POTENTIAL ROLES OF NANOTECHNOLOGY IN SUSTAINABILITY

Kiril Hristovski+, Yang Zhang+, Brian A. Koeneman*, Yongsheng Chen, Paul Westerhoff+, David G. Capco* and John Crittenden+

+Civil and Environmental Engineering Department, Ira A. Fulton School of Engineering, Arizona State University, PO Box 875306, Tempe, AZ 85287-5306
*Cellular and Molecular Biosciences Faculty, School of Life Sciences, Arizona State University, PO Box 874501, Tempe, AZ 85287-4501

Nanotechnology & Sustainability

- Outline
  - Definition of nanotechnology
  - Development of nanotechnology
  - Nanotechnology and sustainability
  - Adverse effect of nanotechnology
  - Nanotechnology research at ASU
  - Nanotechnology life cycle
  - Future of nanotechnology research
  - Acknowledge
  - Related Websites
What is Nanotechnology?

- Nanotechnology is....
  - Creation and/or manipulation of materials, structures and devices at the nanometer (nm) scale, where new physical, chemical and biological properties occur as compared to bulk materials.

Stages of Nanotechnology Development

First Generation ~ 2001: Passive Nanostructures
Nanostructured coatings, particles, metals, polymers, ceramics, catalysts, composites, displays

Second Generation ~ Now: Active Nanostructures
Transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures, sensors, diagnostic assays, fuel cells, solar cells, High-performance nanocomposites, ceramics, metals

Third Generation ~ 2010: 3-D Nanosystems
Various assembly techniques, networking at the nanoscale, new architectures, biomimetic materials, novel therapeutics and targeted drug delivery

Source: Barbara Karn’s presentation, US Environmental Protection Agency
Nanotechnology & Sustainability

- Nanotechnology could substantially enhance sustainability through:
  - Energy
  - Environment
  - Health Care
  - Agriculture

U.S. Federal Funding (849 millions) on Nanotechnology R&D in 2004

Nanotechnology & Energy

Conventional energy production and utilization are extremely destructive to environment.

Nanotechnology can help...
- **Enhance energy efficiency:** thermal insulation nanomaterials, etc.
- **Minimize energy consumption:** energy-saving lighting system with nanotechnology, etc.
- **Develop clean energy source and production processes:** hydrogen energy, solar energy, etc.
- **Improve power transportation:** super conductivity of nanomaterials, etc.
Hydrogen Energy/Hydrogen Economy

- The hydrogen economy is an energy system based on hydrogen.
  - Nanotechnology could promote the hydrogen economy by allowing for hydrogen storage, acting as a catalyst for hydrogen production, acting as a thermal management material, etc.

Hydrogen economy as a network of primary energy sources linked to multiple end uses with hydrogen as an energy carrier.

Source: http://www.aip.org/pl/vol-57/iss-12/p39.html

Hydrogen Fuel Cell

- **Catalysts:** Nanomaterials improve the extraction of pure hydrogen from fuel, such as methanol and ammonia.
- **Fuel Storage:** In the nanophase, hydrogen can be quickly extracted from fuel.
- **Hydrogen Storage:** Nanomaterials enhance hydrogen storage capacity in solid form.
- **Proton Exchange Membrane:** Nanomaterials improve proton conductivity.

Source: http://nano.mtu.edu/HydrogenFuelCell_start.html
Solar Energy

- Although solar technology has been limited for decades, this malaise will soon come to an end due to advancements in nanotechnology.
  - Improving the conversion of light to electricity by collecting a broader range of wavelengths in the solar spectrum.
  - Increasing energy efficiency for solar cells based on quantum dots.
  - Smaller and cheaper solar cells based on nanomaterials than the conventional solar cells.

Solar cell based on inorganic nanorods and semiconducting polymers
(Source: http://www.pathnet.org)

Nanotechnology & Environment

Nanotechnology offers great promise for improving environmental quality and solving environmental problems.

Nanotechnology can help with…
- Pollution Prevention
- Pollution Sensing & Detection
- End of Pipe Treatment
- Contaminant Remediation
Pollution Prevention

• Reduction of:
  – raw materials
  – water
  – other resources

• Waste products are:
  – less toxic
  – renewable
  – environmentally safer

Nanotube in Field Emission Displays
Nanotube will replace toxic heavy metal to use in FEDs and reduce its energy consumption.
(Source: http://www.azom.com)

Pollution Sensing & Detection

• Some research show that sensors based on nanomaterials exhibit substantially higher sensitivity to biological and chemical species than existing solid-state sensors.

Carbon nanotube resonator sensor
It is sensitive to both polar (NH₃) and non-polar gases (He, Ar, N₂, and O₂)

A. Pham, Professor (Department of Electrical and Computer Engineering)

Source: A. Pham, Carbon Nanotube Resonator Sensors for Remote Sensing Systems
Contaminant Treatment & Remediation

- **Nanostructured oxidants, reductants, and nutrients**: promote contaminant transformation and stimulate microbial growth.

- **Photocatalysis of nanomaterials**: produces hydroxyl radicals that oxidize organic contaminants.

- **Nanoparticles deployed in ex situ slurry reactors**: allow for treatment of contaminated soils, sediments, and solid wastes.

- **Nanosorbent properties**: provide excellent absorption potential for organic and inorganic contaminants.

- **Nanofilter membranes**: increase the removal efficiency of contaminants and microbes in water.

Groundwater Remediation

By introducing preprogrammed iron nanoparticles into groundwater, toxic metals, such as arsenic and cadmium, can be reduced into benign substances. Another advantage of nanoparticles is to penetrate the small pore size.

Kim Hayes, Professor (CEE)

Source: Bill Clayton, Nanotechnology – An engineering response to human problem
Nano-biotechnology & Environment

- Carbon Nanotube
  - Combine enzymes to reduce hazardous chemicals
- Diatoms
  - Enzyme matrix for biocatalysis
  - Filter for water clean up
  - Skeleton combined with enzymes for toxic waste decontamination

Acid Cleaned Diatoms (10-20 µm across and holes in nanosize)

Enzyme + Carbon Nanotube for Catalysis

Enzyme molecules inside carbon nanotube -- Increases catalytic activity in non-aqueous solutions

Source: Brent Erickson’s presentation
Source: Jonathan Dordick’s presentation, RPI
Enzyme + Nanomembrane for Waste Treatment

The enzyme organophosphorus hydrolase (OPH) has been embedded in a synthetic nanomembrane (mesoporous silica) that enhances its activity and stability. The OPH transforms toxic substances (purple molecule at left of OPH) to harmless byproducts (yellow and red molecules at right).

Source: http://doegenomestolife.org/benefits/cleanup.shtml

Nanotechnology & Health Care

Nanotechnology will promote our ability to characterize living organisms and cure illnesses.

Nanotechnology provides:

- New instruments to examine tissues in unprecedented detail.
- Precise ways to deliver medicines.
- Detection and identification of cells and their activities.

Quantum Dots

Marking the cells with emitting color

(Source: http://www.evidenttech.com)
Drug Delivery

Nanoparticles joined by strands of DNA can be programmed to identify specific cells and deliver a precise dose of drugs. This increased drug specificity will dramatically reduce side effects on healthy cells.

Jams Baker
(Bionanotechnology)

Source: Bill Clayton, Nanotechnology – An engineering response to human problem

Cell Imaging

Nanoparticles, put into cells by a laser, make the cells highly visible to conventional imaging technology.

O'Donnell, Et. al.
(Dept. of Electrical Engineering and Computer Science)

Source: Bill Clayton, Nanotechnology – An engineering response to human problem
Nanotechnology & Agriculture

Nanotechnology will contribute directly to advancements in agriculture in a number of ways.

Nanotechnology provides:
- Molecular-engineered biodegradable chemicals for plants nourishment and protection against insects
- Genetic improvement for animals and plants
- Nanoarray-based testing technologies for DNA

Adverse Effects of Nanotech for Sustainability

- Unknown Fate in Environment
- Unknown Adverse Toxic Effects and Pathways
- Unknown Protection Ways
- Unknown Remediation and Mitigation Perspectives

Source: Dr. Kevin Ausman’ presentation, Rice University
Nanopathology

- **Tissues reaction:** Against the presence of small-sized foreign bodies, depending on foreign body's chemistry, surface, shape and size.

- **A possible “critical” threshold of size:** A material may no longer be biocompatible when its size is below the threshold.

- **Tissues related to nanopathology:** Lung, liver, colon, blood and lymph, etc.

- **Possible examples:** Silicosis, Asbestosis, Thrombus and Crohn’s disease, etc.

Debris of cobalt–tungsten found in a small thrombus grown in the blood stream

Barium-Sulfate debris in liver cancer

Source: http://www.nanopathology.it

Nanotechnology Research at ASU

**Adsorption for Arsenic (IV)**

- TiO$_2$, Fe$_2$O$_3$, NiO and ZrO$_2$ nanoparticles exhibit good potential for the removal of arsenic in water.

![Graph](image)

Isotherm fitting of collected data for the four metal oxide nanoparticles listed above
Fate of nanoparticles in aqueous environments:

- Aggregation of metal oxide nanoparticles in water.
- Aggregates of nanoparticles are generally ranging from 200nm to >2 mm.

Removal of nanoparticles by conventional flocculation/sedimentation treatment:

- Removal of metal oxides nanoparticles in water is not more than 70%.
- Al(OH)$_3$-nanoparticle flocs settle more easily in nanopure water, compared to tap water.
Bioaccumulation

- TiO$_2$ nanoparticles accumulated faster in carp, compared to arsenic (III).
- High absorption ability of TiO$_2$ nanoparticles to arsenic (III) facilitates transportation of arsenic (III) to carp.
- The presence of TiO$_2$ nanoparticles increases the bioaccumulation of arsenic (III).

The accumulation of As in carp exposed to As-contaminated water both with and without TiO$_2$ nanoparticles

Cytotoxicity of nanoparticles on epithelial cells

- Decreasing in tranepithelial electrical resistance (TEER) after the addition of TiO$_2$ indicates cell death or a weakening of cellular junctions.

Cytotoxicity of TiO$_2$ nanoparticles evaluated by TEER
Nanotechnology exhibit significant potential for sustainability by benefiting resources, environment and society, but risk of adverse effects of nanoparticles should not be neglected. Future work will aim to:

- How to expand basic understanding of mechanisms specific at nanoscale?
- What are more effective ways to synthesize, assemble, utilize functional nano-structured materials?
- How to develop instrumentation and technology based on nanomaterials?
- Which ways to release nanoparticles into environment and body?
- Which aspects do adverse effects of nanoparticles include?
- How to evaluate the risk of nanoparticles, such as toxicity? Should standard methods be established?
- Etc.
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P. Westerhoff, Y. Chen, J. Crittenden, D. Capco, Y. Zhang, K. Hristovski, B. Koeneman

Related Websites:

http://www.nano.gov
http://www.nanopore.com
http://www.research.philips.com/newscenter/pictures
http://www.amsuper.com/products/htsWire/2GWireTechnology.cfm
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