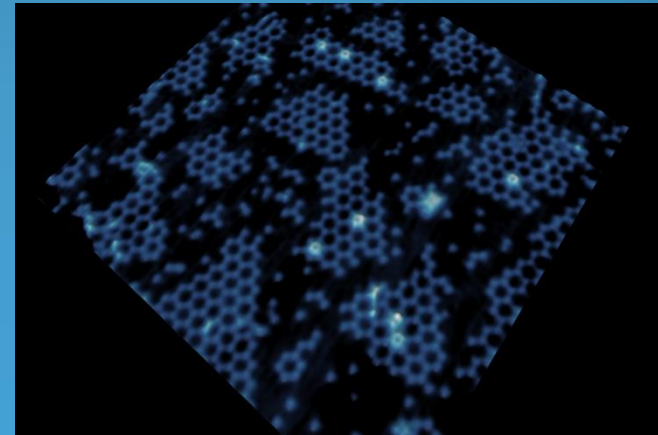
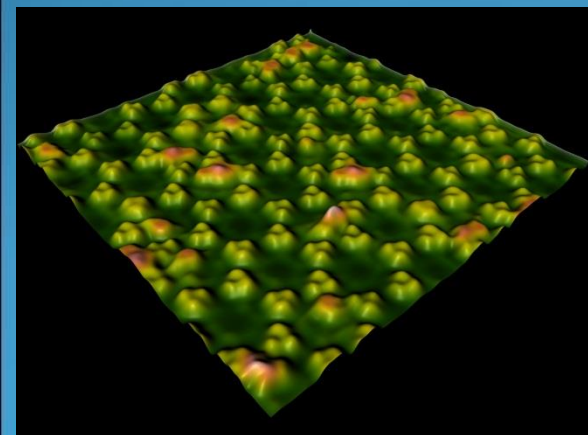


# Nanotechnology : Changing the World at the Nanoscale

**Dr. Esmeralda Yitamben**

*African School of Fundamental Physics (ASP 2024)  
Marrakech, Morocco  
16 July 2024*





UNDER THE HIGH PATRONAGE OF HIS MAJESTY KING MOHAMMED VI

# THE EIGHTH BIENNIAL AFRICAN SCHOOL OF FUNDAMENTAL PHYSICS AND APPLICATIONS (ASP2024)



Co-organized by Cadi Ayyad University and Mohammed V University at Faculty of Science Semlalia, Marrakesh, Morocco

April 15<sup>th</sup>-19<sup>th</sup> and July 7<sup>th</sup>-21<sup>st</sup>, 2024

## ASP MISSION

To increase capacity development in fundamental physics and related applications in Africa. The ASP has evolved to be much more than a school. It is a program of actions with directed ethos toward physics as an engine for development in Africa

## SCIENTIFIC PROGRAM

### TOPICS

- Nuclear & Particle Physics
- Medical and Radiation Physics
- Applied and Industrial Physics
- Theoretical and Computational Physics
- Space Physics, Astrophysics & Cosmology
- Physics for Sustainable Development
- Condensed and Materials Physics Biophysics
- Capacity Development and Retention Discussion
- Physics Education, Outreach and Communication

### ACTIVITIES

- Outreach for Secondary Schools April 15<sup>th</sup>-19<sup>th</sup>, and July 15<sup>th</sup>-19<sup>th</sup>, 2024
- Physics lectures, tutorials and hands-on experimentation for students, July 7<sup>th</sup>-21<sup>st</sup>, 2024
- Workshop for High School Teachers, July 8-12, 2024
- ASP Forum, July 13<sup>th</sup>, 2024

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Farida Fassi (UM5)



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# A little about me ...



**Sandia  
National  
Laboratories**



**Western Digital®**



# Outline



- What is nanotechnology?
- What is its current impact?
- What is its future impact?
- Nanotechnology in Africa



# What is Nanotechnology?

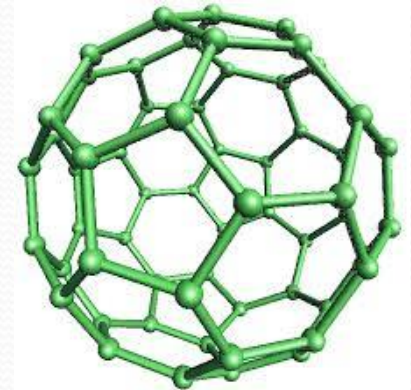
- Exploring and exploiting unique phenomena occurring at the atomic, molecular, and supra-molecular scale to create materials, devices, and systems with new and useful properties and function.
- Scale → 1 – 100 nm
- Highly interdisciplinary
- Potentially disruptive technology



$10^7$  meters



$10^{-1}$  meters



$10^{-9}$  meters



# The Scale of Things – Nanometers and More



## Things Natural



Dust mite  
↔  
200 μm

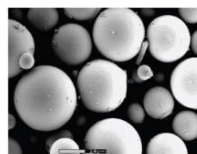


Human hair  
~ 60-120 μm wide

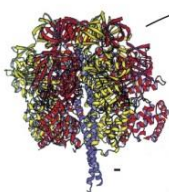
Red blood cells  
(~7-8 μm)



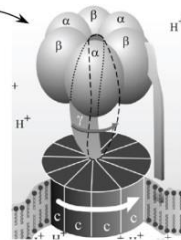
Ant  
~ 5 mm



Fly ash  
~ 10-20 μm



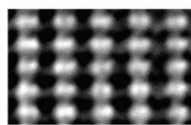
~10 nm diameter



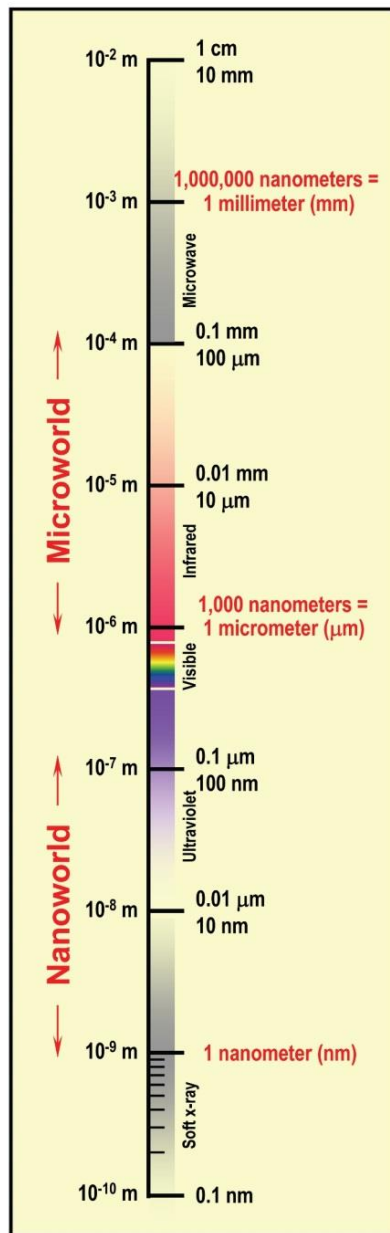
ATP synthase



DNA  
~2-1/2 nm diameter



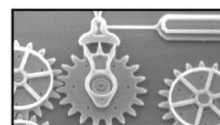
Atoms of silicon  
spacing 0.078 nm



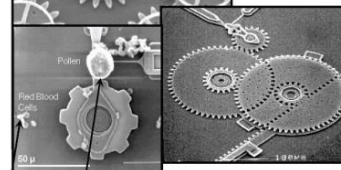
## Things Manmade



Head of a pin  
1-2 mm

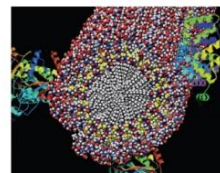


MicroElectroMechanical (MEMS) devices  
10 -100 μm wide

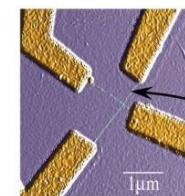


Pollen grain  
Red blood cells

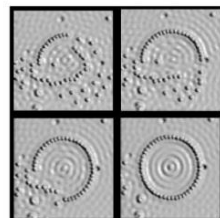
Zone plate x-ray "lens"  
Outer ring spacing ~35 nm



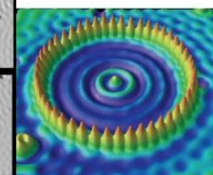
Self-assembled,  
Nature-inspired structure  
Many 10s of nm



Nanotube electrode

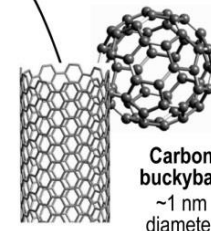


Quantum corral of 48 iron atoms on copper surface  
positioned one at a time with an STM tip  
Corral diameter 14 nm



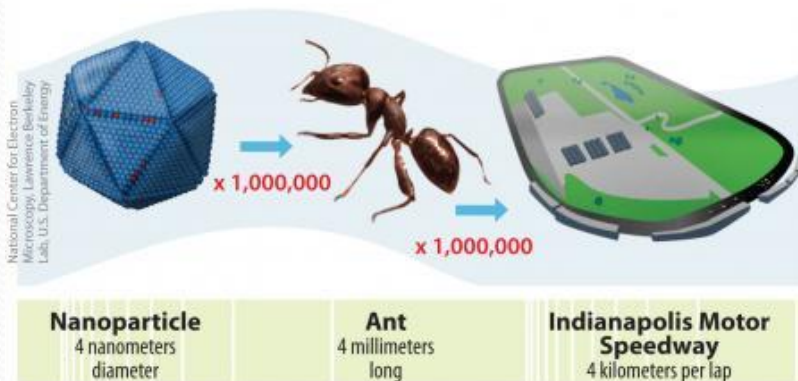
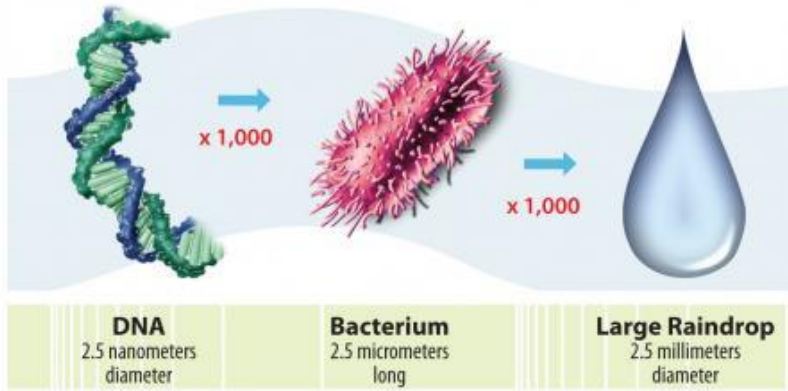
### The Challenge

Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.



Carbon nanotube  
~1.3 nm diameter

# A Little More on the Scale of Things



- A sheet of paper is ~ 100,000 nm thick;
- A human hair is ~ 80,000 – 100,000 nm wide;
- Hemoglobin, which carries oxygen through the bloodstream is 5 nm in diameter;
- A strand of human DNA is ~ 2.5 nm in diameter;
- A single gold atom is ~ 1/3 nm;
- 1 nm is approximately as long as your fingernail grows in 1s.

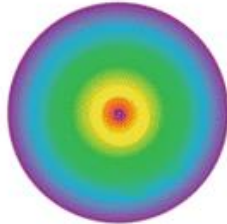
National Nanotechnology Initiative  
<http://www.nano.gov/nanotech-101/what/nano-size>



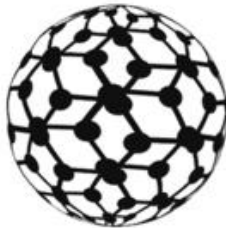
# NMs classification based on dimensionality

## 0D

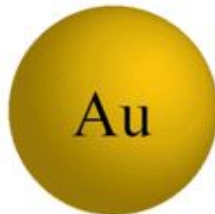
Nanospheres,  
clusters



Quantum dots



Fullerenes



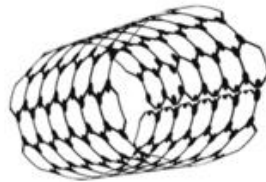
Gold nanoparticles

## 1D

Nanotubes,  
wires, rods



Metal nanorods,  
Ceramic crystals



Carbon nanotubes,  
Metallic nanotubes



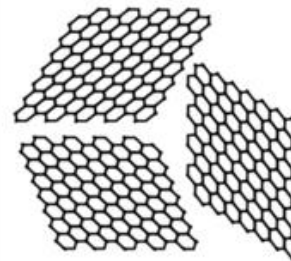
Gold nanowires,  
Polymeric nanofibers,  
Self assembled structures

## 2D

Thin films, plates,  
layered structures



Carbon coated  
nanoplates



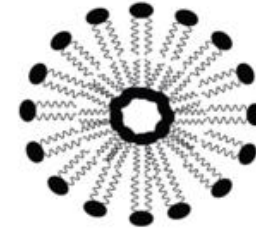
Graphene sheets



Layered nanomaterials

## 3D

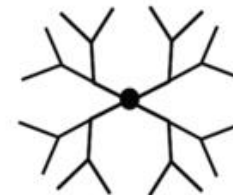
Bulk NMs,  
polycrystals



Liposome



Polycrystalline



Dendrimer





# Pre-modern Examples of Nanotechnology



*The Lycurgus cup (Rome) at the British Museum, 4<sup>th</sup> century*



*Polychrome lustreware bowl (Iraq) at the British Museum, 9<sup>th</sup> Century*



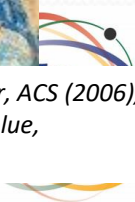
*Stained glass window in a church in Europe in the 11<sup>th</sup> century*



*Maya warrior, The Cleveland Museum of Art, 250 – 900 AD*



*(A) Egyptians produced dye for hair, ACS (2006);  
(B) Egyptians produced Egyptian blue, ACS(2013)*





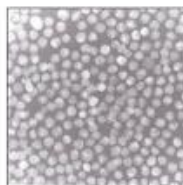
Ancient stained-glass makers knew that by putting varying, tiny amounts of gold and silver in the glass, they could produce the red and yellow found in stained-glass windows. Similarly, today's scientists and engineers have found that it takes only small amounts of a nanoparticle, precisely placed, to change a material's physical properties.

#### Gold particles in glass

Size\*: 25 nm  
Shape: sphere  
Color reflected:

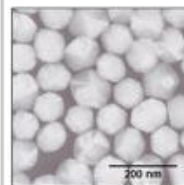


100 nanometers =  
0.0001 millimeter



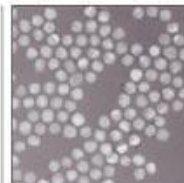
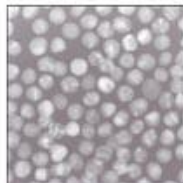
#### Silver particles in glass

Size\*: 100 nm  
Shape: sphere  
Color reflected:



Had medieval artists been able to control the size and shape of the nanoparticles, they would have been able to use the two metals to produce other colors. Examples:

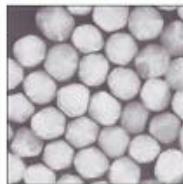
Size\*: 50 nm  
Shape: sphere  
Color reflected:



Size\*: 40 nm  
Shape: sphere  
Color reflected:



Size\*: 100 nm  
Shape: sphere  
Color reflected:



Size\*: 100 nm  
Shape: prism  
Color reflected:

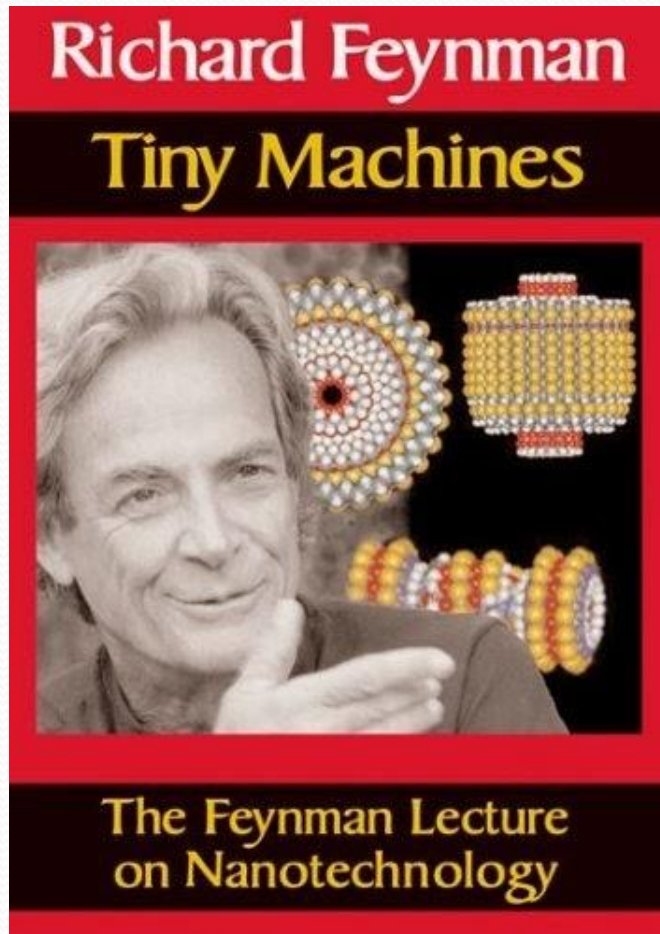


Source: Dr. Chad A. Mirkin, Institute of Nanotechnology, Northwestern University

\*Approximate



# Where it all started: "There's plenty of room at the bottom."



On the Basic Concept of 'Nano-Technology'

Norio TANIGUCHI  
Tokyo Science University  
Noda-shi, Chiba-ken, 272 Japan

### Abstract

'Nano-technology' is the production technology to get the extra high accuracy and ultra fine dimensions, i.e. the preciseness and fineness of the order of 1 nm (nanometer),  $10^{-9}$ m in length. The name of 'Nano-technology' originates from this nanometer. In the processing of materials, the smallest bit size of stock removal, accretion or flow of materials is probably of one atom or one molecule, namely 0.1~0.2 nm in length. Therefore, the expected limit size of fineness would be of the order of 1 nm. Accordingly, 'Nano-technology' mainly consists of the processing of separation, consolidation and deformation of materials by one atom or one molecule. Needless to say, the measurement and control techniques to assure the preciseness and fineness of 1 nm play very important role in this technology.

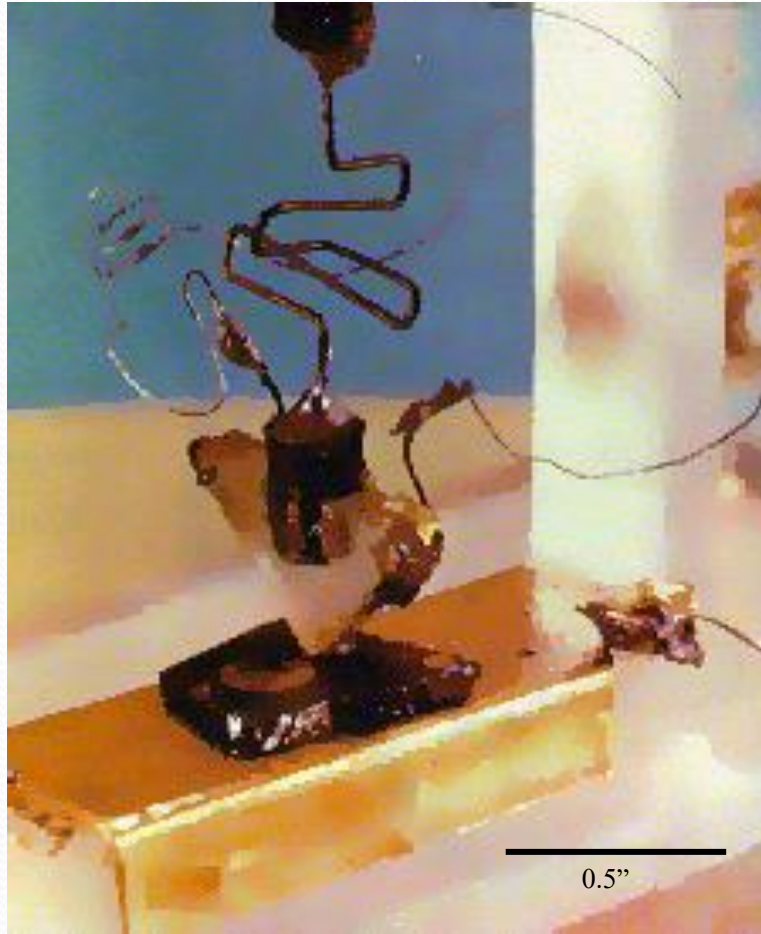
In the present paper, the basic concept of 'Nano-technology' in materials processing is discussed on the basis of microscopic behaviour of materials and as a result the ion sputter-machining is introduced as the most promising process for the technology.

Norio Taniguchi first termed the word "Nanotechnology" in 1974, in his paper on ion sputtering: *N. Taniguchi, Proc. Intl. Conf. Prod. Eng. Tokyo Part II, Japan Society of Precision Engineering, 1974, pp 18-23.*

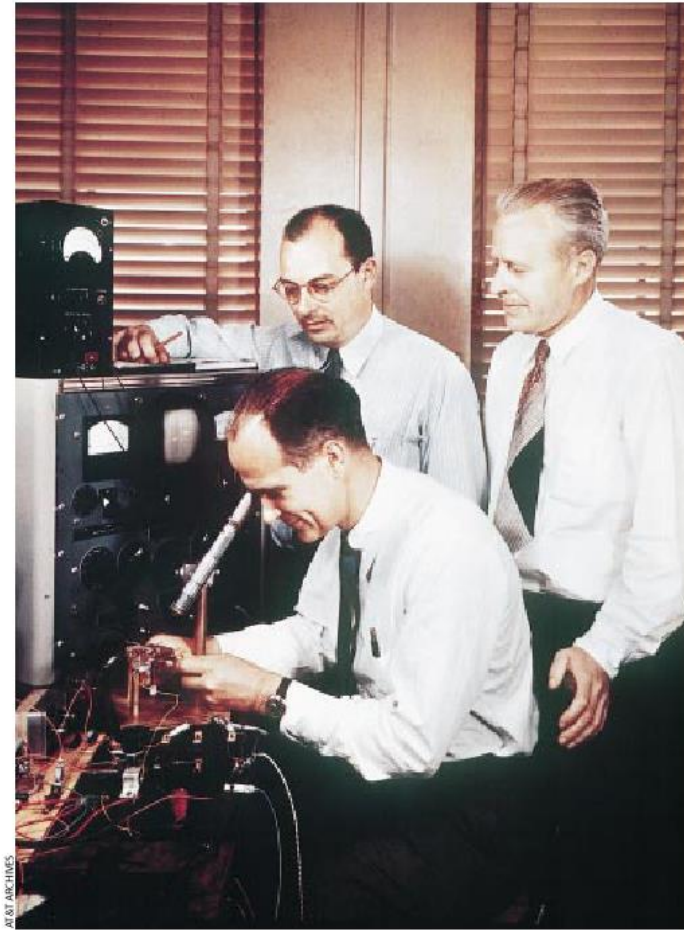
"There's Plenty of Room at the Bottom" was a lecture given by physicist Richard Feynman at an American Physical Society (APS) meeting at Caltech on December 29, 1959. This talk inspired the conceptual beginnings of the field decades later.



# The Beginning: at Bell Labs in 1947



the first transistor made of Germanium



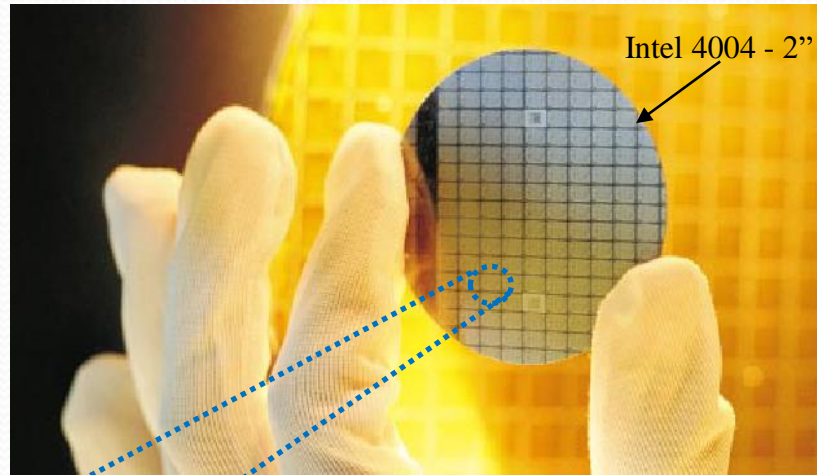
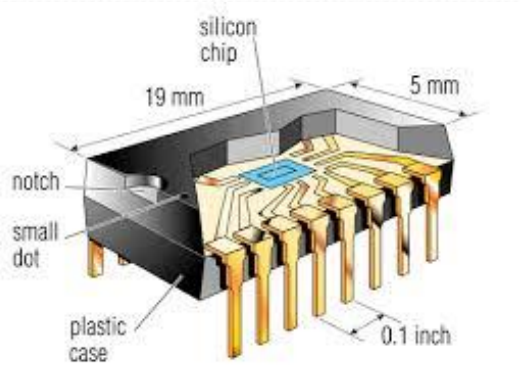
INVENTORS Shockley (*seated*), Bardeen (*left*) and Brattain (*right*) were the first to demonstrate a solid-state amplifier (*opposite page*).

AT&T Archives

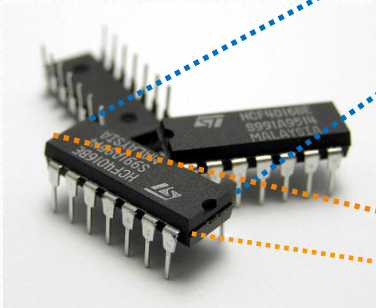
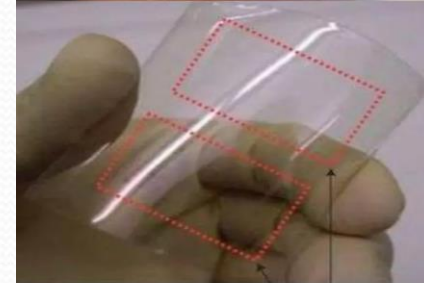
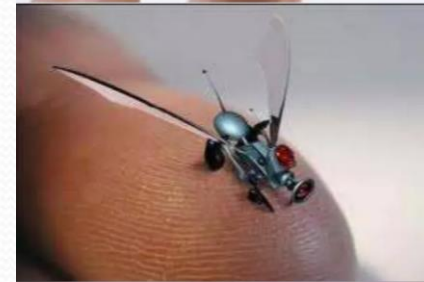
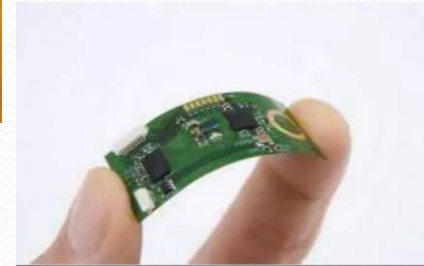
In 1956, Schockley, Bardeen, and Brattain were awarded the Nobel Prize in Physics, "for their researches on semiconductors and their discovery of the transistor effect"



# Integrated circuits: The heart of the computer



Intel.com  
today's wafers-12''



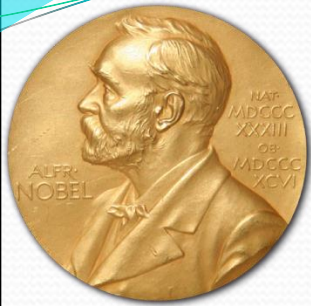
Three 14-pin (DIP14) plastic dual in-line packages containing IC chips packaged chip

Wikipedia.org



modern pc

# Visualization? : Nobel Prize in Physics 1986



"for his fundamental work in electron optics, and for the design of the first **electron microscope**"



**Ernst Ruska**

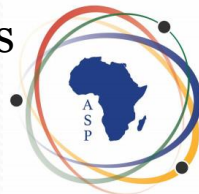


**Gerd Binnig**

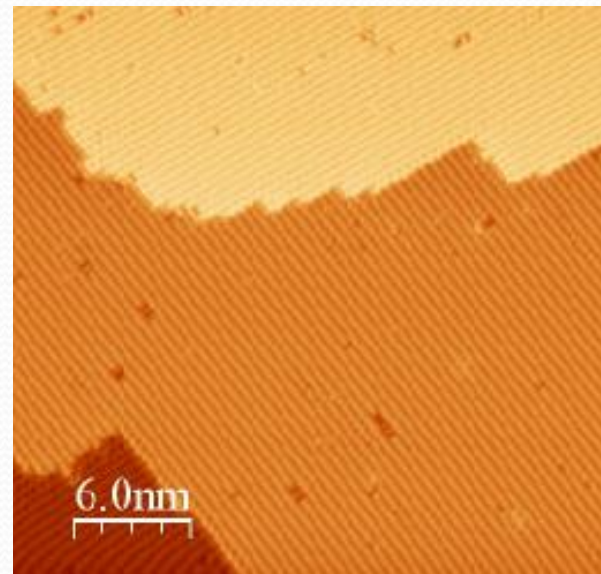
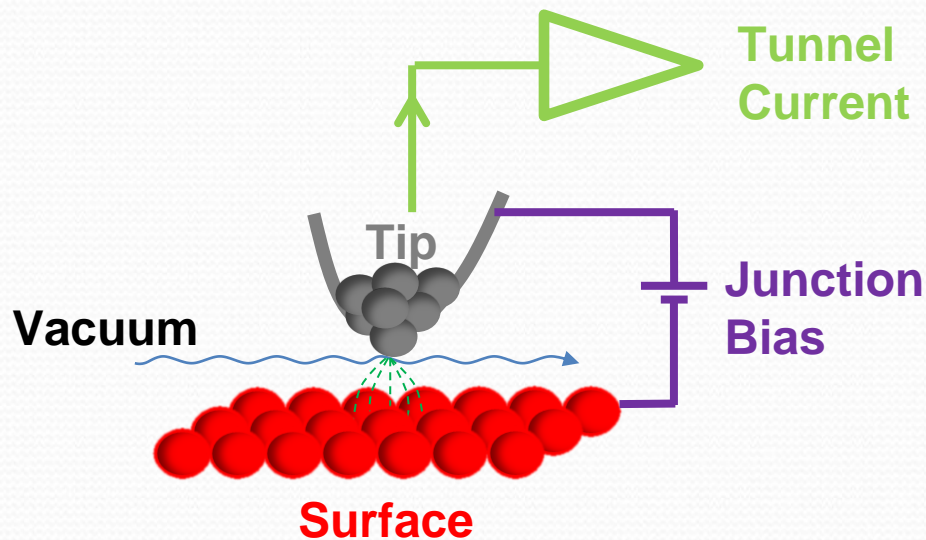


**Heinrich Rohrer**

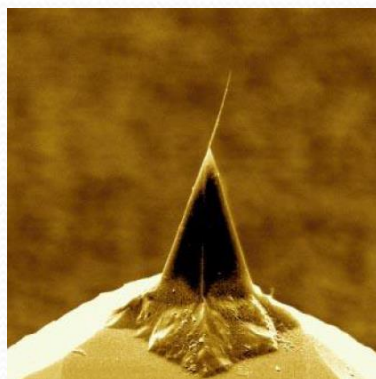
Their work helped visualize individual atoms through the probing of surfaces



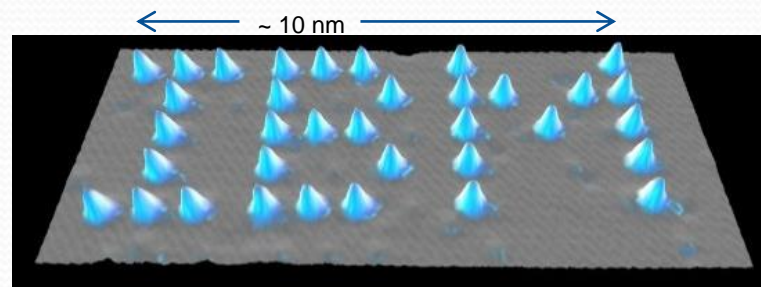
# Scanning Tunneling Microscopy: A Revolution for Tunneling



Imaging



STM tip



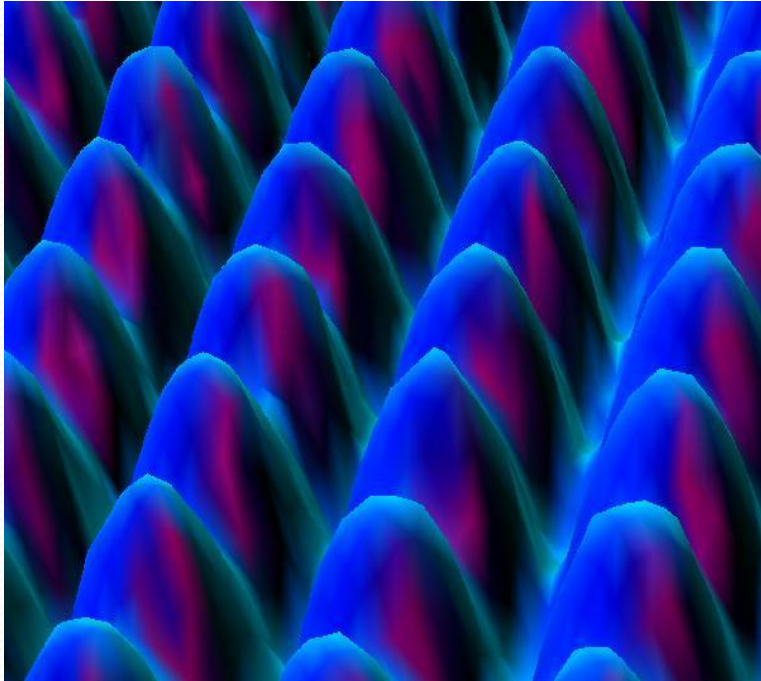
*Eigler, D., Nature 344, 524 (1990)*

Atomic manipulation



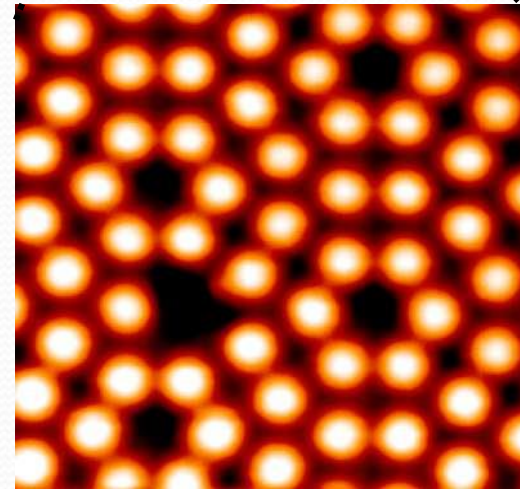
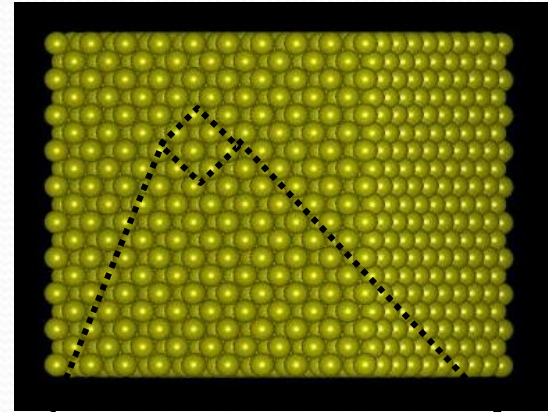
# STM observing surfaces

Nickel



↔  
3 Angstroms = 0.3 nm

Silicon



STM of Si(111) 7 x 7 reconstruction

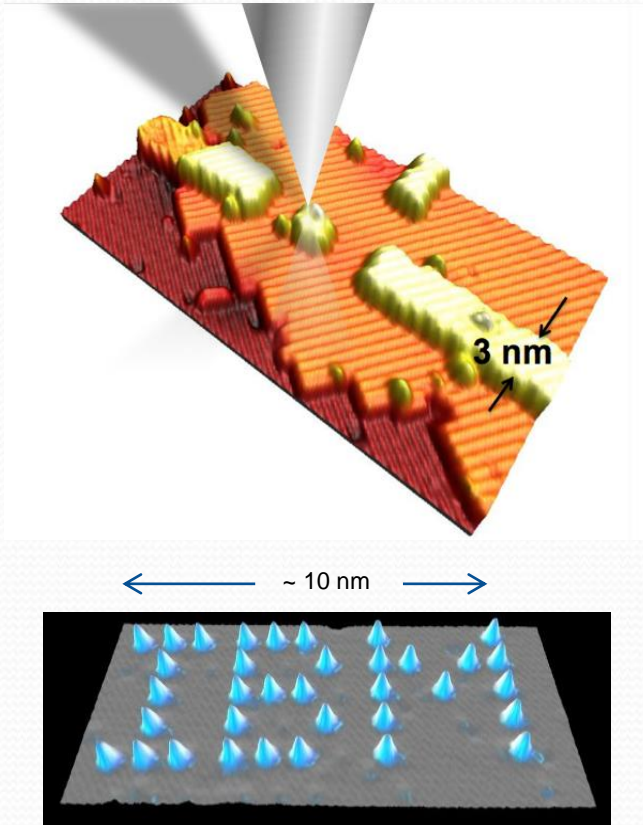




# Nanofabrication: Writing Devices

## Pick and Place

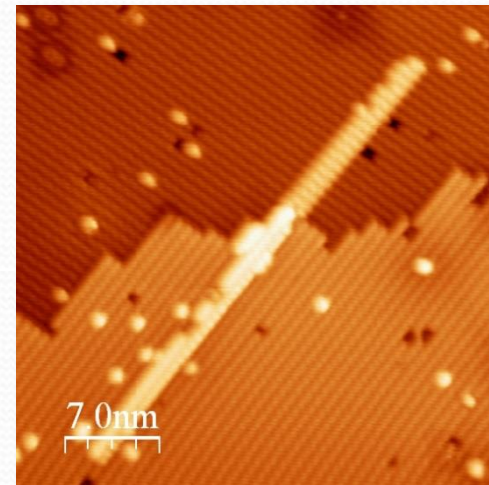
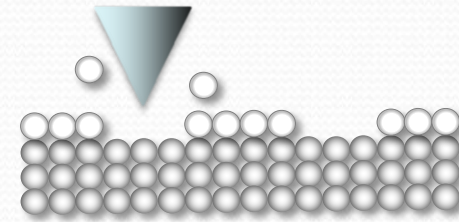
STM assisted nanofabrication



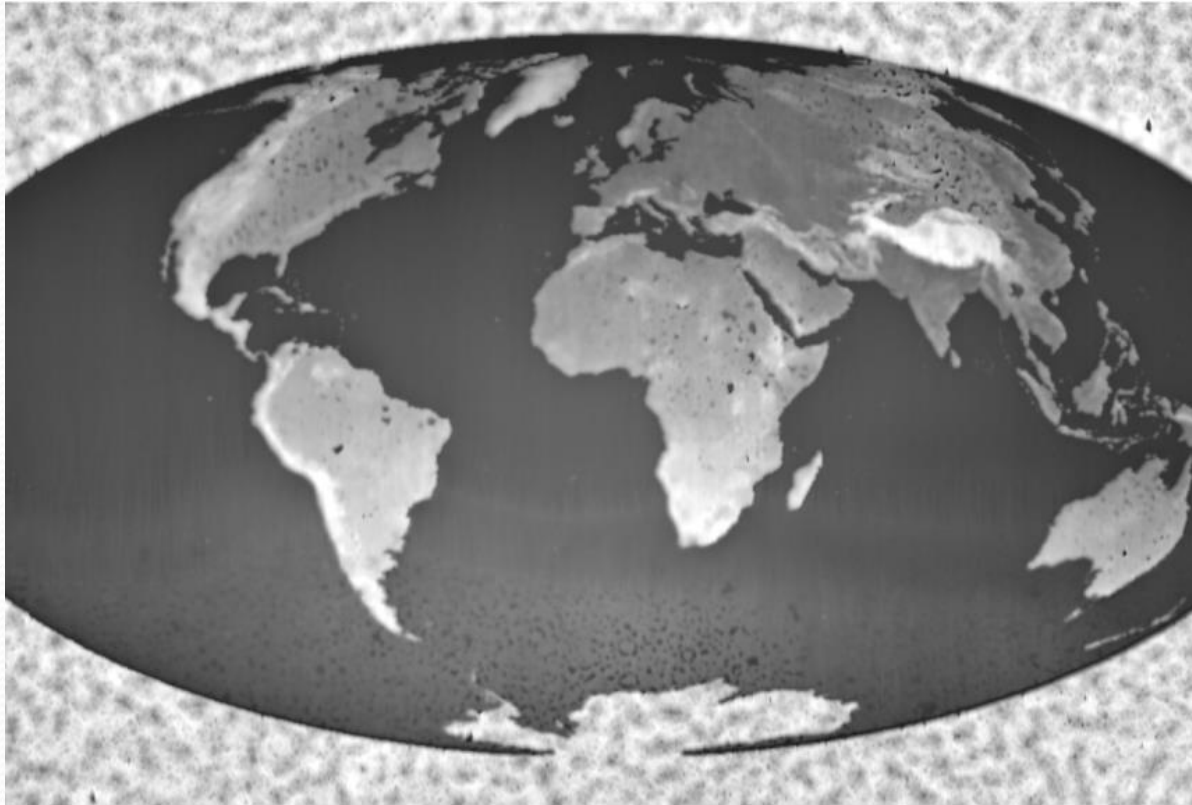
*Eigler, D., Nature 344, 524 (1990)*

Atomic manipulation

## Write ...



# The World's Smallest Map

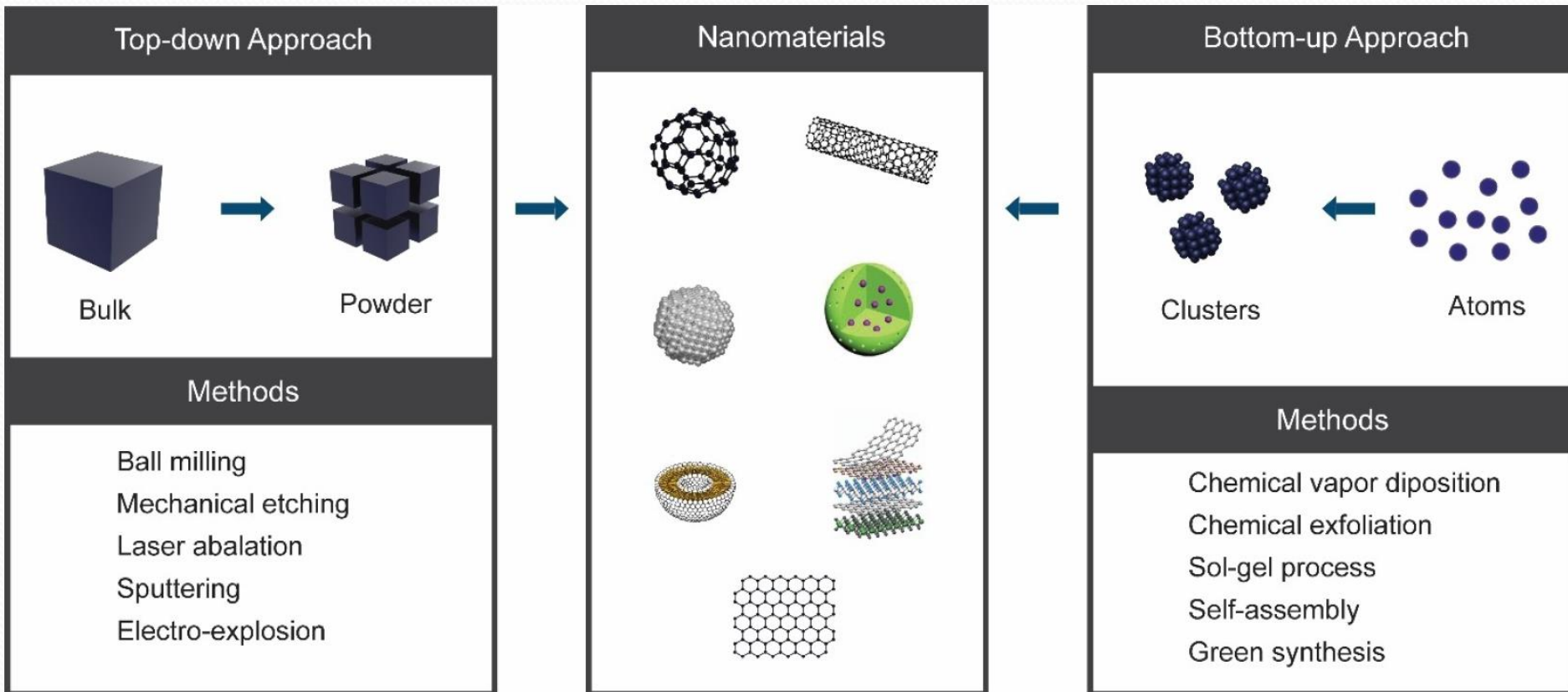


22  $\mu\text{m}$   $\times$  11  $\mu\text{m}$  3D map written on a polymer  
IBM, 2012



# Approaches

- **Top-Down:** Starting from larger structures and breaking them down into smaller components
- **Bottom-Up:** Building from individual atoms and molecules to create functional systems



# Nanotechnology – Tools & Technology

- There are several important modern developments
  - Atomic Force Microscopy (AFM)
  - Scanning Tunneling Microscopy (STM)
- Advances in nanolithography
  - X-ray lithography
  - Dip-pen nanolithography
  - Electron beam lithography (inkjet printer)
- Advances in deposition techniques
  - PVD, ALD, ALE, ASD, CVD, PLD



# Nano → New Shapes and New Properties = Good

- Optical properties
- Magnetic properties
- Mechanical properties
- Surface reactivity
- Melting point
- Specific heat
- Conductivity
- Biocompatibility



*Stained glass window in a church*



*Evident Technologies*

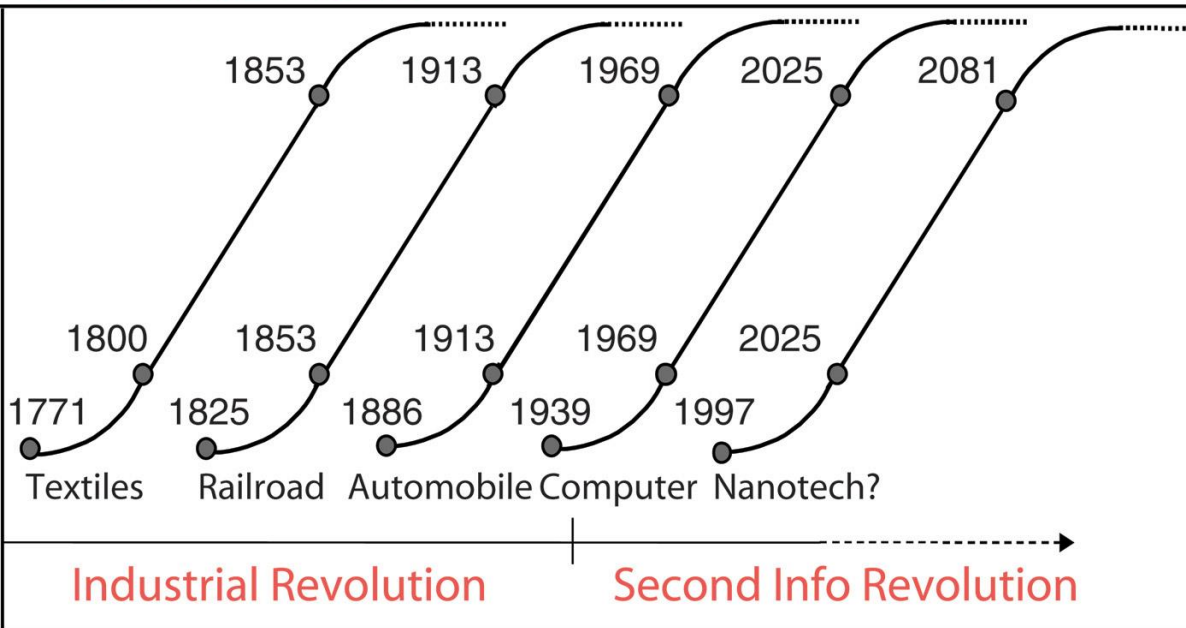


*Maya warrior, The Cleveland Museum of Art, 250 – 900 AD*

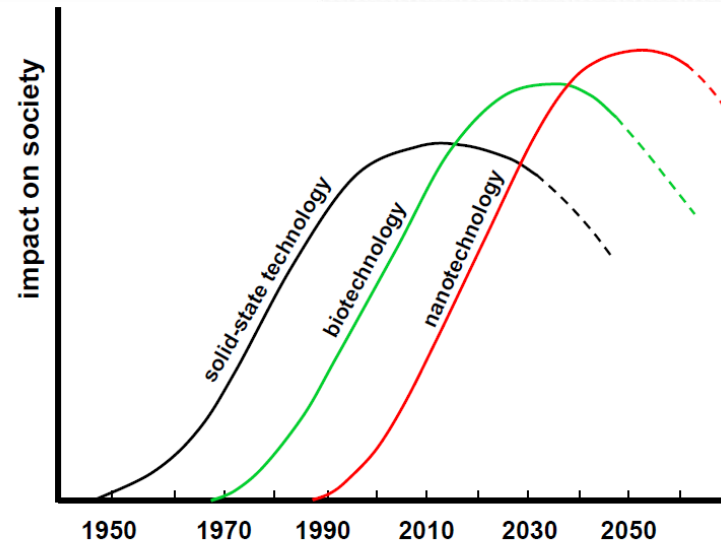


# Nanotechnology Growth

## Growth Innovations



Sources: Norman Poire, Merrill Lynch



A. ten Wolde: "Nanotechnology; towards a molecular construction kit", Netherlands Study Centre for Technology Trends (STT), 1988



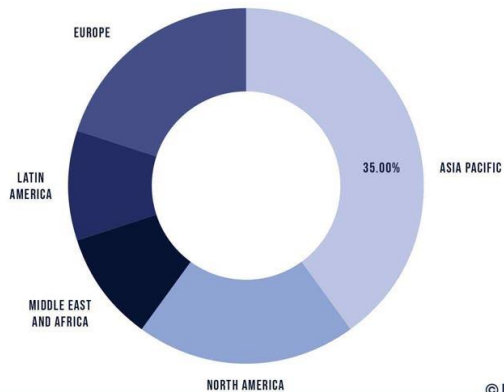
# Predicted Global Market Growth

PRECEDENCE  
RESEARCH

## NANOTECHNOLOGY MARKET SIZE, 2021 TO 2030 (USD BILLION)



## NANOTECHNOLOGY MARKET SHARE, BY REGION, 2022 (%)



© PRECEDENCE RESEARCH



# Nanotechnology → Multidisciplinary

Chemical  
engineering

Biology

Industrial  
engineering

Physics

Electrical  
engineering

Medicine

Chemistry

Materials Science

Forestry

Mathematics

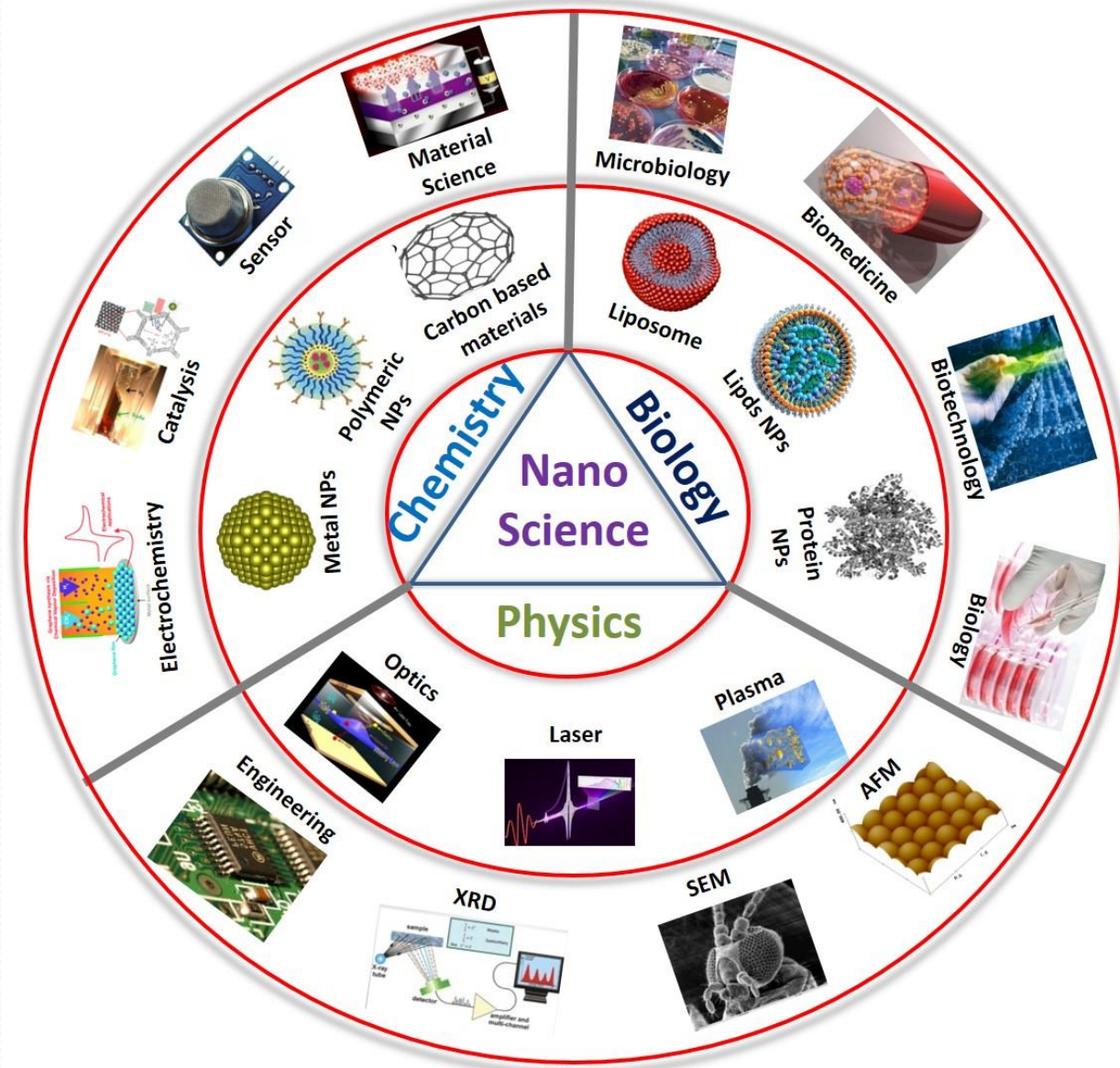
Food Science

Mechanical  
Engineering

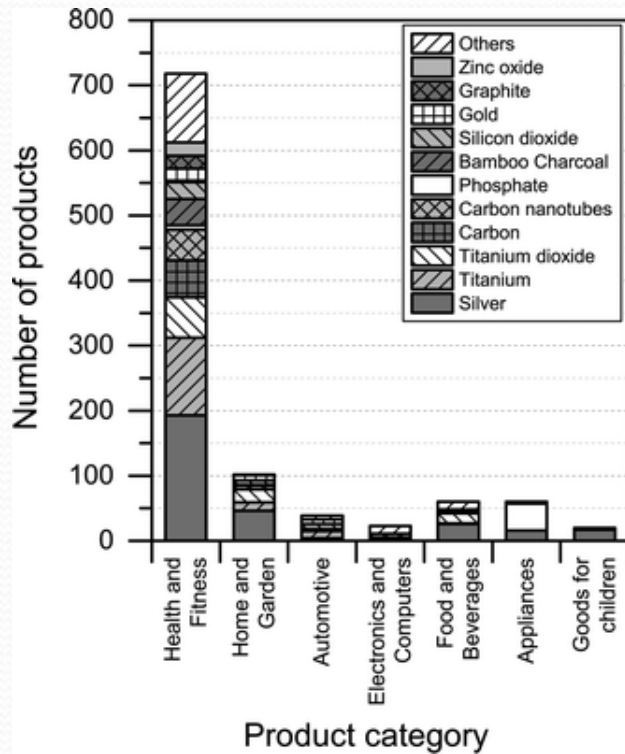




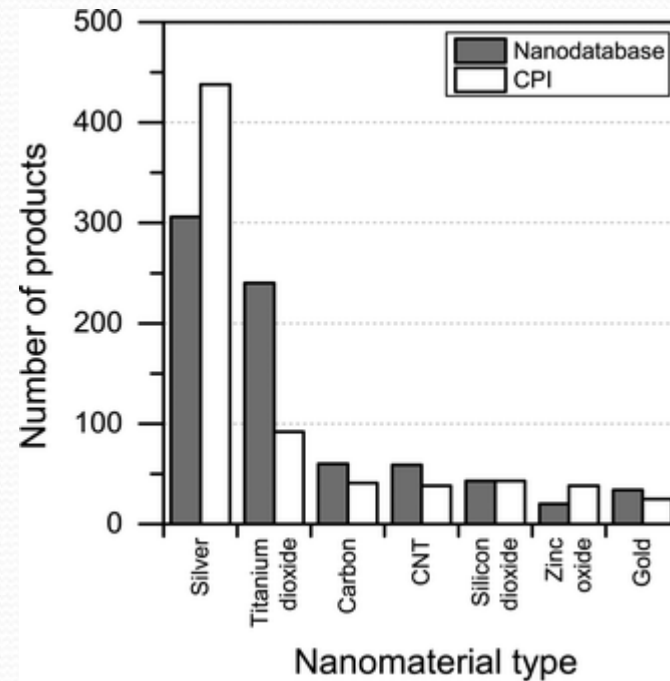
# Nanotechnology → Multidisciplinary



# Materials in Use



Identity of nanomaterials claimed to be used in different product categories



Silver is a powerful anti-microbial agent and more than 300 products use nanoscale silver to make anti-bacterial surfaces, cosmetics, and clothing.

Hansen, S., et al., *Environ. Sci. Nano*, 2016, 3, 169-180



# Examples of the Use of NanoSilver: Almost Everywhere ...



Nano silver beauty soap



Nano silver hair shampoo



Nano silver body cleanser



Nano silver toothpaste



Nano silver hand sanitizer



Nano silver facial mask sheet



Nano silver skin care line



Nano silver makeup line



Nano silver wet wipes



Nano silver disinfectant spray



Nano silver toothbrush



Nanosilver hair conditioner



Nano silver wash dish & laundry detergent



Nano silver colloid



Nano silver antimicrobial masterbatch

# Some Uses of Nanotechnology



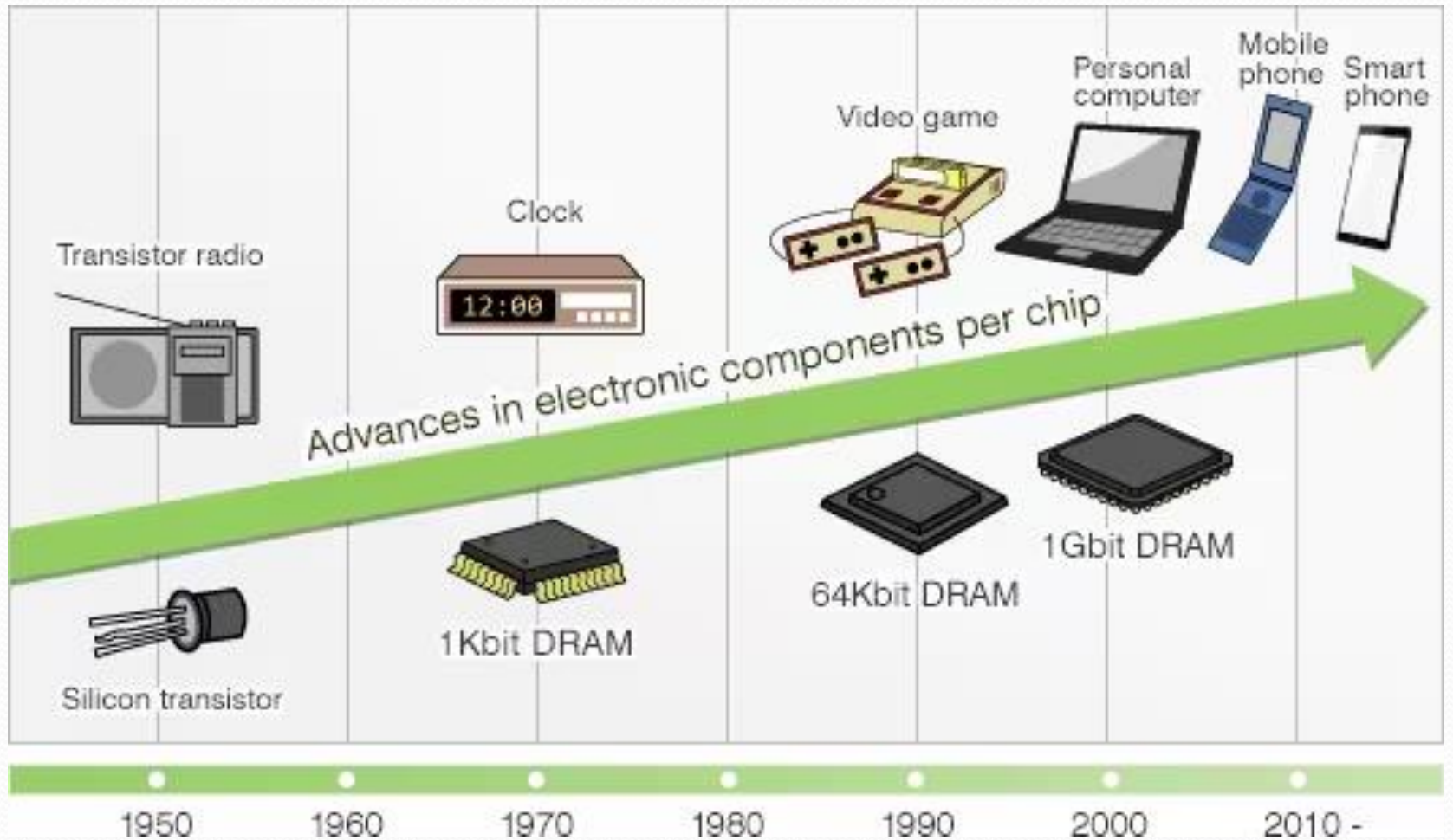
1. Organic light emitting diodes (OLEDs) for displays;
2. Photovoltaic film that converts light into electricity;
3. Scratch proof coated windows that clean themselves with UV;
4. Fabrics coated to resist stains and control temperature;
5. Intelligent clothing measures pulse and respiration;
6. Bucky-tubeframe is light, but very strong;
7. Hipjoint made from biocompatible materials;
8. Nano-particle paint to prevent corrosion;
9. Thermo-chromic glass to regulate light;
10. Magnetic layers for compact data memory;
11. Carbon nanotube fuel cells to power electronics and vehicles;
12. Nano-engineered cochlear implant.



# Consumer Products

- **Nanoelectronics** → XBOX One by Microsoft; Intel hard drives.
- **Nano air filters** → NanoBreeze Car Air Purifier by NanoTwin Technologies Inc.
- **Cosmetics** → TiO<sub>2</sub> or ZnO nanoparticles are used in sunscreens.
- **Clothing** → Swimsuits, rain jackets, body armor, stain-repellant fabric.
- **Nanochocolate** → Nanoceuticals Slim Shake Chocolate by RBC Life Sciences, Inc.
- **Nanocomposites** → BMC Racing Fourstroke FS01 (BMC Cycling); light tennis rackets; artificial muscles.
- **Targeted imaging probes** → CellTracks [Immunicon Corporation].





# Applications of Nanotechnology in Medicine

## Nanotechnology in Medicine

Prevention and  
Control of Cancer

Multifunctional  
Therapeutics

Imaging  
Diagnostics

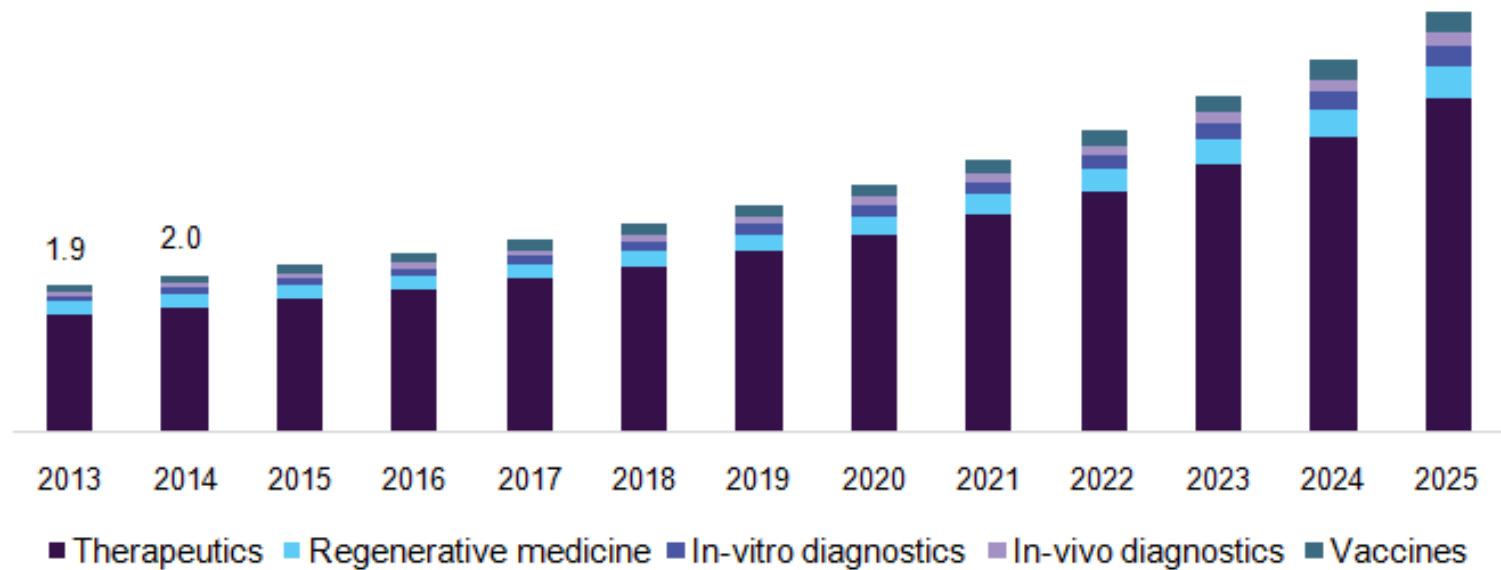
Early Detection  
and Proteomics

Interdisciplinary  
Training



# Growth of Nanomedicine

U.S. Nanomedicine market by products 2013 – 2025 (\$Billions)

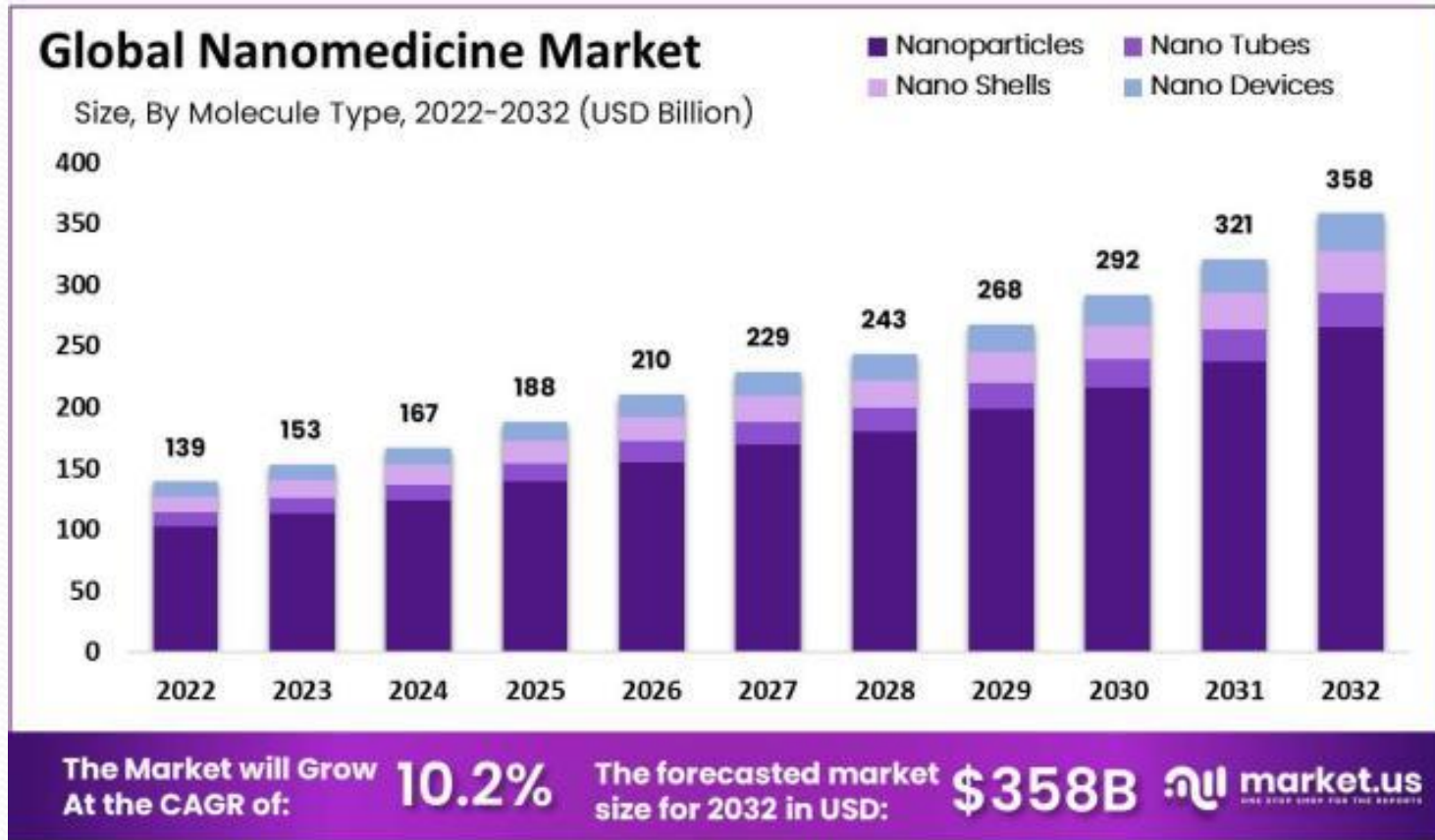


Grand View Research, Market Research Report (2017)





# Global Nanomedicine Market



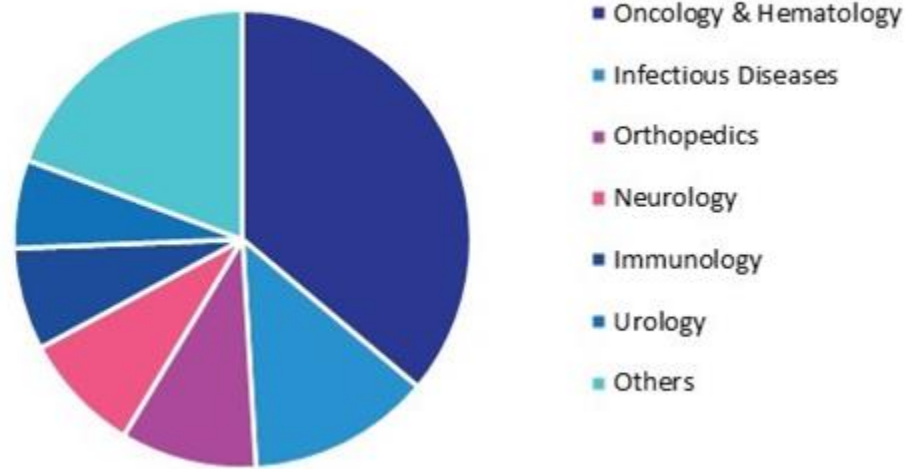
Yahoo Finance (2022)



# Global Nanotechnology Drug Delivery Market

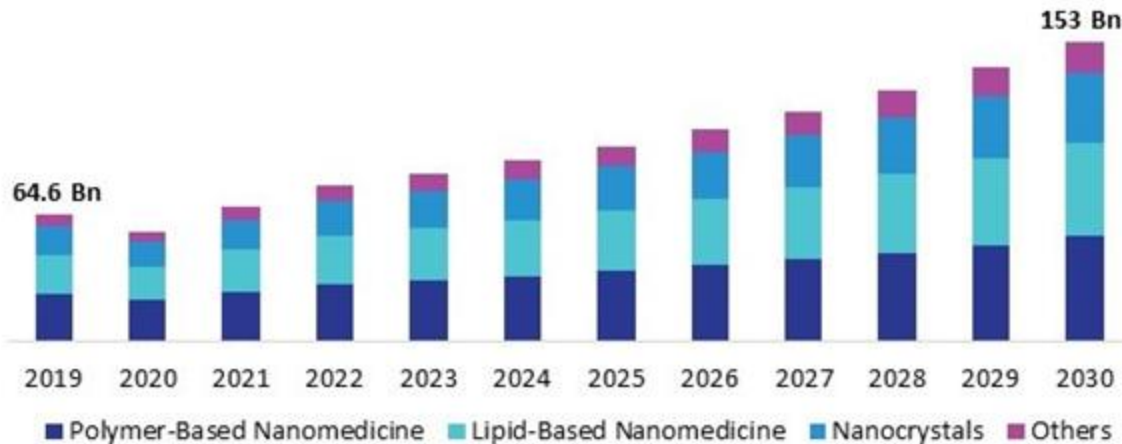
## Global Nanotechnology Drug Delivery Market

Share, by Application, 2022, (%)

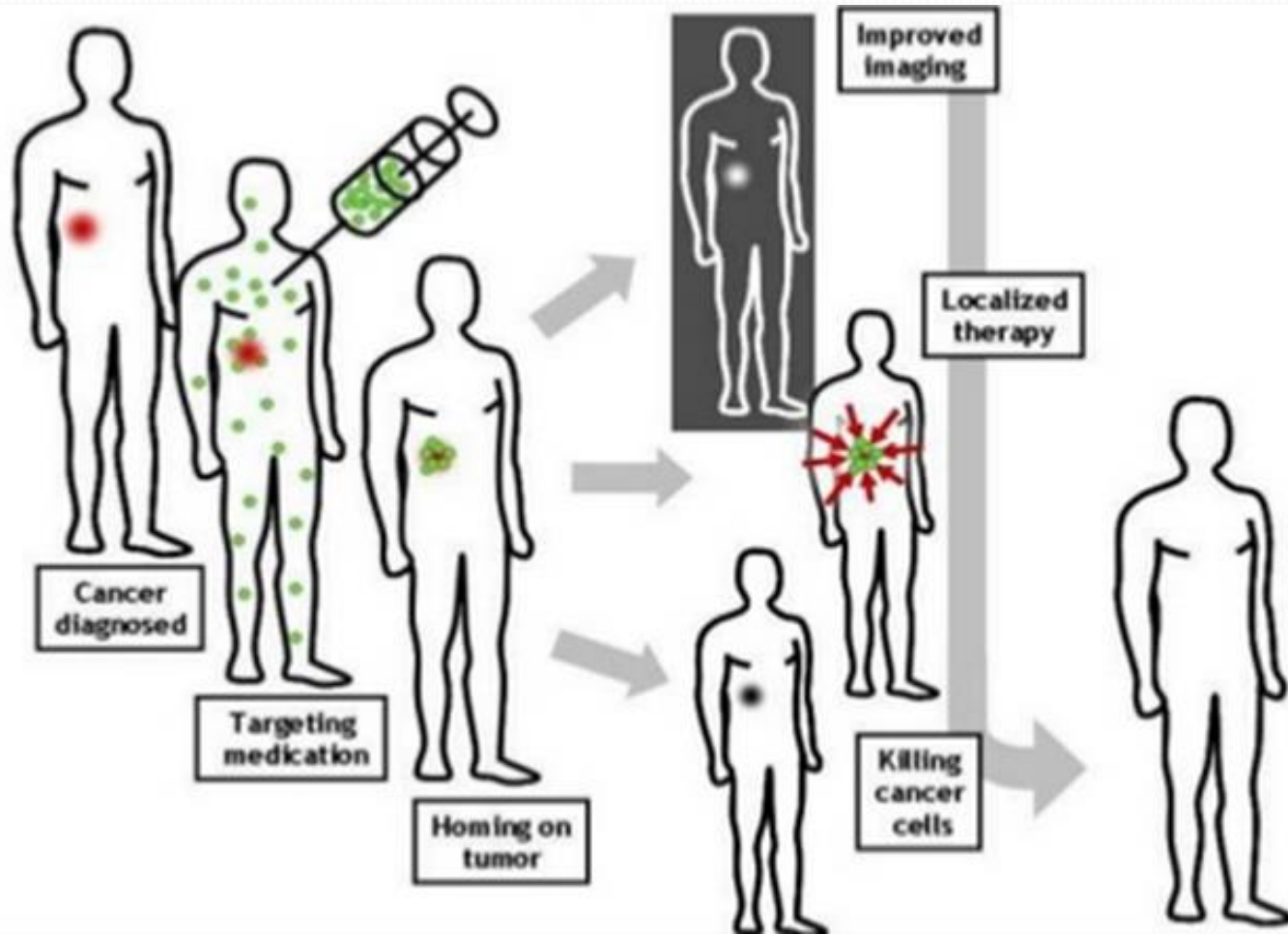


## Global Nanotechnology Drug Delivery Market

Size, by Formulation, 2019 - 2030, (USD Billion)



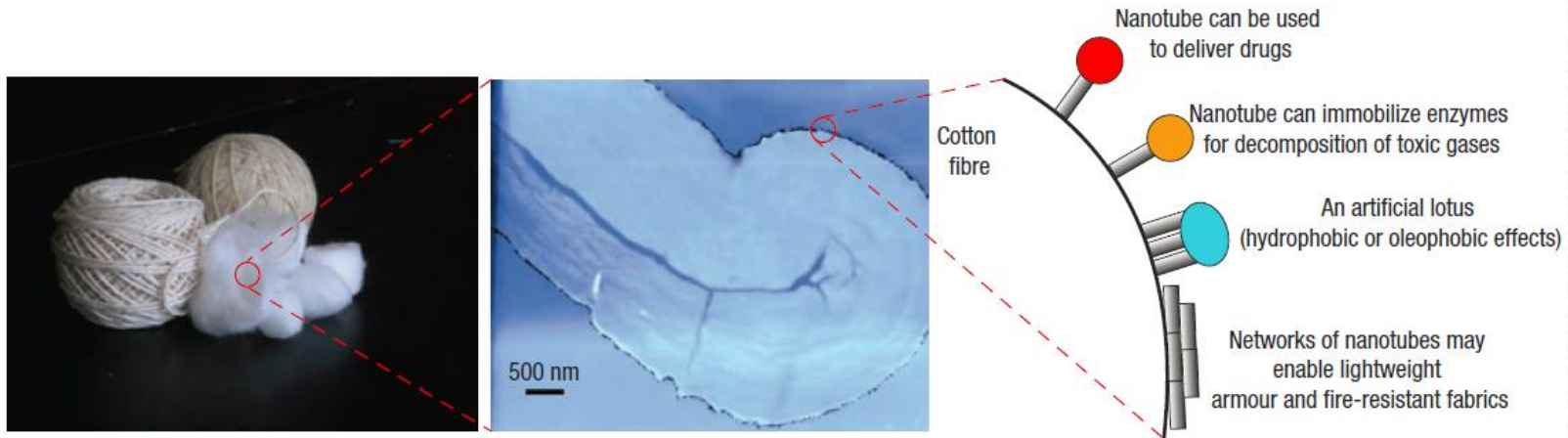
# Example of Medical Application: Molecular Imaging and Therapy



Wikipedia



# Nanotechnology in Textiles

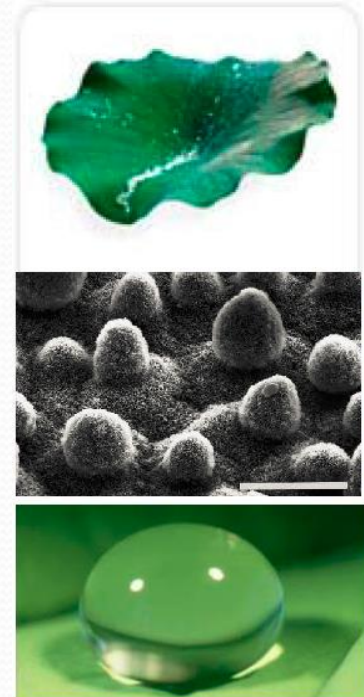


A. Avila et al., *Nature Nanotechnology* 3, 458 (2008)



Yetisen, A.K., *ACS Nano* (2016) 10, 3, 3042

## Lotus Effect



<http://www.nanoprotect.co.nz/>

# In Essence, Nanotechnology in Textiles ...





Toyota Center, home of the NBA Houston Rockets, nanotechnology-treated upholstery for stain-resistance and easy cleaning

M. Gurian, Upholstery Journal Feb/Mar(2009)



The intelligent knee sleeve is a bio-feedback device monitoring the knee joint

S. Coyle et al. MRS Bulletin 32, 434 (2007)



Lumalive textile from Philips features flexible arrays of colored LED fully integrated to the clothes



# Nanotechnology in Sports



AP photo 1 July 2024

Tennis /  
Badminton

Golf

Kayaking

Archery

Skiing

Cycling

Fly-fishing

Carbon  
nanotubes

Silica  
nanoparticles

Fullerenes

Carbon  
nanofibers

Nano clay

Enhance stiffness  
and durability

Reduce the  
vibration impact

Reduce weight

Improve crack  
resistance

Better vibration  
control in arrows

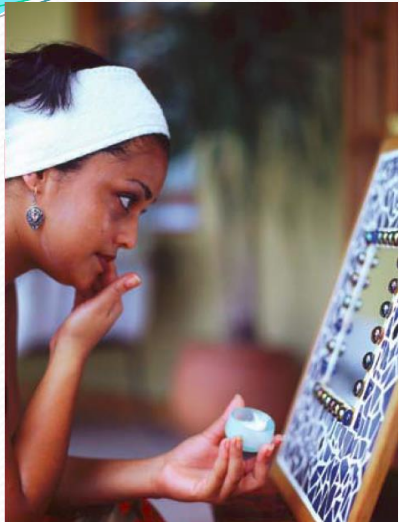
Enhance hoop &  
strength

Improve  
flexibility

Increase  
bouncing of balls

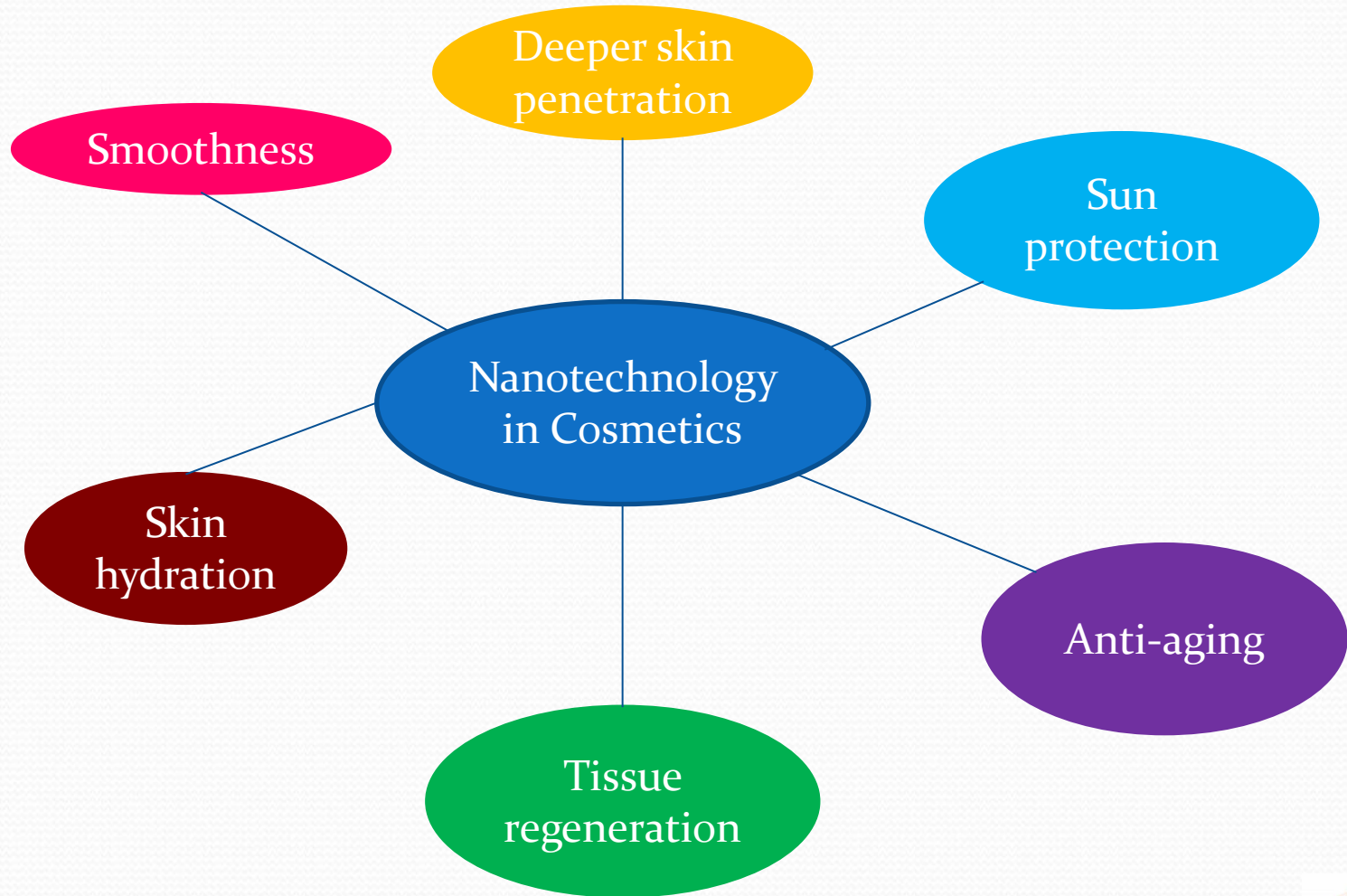


# Nanotechnology in Cosmetics





# Nanotechnology in Cosmetics

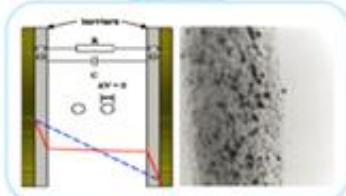
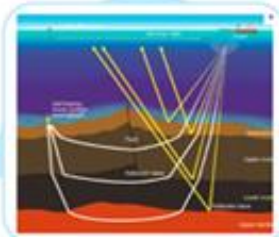


# Nanotechnology in the Oil Industry

## Nanotechnology for enhanced oil recovery

### SEISMIC SURVEYING

- New seismic survey that provides information about the fracturing of the oil reservoir
- Development of impulsive source elements for marine seismic surveying



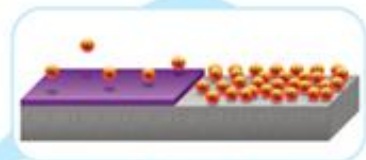
### ELECTROCOALESCENCE

- Water/Oil separation by electric field



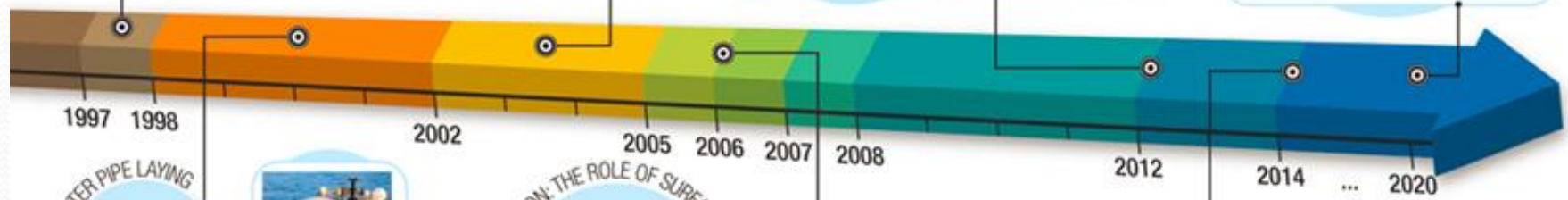
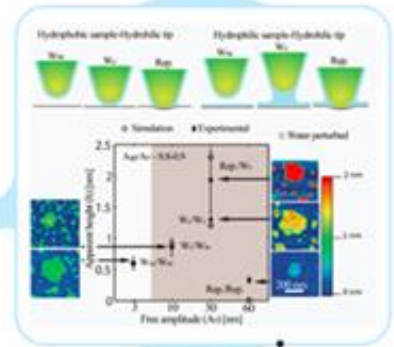
### NANO-COATING

- Anti-fouling coatings
- Thermal coatings
- Lubricant coatings
- Anticorrosion coatings



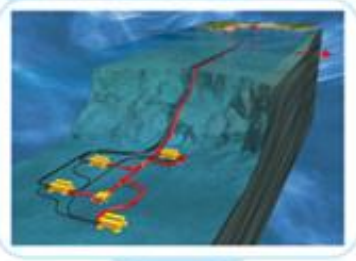
### CAPILLARY INTERACTIONS

- Microwave excitation of the oil reservoir for EOR



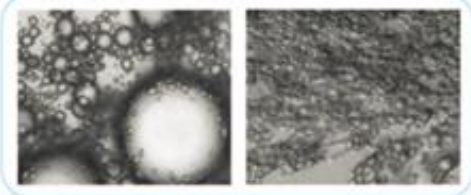
### DEEP WATER PIPE LAYING

- Linking advanced fracture model to structural analysis



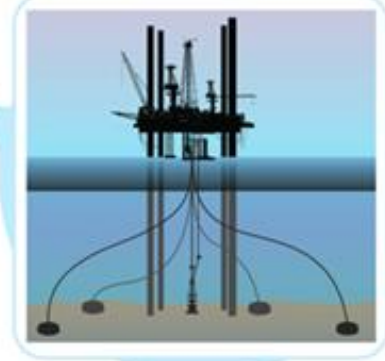
### WATER/OIL SEPARATION: THE ROLE OF SURFACE SCIENCE

- Understanding surface chemistry of oil and water, knowledge inherited to LENS from previous industrial experience

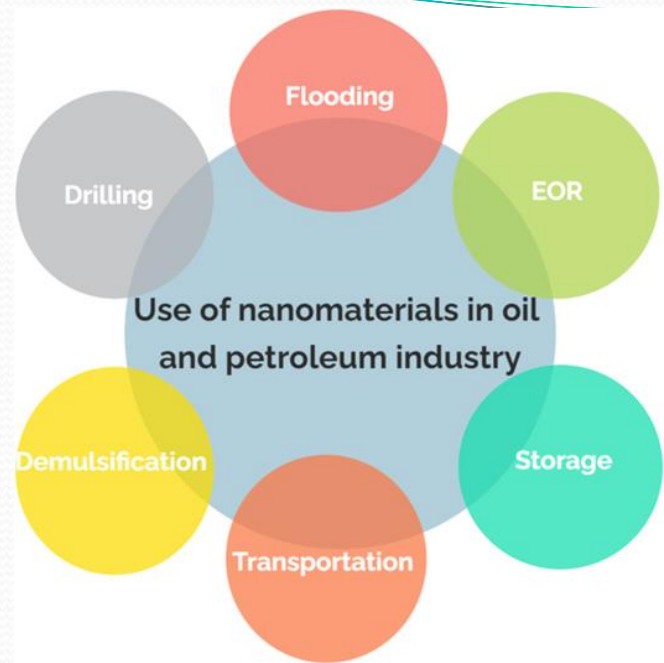


### RESERVOIR SURVEILLANCE

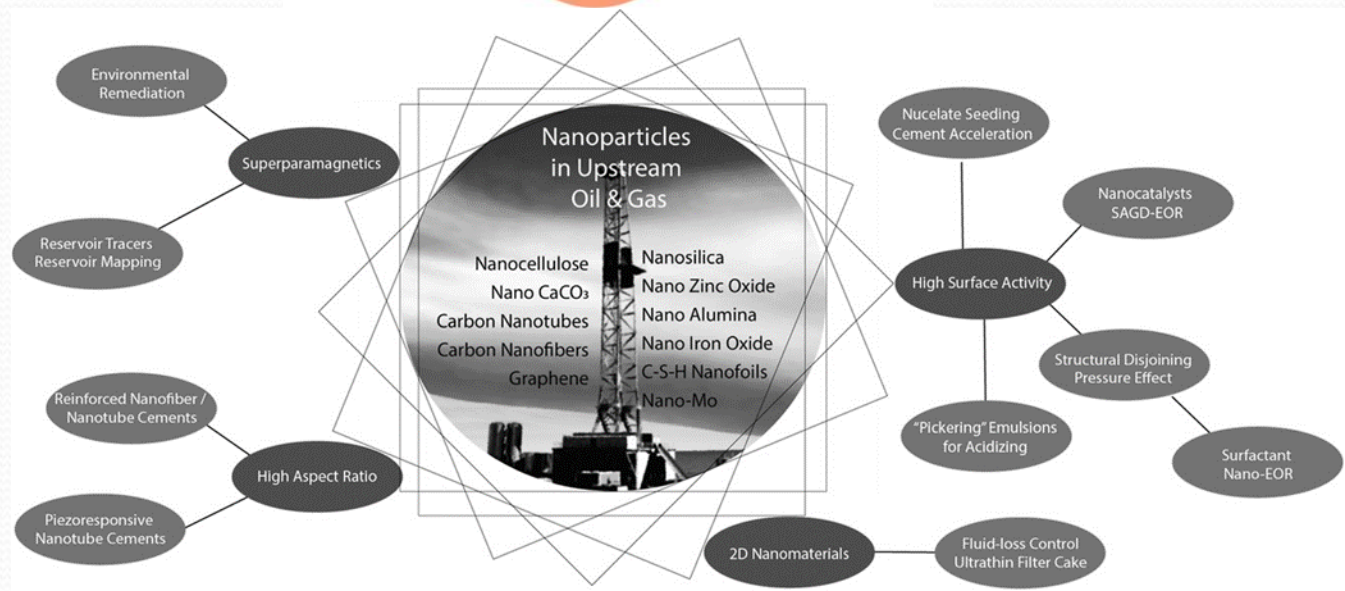
- Nanoparticle injection to monitor water breakthrough



# Use of Nanomaterials in the Oil & Petroleum Industry



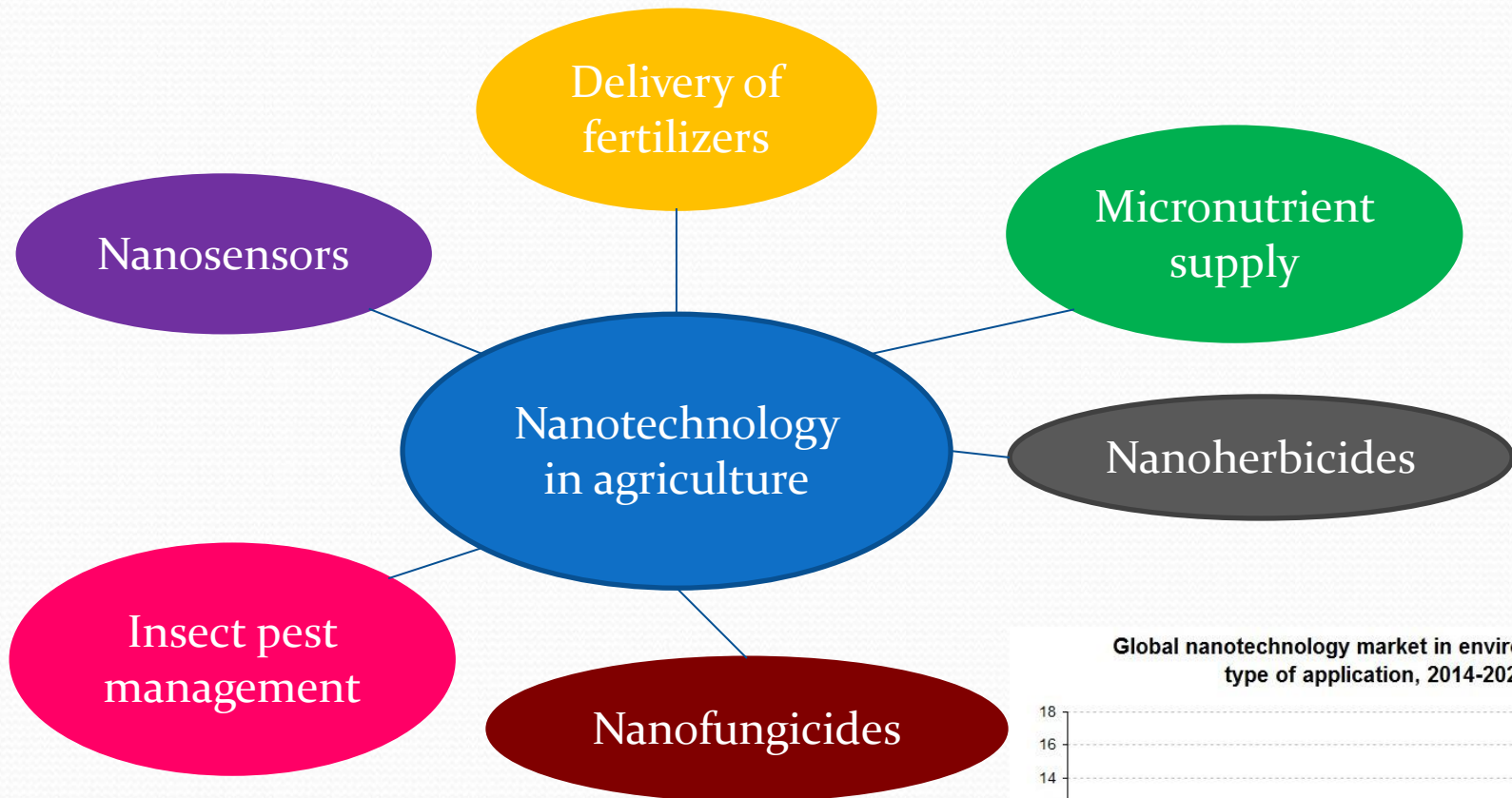
Roy, A., et al Nano Ex. 4, 022002 (2023)



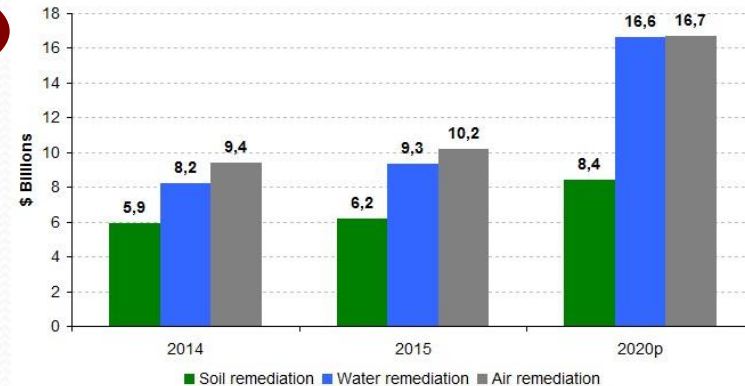
Boul, P.J., et al., Energy Tech, 8, 1, (2019)



# Nanotechnology in Agriculture



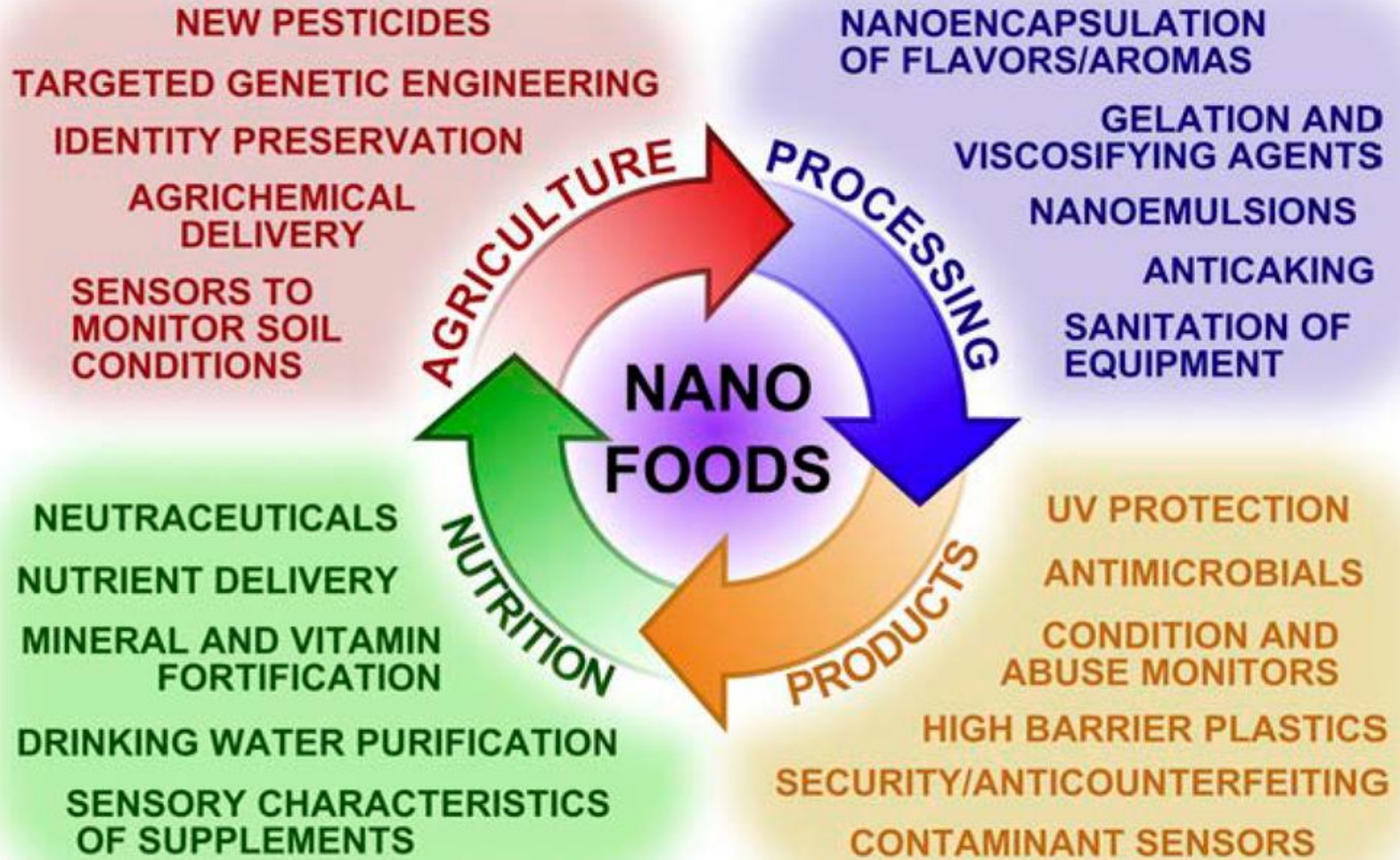
Global nanotechnology market in environmental, by type of application, 2014-2020



p = projections

Sources : BCC Research, July 2009 and November 2015.

# Nano-Foods



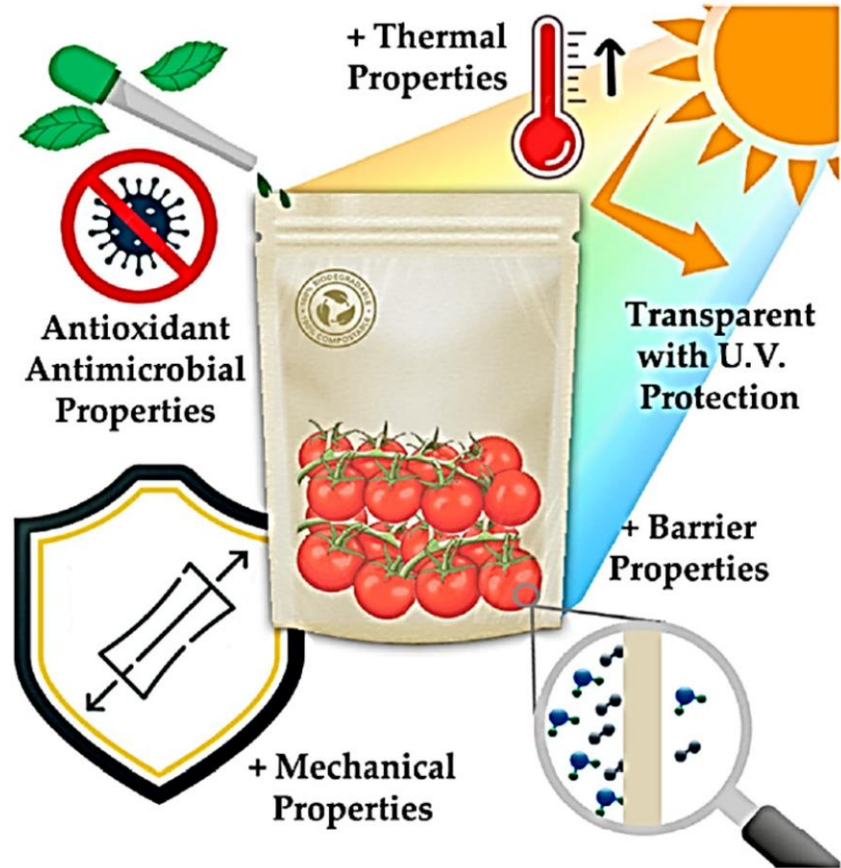
# Nanotechnology – Enhancing Food Packaging Solutions



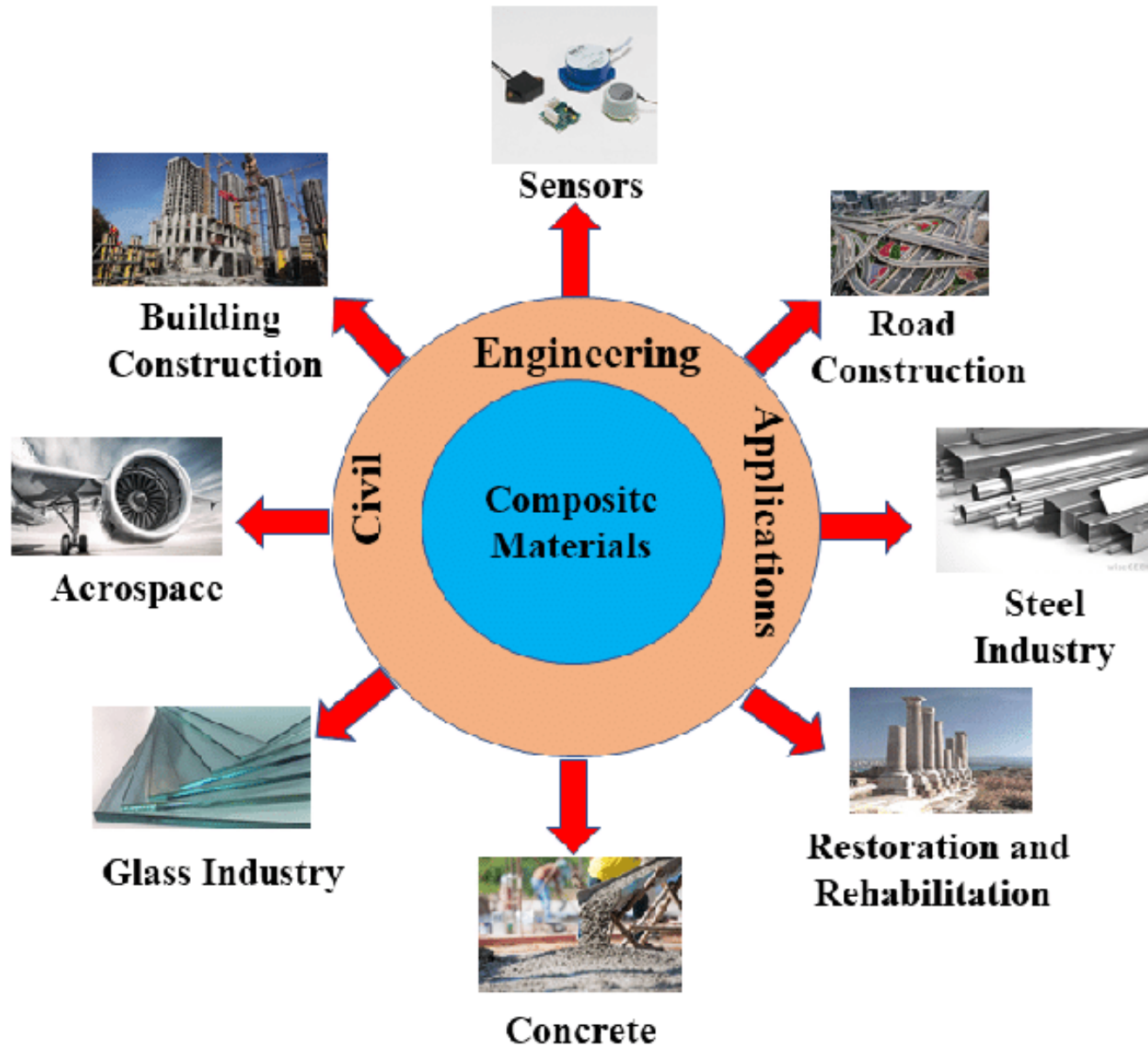
**Traditional  
Plastic Packaging**



**Bionanocomposite  
Packaging**



# Nanotechnology in Construction



# Nanotechnology in Construction

Self-healing  
concrete

Nano-fiber  
reinforced  
concrete

Improved  
durability

Energy  
efficient  
buildings

Fire resistance

Smart  
windows

Lightweight  
materials

Structural  
health  
monitoring

Seismic &  
tsunami proof

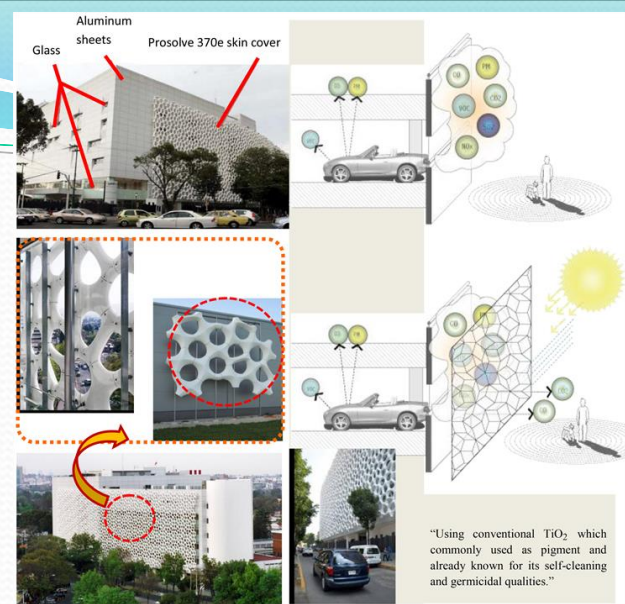
Air  
purification



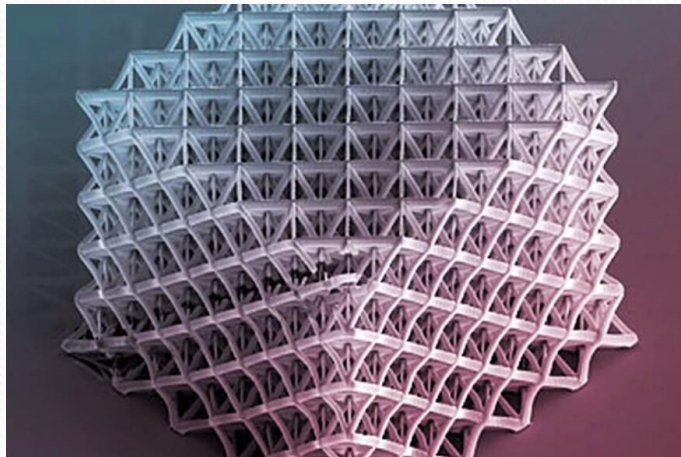




The Jubilee Church in Rome,  
[quartiermagazin.com/quartier08/der-weise-riese](http://quartiermagazin.com/quartier08/der-weise-riese)



Manuel Gea Gonzalez Hospital using conventional  $TiO_2$ —CNN



A nanotruss structure fabricated by Caltech Prof. Julia Greer



MIT Scientists Create Smart Window that Can Shut Out Light (futurism.com)



Inside Ethiopian airlines flight – Boeing

# NanoProducts

Where is it used?



Future use?



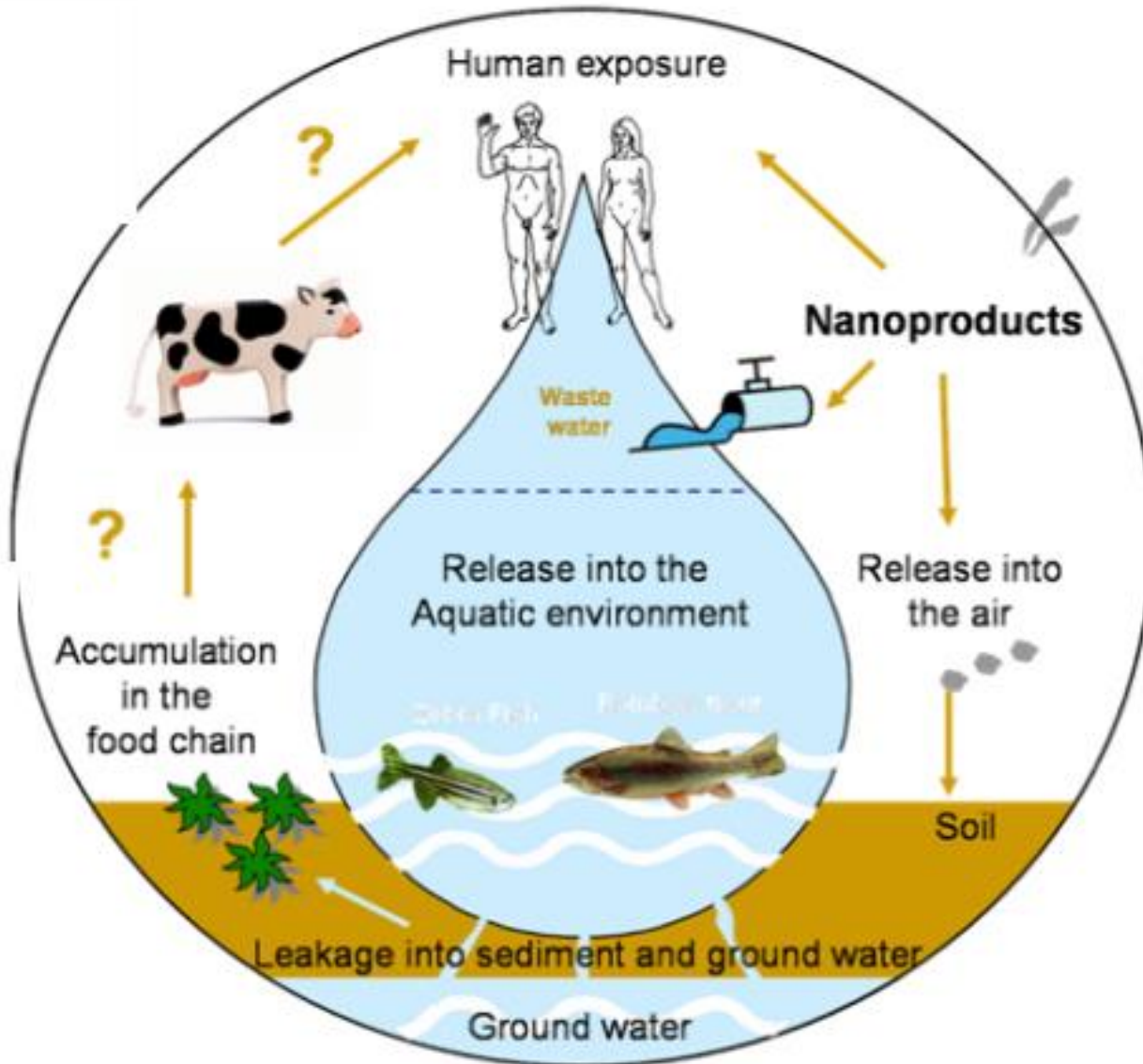
How do you dispose of it?



A user's guide to Nanotechnology  
<http://www.theguardian.com/nanotechnology-world/a-user-s-guide-to-nanotechnology>



# Risks: Toxicity, Assessment, Exposure



Exposure routes in humans?

Reaction with the environment ?

Primary issues

Detection techniques

Solutions



# Discussion Points

- What will be the impact of nanotechnology in Africa?
- What areas/fields will be impacted?



# Nanotechnology in Africa

*The African Union recognizes nanotechnology as a compelling imperative and identifies nanotechnology as one of six priority areas in its Science, Technology and Innovation Strategy for Africa 2024.*



# Nanotechnology in Africa

Synthesis of nanoparticles

Nanophase catalysts  
and electro-catalysts

Synthesis of  
quantum dots

Development of better and  
cheaper solar cells

Fuel cell  
development

Synthesis of  
nanotubes

Composites  
development

Human and  
animal health

Nanotechnology  
and occupational  
health

Water purification

Nutrition



# Nanotechnology in Africa



## Egypt

Top nanotechnology research country in Africa – Big collaboration with IBM (health, oil, photovoltaics,...)

## South Africa

African country with the most patents, nanotech emerging companies & institutions, SANi

## Nigeria

Nanotechnology in medicine, nutrition, electronics, catalysis

## Kenya

Efforts focus in medicine, agricultural productivity, water treatment, purification

## Ethiopia

Water purification, nanomaterials, solar energy and single-walled carbon nanotubes

## Senegal

Synthesis, characterization, & application of nanomaterials

## Tanzania

Nanotechnology for human and animal health and in biotechnology

## Sudan

Synthesis & characterization of nanomaterials, and drug delivery

## Cameroon

Synthesis & characterization of nanomaterials, water purification and treatment

*African Newsletter on Occupational Health and Safety, 22, 3 (2012)*

*All African Nanoscience-Nanotechnology Initiative (2014)*

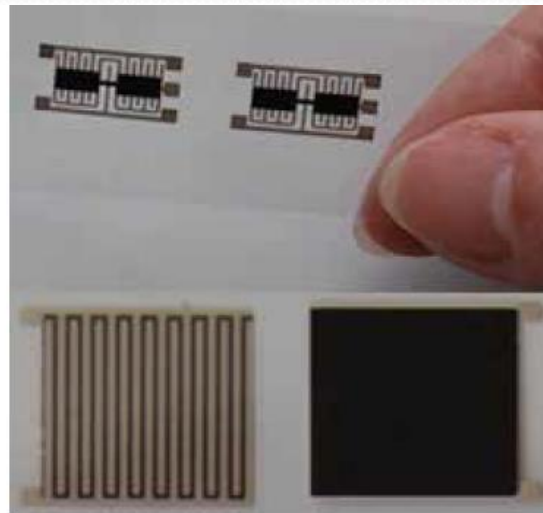
*Towards an African nanotechnology future, United Nations, Economic Commission for Africa (2020)*



# Nanotechnology in Africa: Some Examples



Water purification plant in Tanzania



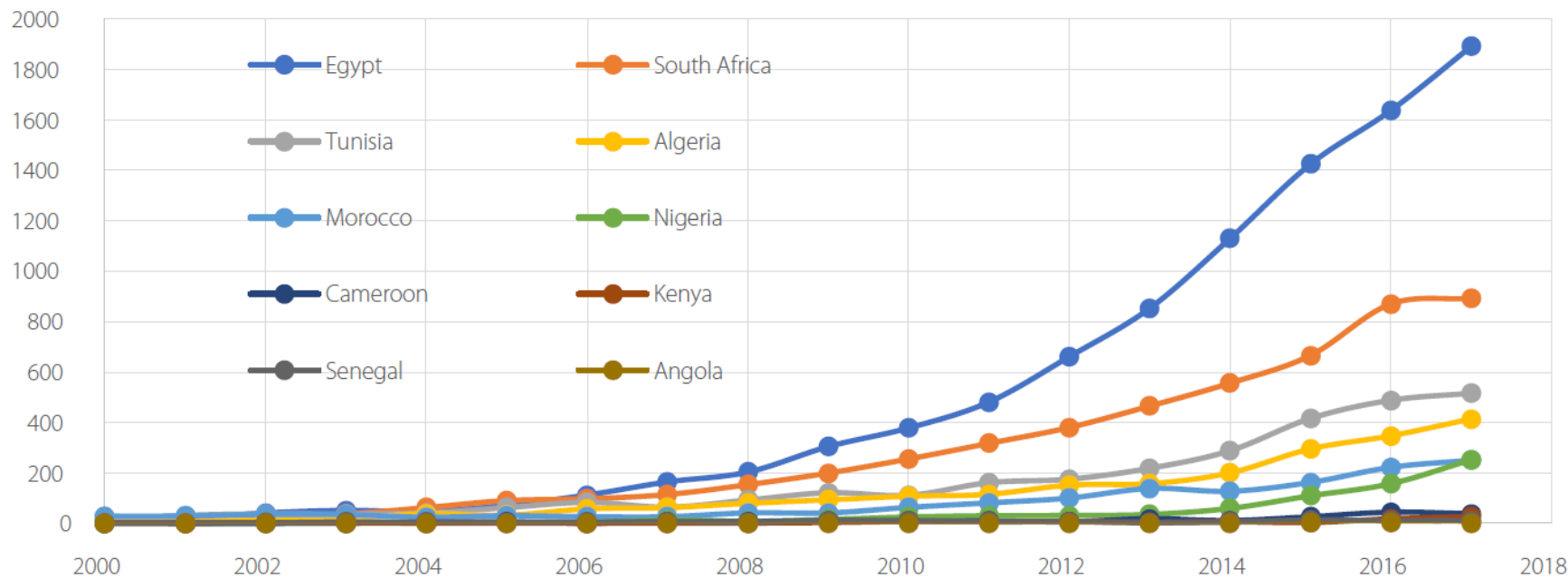
Heat sensors using innovative technology in South Africa



NanoTech in Egypt manufacture custom-tailored nanomaterials



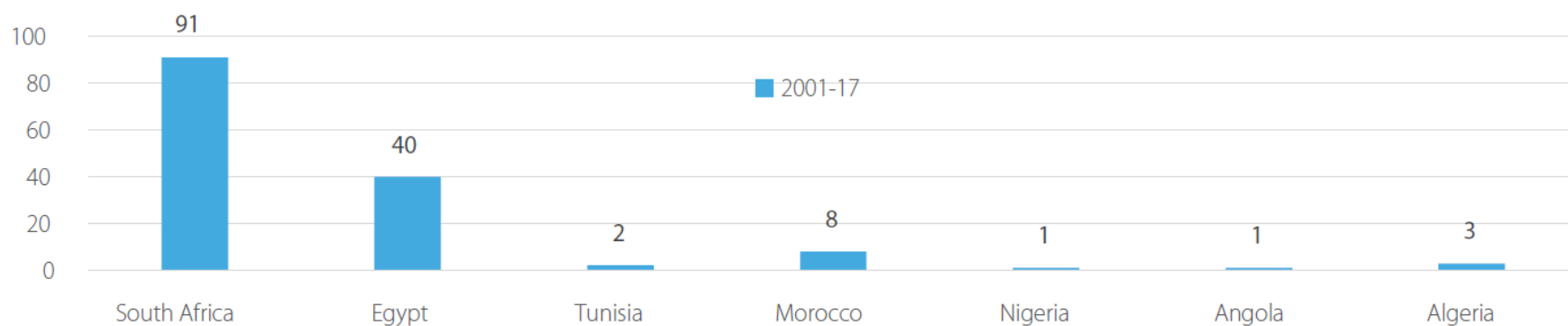
# Nanotechnology Publications in Top 10 African Countries



Source: NanoStat database.



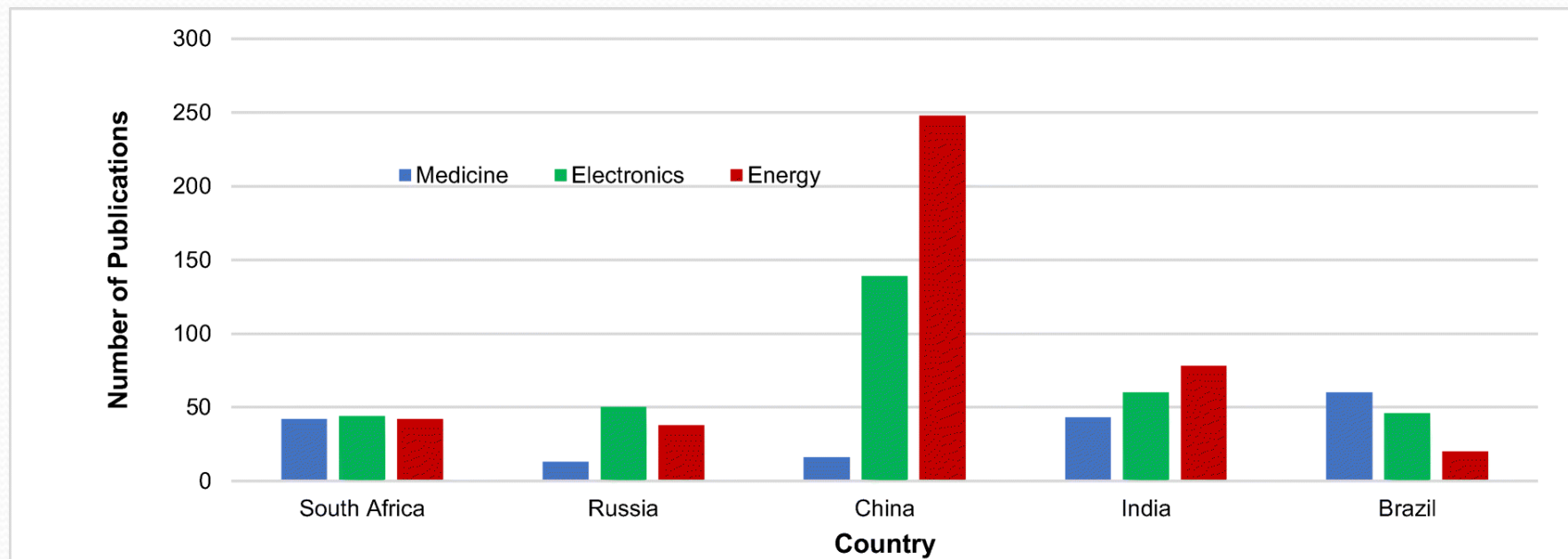
# Patent Applications per Selected African Countries (2001 – 2017)



**Source:** NanoStat database.



# Number of Publications Nano-related in the BRICS (2021)



South Africa publications reporting on nano-enabled products relative to BRICS countries, Masara, B., J. of Nanoparticle Res., Vol. 23, 92 (2021)



# Strategy for Nanotechnology Innovation in Africa



*Jhurry, D., Univ. World News, Africa Edition (2022)*



# Water Purification

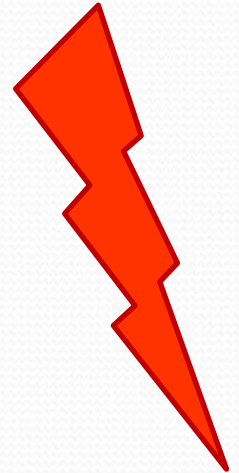


Mining



*wikipedia.*

Effects on population



Nanofiltration membranes

Nanocatalysts and magnetic nanoparticles

Nanosensors



# How Nanotechnology saved a Contaminated Lake in Peru

El Cascajo Wetlands in Peru were cleaned using micro nano bubbling system and a biofilter



Marino Morikawa

<http://www.tea-after-twelve.com/all-issues/issue-02/issue-02-overview/chapter3/the-nanotechnology-miracle/#>



# Agriculture & Forestry



Plant  
treatment

Tracking &  
Conservation



Preservation &  
Prevention



# Natural Extracts

Using green chemistry only → no harsh acids / no harsh bases

*Pr. Malik Maaza, South Africa*



Hibiscus flowers



Callistemon viminalis



Agathosma betulina



Alfalfa



Tamarind





# Other Plants?



Eucalyptus



Lantana



Calendula

Moringa oleifera

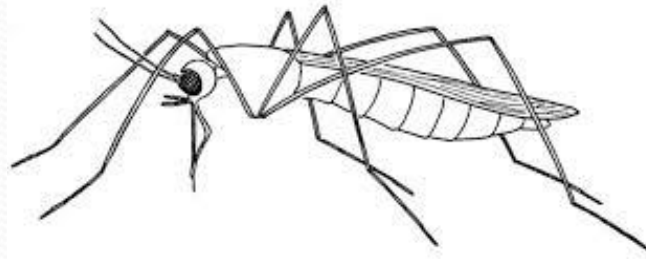


# What if I am a Theorist?

Paper battery



TB or malaria detection?



Air quality



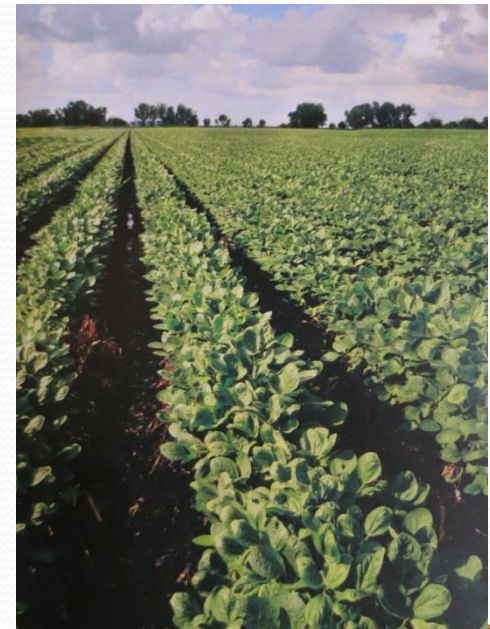
Solar energy



AI



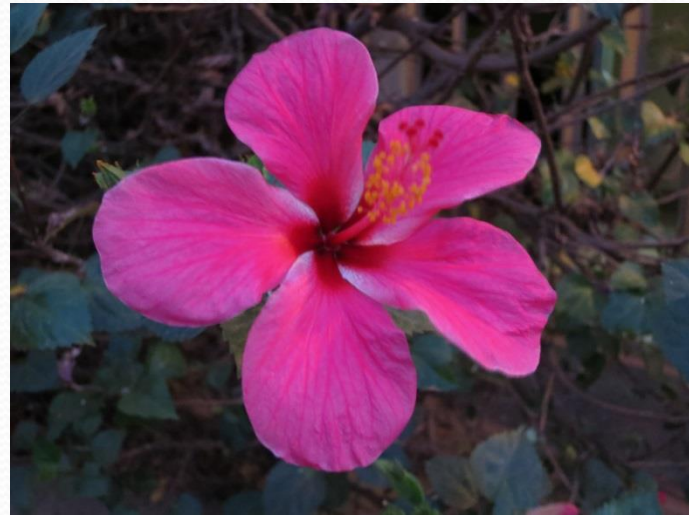
Lengau - Africa's fastest computer



Precision farming



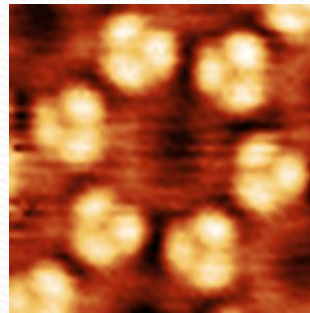
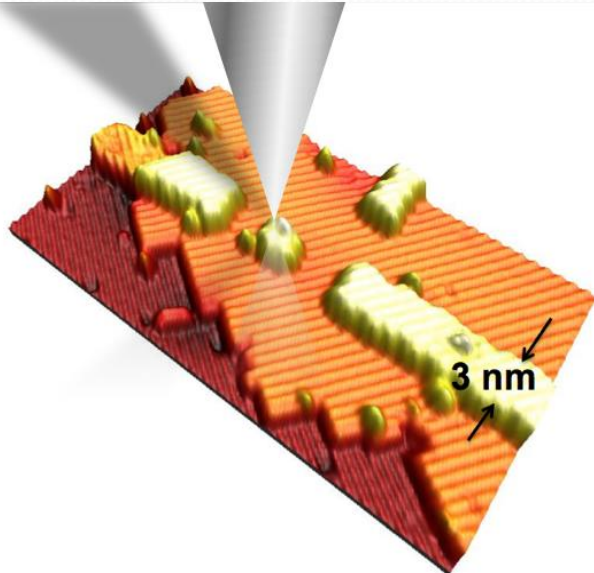
# Thank you for your attention



شكراً



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- <http://www.tea-after-twelve.com/all-issues/issue-02/issue-02-overview/chapter3/the-nanotechnology-miracle/#>
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- Statnano database
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- African Newsletter on Occupational Health and Safety, 22, 3 (2012)
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