

## Introduction to Nanotechnology

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FUNCTIONAL MATERIALS DIVISION, ICT SCHOOL – KTH 1 Sep 2014

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#### **Nanomaterials**



#### Nanostructured materials

**Nanomaterials** 

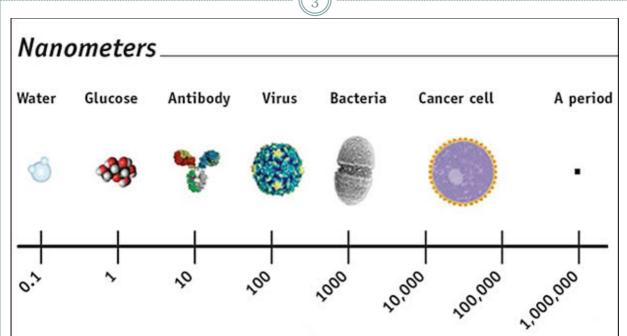
Nanophase materials

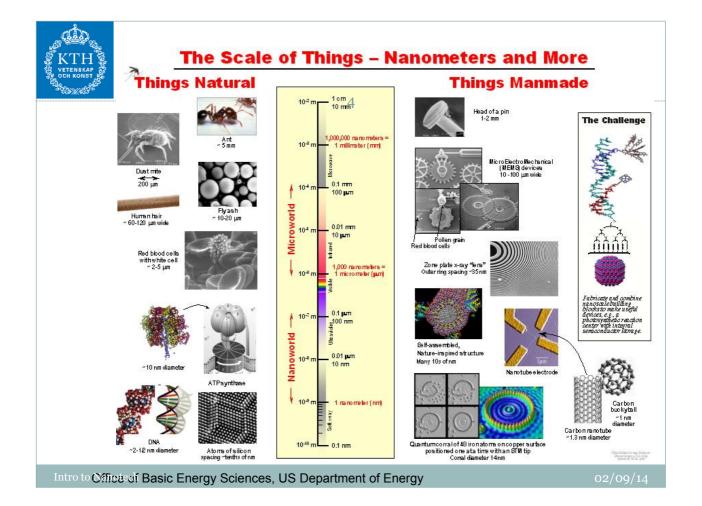
Ultrafine particles

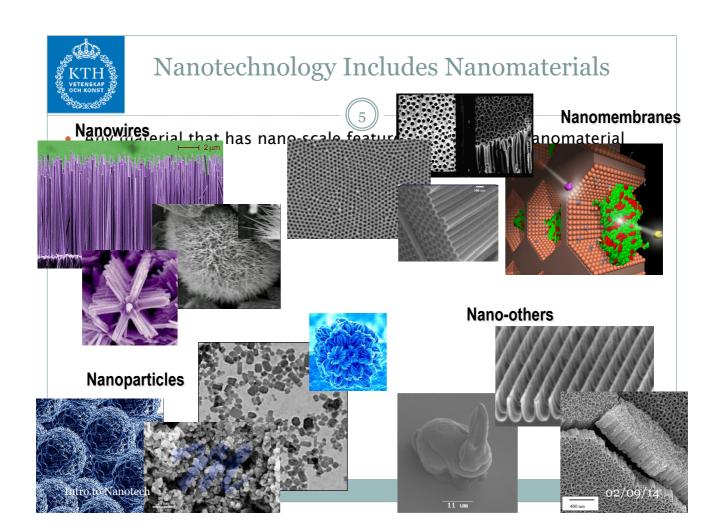
- Artificial materials with a microstructure the characteristic length scale of which is on the order of 1–100 nanometers.
- Exhibit unique size dependant phenomena



## Length Scale









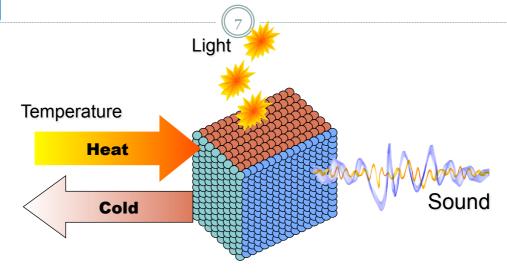
#### Nanomaterials



MOLECULES			0D* <b>A</b> * • * <b>F</b>
	Size (approx)	Materials	
anocrystals and clusters quantum dots)	1 - 10 nm (diam.)	Metals, semiconductors, magnetic materials	
Other nanoparticles	1 - 100 nm (diam.)	Ceramic oxides	nanopart
Nanowires	1 - 100 nm (diam.)	Metals, semiconductors, oxides, sulfides, nitrides	1D
Nanotubes	1 - 100 nm (diam.)	Carbon, layered metal chalcogenides	
Nanoporous solids	0.5-10 nm (pore diam.)	Zeolites, phosphates	nanowi
2D arrays (of nanoparticles)	Several nm² - μm²	Metals, semiconductors, magnetic materials	2D
Surfaces and thin films	1-100 nm (thickness)	A variety of materials	20
3D structures (superlattices)	Several nm in the three dimensions	Metals, semiconductors, magnetic materials	
	BULK MATE	RIALS	film



#### Surface Atoms Interact more with the Environment



The forms of energy that affect us in the environment can affect molecules.

Energy comes from the environment to affect molecular nature. Since more molecules are on the surface, the effect is more pronounced.

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#### Size Dependant Properties



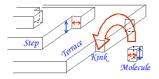
Properties	Examples		
Catalytic	Better catalytic efficiency through higher surface-to-volume ratio		
Electrical	Increased electrical conductivity in ceramics and ceramic nanocomposites, increased electric resistance in metals.		
Magnetic	Increased magnetic coercivity up to a critical grain size, superparamagnetism		
Mechanical	Improved hardness and toughness of metals and alloys, ductility and superplasticity of ceramics		
Optical	Spectral shift of optical absorption and fluorescence properties, incresed quantum efficiency of semiconductor nanoctystals		
Biological	Increased permeability through bilological barriers (membranes, blood-brain barrier, etc.)		

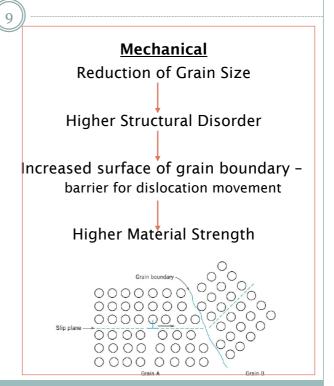


#### Effect of Size on ... Performance

# Catalytic Higher Structural Disorder Steps, Kinks, Dangling Bonds Higher Surface Area (higher surface to volume ratio)

Better Catalytic Performance Higher Reactivity





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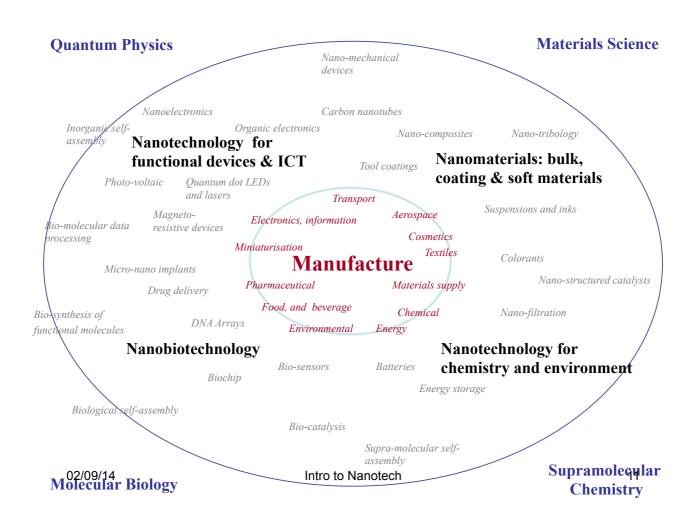
## Nanotechnology

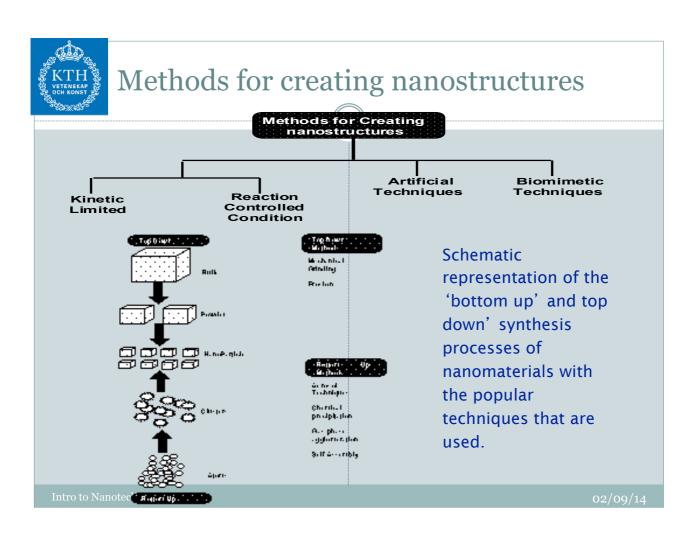


"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications."

"Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

National Nanotechnology Initiative, 2007







#### Main Research Areas

- Nanoparticles for biomedical applications
- Drug delivery, Bio-sensors, MR imaging
- Nanostructured materials for energy
- Enhanced surfaces
  Fuel Cells
  Solar cells
  Thermoelectrics
  Fission Reactors



Functional Nanocomposites Fission Reactors

Polymeric nanocomposites Inorganic nanocomposites Quantum dots Nanofluids Catalysis



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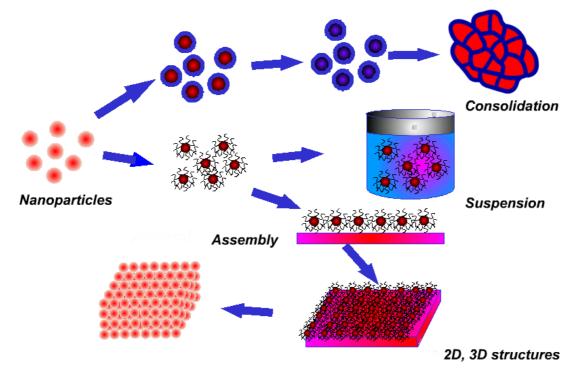
#### **Fabrication Strategies**







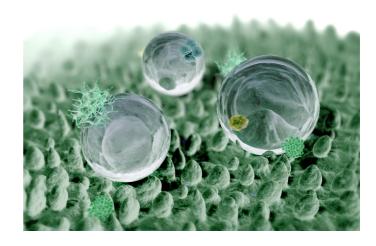
## **Nanoparticle Engineering**



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#### **Biomimetics**

- ➤ Learning Design Principles from Nature
- > Implementing them in synthetic processes



Lotus leaves → no stain → repells water





#### Methods for creating nanostructures



#### **Gas-Phase Methods**

Vapor Evaporation/Condensation Chemical Vapor deposition Laser Ablation

#### **Chemical Methods**

Precipitations
Sol gel
Spray Drying / Spray Pyrolysis
Thermal Decomposition

#### **Mechanical Deformation**

Mechanical alloying
Chemo-mechanical alloying
Severe mechanical deformation

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## Ball Milling – Mechanochemical Alloying

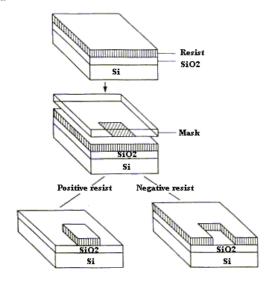
• **Ball Milling:** is a mechano/chemical process, relying on the energy released at the point of collision between hard balls in a ball mill to activate the chemical reaction.



Schematic Diagram for ball milling technique



## Top-Down: Photolithography



Step 1: Spin photoresist (a UV-sensitive polymer) and bake to cross link polymer

Step 2: UV expose to a mask—UV light will break cross-linked bonds

Step 3: Develop with developer

http://www.ebengatech.edu/research/labs/vc/theory/photolith.html

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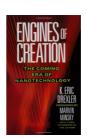


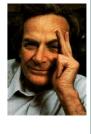
## History of Nanotechnology

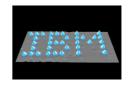


- ~ 2000 Years Ago Sulfide nanocrystals used by Greeks and Romans to dye hair
- ~ 1000 Years Ago (Middle Ages) Gold nanoparticles of different sizes used to produce different colors in stained glass windows
- 1959 "There is plenty of room at the bottom" by R. Feynman
- 1974 "Nanotechnology" Taniguchi uses the term nanotechnology for the first time
- 1981 IBM develops Scanning Tunneling Microscope
- 1985 "Buckyball" Scientists at Rice University and University of Sussex discover  $C_{60}$
- 1986 "Engines of Creation" First book on nanotechnology by K. Eric Drexler. Atomic Force Microscope invented by Binnig, Quate and Gerbe
- 1989 IBM logo made with individual atoms
- 1991 Carbon nanotube discovered by S. lijima
- 1999 "Nanomedicine" 1st nanomedicine book by R. Freitas









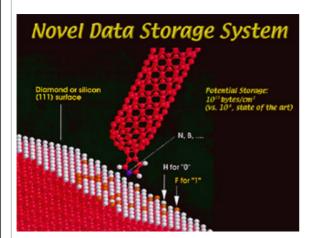
2000 – "National Nanotechnology Initiative" launched

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## Impact of Nanotechnology





Nanotechnology is an enabling technology

- Information Technology
  - Computing, Memory and Data Storage
  - Communication
- · Materials and Manufacturing
- · Health and Medicine
- Energy
- Environment
- Transportation
- · National Security
- · Space exploration

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## Nanomaterials Production Technology



- Ability to synthesize nanoscale building blocks with control on size, composition etc. further assembling into larger structures with designed properties will revolutionize materials manufacturing
  - Metals, ceramics, polymers, etc. 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
- Challenges ahead
  - Synthesis, large scale processing
  - Making useful, viable composites
  - Multiscale models with predictive capability
  - Analytical instrumentation

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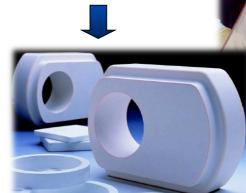


## Nanomaterials Manufacturing – Recent Advances



- · Carbon Nanotubes
- Nanostructured Polymers
- Optical fiber performs through sol-gel processing of nanoparticles
- · Nanoparticles in imaging systems
- · Nanostructured coatings
- · Ceramic Nanoparticles for netshapes







Source: IWGN Report

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#### Nanotech in Materials and Manufacturing



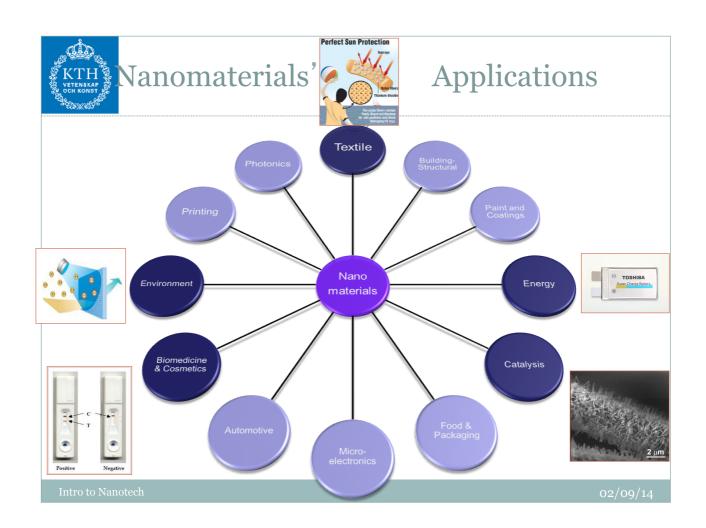
- · Nanostructured metals, ceramics at exact shapes without machining
- · Improved color printing through better inks and dyes with nanoparticles
- Membranes and filters
- · Coatings and paints (nanoparticles)
- · Abrasives (using nanoparticles)
- Lubricants
- · Composites (high strength, light weight)
- Catalysts
- · Insulators



## Various Nanomaterials and Nanotechnologies

- · Nanocrystalline materials
- · Nanoparticles
- · Nanocapsules
- · Nanoporous materials
- Nanofibers
- Nanowires
- Fullerenes
- Nanotubes
- · Nanosprings
- · Nanobelts
- Dendrimers
- ...

- Molecular electronics
- · Quantum dots
- NEMS, Nanofluidics
- · Nanophotonics, Nano-optics
- Nanomagnetics
- Nanofabrication
- Nanolithography
- · Nanomanufacturing
- Nanomedicine
- · Nano-bio
- · Nano-food
- Nano-energy





#### Products built with Nanotech



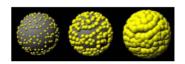
#### exploit sizedependent properties to do amazing things



Carbon nanotube crossbar memory (LSI Logic, BAE Systems licensing from Nantero) Van der Waals forces hold nanotube crossbars together



Semiconductor nanocrystal biolabels (Invitrogen though Quantum Dot Corp acquisition) Diameter of particle determines color of light emitted



Gold nanoshell cancer treatment (Nanospectra Biosciences) Size and curvature of shell determines light absorption



Artificial setae (U.S. Army contracting with Nanosys to develop) Weak atomic interactions allow soldiers to climb walls



#### Nanotech Value Chain



#### **Nanomaterials**

Nanoscale structures in unprocessed form

Nanoparticles. nanotubes, quantum dots, fullerenes, dendrimers, nanoporous orthopedic materials, materials...

#### **Nanointermediates**

Intermediate products with nanoscale features

Coatings, fabrics, memory and logic chips, contrast media, optical components, superconducting wire...

#### Nano-enabled products

Finished goods incorporating nanotechnology

Cars, clothing, airplanes, computers, consumer electronics devices, pharmaceuticals, processed food, plastic containers, appliances...

#### **Nanotools**

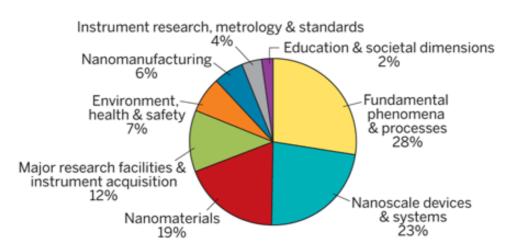
Capital equipment and software used to visualize, manipulate, and model matter at the nanoscale

Atomic force microscopes, nanoimprint lithography equipment, nanomanipulators...



#### **US** Investment





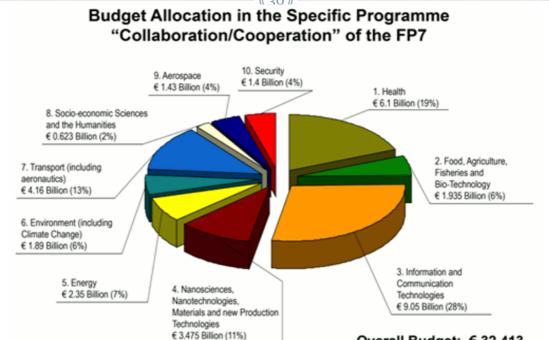
Proposed 2011 federal funding = \$1.8 billion

SOURCE: US National Science & Technology Council

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#### **EU Investment**



http://www.bayfor.org/media/uploads/ktml/media/grafik-kooperationen-en.gif

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Overall Budget: € 32.413



#### **KTH Priorities**

The KTH Research Platforms encompass:

#### Energy

Batteries, Biomass, Carbon Capture, Fuel Cells, Fusion, Heat Pumps, Households, Hydropower, Nuclear, Solar, Transmission & Distribution, Public & PrivateTransportation, Wind Power

#### • Information and Communication Technology

Communication Networks, Mobile and Wireless Systems and Services, Distributed Systems, Electronic Systems Design, Wireless@KTH Center

#### Materials

Metallic Materials, Fibres & Polymers, Photonic & Electronic Applications, Advanced Characterisation, Energy Applications

#### • Life Science Technology

Bioimaging, Biomolecular Tools & Biomaterials, Mathematical and Computational Sciences, Infrastructure in Health, Medical Devices, Life Science Research

#### Transport

Holistic Transport Systems, Future Transportation Infrastructure, Innovative Vehicle Concepts, Transport in the Information Era, Policy and Institutional Frameworks

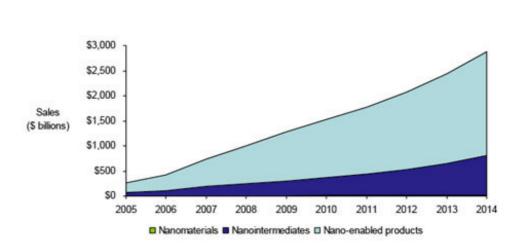
The main role of the Platforms is to coordinate large, multidisciplinary research initiatives involving KTH professors and graduate students working in concert with external partners.

#### http://www.kth.se/en/forskning/forskningsplattformar

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## Nano-enabled product market



(Source: Lux Research Report "Sizing Nanotechnology's Value Chain")

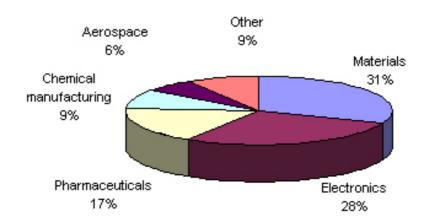
http://www.nanowerk.com/spotlight/spotid=1792.php



#### Nanotechnology business forecast



## **Estimates of the nanotechnology market - by 2010-2015**USD trillions: 1.1



Source: National Science Foundation

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## Nanotechnology for Energy Applications



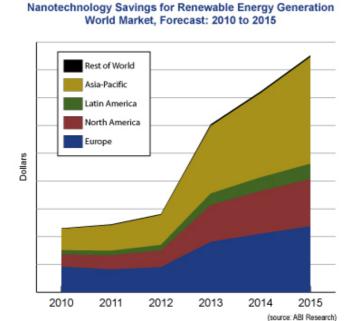
BATTERIES

HEAT EXCHANGE PLATES

THERMOELECTRIC MATERIALS

SOLAR CELLS

**TRANSPORTATION** 



http://solarsofa.com/nanotechnologies-cut-the-cost-of-green-energy-says-abi-research/

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## Nanoscience Research for Energy Needs



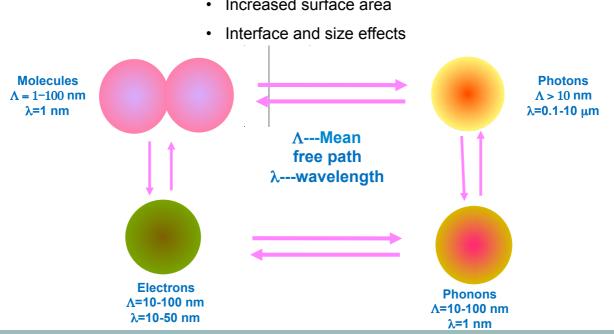
- Catalysis by nanoscale materials
- Using interfaces to manipulate energy carriers
- Linking structures and function at the nanoscale
- Assembly and architecture of nanoscale structures
- Theory, modeling, and simulation for energy nanosciences
- Scalable synthesis methods



## Nanotech for Energy



Increased surface area

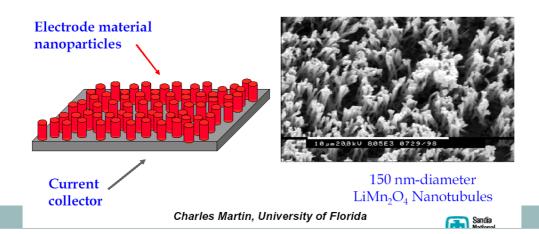




#### **Batteries**

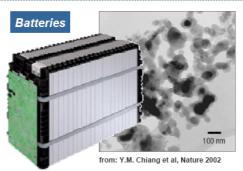
Change electrode materials by nanostructuring (texturing) to improved electrical performance; nanoscale particles boost energy storage and power delivery by reducing the distance Li ions travel during diffusion

Nanobattery: Fill a nanoscale membrane with an electrolyte, cap with electrodes; contact with a probe tip





## **High Performance Batteries**



Nanophosphate<sup>™</sup> technology

**Excellent Recharge Performance** 

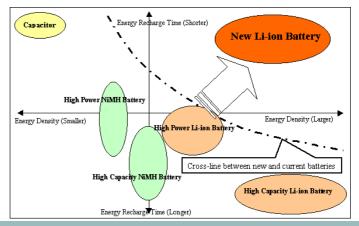
**High Energy Density** 

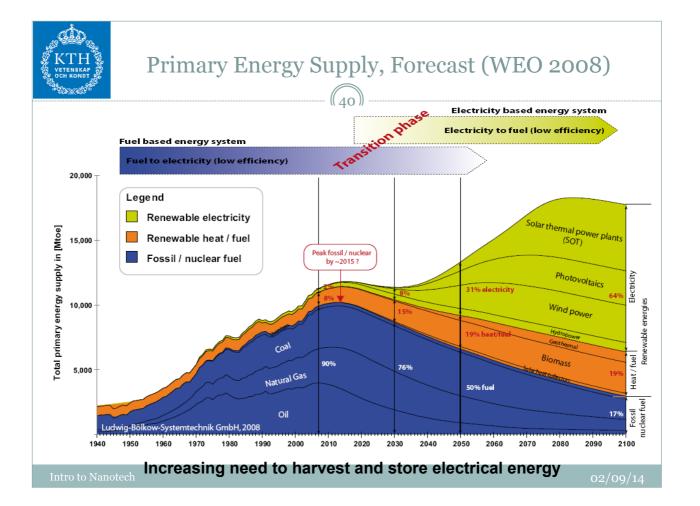
Long Life Cycle

**Eco-friendly Battery** 

## Improved Cathode Material

- Nanoscale doped LiFePO4
- · Increased ionic conductivity by
  - o nano-C coating
  - o doping with cations (Al, Nb, Zr)



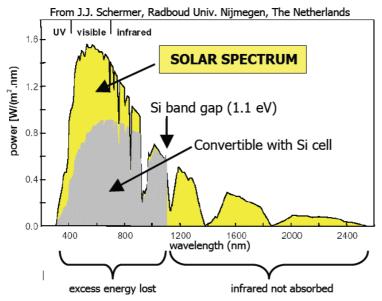




#### Solar Cells - Silicon



#### Efficiency limited: not all incident solar energy convertible to electricity



#### Efficiency:

Theor. (AM1.5G) 33 % Max. achieved 24 % Usual 15-20 %

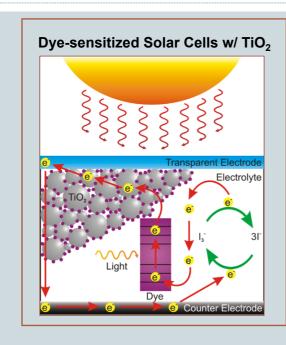
#### Theoretical losses:

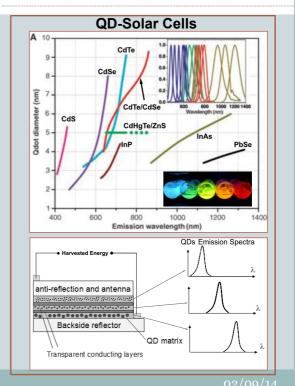
- 47 % thermalization
- 18 % not absorbed IR
- 2% rad. recombination/ thermodynamic loss

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#### Solar Cells - Harvesting of Light





o Nanotech O2/09/14



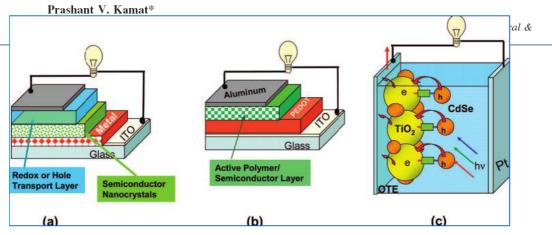
## **QD** Solar Cells

J. Phys. Chem. C 2008, 112, 18737–18753

18737

#### CENTENNIAL FEATURE ARTICLE

Quantum Dot Solar Cells. Semiconductor Nanocrystals as Light Harvesters†



The strategies to develop QD based solar cells: (a) metal-semiconductor junction, (b) polymer-semiconductor, and (c) semiconductor-semiconductor systems.

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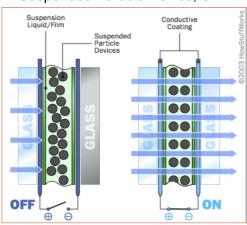


#### Optical Applications: Smart Window



#### Needle shaped nanoparticles of polyiodides.

#### Suspended Particle Device, SPD





- The electric field causes the particle material to polarize (induced electric dipoles)
- The induced electric dipoles interact and the particles align in chains which maximizes their attraction.

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## Nanotech in Transportation



- · More efficient catalytic converters
- · Thermal barrier and wear resistant coatings



- · Battery, fuel cell technology
- · Improved displays
- · Wear-resistant tires



- · High temperature sensors for 'under the hood'; novel sensors for "allelectric" vehicles
- · High strength, light weight composites for increasing fuel efficiency

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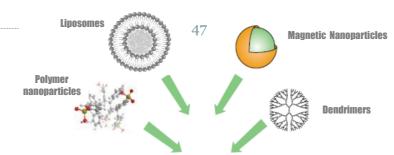
## Nanotechnology for Biomedical Applications



DRUG DELIVERY
CONTRASTING AGENT
PHOTODYNAMIC THERAPY



#### Nanomedicine

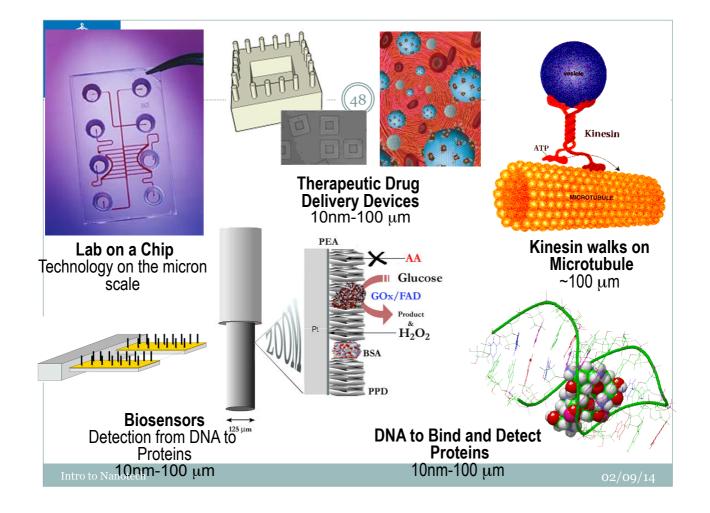


- Fast and more efficient biosensors
- Targeted drug delivery to specific cells
- Novel cancer theraphy and

- Magnetic resonance imaging enhancement
- Single cell study and biomanipulation
- Novel diagnostic tools for early stage detection of diseases

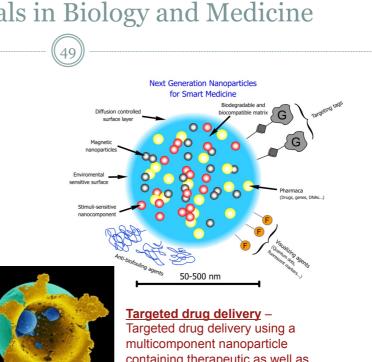
hyperthermia treatments

Nature Nanotechnology, 2007, 2, 469-478





## Nanomaterials in Biology and Medicine





containing therapeutic as well as biological surface modifying agents

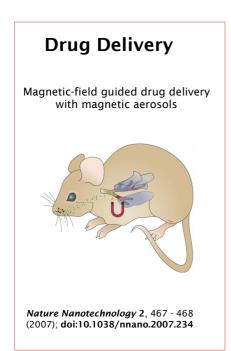
http://www.jnanobiotechnology.com/content/2/1/3#IDAFGPQ1

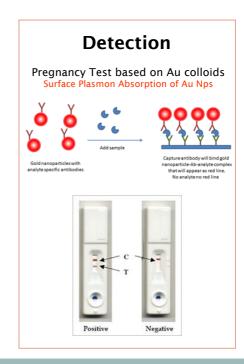
OM: Salata, ulternal of Nanobiotechnology 2004, 2, pp. 1-6.



#### Nanoparticle-Based Systems









## Nano-Therapeutics: Hyperthermia

#### injectable magnetic implants

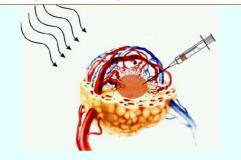
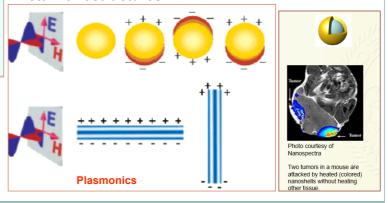


Figure 1: The formulation developed allows, after a simple intratumoral injection, the *in situ* formation of a solid implant embedding superparamagnetic nanoparticles (SPIONs). Under an external magnetic field, the implant releases a mild heat for antitumoral treatment.

## Interaction of an electromagnetic radiation with metal nanostructures



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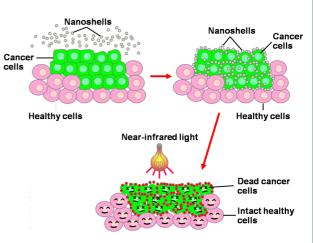


## Nanotechnology in Health Care



#### Thermal ablation of cancer cells

- Nanoshells have metallic outer layer and silica core
- Selectively attracted to cancer shells either through a phenomena called enhanced permeation retention or due to some molecules coated on the shells
- The nanoshells are heated with an external energy source killing the cancer cells



Thermal ablation of cancer cells assisted by nanoshells coated with metallic layer and an external energy source – National Cancer Institute

## Nanotechnology for Environmental Applications



## WATER REMEDIATION AIR FILTERING

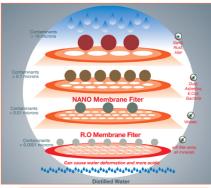
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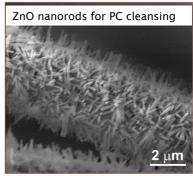


## Water Purification



- · CNT ultra filtration membranes/mesh filters
  - o Remove turbidity, bacteria, viruses, organics
  - o Replace RO for lower pressure desalination
- NanopowderAdsorbents
  - o TiO<sub>2</sub> or Magnetite for As, MnO for VOCs
- Nanoporousceramic
  - o bacteria attach and digest organics
  - o Can be treated to remove Hg, heavy metals, PO4
- Charged Nano Alumina Fibers
- Nanosensors for the detection of contaminants
- Nanocatalysts



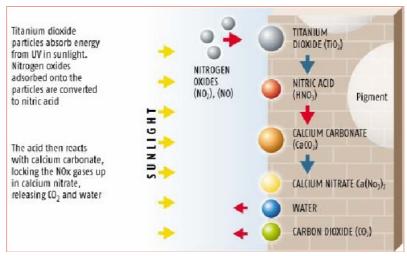




## Smart air-cleaning paints (ecopaints)



#### Photo-catalysis for self-cleaning surfaces



British company Millennium Chemicals: (based in Grimsby) holds the patent for Ecopaint

In a typical 0.3-millimetre layer of Ecopaint, there will be enough calcium carbonate to last five years in a heavily polluted city. Polysiloxane is resistant to attack by titanium dioxide.

Intro Europe-fiteded Photocatalytic Innovative Coverings Applications for Depollution Assessment programme (PICADA) 02/09/14

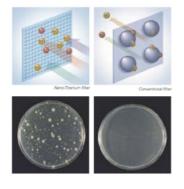


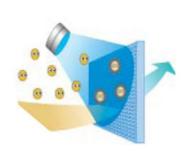
#### Nano TiO2 Air Purifier with UV light



## Photo-catalyst Filter containing TiO2 nanoparticles Nano Ag - antibacterial

Bread down poisonous fumes, e.g. formaldehyde, benzene, ammonia into  $CO_2$  and  $H_2O$  Destroy cigarette, smoke and other odors.

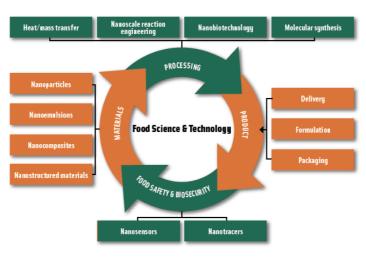






## Nano-food





Til Tarvert (Flora Mahotechnology." Food Technology Magazine. 2006, 60(11), 22-26.

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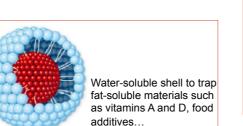


#### Nanotechnology in the Food Industry



NANOFOOD: Food which has been cultivated, produced, processed or packaged using nanotechnology techniques or tools, or to which manufactured nanomaterials have been added.

- Food formulations
- Increase nutrients
- Coatings and barriers
- Controlled release of particles
- Packaging and storage











Nanotechnology in Food & Agriculture Report; http://www.foeeurope.org/activities/nanotechnology/index.htm T. Tituvato ให้งาว Nanotechnology." Food Technology Magazine. 2006, 60(11), 22-26.



## Food Packaging



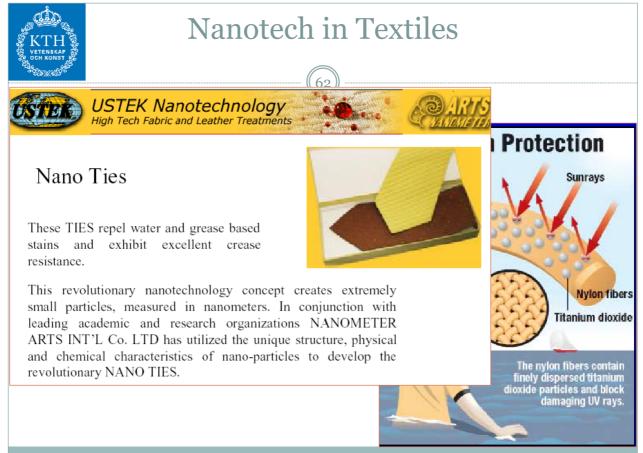


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## Nanotech in consumer products

60

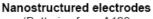






#### Nanotech for Communication





(Batteries from A123 Systems, supercapacitors from Cap-XX, fuel cells from many)

#### **OLED or LEP display**

(Universal Display, Cambridge Display Technologies)

#### Antimicrobial coating (Nanux, Bio-Gate,

(Nanux, Bio-Gate, NanoHorizons, others)

#### Nano-enabled multipurpose memory

(Altis, Freescale, Nantero, Zettacore)

#### Nanopatterned logic chip (Molecular Imprints, EV

(Molecular Imprints, EV Group, SUSS MicroTec)

#### Nanostructured chip cooling system

(CoolChips, Thorrn Micro Technologies, Nanoconduction)

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#### **Summary**



- · Nanotechnology is an enabling technology that will impact medicine, electronics, computing, data storage, communications, materials and manufacturing, health and medicine, energy, transportation, environment, food, national security, etc....
- · Opportunities and rewards are great and hence, tremendous worldwide interest



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