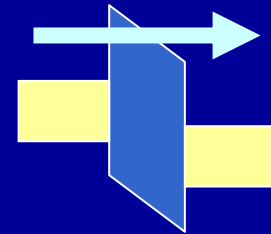
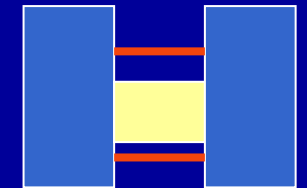
De Broglie:  $\lambda = h / p$  (cca 10nm)  $h$  ... Planck constant

$$h = 6.626 \times 10^{-34} \text{ Js} \quad \hbar = h / 2\pi$$

$p = mv$  ...electron momentum

quantum effects:

- **discrete energetic levels**  
(in quantum well...)
- **tunneling** through the barrier  
(band-to-band...)
- **interference** of wavefunctions  
(reflection, diffraction...)



## Theoretical Limits

- uncertainty principle
- thermal limit
- power dissipation limit

$$E / f > 100 h$$

$$E > 100 kT$$

$$( 2 \text{ eV for } 300K )$$

$$E f N < 100 \text{ W / cm}^2$$

## Technology Limits

- nm epitaxy - MBE, MOVPE, ALE
- sub 100 nm lithography - new generation lithography

top - down  $\longrightarrow$  bottom - up approach

Photolithography

Electron Beam Lithography (EBL)

Focused Ion Beam (FIB)

## New Generation Lithography (NGL)

Extreme UV (EUV)

Electron Projection (SCALPEL)

Ion Projection Lithography (IPL)

X-Ray

Imprinting

Micro Contact Printing

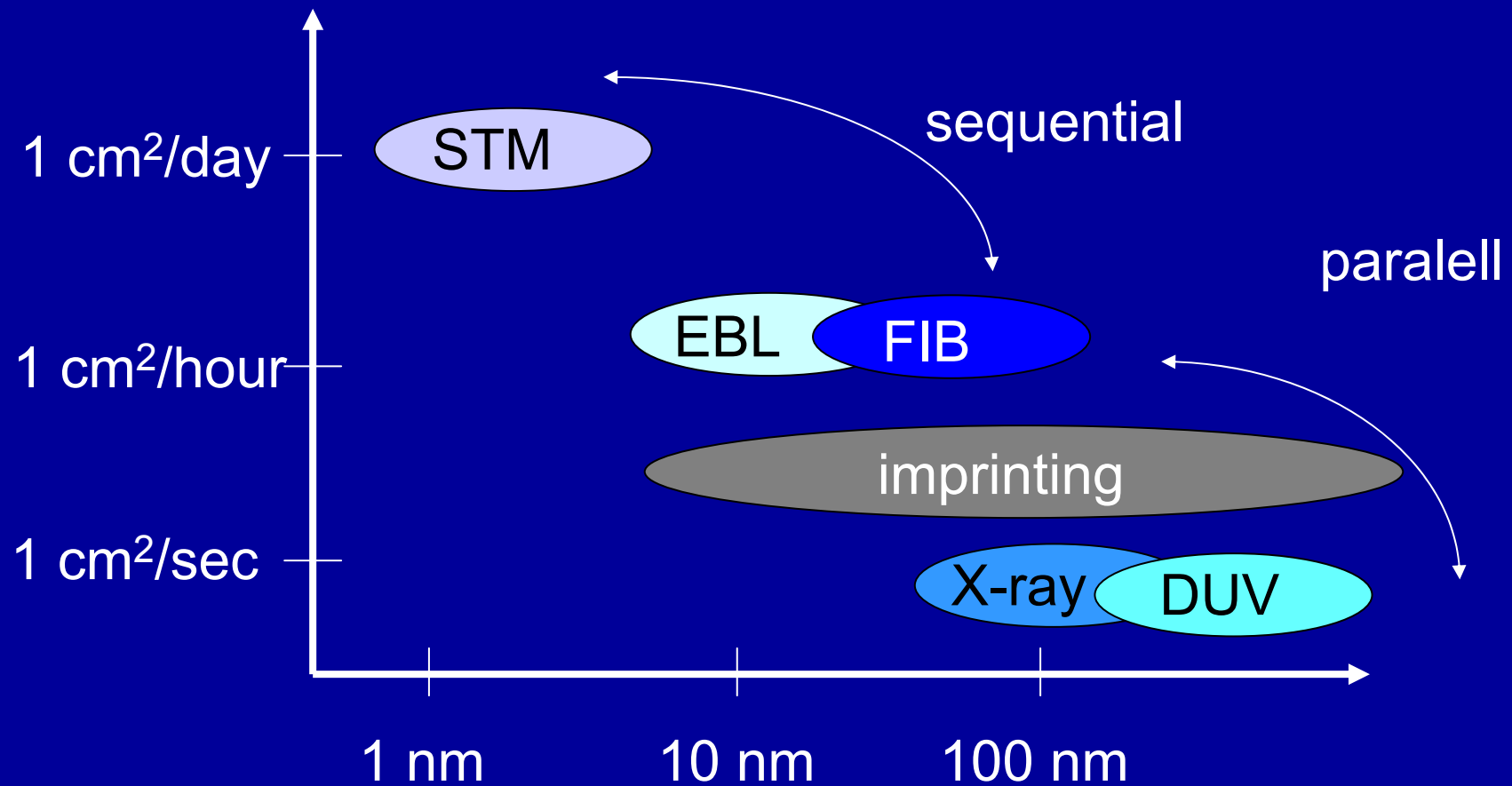
STM Lithography

AFM Litography

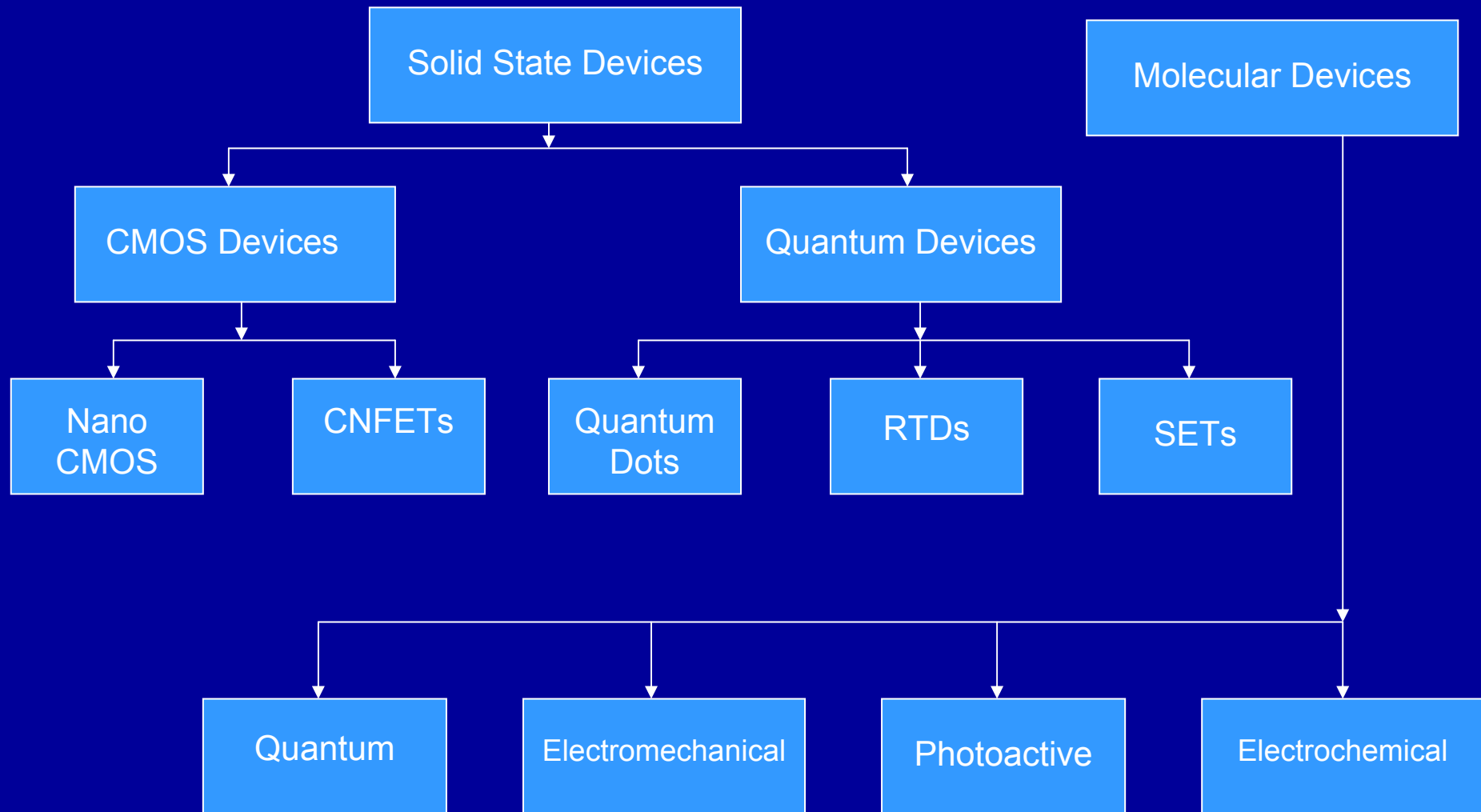
Self Assembly



# Exposure rate vs. resolution

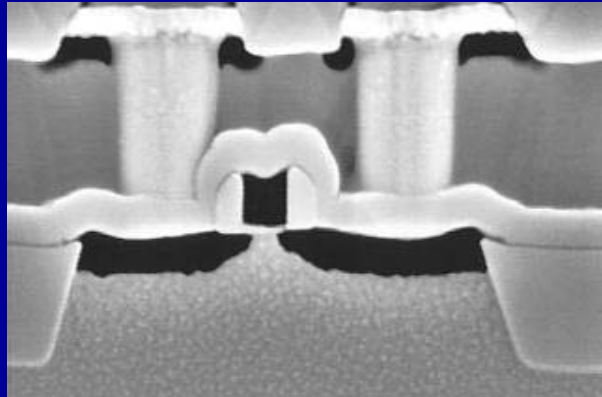


# Emerging Nanodevices

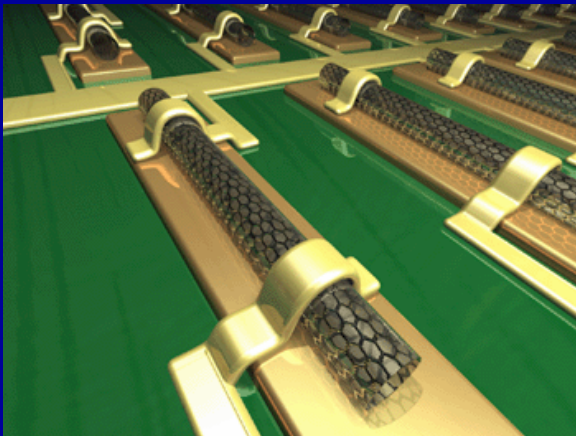


# Nanotransistors

Silicon transistors:  
 $L \sim 10 \text{ nm}$

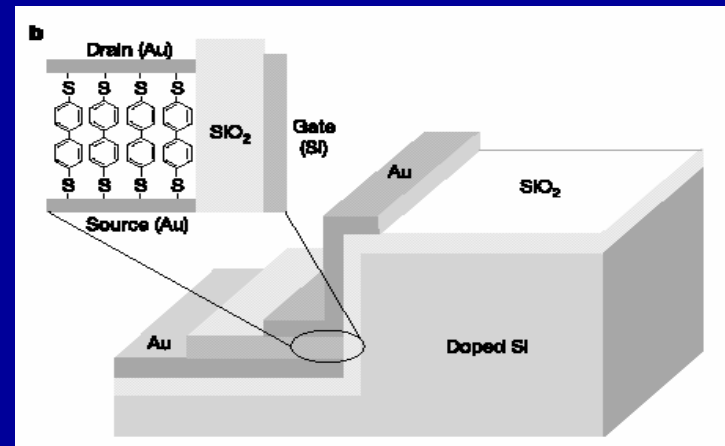


Carbon nanotube transistors:  
 $L \sim 1 \text{ nm}$



Bachtold, et al., *Science*, Nov. 2001

Organic nanotransistors:  
 $L \sim 0.2 \text{ nm}$



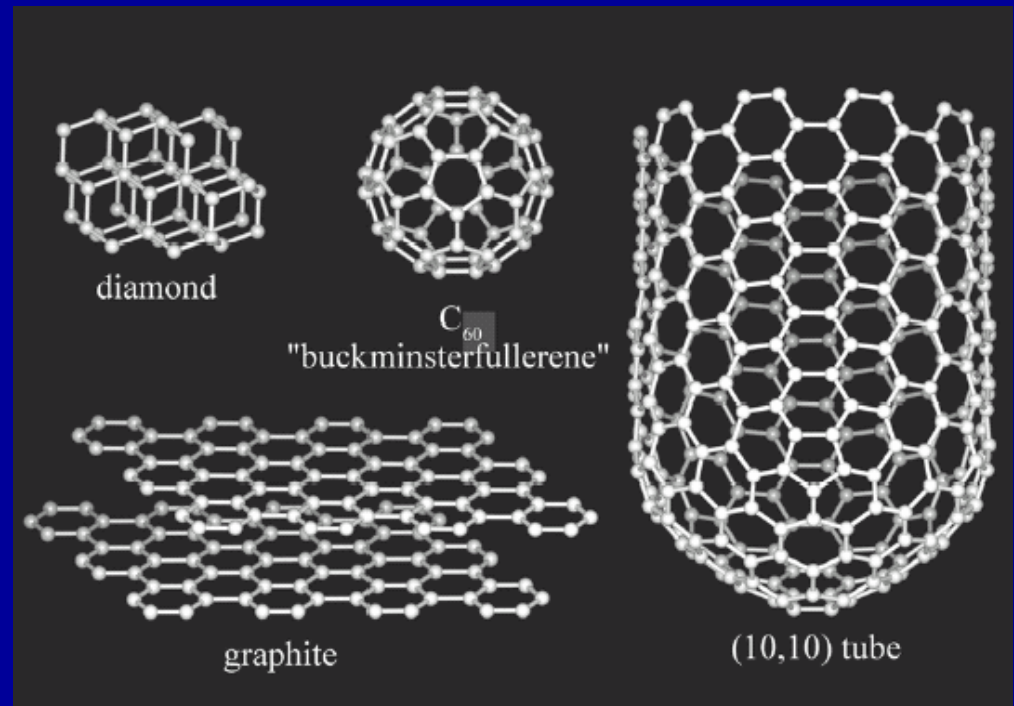
Schön, et al., *Nature*, **413**, 713, 2001

# Carbon Based Nanostructures

Carbon-based nanostructures occur naturally and have been found in interstellar dust and geological formations

Forms:

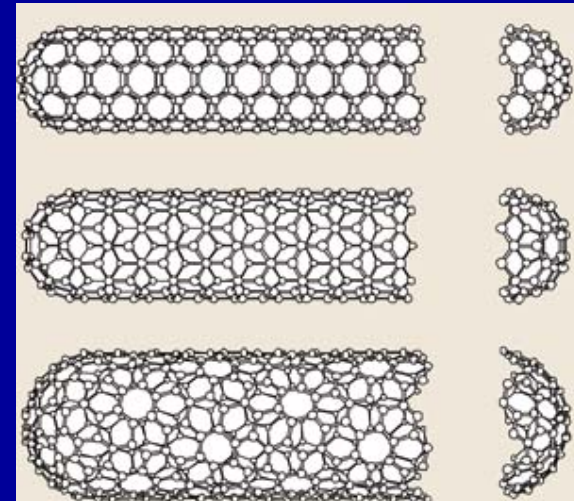
- Carbon nanotubes
- Carbon onions
- Buckyballs ( $C_{60}$ )



# Carbon Nanotubes

Carbon nanotube properties:

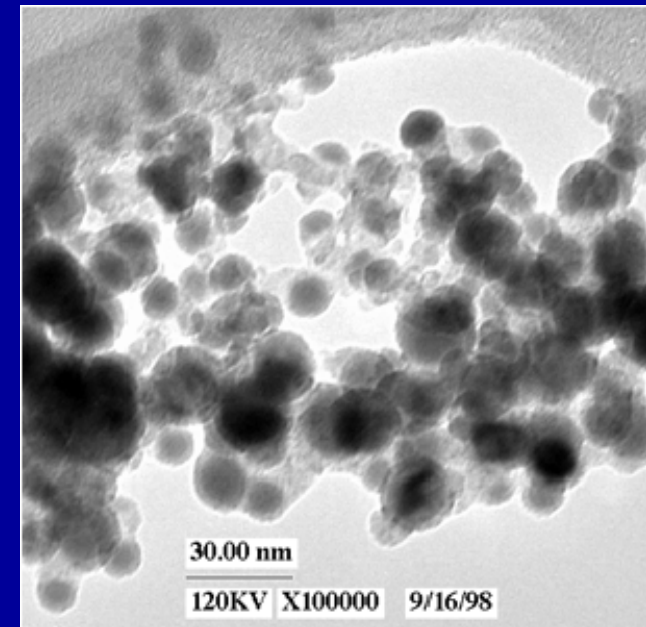
- One dimensional sheets of hexagonal network of carbon rolled to form tubes
- Approximately 1 nm in diameter
- Can be microns long
- Essentially free of defects



<http://physicsweb.org/article/world/11/1/9/1>

# Nanoparticles / Quantum Dots

- “Zero-dimensional” particle
- Surface effects/chemistry important
- Radius < 100 nm
- <  $10^6$  atoms per nanoparticle
- Nano/quantum physical phenomena present
- Synthesis: RF plasma, chemical, thermolysis, pulsed laser



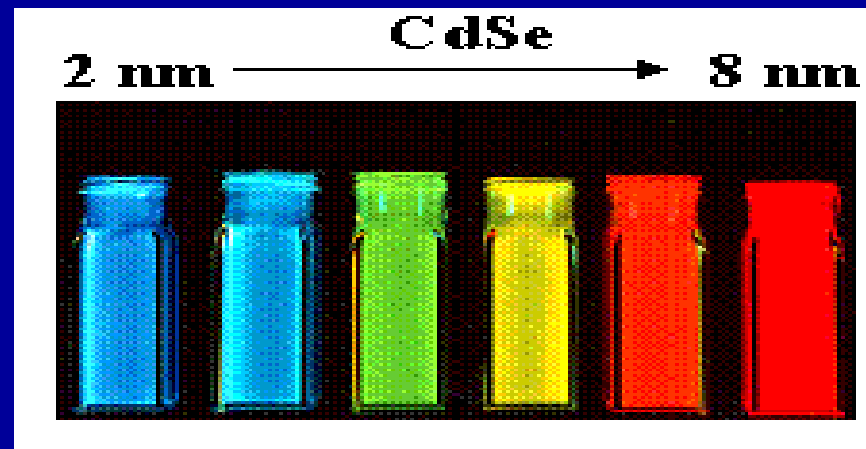
Metalic nanoparticles

<http://www.bnl.gov/bnlweb/pubaf/pr/2002/bnlpr071802.htm>

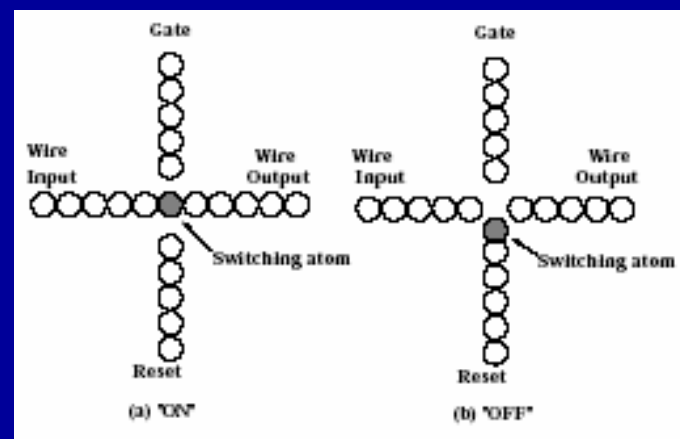
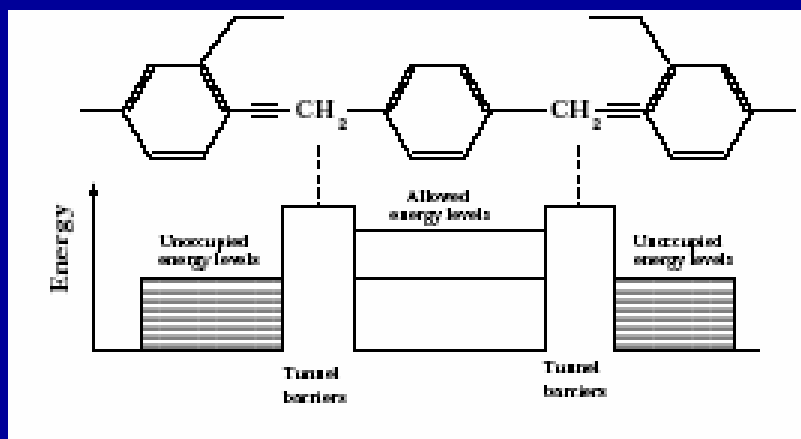
# Semiconductor Nanoparticles

- Nanoparticles comprised of “bulk semiconductor” elements exhibit unique optical properties
- Shift in optical absorption particle toward shorter wavelengths with reduced size

Fluorescence at different wavelengths from a single UV light due to quantum confinement in semiconductor quantum dots



# Molecular Electronics



## Mechano-synthesis

- Molecules aligned using STM
- Fabrication done molecule by molecule using STM tip

## Chemo-synthesis

- Molecules aligned in place by chemical interactions
- Self assembly
- Parallel fabrication



# Molecular Electronics Applications

## Robotics and Manufacturing

- components become smaller and conventional robotic methods will fail.
- Self-assembly offers a new approach to the assembly of parts with nanometer dimensions.

## Microelectronics

- Self-assembly offers a possible route to three-dimensional microsystems

# Spintronics

Conventional electronics:

charge of electron

used to achieve functionalities – diodes, transistors, detectors, lasers...

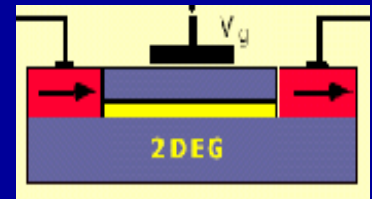
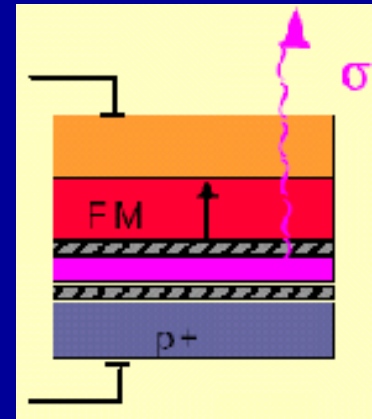
Spintronics:

manipulate electron spin (or resulting magnetism)

to achieve new/improved functionalities - spin transistors, memories, higher speed, lower power, tunable detectors and lasers, bits (Q-bits) for quantum computing....

# Device Applications

- spin-LED structure - circularly polarised light emission.
- spin-polarised field effect transistor (spin-FET) - change properties of magnetic layer by applied gate voltage.
- spin resonant tunneling device (spin-RTD)
- Multilayers with alternating magnetic and non-magnetic semiconductors giant magnetoresistance (GMR) effect - magnetic field sensors, hard disk industry.
- magnetoresistive random access memory (MRAM).
- quantum information processing— qubits using coherent spin states in quantum dots



# Advantages of Spintronics

- nonvolatility,
- increased data processing speed,
- decreased electric power consumption,
- increased integration densities compared with conventional semiconductor devices.

# Technology Computer Aided Design (TCAD)

Many of the difficulties and of the limits of candidate technologies for nanoelectronics and molecular electronics could be predicted, anticipated and, hopefully, solved if detailed modelling tools of realistic devices and structures were available.

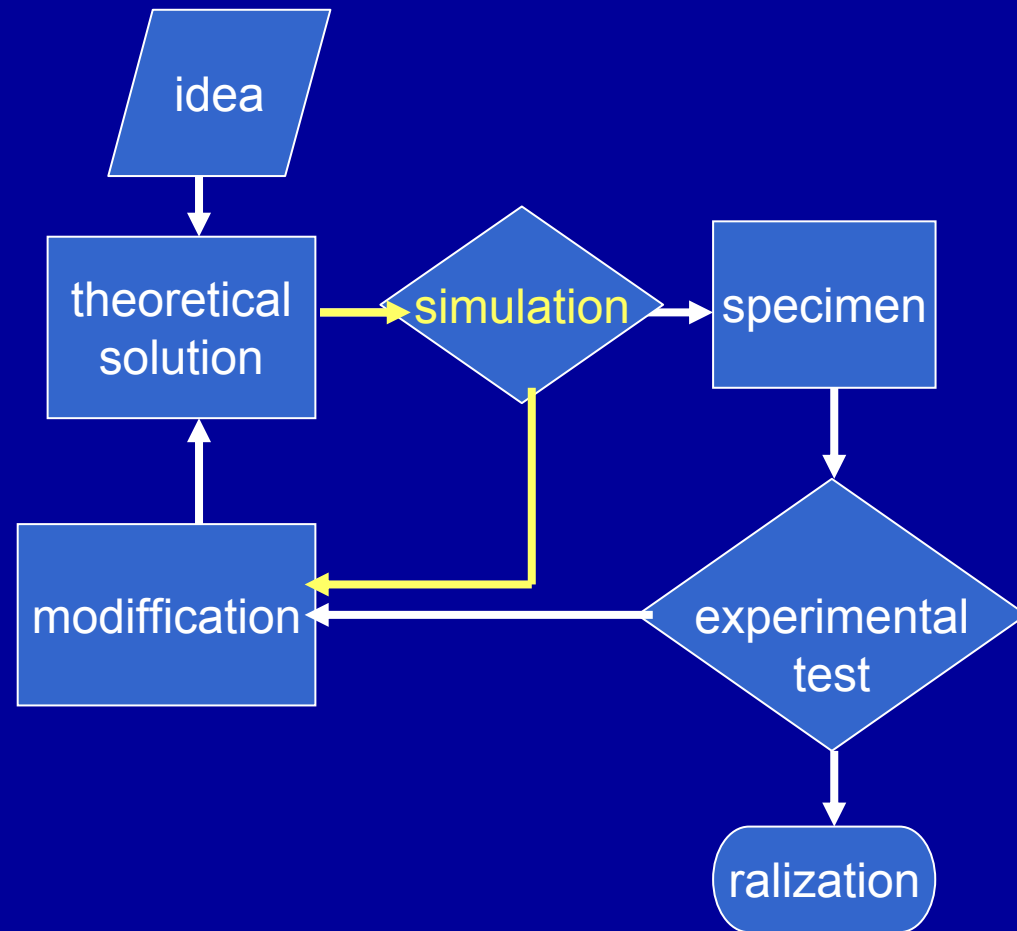
- Process, device and circuit simulation modules
- Thermal and optical analysis as well.
- The semi-classical and quantum models are taken in the account.

# Design loop

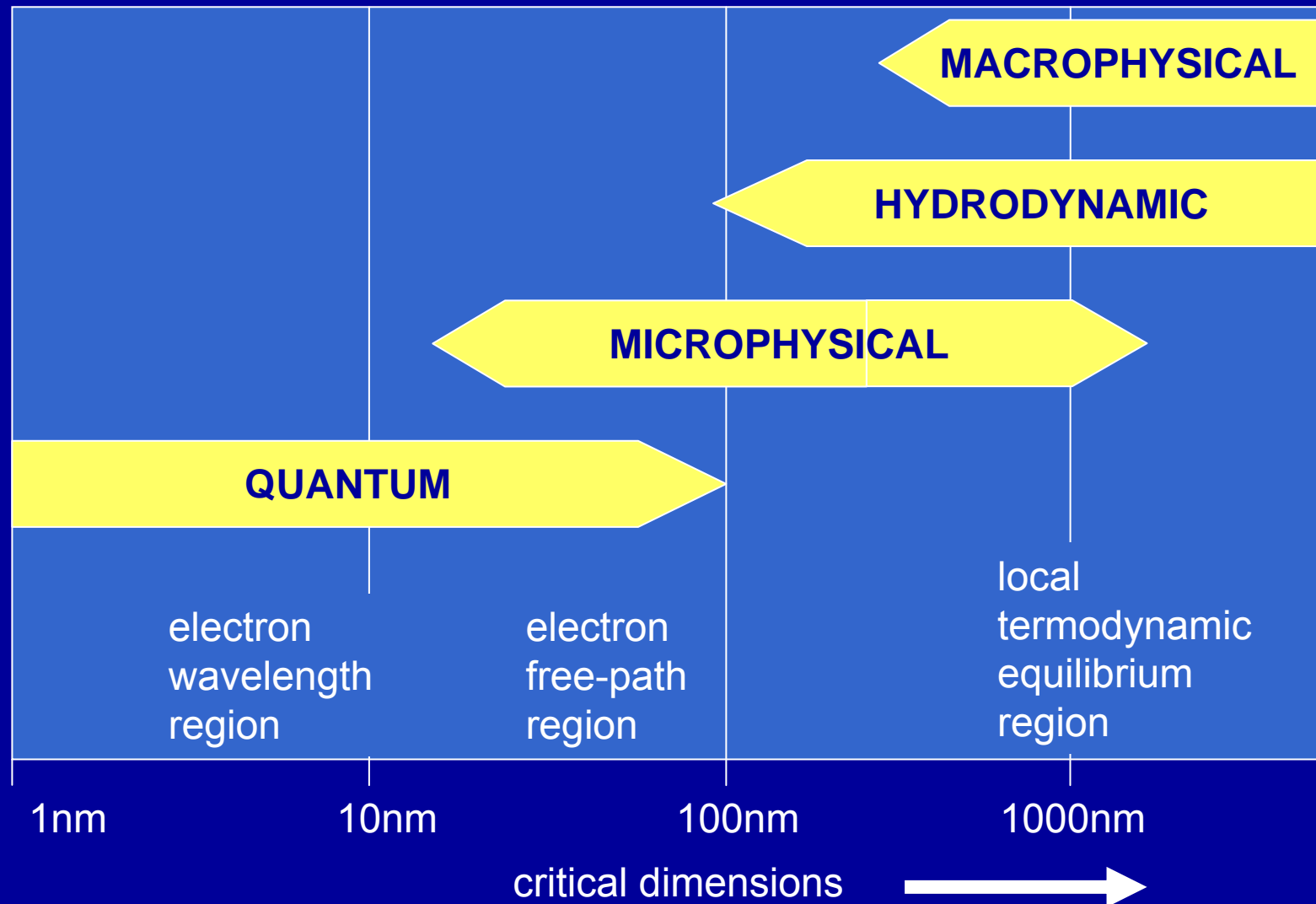
**simulation**

↓

time savings  
+  
cost savings



# Physical model levels



# Nano-Characterisation Techniques

- Atomic Force Microscopy (AFM),
- Scanning Tunneling Microscopy (STM)
- Scanning Electron Microscopy (SEM)

necessary for the correct implementation of physical models into predictive simulation tools.



# Nanotechnology Impacts

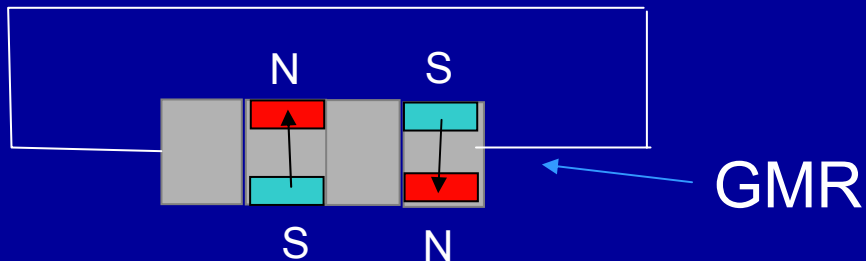
- industry
- health and society
- ethical aspects
- jobs
- skill needs
- education
- training

# Nanodevices

## Present Impact

GMR read heads

Current cannot pass through



## Potential Impact

Terabit memory  
and microprocessing  
Single molecule DNA sizing  
and sequencing  
Biomedical sensors  
Low threshold lasers  
Nanotubes for high  
brightness displays

# Dispersions and Coatings

## Present Impact

Thermal barriers  
Information-recording layers  
Optical (visible and UV) barriers  
  
Imaging enhancement  
Ink-jet materials  
Coated abrasive slurries

## Potential Impact

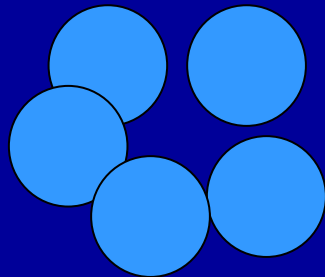
Targeted drug delivery  
Gene therapy  
Multifunctional  
nanocoatings

# High Surface Area Materials

## Present Impact

Molecular sieves  
Drug delivery

Tailored catalysts  
Absorption/  
desorption materials



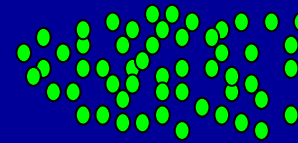
Microparticles

## Potential Impact

Molecule-specific sensors  
Large hydrocarbon  
or bacterial filters

Energy storage

Grätzel-type solar cells

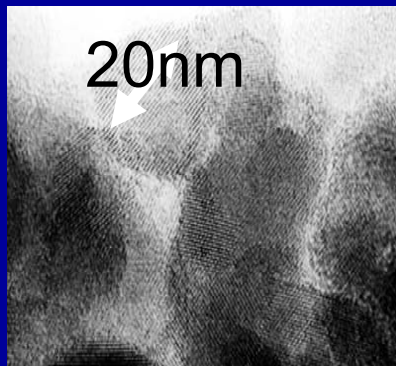


Nanoparticles

# Consolidated Materials

## Present Impact

Low-loss  
soft magnetic materials  
High hardness, tough  
WC/Co cutting tools  
Nanocomposite cements



Ceramic Nanoparticle

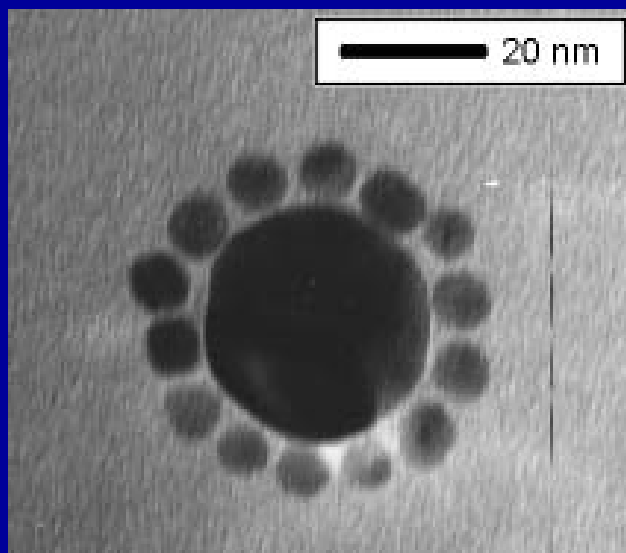
## Potential Impact

Superplastic forming  
of ceramics  
  
Ultrahigh-strength,  
tough structural materials  
Magnetic refrigerants  
Nanofilled polymer  
composites  
Ductile cements

# Additional Biological Aspects

## Present Impact

### Biocatalysis



8 nm gold particles attached to a  
31 nm gold particle with DNA

## Potential Impact

### Bioelectronics

Bioinspired prostheses

Single-molecule

sensitive biosensors

Designer molecules

<http://www.chem.nwu.edu/~mkngrp/dnasubgr.html>

# Nanotechnology Implications

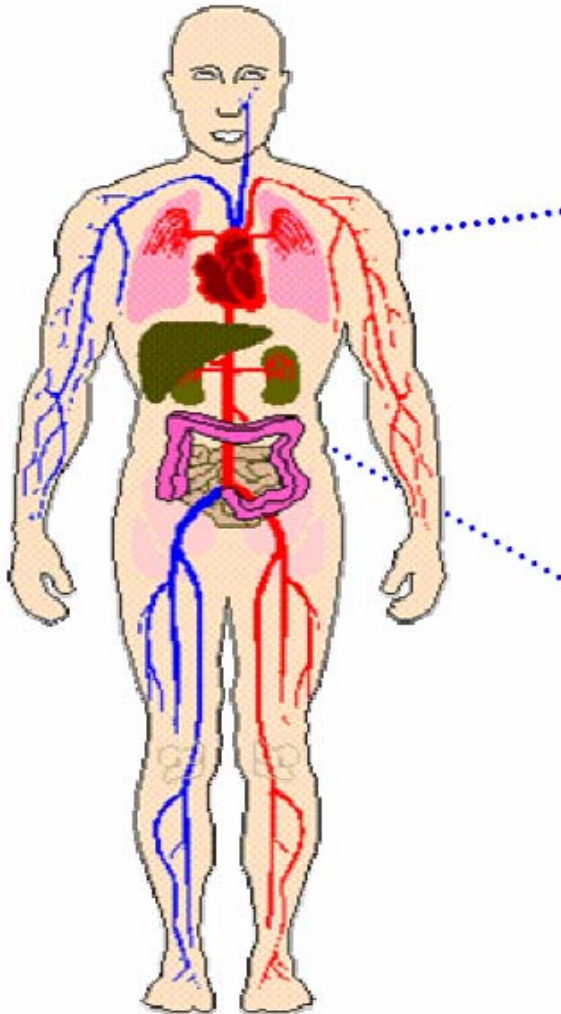
- Nanotechnology will impact many technologies on short and long term time frames
- Eventually nanotechnology will alter the way we make things and have the broad impact of the industrial or information revolutions
- New ways of making chemical and products may impact distribution, consumption, energy use, environmental contamination. Potentially large impacts on the way we live.
- Rate of change and information growth is very rapid
- The large impacts and rapid rate of change will likely cause disruption of some type and fear

# Impact on the Public Health, Safety and Environmental Protection

- Nanotechnology allow virtually total control of matter.
- Possible ethical issues includes non-therapeutic human enhancement
- Invasion of privacy due to invisible sensors.
- Much nanotechnology development is in the hands of private companies that are beyond direct public control.
- 'nano-divide' may arise between those countries or regions that understand the new technological approach and those that do not.



# Health Risks



Nanoparticles have a greater reactive surface area per unit mass than larger particles, their **toxicity** and potential health effects may also increase. Inhaled particles could induce inflammation in the respiratory tract, causing tissue damage.

Ingested nanoparticles may cause liver damage: ingested nanoparticles accumulate in the liver, which could eventually provoke excessive immune responses causing permanent liver damage.

# Impact on the Public Health, Safety and Environmental Protection

All applications and use of nanotechnology must comply with the high level of public health, safety, consumers and workers protection, and environmental protection.

- Adequate transparency in research is essential, and a safe set of rules must be put in place.
- Public power, through politicians and public opinion, should therefore have the cultural instruments and access to appropriate qualified expertise to assess, steer and – where appropriate – constrain developments.
- Societal acceptance and confidence in nanotechnology

# Impact on the Jobs, Education and Training

Two competing processes begin to affect jobs.

- boom time for jobs for the science and engineering workforce.  
need for supporting labour services,  
persons in sales, clerical and office work,  
service workers of different types.
- the technology reduces the number of workers needed to  
produce a given level of output.

# Cost-reducing effect of nano

- nanotechnology lowers the cost of products, which increases demand for goods and expands jobs
- nanotechnology as a productivity enhancing technology
- improves real wages and living standards.
- generates additional consumer demand for all sorts of products and thus contribute to the growth of employment.

# Skill needs

We need skilled people to produce the products and also to use the products.

- (more than 1 mil. researchers in Europe for nanotechnology)
- In Europe is lack of people with skills in business and entrepreneurship

Needs:

- Interdisciplinarity
- Better communication skills
- Team work skills

# Interdisciplinarity

- Nanoscience and nanotechnology are not one cohesive discipline.
- Nanotechnology is composed of multiple disciplines  
Chemistry, physics, biology and information storage at the  
are linked at the nanoscale.
- Interdepartmental cooperation in making nanoscience and  
nanotechnologies course
- Problem-based learning -> natural interdisciplinarity
- PhD's with joint supervision from different disciplines
- Overcome institucional obstacles to interdisciplinary  
research

# Communication skills

- Interdisciplinary nature of the work requires communication across technical and scientific fields, focusing on physics, chemistry, biology, toxicology and engineering, but also including entrepreneurial studies, risk assessment, and social and human sciences
- Each of the sciences and engineering represent distinct ways of seeing the natural world, with different jargon, culture, and analytical tools.
- Nanotechnology workers must possess sufficient understanding of more than one discipline to promote efficient communication.
- Important to develop a common language that will permit an integrated exploration of nanotechnology.

# Team Work

- Need local multi-disciplinary research centers
- Best knowledge sharing - Scientific Hub
- Frequent and informal interactions - Quick feedback loop
- Best equipments sharing - Technological Hub
- Brings complementary skilled scientists to Nano
- Easy « bottom-up » - Self -assembly due to low local barriers
- Bottom-up = motivation + confidence = creativityProject / team - based learning
- New research organization - Multi-disciplinary teams in a fractal network
- International cooperation



# Recruitment

- Many scientifically trained graduates have left scientific fields in favour of positions in finance, management or other non-science related jobs.
- Many students have become disillusioned with the sciences as a career option.
- Nanoscience and nanotechnology are very attractive
- Hope that some will prefer nano-fun to law-money
- Working on on nanotech problems involving background knowledges

# Nanotechnology Education

More than one type of education is needed needed:

- Experts – research, engineering, manufacturing, policy, safety and regulation
- Workforce skills need to be identified and taught (clean room skills, computer skills...)
- Need deeper understanding of characterization tools and metrology for manufacturing and commerce
- Need terminology appropriate for education, regulation and manufacturing
- Need to facilitate formation of creative multi-disciplinary teams
- Not technical skills – social issues, ethic, philosophy, safety, health, environment, communication

# Long Term Education Needs

- Primary and secondary - Nanoscience information integrated into course structures. Development of concepts and language.
- Tertiary – Specific courses in nanoscience and integration of nanoscience into other science and math courses.
- Graduate – Combine knowledge depth in at least one skill area with skills to participate in and lead multi-disciplinary teams.
- Lifelong education – With the rapid knowledge growth, education is a continual process

# Primary and secondary schools

- To stimulate future interest for the intellectual challenges of science and research, observation, analysis, interpretation, abstraction and prediction skills have to be developed in primary and secondary schools
- Contact with science is essential at early ages - primary school (5-12)
- Initiate to scientific reasoning
- Demonstrate simple phenomenon - « fun » science
- Use nano-fascination to attract students - Science is alive and fascinating
- Visit the labs

# Tertiary Education System

- Conceptual and language barriers prohibit fruitful collaborations collaborations \_
- Background education in all important disciplines for nanotechnology Physics, biology, chemistry, engineering
- All aspects including ethics and societal impact
- Nanooriented courses
- Nano science, nanofabrication, nano characterisation
- Specific nano Diploma
- Potentially attractive for students
- Opportunity: The new bachelor -master system

# Tertiary Education System

A distinction should be made between first (bachelors) and postgraduate degrees in nanotechnology.

- It is still unknown whether a three or four year taught course at the first degree level will allow students to gain the required level of expertise in any discipline to be useful to future employers
- would be better to have a sound understanding of one area of science first and then broaden this to include other disciplines.

postgraduate courses

- specifically designed to give multidisciplinary skills.
- adding elements of entrepreneurship or business skills

# Continuous Training

Career re-orientation and follow-up are essential in a rapidly changing technology

- important opportunity for university-industry collaborations
- reorientation courses, summer schools, and workshops
- mid-career post-doctorates
- international co-operation

# Public Education

- Awareness of potential risk should also include potential benefits of nanotech
- Information to broader public is indispensable in order to ensure an informed dialogue
- Avoid exaggerating the technological potential and respond to irrational fears
- Educated politicians, more scientists in policy decision positions
- Societal acceptance and confidence in nanotechnology



# Basic Research

Basic research remains the essential element to technical infrastructure.

- Knowledge flows primarily from academic labs to industry.
- Industry do not readily profit from investing in basic science (no commercial value in any reasonable time period)
- Temptation to allow industry to control it or to dictate the direction of academic research
- Reduce the government's burden for funding academic science.

dangerous strategy - firms have a strong incentive to restrict the knowledge that they help to create, which would result in a slowdown of the overall pace of basic research.

# European and Czech Nano-Infrastructure

- poles of excellence
- education
- institutes

# Poles of Excellence

Communication Towards a European Strategy for Nanotechnology adopted by EC Commission in 2004

- Research and development infrastructure system of comprises 'single sited' (in one location) and 'distributed' (networked) facilities.
- nanotechnology requires a critical mass of resources that are beyond the means of regional and often even national governments and industry.
- Poles-of excellence can bring together faculty members of different disciplines under a single organization
- these researchers may retain a desk at their 'home' department.

# Regions of Knowledge

Special attention will be paid to the needs of industry.

- Small and medium sized enterprises (SMEs) reinforce cooperation and technology transfer from academic teams to conceive advanced prototypes and validate them in industrially relevant environments.
- SMEs and regional technological clusters integrating industry, research institutes and universities can play a crucial role in particular at regional level.
- 'Regions of Knowledge' initiative could contribute towards establishing effective clusters and networks.



# Nanotechnology Education in The Czech Republic

The ministry for Education, Youth and Sports  
is responsible for nation's science, technology, and  
engineering education

The research and development council of the government  
is responsible for shaping the R&D system.

five national grant agencies fund research.

The Czech Academy of Science carry out a larger part of  
the research

Universities are more responsible for higher education.

# National Research Program

- approved by the Czech government in April 2003
  - for the period from 2004 to 2009
  - consists of five thematic programs
  - program No.3 "Competitiveness in Sustainable Development"
  - six sub-programs
- 
- the sub-program "Manufacturing Processes and Systems"  
key research direction "Electronic and Photonic Materials and Structures", also focuses on Nano-Electro-Mechanical-Systems (NEMS), molecular electronics, new carbon and bio-mimetic materials.
  - the sub-program "Emerging Technologies" includes the key research direction "Nanotechnologies and Nanomaterials"

# Nanotechnology Infrastructure

To realize the mentioned potential of nanotechnology research, the Czech Republic needs a population of interdisciplinary researchers and engineers who can generate knowledge and ensure that this is, in turn, transferred to industry. To meet the need of the nanotechnology infrastructure of research and education at the national and international level, new and existing nanotechnology networks are developed and shared. A hierarchal infrastructure has recently been completed.

# University Level

## Centre NANOTECH CTU

- was established in 2004
- workgroup for micro- and nanotechnology of the Czech Technical University
- continuous communication between teams of different but complementary research profiles
- results in advances for future application of nanotechnologies
- improved education in nanotechnology, especially in the PhD study programs





# National Level

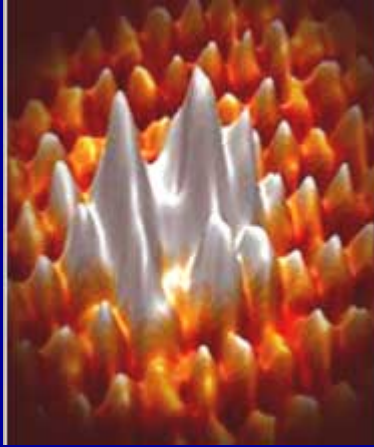
The Czech Society of New Materials and Technologies was founded in 2002 its "Nanoscience and Nanotechnology Section" with more than 100 members with several working groups

the working group Education

organizes the network of Czech universities with the aim:

- to build up the infrastructure for experience exchange
- to establish new courses and curricula in the field of nanotechnology
- to encourage the collaboration with the Czech Academy of Science

coordination role in the process of implementation.



# Nano-team

- the research group formed by about 17 scientists
- each representing a group of 3 - 20 researchers, experienced in different areas of the "Physics of Nanostructures and Nanotechnologies". (AFM, STM and SEM)
- basis for projects on national and international level.
- contribute to the education of nanosciences at different levels.

# Institute of Applied Sciences

All groups in this region are cooperating in preparation of a new Institute of Applied Sciences - IAS.

There are four main proposed research areas in IAS:

- nanosciences,
- special chemistry,
- new energy sources
- applied mathematics.

Institute will concentrate expensive equipments for the electron lithography and nano characterisation techniques.

Mainly PhD students will take part in the IAS research.

It could be be a new "pole of excellence".



# European Level

## Network for Nanostructured Materials - NENAMAT

- proposed by 10 Centres of Associate Candidate Countries (the Czech coordinator in the Technical University in Brno)
- founded in 2004
- to improve the knowledge base of application-oriented nanosciences and technology
- to help in building of the European nanotechnology related industry.

# European Level

Network **MNT ERA-NET** (Micro- and Nanotechnology European Research Area Network)

- integrates nanotechnology programs of new participants into the already existing network.
- The Czech Republic is planned to be included as an associated member.

The planned activities include

- the systematic exchange of information about programs,
- implementation of joint activities, co-operation programs, transnational research activities, and the institutionalization of co-operation.

# Global level

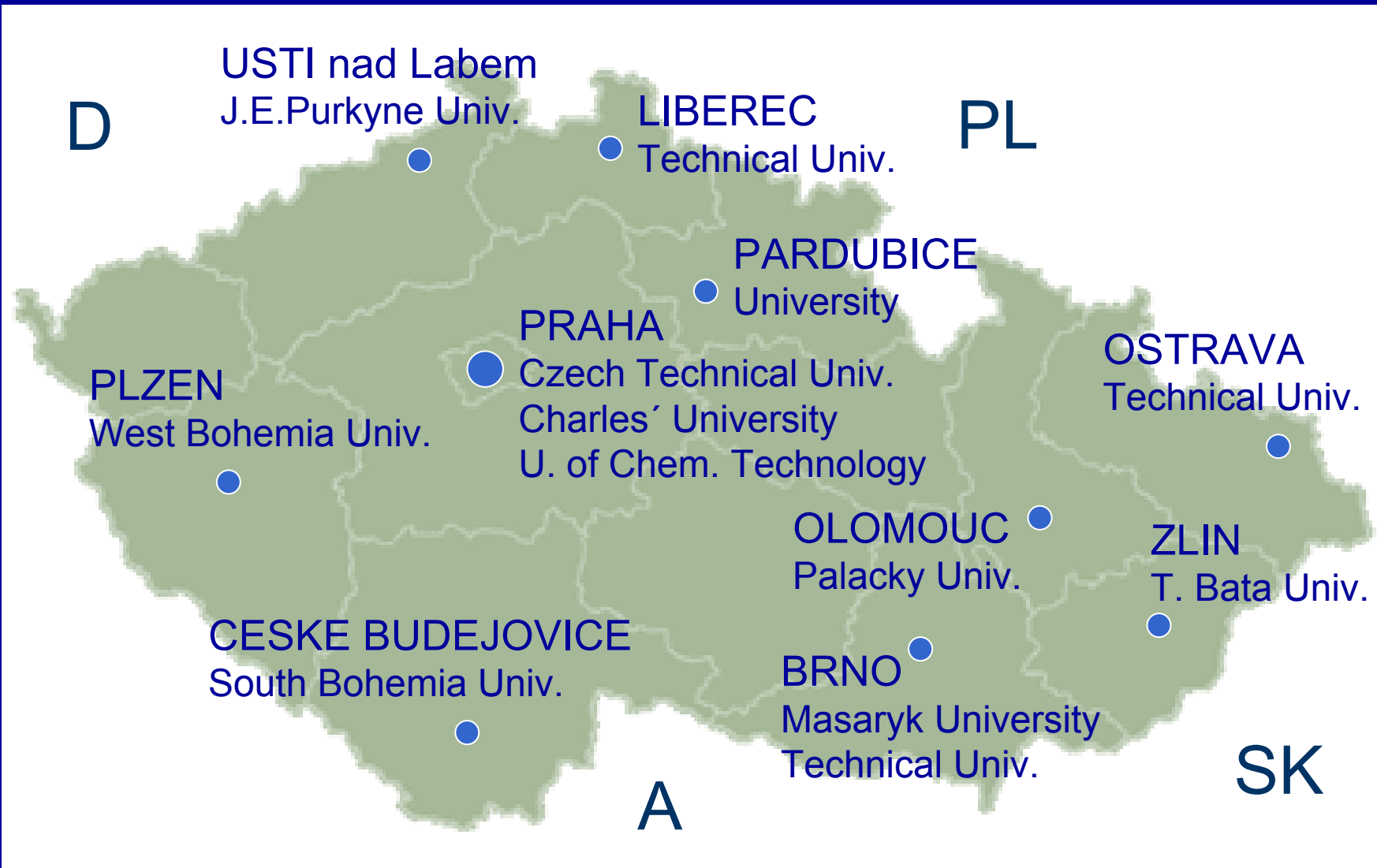
"International Dialogue on Responsible Research and Development of Nanotechnology"

- global group of experts involved with nanotechnology from 25 countries
- met in 2004 in USA.
- The NSF USA, EU and Japan will continue to organize future meetings of the expanded group.
- The Czech Republic has been nominated into the group, which is responsible for conceptual education for nanotechnology .

# Czech Universities

Currently there is no specific state program supporting the related research and development and no specific study program focusing on nanotechnology (or curricula, specialization or course) at Czech Technical Universities. Nanoscience and nanotechnology are only partially included in courses like physics, chemistry, physical chemistry, electronics, materials engineering, etc.

# Czech Universities





# Czech Universities

## Czech Technical University in Prague:

Diagnostics of nanomaterials, nanoelectronics, subnanometric InAs/GaAs laser structures, nanostructural coatings, biomedical engineering, biocybernetics, low-dimensional semiconducting structures, self-assembly of carbon colloids, nanocrystalline diamond like layers, microalloyed steels, polymeric nanocomposite materials.

Nanotechnology is included in the education as well in these subjects: New trends in Electronics. Electronics of Semiconductors, TCAD for Electronics and in the new subject Nanotechnology at the Department of Microelectronics and the Department of Mechanics and Material Science, Faculty of Electrical Engineering CTU.

## Charles University in Prague:

II-VI and III-V semiconductor based nanostructures. Nucleation and growth of metals on Si for nanoelectronics. Nanotechnology is included in the MSc. course in Chemistry at the Faculty of Science.

## University of Chemical Technology in Prague:

Chemical and structural analysis, submicron polymeric films with high permittivity, diffusion in nanometric scale.

# Czech Universities

## Technical University in Brno:

Nanolithography by SPM. Nano-structured thin layers, functional gradient materials, nano-structured ceramics, AFM, near field optical microscopy .

## Masaryk University in Brno:

Low-dimensional semiconducting structures, plasma-chemical deposition, structure and function of biomolecules and proteins, processing of fullerenes and nanotubes, diagnostics of nanomaterials, near-field optical microscopy, AFM, magnetic-force microscopy.

Nanostructures in III-V semiconductors and cuprates/manganites.

## Tomas Bata University in Zlin:

Nanotechnology is included in the M.Sc. course Material Science

## Palacky University Olomouc:

Nanocomposite and nanobiotechnology. Amorphous and nanocrystalline iron oxides.

# Czech Universities

## Technical University in Ostrava:

Periodic nanostructures, magneto-optics, layered nanostructures, nanoparticles and nanocomposites, clay-polymer, anticorrosion layers.

## West Bohemia University in Plzen:

Thin and hard layers. Nanotechnology is included in the M.Sc. course Applied Science.

South Bohemia University in Ceske Budejovice: Nanoparticles in biosciences.

## J. E. Purkyne University in Usti nad Labem:

SnO<sub>2</sub> thin films and nanometer surface analysis.

Technical University in Liberec: Nanofibers.

University in Pardubice: Amorphous chalcogenides.

# Research Institutes

## Institute of Physics in Prague:

Quantum size MOVPE grown IIIIV nanostructures. Nano/micro-crystalline Si and Si nanocrystals. Nano-phenomena on metal interfaces. Dielectric properties of nano-inhomogeneities in condensed matter. MBE IIIIV nanostructures and diluted magnetic semiconductors.

## Institute of Radio Engineering and Electronics in Prague:

Nano-porous IIIIV structures.

## Institute of Scientific Instruments in Brno:

Diagnostics of nanostructures with very low energy electrons.

# Research Institutes

## Institute of Macromolecular Chemistry Prague:

Macromolecular assemblies, bioanalogous polymers, synthetic drug and gene carriers. Polymeric quantum dots, molecular wires and switches,, structure and preparation of polypeptide systems, self-assembly, biocompatible interfaces. Polymer-based luminescent complexes.

J. Heyrovsky Institute of Physical Chemistry in Prague: Nanostructured Carbon Allotropes and their Derivatives.

Institute of Inorganic Chemistry in Řež near Prague: Nanocomposites with controlled size of nanoparticles, nanostructures for optoelectronics.

Institute of Experimental Technology in Prague:  
Quantum light generators.

Institute of Microbiology in Prague: Nanobiotechnology.

Institute of Biophysics in Prague: Study of DNA and proteins.

Institute of Organic Chemistry and Biochemistry in Prague: Study of proteins.

# Conclusions

- Interdisciplinary research and education is the most important aspect in nanotechnology.
- Universities should introduce courses based on nanoscale science and integrate nanotechnology with physics, chemistry, biology, electronics, medicine, engineering and other fields.
- To meet the needs of the research and education in nanotechnology the infrastructure at the national and international level has recently been formed.
- Poles of excellence will play a central role in the development of the society of knowledge needed for the nanotechnology.
- International collaboration and academy-industry cooperation is necessary.
- Because of the fact that manufacturing at the nanoscale has potential to decrease the consumption of energy, water, materials, waste, contaminants and because some nanotechnologies include also serious potential risks, nanotechnology education must also include environmental, health, ethical, and legal aspects.