Environmental Impacts of Nanotechnology

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Outline

- Does nano-X pose an environmental risk? Inquiring minds want to know
- Proposed Center for Environmental Implications of Nanotechnology (CEIN)
- Successes by ASU researchers

Why do we care about environmental risks of nanotechnology?

Cytotoxicity studies of selected nanomaterials

Nanomaterial	Effects observed
Fullerene	
C_{60} water suspension	Antibacterial; cytotoxic to human cell lines; taken up by human keratinocytes; stabilizes proteins
C_{60} encapsulated in poly(vinylpyrrolidone), cyclodextrins, or poly(ethylene glycol)	Damages eukaryotic cell lines; antibacterial
Hydroxylated fullerene	Oxidative eukaryotic cell damage
Carboxyfullerene (malonic acid derivatives)	Bactericidal for Gram-positive bacteria; cytotoxic to human cell lines
Fullerene derivatives with pyrrolidine groups	Antibacterial; inhibits cancer cell proliferation; cleave plasmid DNA
Other alkane derivatives of C_{60}	Antimutagenic; cytotoxic; induces DNA damage in plasmids; inhibits protein folding; antibacterial; accumulates in rats' livers
Metallofullerene	Accumulates in rats' livers
Inorganic	
Silicon dioxide (SiO_2)	Pulmonary inflammation in rats
Anatase (TiO_2)	Antibacterial; pulmonary inflammation in rodents
Zinc oxide (ZnO)	Antibacterial (micrometer scale); pulmonary effects in animals and humans

Wiesner et al., ES&T 2006

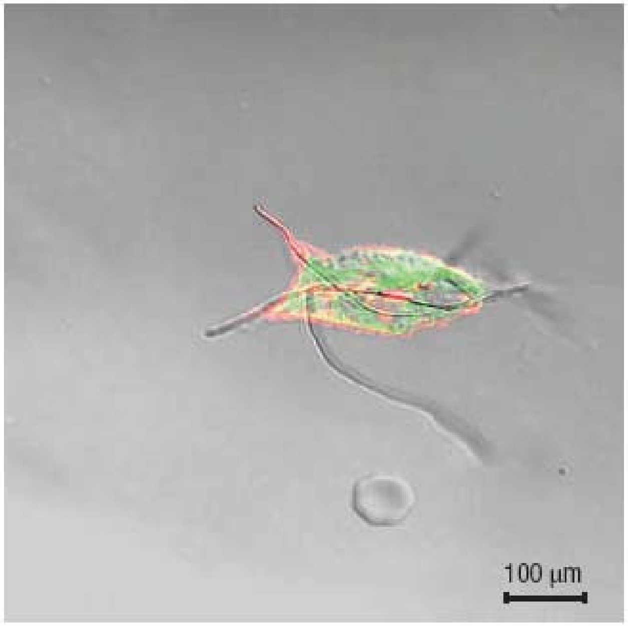


Figure 1 A rat lung cell attempting to ingest carbon nanotubes that are longer than the distance that the cell can stretch, which means that the rat cannot remove such nanotubes from the body. This optical microscopy image is superimposed with confocal images of the protein cytoskeleton that gives the cell structure and its ability to move. F-actin is shown in red; tubulin in green. (Image provided by D. Brown, Napier Univ. and I. Kinloch, Univ. Manchester).

Stone & Donaldson, 2006

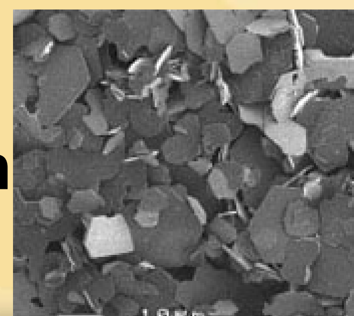
Nanomaterials are used in everyday life (> 500 products to date)

Nano ZnO "transparent" sunscreen

Fullerene in "revitalizing" night creams

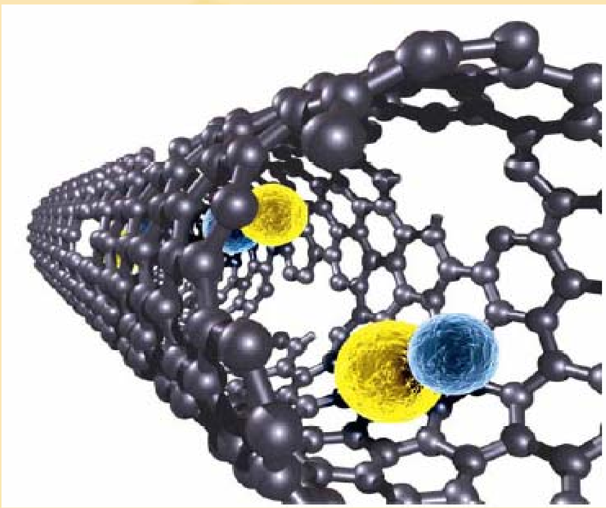
Nano-silver in Bandages & socks

Nano-Aluminum in cosmetics

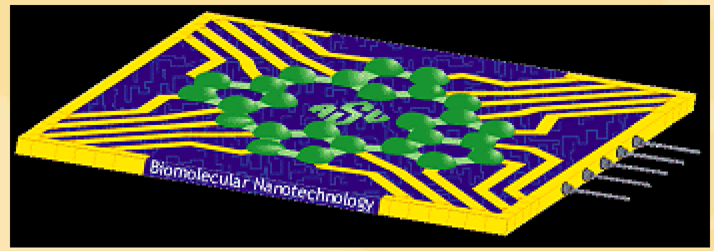


Nano-sized "additives"

Bio-Medical and Bio-Electronic Applications



Ultra-short, single-walled carbon nanotubes can be loaded with contrast agents for enhanced medical imaging. (Rice Univ.)



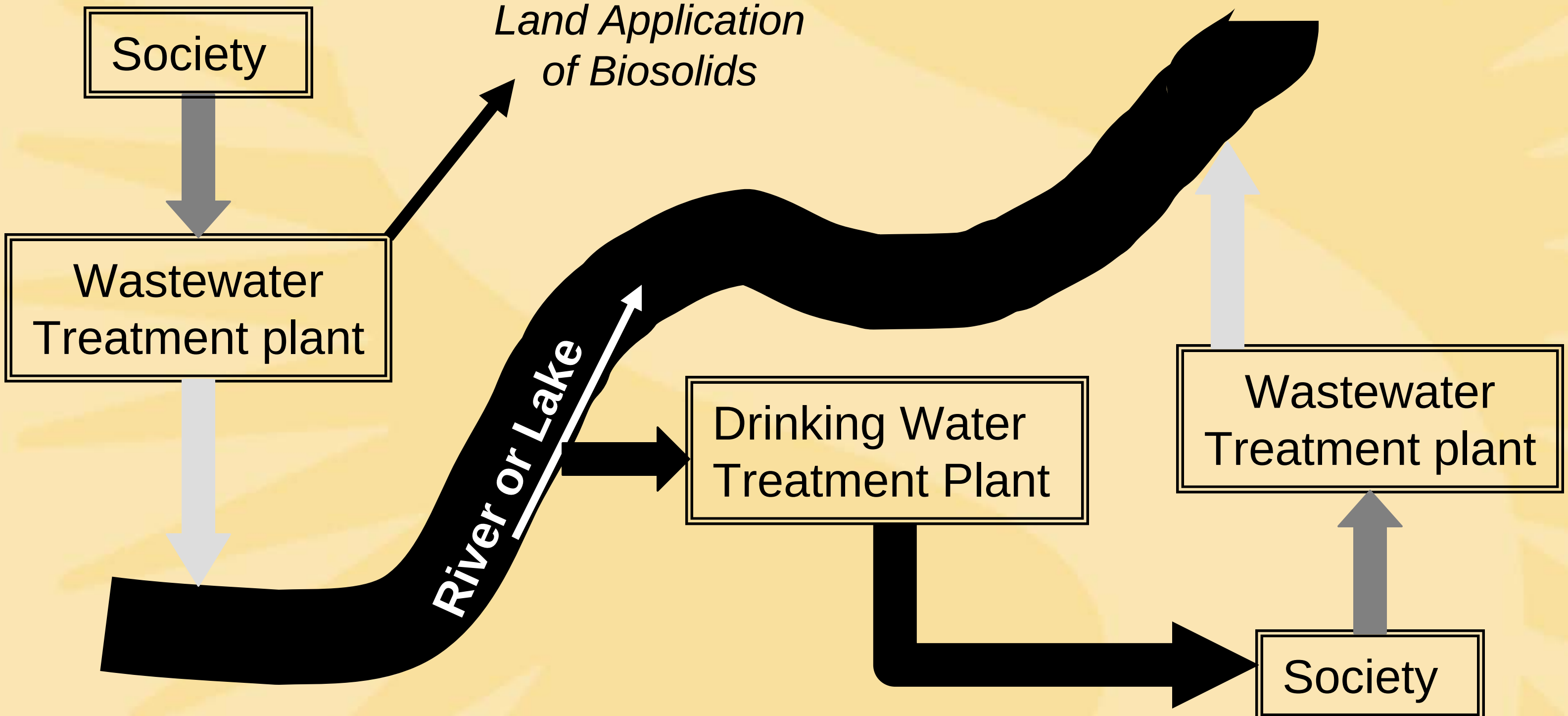
AuroShell™ microparticles designed to absorb various wavelengths of light (the six vials on the right), compared to solid gold particles (far left).

Consider:Nano-Ag used in clothing as anti-microbial agent

Socks contain nano-silver

- Washing socks releases nano-Ag and Ag+ into sewage water
- Bacteria in wastewater treatment plant biosorb silver
- Some discharged into streams where it is toxic to fish

Framework for Fate of Nanoparticles in Engineered Systems



>75% of the US population is served by centralized wastewater treatment facilities

Not Everyone Lives Upstream

US Environmental Protection Agency (and NSF / DOE / ...)

- $1.4 Billion per year on National Nanotechnology Initiative
- A few percentage on environmental issues turns out to be a lot of $
- NSF solicits $50 M / 10 year center on Implications of Nanotechnology

Center for Environmental Implications of Nanotechnology

- ASU / UF / Battelle / USGS partnered
- Preproposals – December 2007
- Full proposals – March 2008
- *Reverse site visits – May 2008*
- *Award by end of fiscal year*

RFP States Need

- Focus: fundamental research and education on the **interactions of naturally derived, incidental (i.e., derived from human activity) and engineered nanoparticles and nanostructured materials, devices and systems (herein called "nanomaterials") with the environment** and living world **at all scales**. The **goal** of this Center is to understand the potential implications of nanotechnology for **environmental health and safety**.
- Essential elements of this Center will include:
  - Understanding the **bioaccumulation of nanomaterials** and their effects on living systems including their routes of environmental exposure, deposition, transformation, bio-persistence, clearance, and translocation, as well as mechanisms for their absorption, distribution, metabolism, and excretion by organisms.
  - Understanding the **interactions of nanomaterials with cellular constituents**, metabolic networks and living tissues including interactions at the molecular, cellular, organ, and systemic levels, and effects on organism ontogeny and multi-generational life histories.
  - Determining the **biological impacts of nanomaterials** dispersed in the environment including the **ecological and evolutionary effects of nanomaterials on aquatic and terrestrial ecosystems** such as: species interactions, factors that contribute to bioaccumulation and biomagnification of nanomaterials in food webs, distribution of nanomaterials and their byproducts within ecosystems, biotic processes that influence the persistence and chemical transformations of nanomaterials in the environment, and the mode and duration of effects on ecosystems.
- Proposals may include supporting activities such as the development of sensors to detect and characterize nanomaterials and strategies to address the diversity of nanomaterials including standard reference materials, measurement standards and protocols.

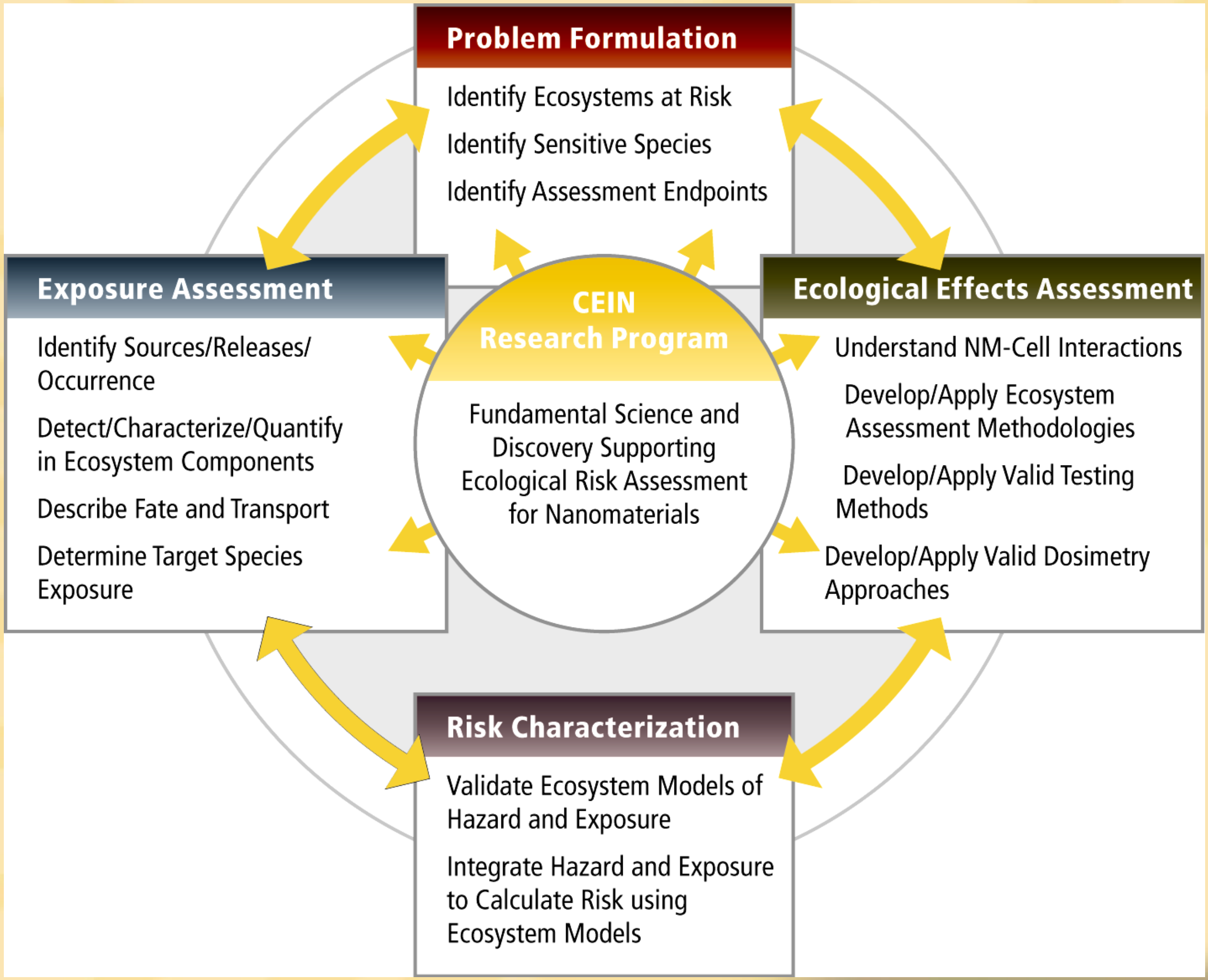
ASU Team

Name	Affiliation
Abbaszadegan, Morteza	Civil and Environmental Engineering (FSE)
Alford, Terry	School of Materials
Allenby, Braden	Civil and Environmental Engineering (FSE)
Anbar, Ariel	Biochemistry (SESE)
Capco, David	Biology (SOLS)
Chang, Yung	Biology (SOLS)
Chen, Yongsheng	Civil and Environmental Engineering (FSE)
Crittenden, John	Civil and Environmental Engineering (FSE)
Elser, James	Biology/zoology (SOLS)
Fraser, Matthew	School of Sustainability
Grimm, Nancy	Ecology, Evolution and Environmental Sciences (SOLS)
Guston, David	Political Sciences (CLAS)
Halden, Rolf	Civil and Environmental Engineering (FSE; AZ Bio)
Herckes, Pierre	Chemistry and Biochemistry (SOLS)
Hristovski, Kiril	Micro/Nanofluidics Laboratory (FSE)
Hu, Qiang	Department of Applied Biosciences (ASU Polytech)
Meldrum, Deirdre	Electrical Engineering (FSE; AZ Bio)
Pizziconi, Vincent	Bioengineering (FSE)
Posner, Jonathan	Mechanical and Aerospace Engineering (FSE)
Ramakrishna, B.L.	Plant Biology (SOLS)
Rittmann, Bruce	Civil and Environmental Engineering (FSE; AZ Bio)
Sabo, John	Biology (SOLS)
Shock, Everett	Chemistry and Biochemistry (SESE)
Wang, Joseph	Chemical Engineering; Chemistry and Biochemistry (AZ Bio; SOLS; FSE)
Westerhoff, Paul	**Civil and Environmental Engineering (FSE)**

Team Vision

- Vision: to provide the knowledge base necessary to ensure the environmental and ecological safety of nanotechnologies. This vision will be realized through achieving the following goals:
  - Develop the capabilities to assess the movement, transformations, and biological effects of NMs in the environment.
  - Develop integrated models for predicting the interactions of nanomaterials with the living world at all scales.
  - Educate and train future scientists and leaders using novel programs directed toward understanding the implications of NMs for environmental health and safety.
  - Engage the scientific, regulatory, commercial, and public stakeholders to foster development of scientifically sound public policy and sustainable business practices in nanotechnology

Research Paradigm: Risk Assessment



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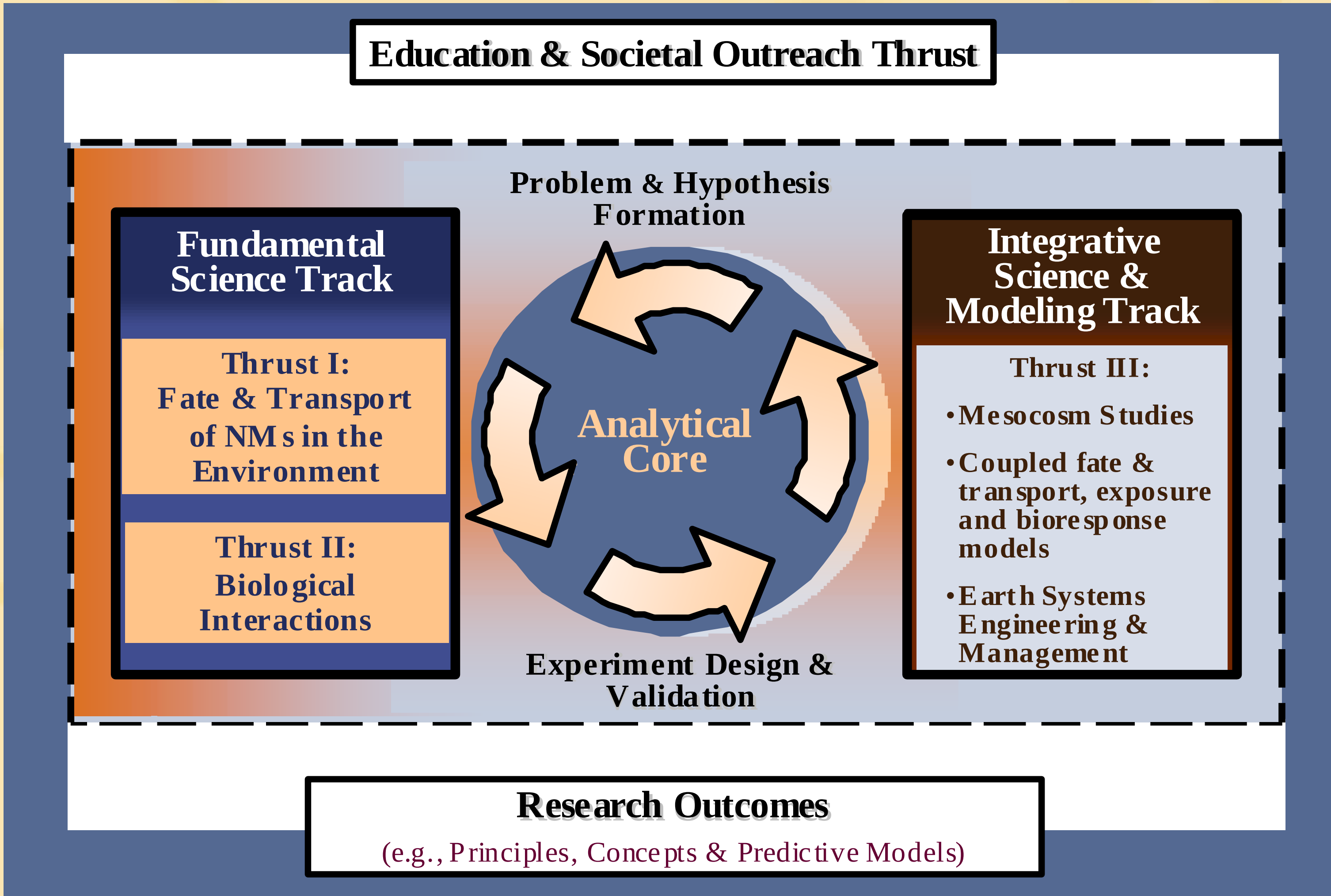
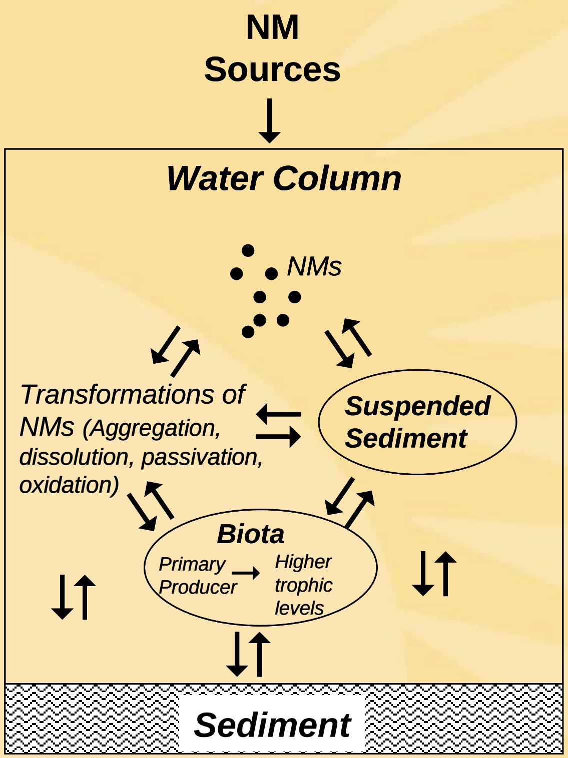
Structure of research teams



Thrust I - Sources, fate, transport, transformation, and bioaccumulation of NMs in the environment

- **Sources, release rates and natural occurrence of NMs in the environment**
  - ***What are the release rates into, occurrence of NMs in, and removal mechanisms from wastewater treatment plants (WWTPs)?***
  - ***How do airborne and terrestrial-based NMs enter aquatic systems?***
- **Abiotic fate and transport**
  - ***How do NM properties (dissolution, passivating layers, zeta potential) in aquatic environments change over time? How does this affect interactions between NMs and between NMs and other abiotic surfaces?***
  - ***Can partitioning models adequately describe the distribution of NMs among aquatic components?***
- **Biotic fate and transport.**
  - ***Where, to what extent and how rapidly do NMs accumulate in aquatic organisms?***
  - ***How do NMs facilitate pollutants uptake in aquatic organisms?***



Thrust II - Biological Interactions

- **Exposure methodology**
  - **What is the correct protocols & systems to test biological interactions?**
- **Toxicity testing in model organisms.**
  - ***For each nanomaterial studied, does it influence growth, reproduction, or survival at environmentally plausible concentrations? If so, how does susceptibility to toxicity vary among species and life stages? Do size and shape of the NM affect organismal responses? Are results affected by water and/or sediment chemistry?***
  - ***How does NM dissolution, surface passivation and aggregation affect organism response?***
  - ***For NM that dissolve, is there a qualitative or quantitative difference in the response of organisms to the material in nanoparticulate form versus soluble form?***
  - ***Do NMs alter rates of mutation or exert selective pressures that result in adaptive changes?***
- **Exposure Dosimetry.**
  - ***Is tissue NM concentration a better predictor of response than water (or sediment) concentration?***
  - ***Are there specific molecular changes induced by exposure to NMs that can be used to quantify nanomaterial exposure?***
- **Biokinetics related to response (toxicokinetics).**
  - ***Can differences in uptake, distribution, or elimination can explain species or lifestage differences in biological response?***
- **Toxicodynamics.**
  - ***What is the mode of action for the observed response?***

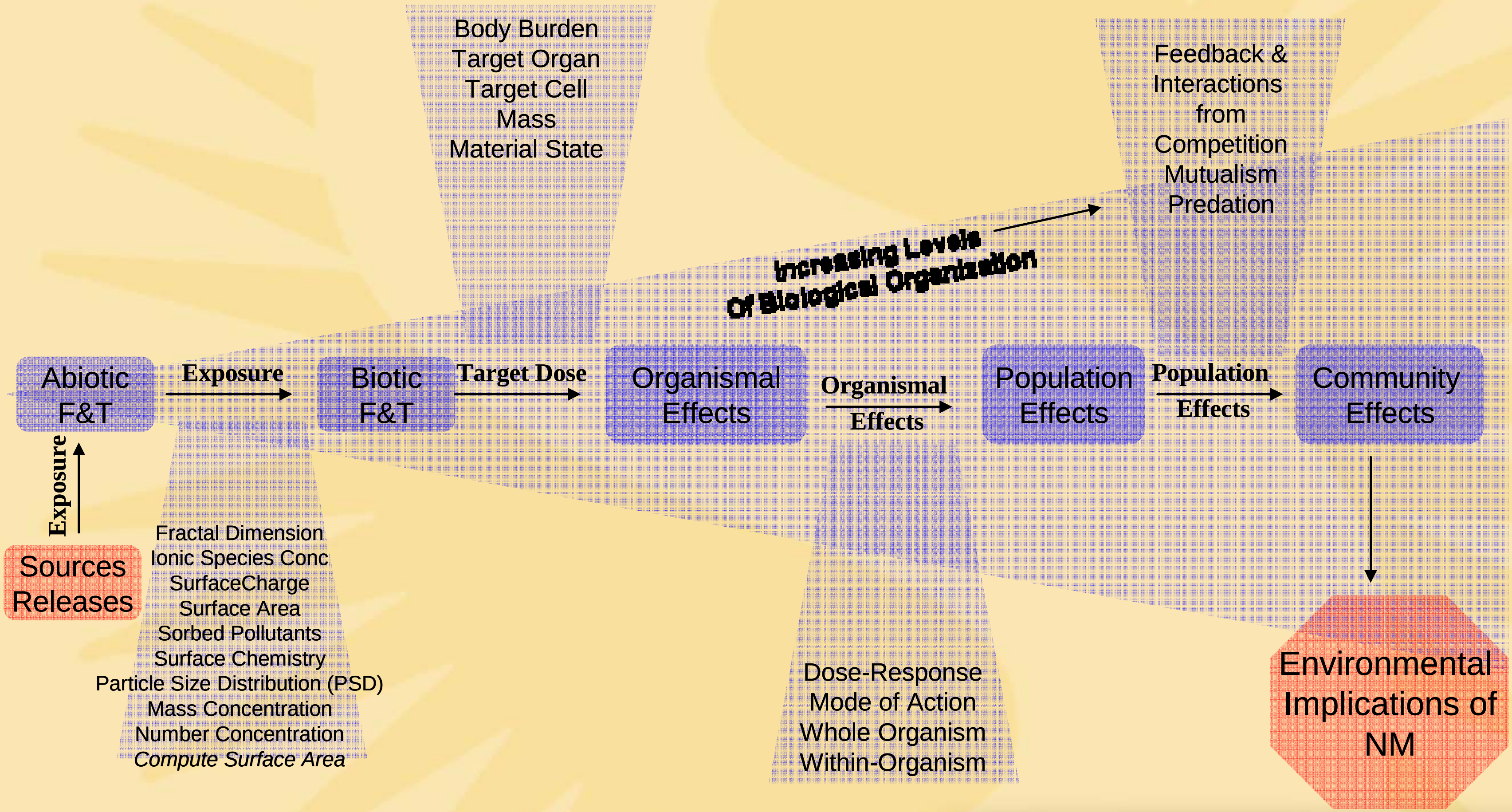
Thrust III: Integrative Ecological Experiments, Theory and Computational Approaches

- **Mesocosm Experimental Systems, and Observatories (NanoTron)**

- **Integrative Exposure and Ecosystem Impact Modeling**

- ***Earth systems engineering and management (ESEM)***

Modeling Approach



Thrust IV - Education and Societal Outreach

- **Mission**
  - Educate and train future science and engineering leaders as well as industry and government professionals using novel programs directed toward understanding the implications of nanomaterials for environmental health and safety.
  - Engage the scientific, regulatory, commercial, and public stakeholders to foster development of scientifically sound public policy and sustainable business practices in nanotechnology.
- **Scope**
  - The program will both develop novel educational opportunities in this emerging area for learners across the continuum from pre-collegiate through lifelong learners, and leverage with existing programs across both campuses and at other national nano centers that have developed best practices.

Analytical Core - Synthesis, Characterization, Detection and Monitoring of NMs

- Engineer and synthesize customized model nanoparticles
- Characterization in abiotic and biological media
- Detection and monitoring of NMs in environmental settings – water and sediment.
- Promote standardized materials and methods applicable to NM research

Current Success by ASU Eco-Nano Group

- 4 USEPA Projects ($400K each) - PIs are Westerhoff or Chen
- 1 DOE Project ??? ($400K) – Posner is PI
- Water Environment Research Foundation Award ($100K) – Westerhoff is PI
- Numerous projects related to beneficial use of nano-X for environmental applications
- Numerous invited talks, book chapters and journal publications
- See our POSTER for some details
- Contact: p.westerhoff@asu.edu