Research Priorities on Safe(r!!!) Nanotechnologies

Mark R. Wiesner

Duke University

wiesner@duke.edu

CEINT

Center for the Environmental Implications of NanoTechnology

www.ceint.duke.edu

Priorities

- *Make the safest nanotechnologies possible*

- *Make them using environmentally benign procedures*

- *Produce information on risks and benefits of emerging technologies that allows for timely, informed decision making*

NRC Conceptual framework for Nano EHS research

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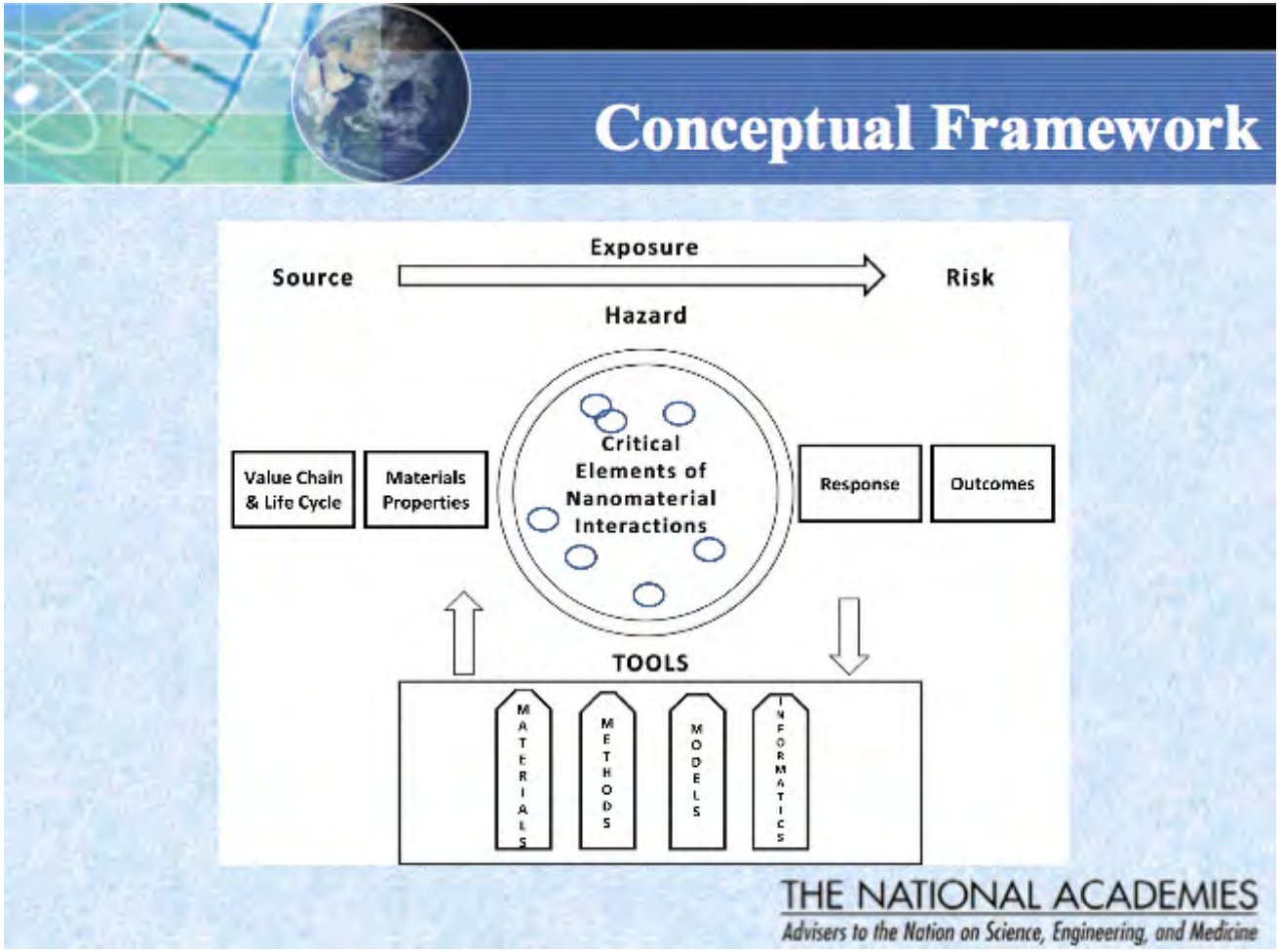

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NRC Committee identified four priority areas

- *Identification, characterization, and quantification of the origins of nanomaterial releases*
- *Processes that affect both potential hazards and exposure*
- *Nanomaterial interactions in complex systems ranging from subcellular systems to ecosystems*
- *Adaptive research and knowledge infrastructure for accelerating research progress and providing rapid feedback to advance research*

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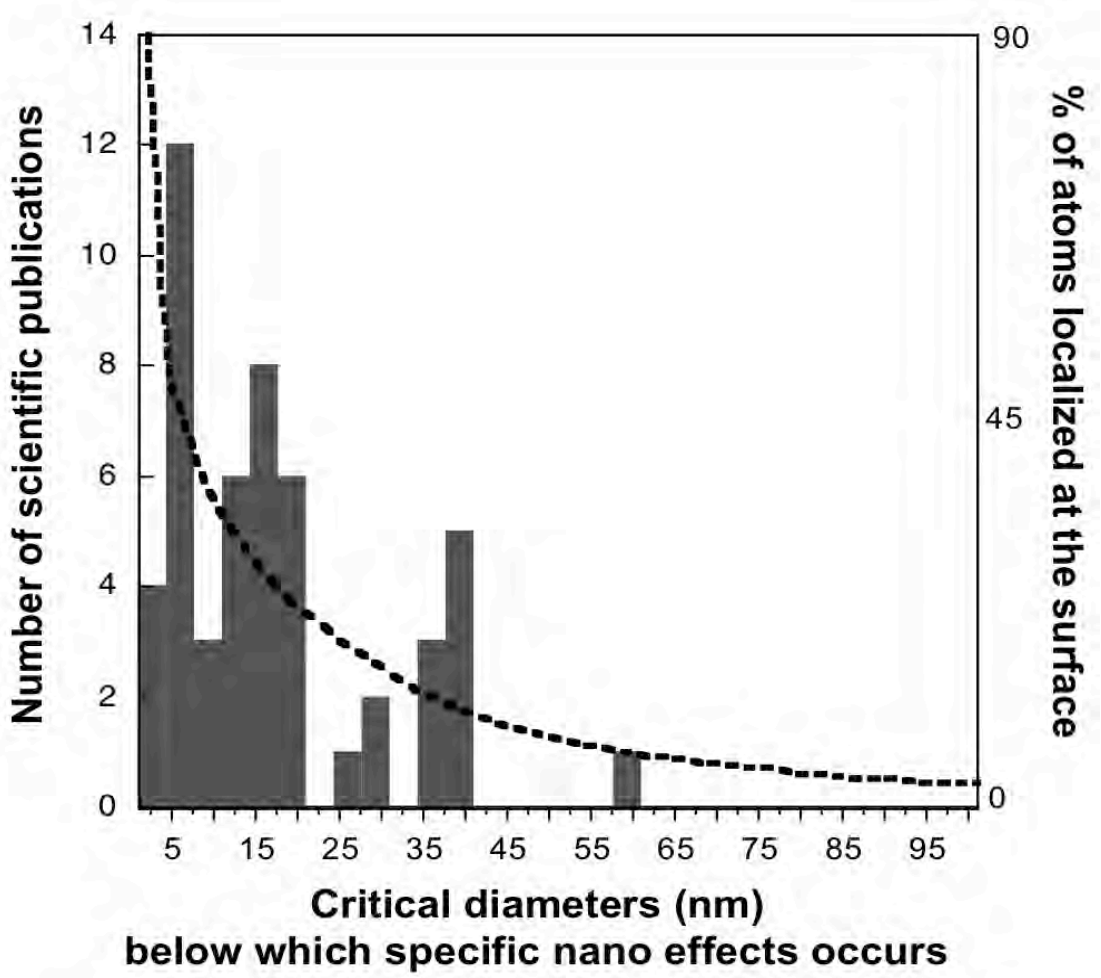
Research Priorities recognize

- *Need to continue to explore "first generation" issues*
- *Transformations and measurements of nanomaterials in real, complex systems*
- *Bioüptake*
- *Differences between natural, incidental and engineered NPs*
- *Next generation nanotechnologies*
- *How nanomaterials are used (value chain considerations)*
- *Life cycle assessment of nanotechnology*
- *Likely options for risk management*

Defining nanomaterials remains a challenge

- *Small*
- *Novel Properties*



Auffan et al., Nature Nanotechnology 2009

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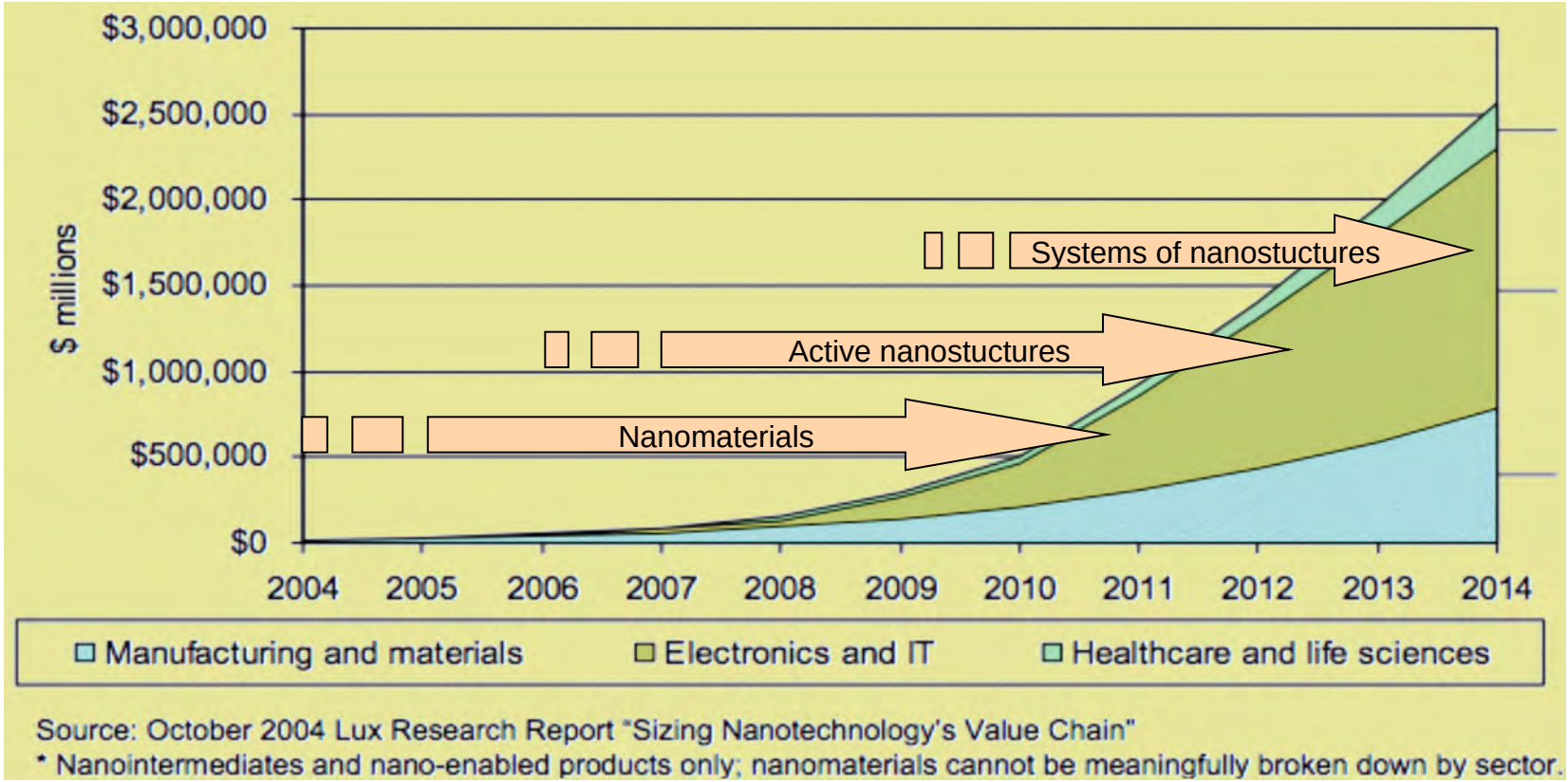
Environmental considerations of nanotechnology- behind the curve



Source: October 2004 Lux Research Report "Sizing Nanotechnology's Value Chain"
* Nanointermediates and nano-enabled products only; nanomaterials cannot be meaningfully broken down by sector.

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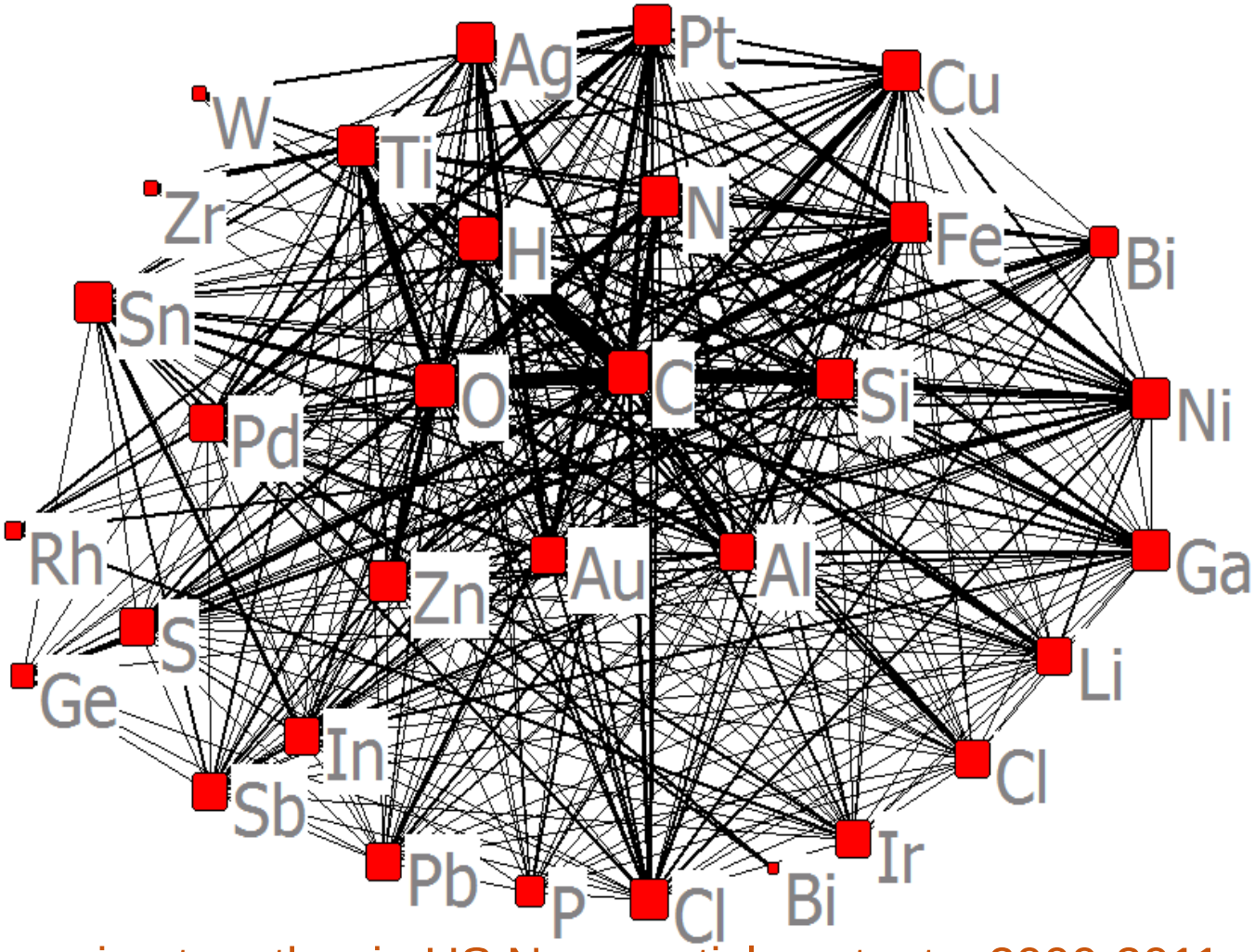
Next (Current!) generation nanomaterials



Elements appearing together in US Nanoparticle patents, 2000-2011

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Value-chain driven evaluations

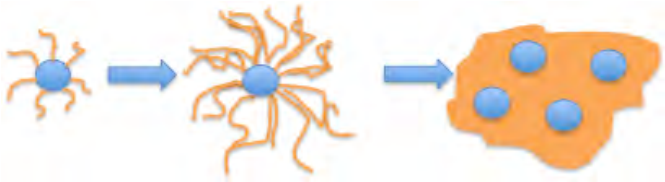
Primary → Formulations → End Products

Primary nanomaterials

- *Graphene*
- *Tungsten sulfide*
- *MoS_2*
- *Ferrofluids (Fe_3O_4)*
- *Al_2O_3*
- *Fe-C60 composites*
- *SWCT-quantum dot composites*
- *Protein-derived NPs*

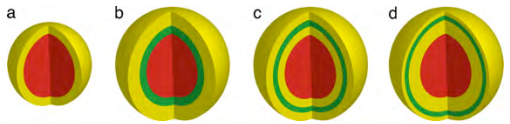
Formulations - Chemical modifications to stabilize nanomaterials

Nanoparticle-polymer composites (a continuum)



Nanoassemblages/ Hybrids – combinations of nanomaterials in various configurations

- Metal oxides on carbon
- Carbon nanotubes/quantum dots
- Electron donors/electron shuttles
- Photon harvesters/electron shuttles
- Core-shell structures
- Nanotubes filled with nanomaterials
- Organic/inorganic hybrids



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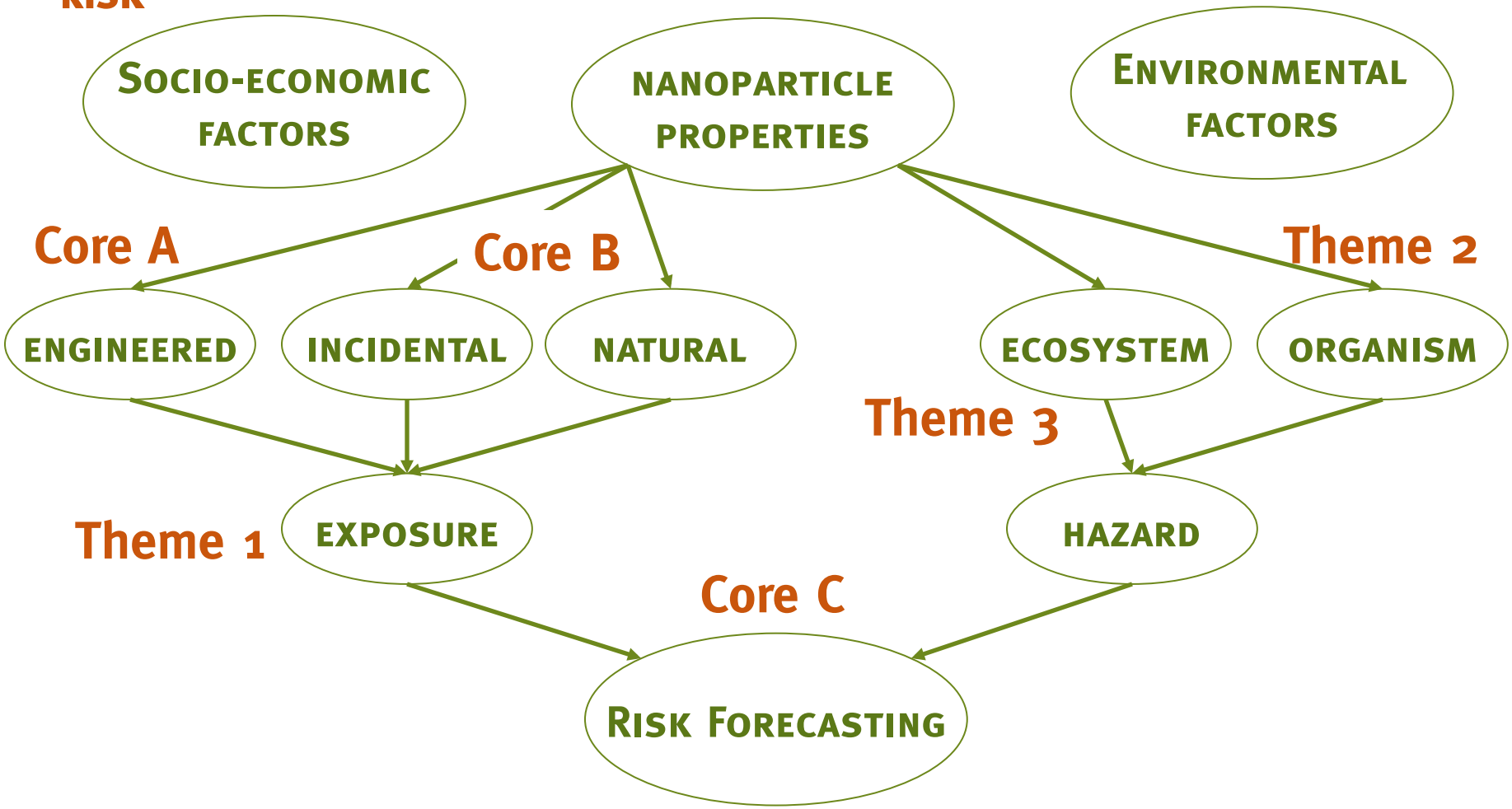
Elucidate principles that determine environmental behavior of nanomaterials and translate this knowledge into the language of risk



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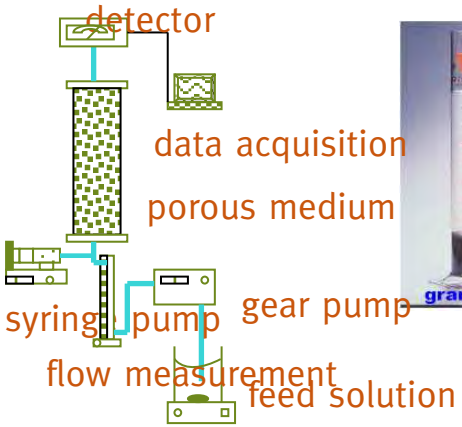
Initial Intrinsic properties

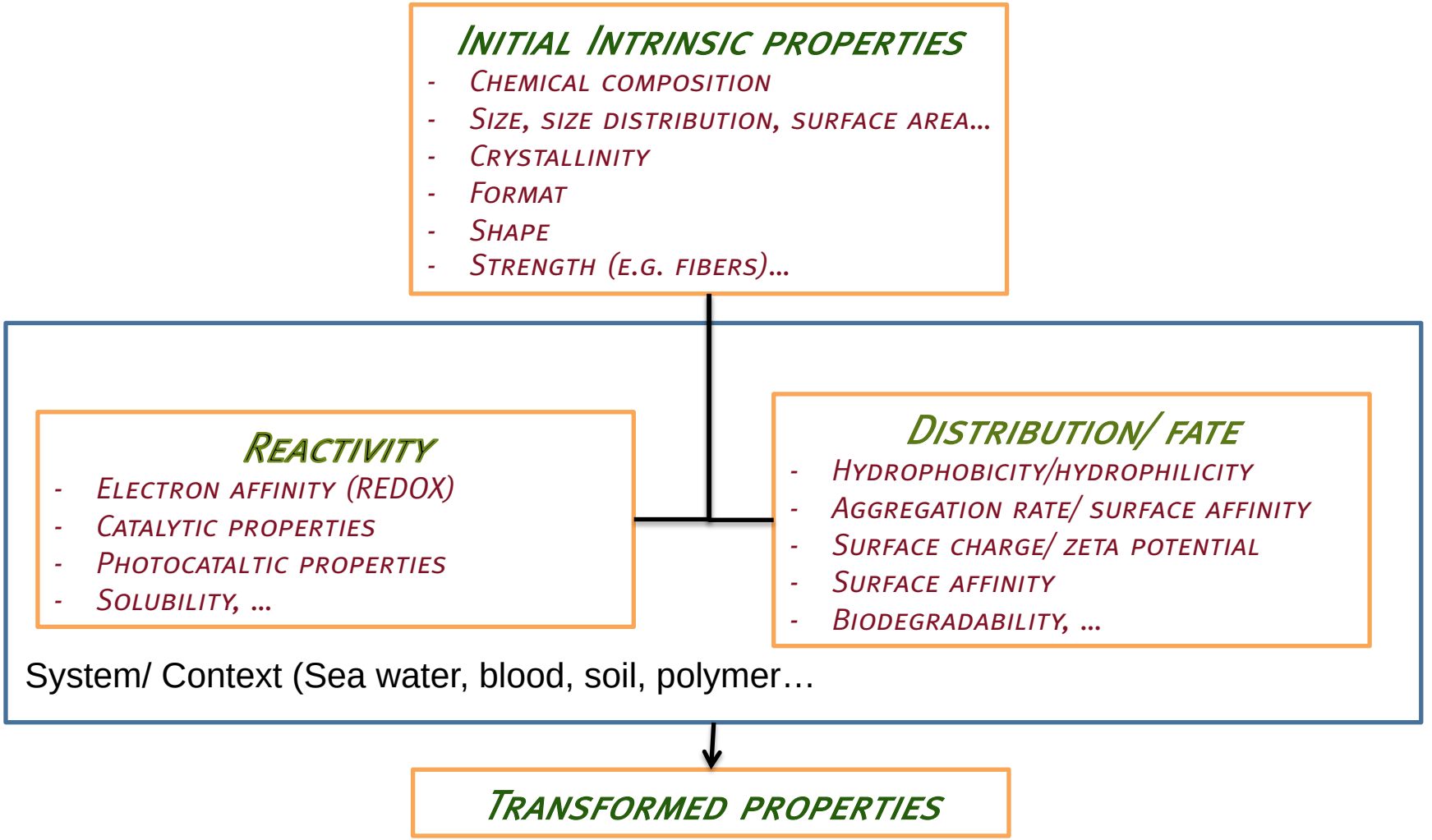
- Chemical composition
- Size, size distribution, surface area…
- Crystallinity
- Format
- Shape
- Strength (e.g. fibers)…



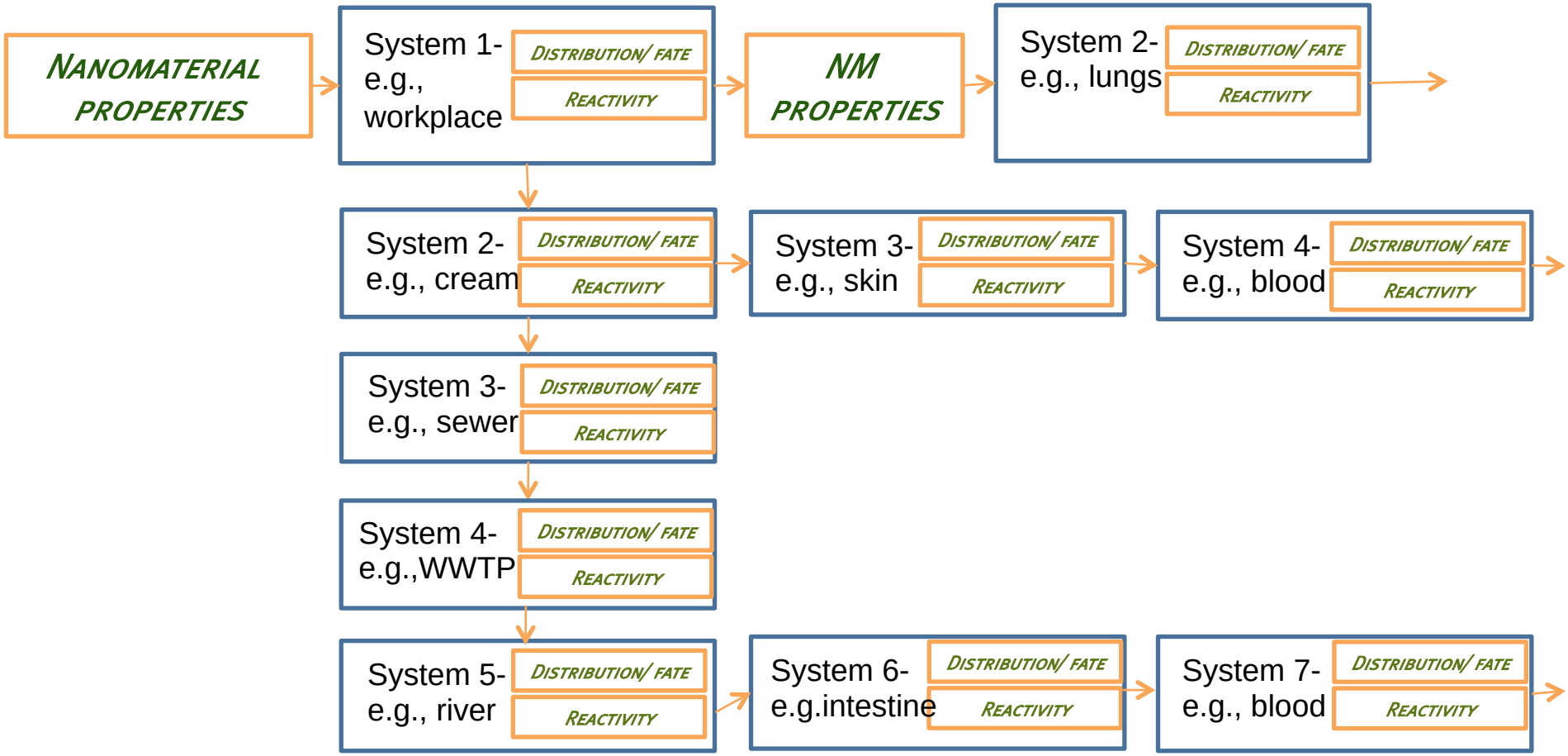
Nanoparticle properties (size, charge… → Affinity coefficient for reference surface(s), α_{ref} → Laboratory –determined distribution coefficients, Kd → Removal by wastewater treatment plant

Nanoparticle properties → Lab-based measure ("Ames test") → Toxicity

Parameterizing Nanomaterial Risk



Nanomaterial properties will change as a function of the system where the nanomaterials are present



Environmental Transformations of Nanomaterials

- *Aggregation*
  - Reactivity and toxicity
- *Redox reactions*
  - biomolecules
- *Biotransformations*
  - Biodegradation of coatings
- *Dissolution/solubility*
  - Effect of NP properties and coatings
- *Adsorption*
  - Proteins, humic substances, polysaccharides,…
- *Weathering of nanomaterial-containing matrices*

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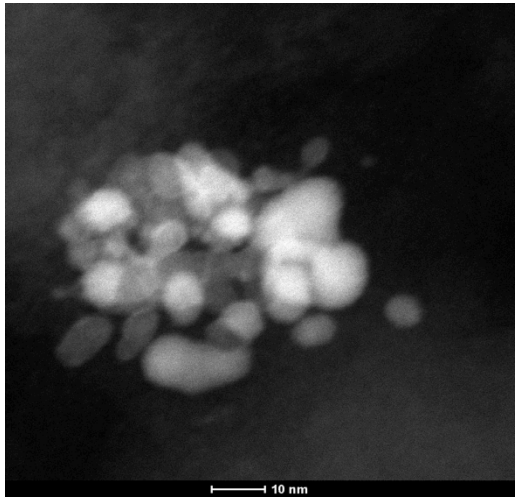
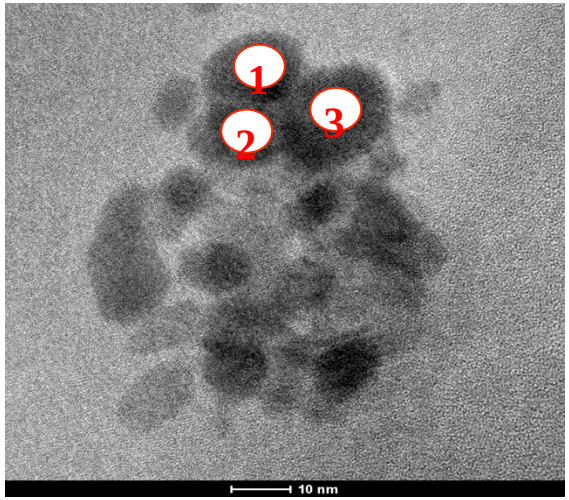
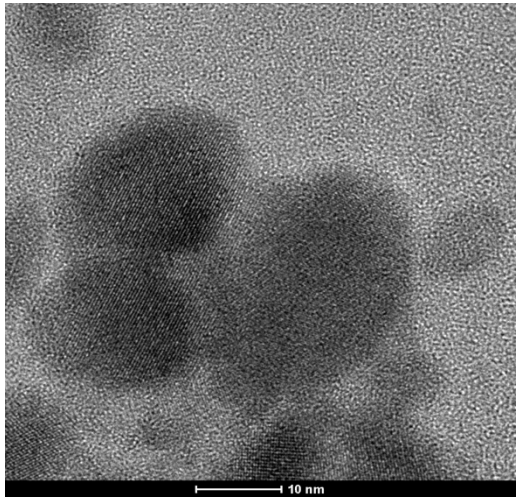
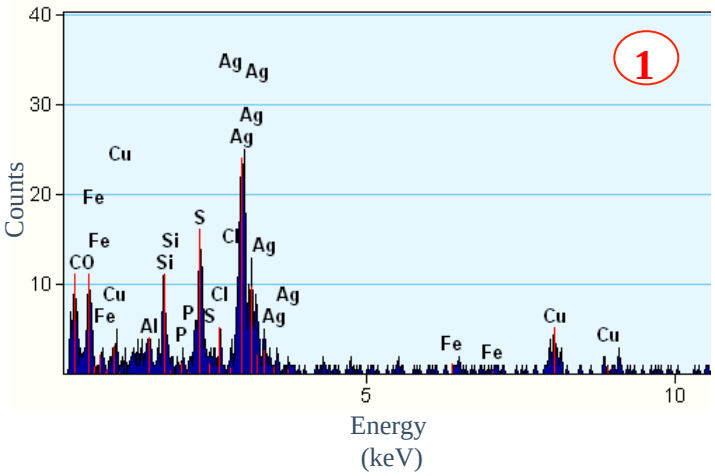
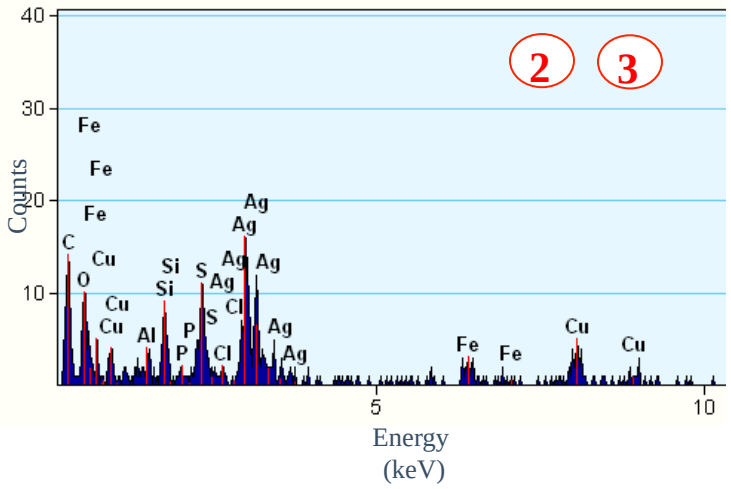
AgNPs identified in wastewater, but unclear if they are manufactured or incidental



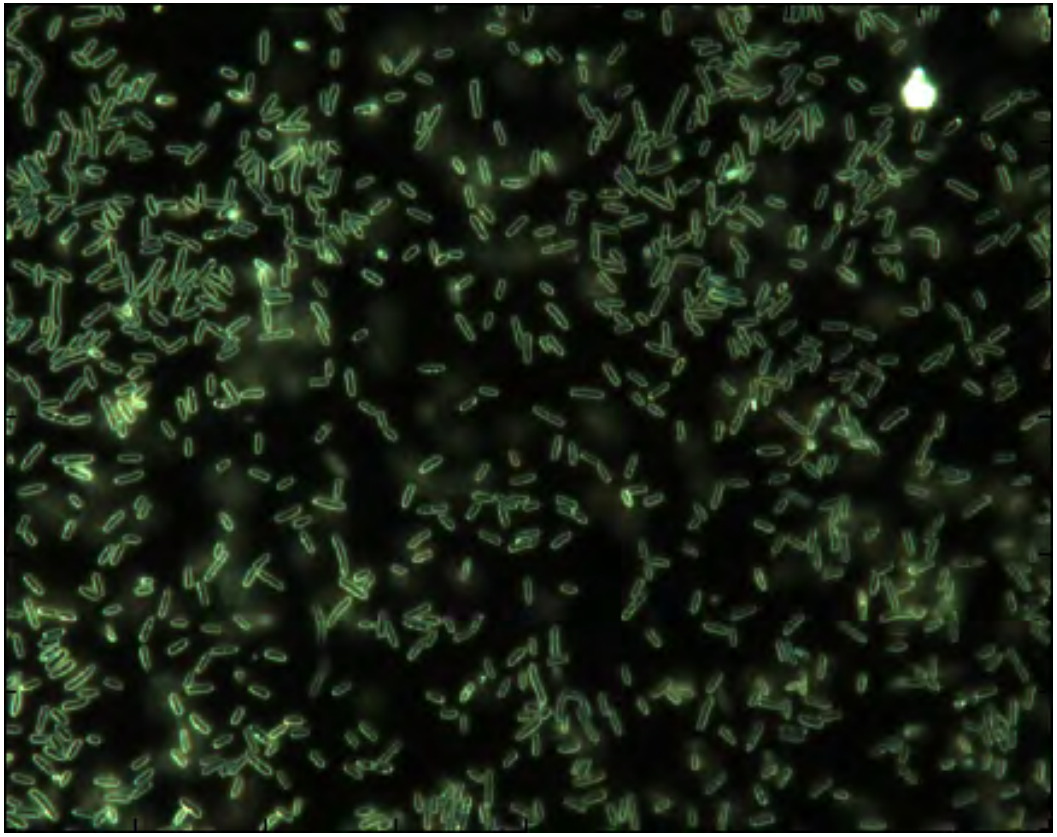




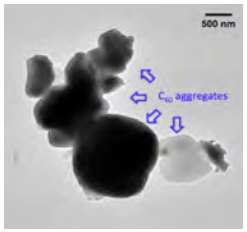


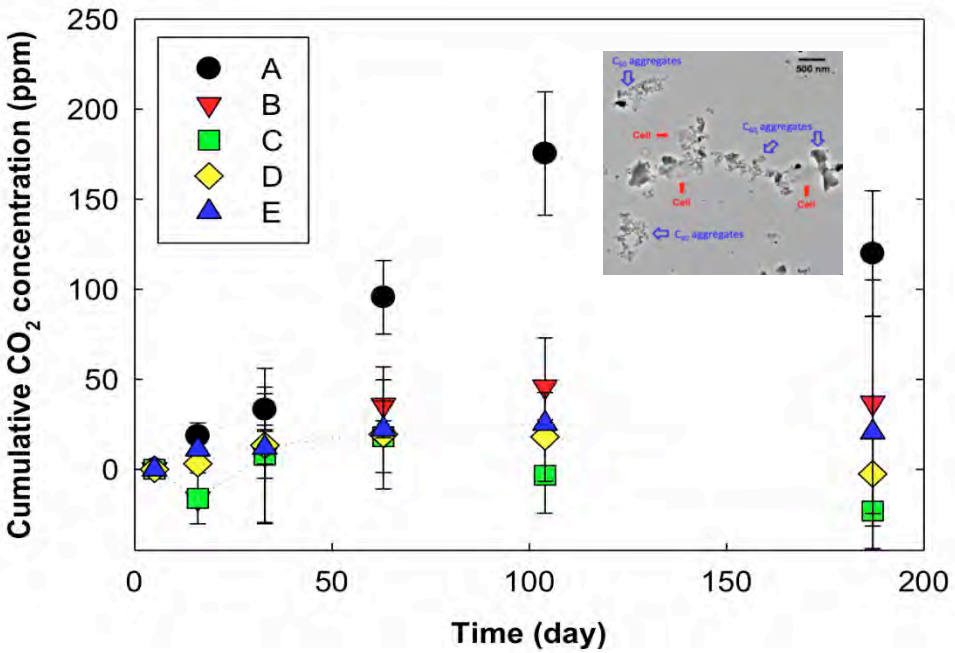


Dissolved species rapidly converted to nanoparticles



Bacterial transformation and degradation of C_{60}





Sample	Total C disappeared in water (μg)	Total C produced in headspace (μg)	Mass Balance
A	72.0	67.1	93.2%
B	50.5	46.3	91.7%
C	40	38.1	95.3%
D	39	37.8	97.0%
E	35.5	34.0	95.8%

Data from Wiesner lab, Duke University

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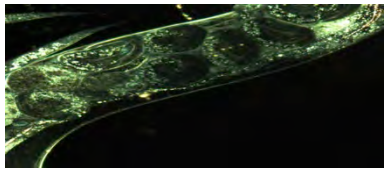
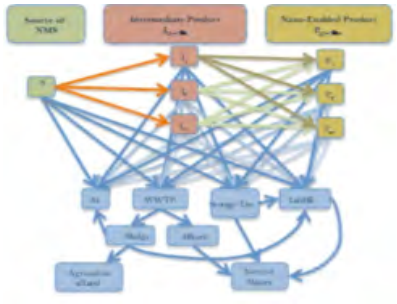
Highlights of progress to date in CEINT

- *Clear Evidence of nanoparticle-specific effects*



- *Identification of key parameters controlling spatial and temporal distribution of nanomaterials in the environment*

- *Elaboration of sources and processes generating nanoparticles in natural and engineered systems*



- *Risk Forecasting*

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Nanoparticle effects on organisms

CEINT has shown:

- *Bioüptake*
- *Toxicity*
- *Trophic transfer*
- *Maternal transfer*

Image from Bertsch lab, University of Kentucky

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It was nano all along

"In your typical plant biology course, you don't learn that metals are taken up by plants in the form of particles."

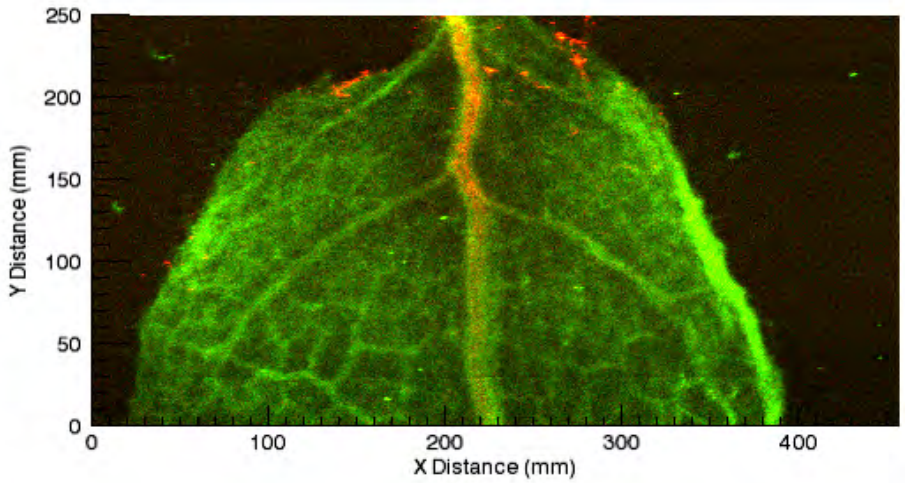

Image from Bertsch lab, University of Kentucky

William Schlesinger,
Cary Institute of Ecosystem Studies,
CEINT EAB member

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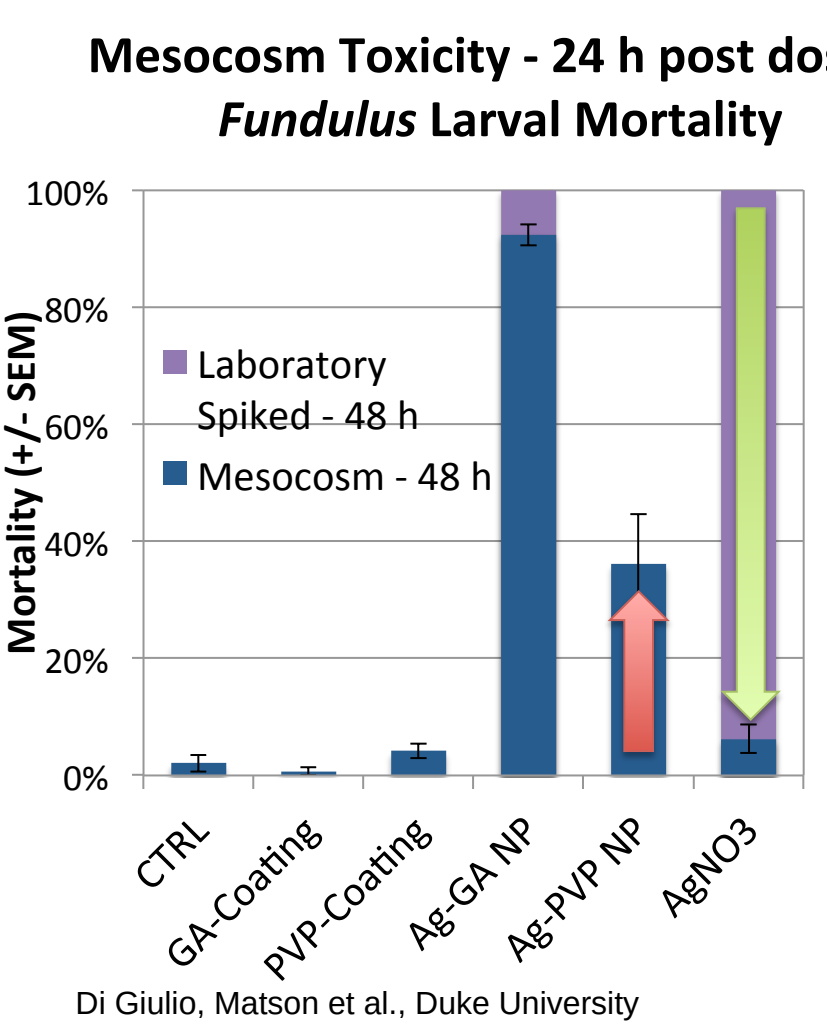
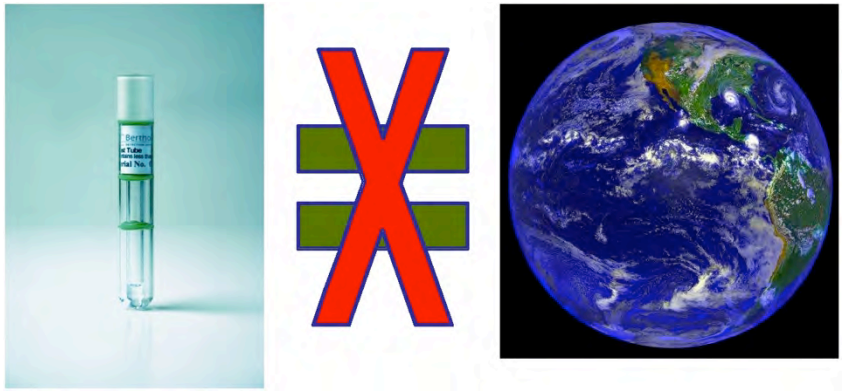
Mesocosm Results



Di Giulio, Matson et al., Duke University



NSF EF-0830093

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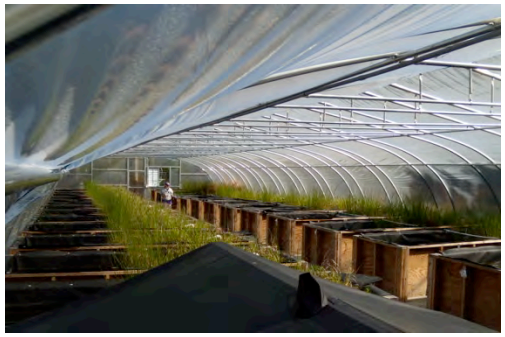


Nanomaterials in real, complex systems

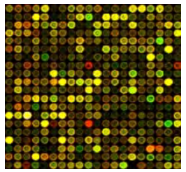
mesocosm

Theory
&
Risk Forecasting

lab

HTS

microcosm



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Transport & fate

What nanomaterial properties and environmental conditions control the spatial and temporal distribution of nanomaterials in the environment?

Solutes	Nanomaterials
Distribution Coefficient	Distribution Coefficient
K_{ow}	Surface affinity
	Hydrophobicity, surface charge…
solubility	Dissolution rate
Henry's constant	N/A
Vapor pressure	??
Bioaccumulation factor	Bioaccumulation factor
Biodegradation rate	Bio-disassembly rate
Reaction rates	Transformation rates

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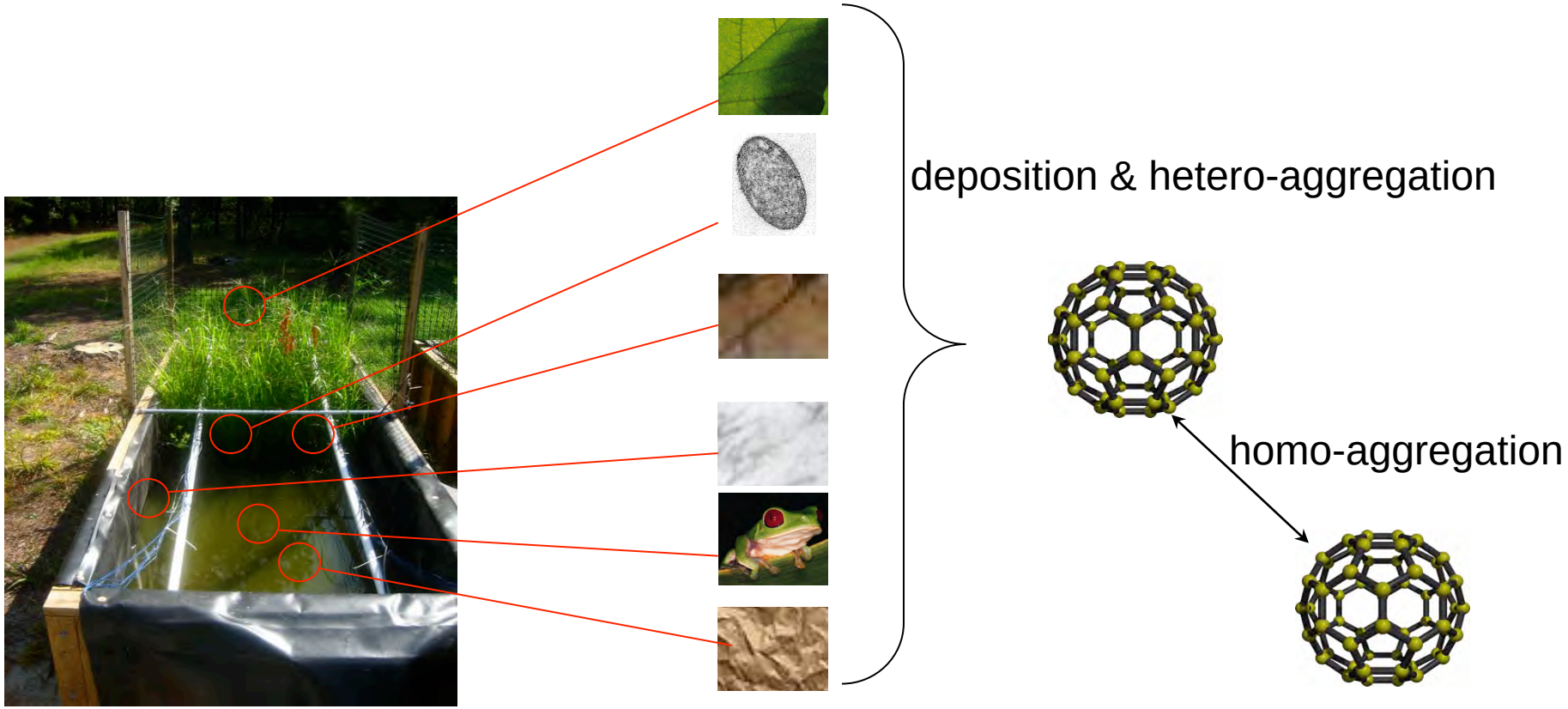
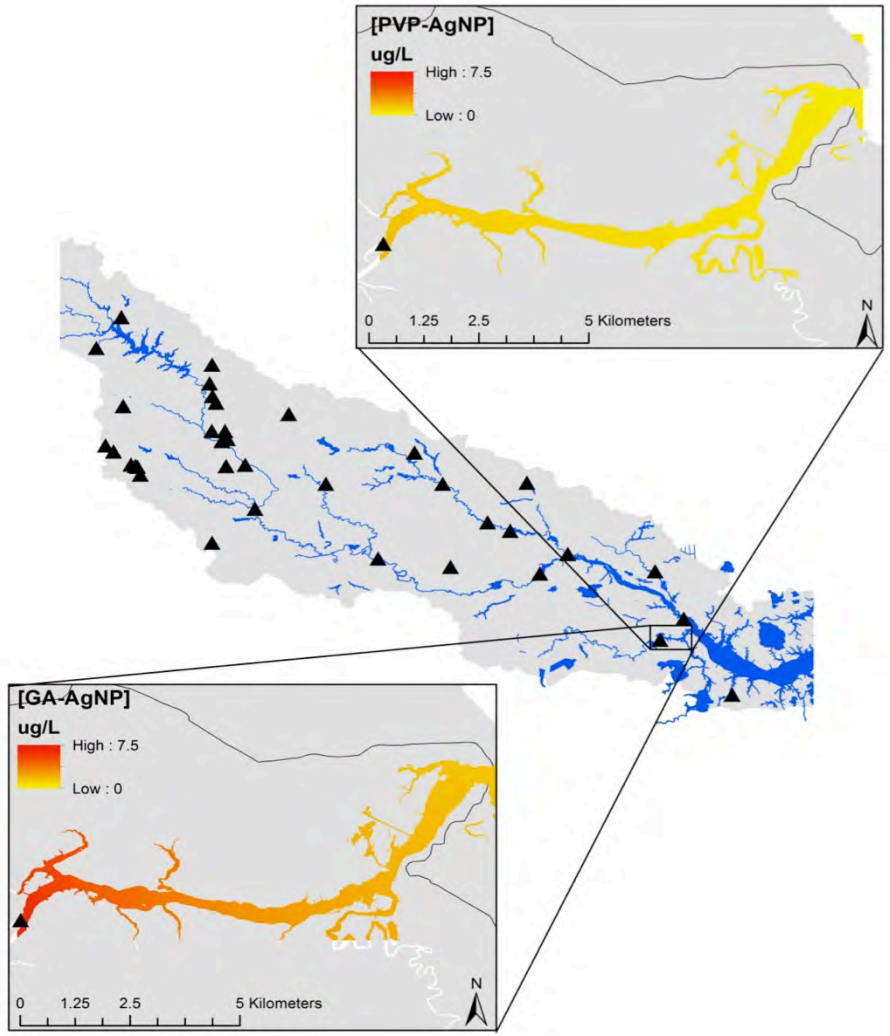
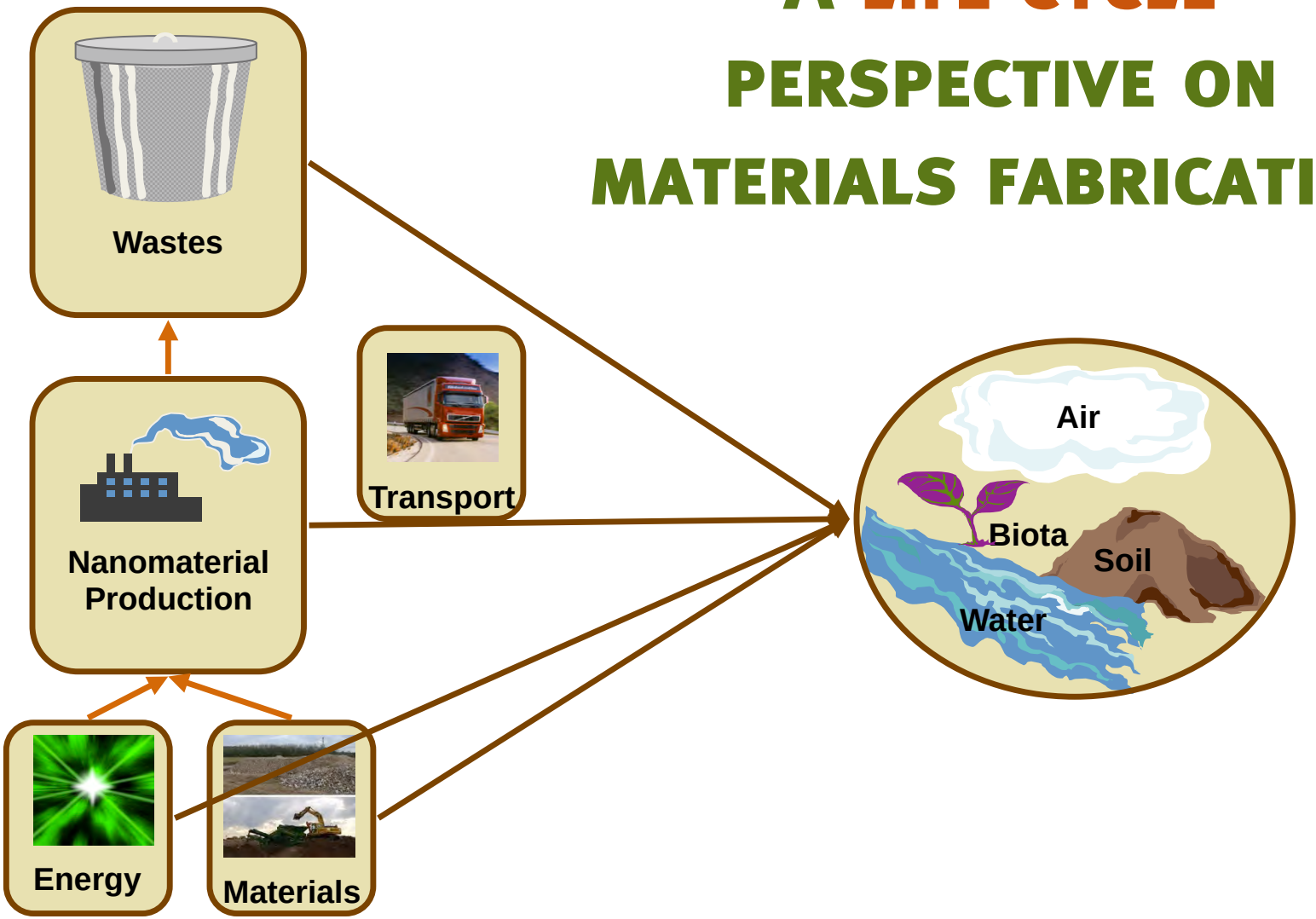
Parameters for predicting nanoparticle fate: Affinity of nanoparticles for various surfaces



Bayesnet simulations of nanosilver exposure potential



A LIFE CYCLE PERSPECTIVE ON MATERIALS FABRICATION



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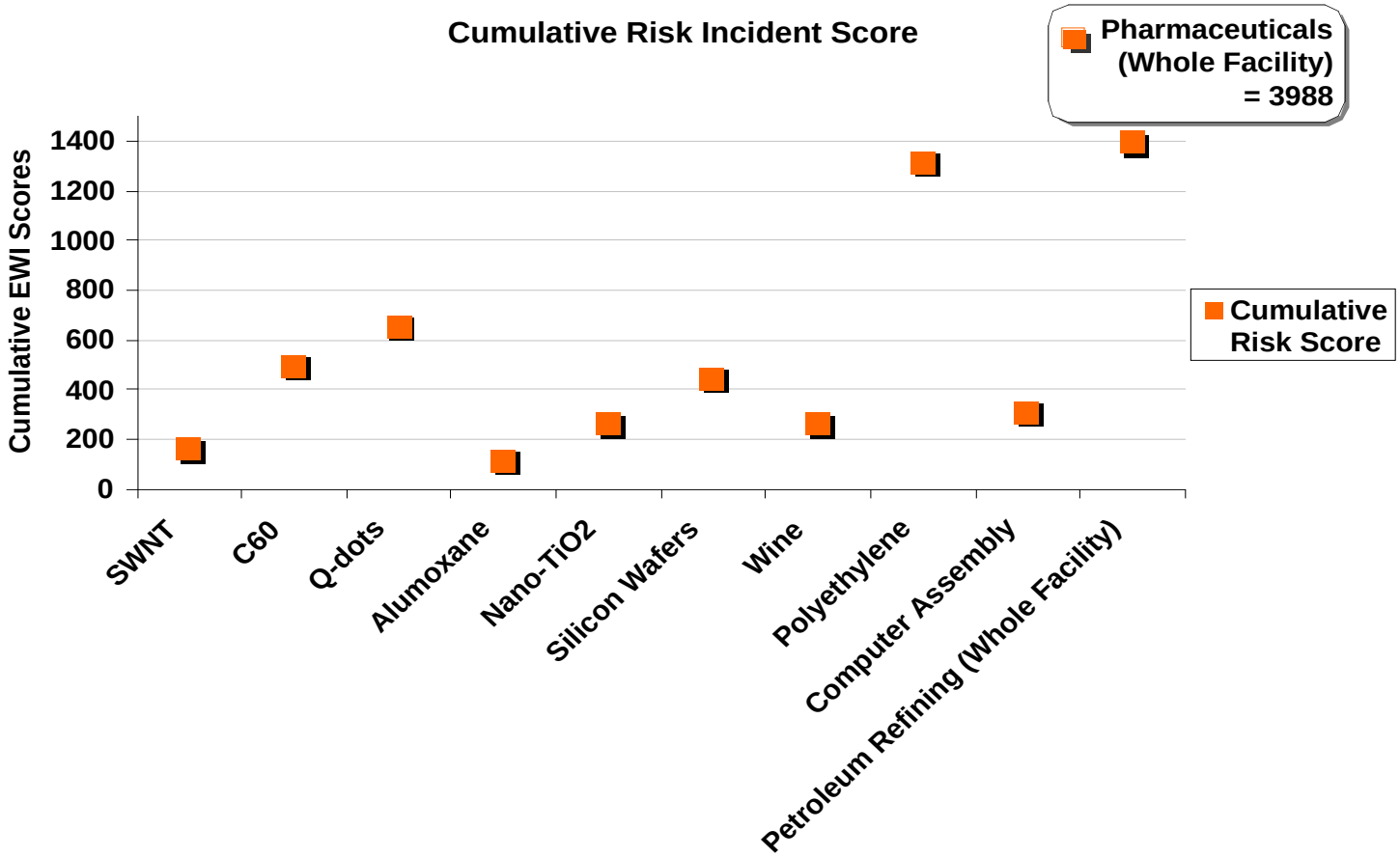
Materials used to make nanomaterials introduce risk to workers and the environment



Robichaud, Tanzil, Weilenmann, and Wiesner, 2005

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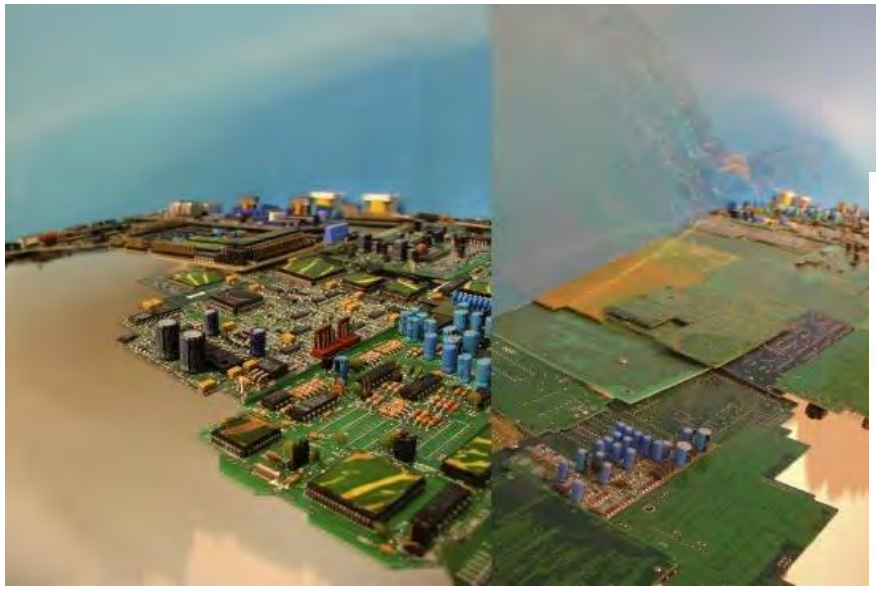
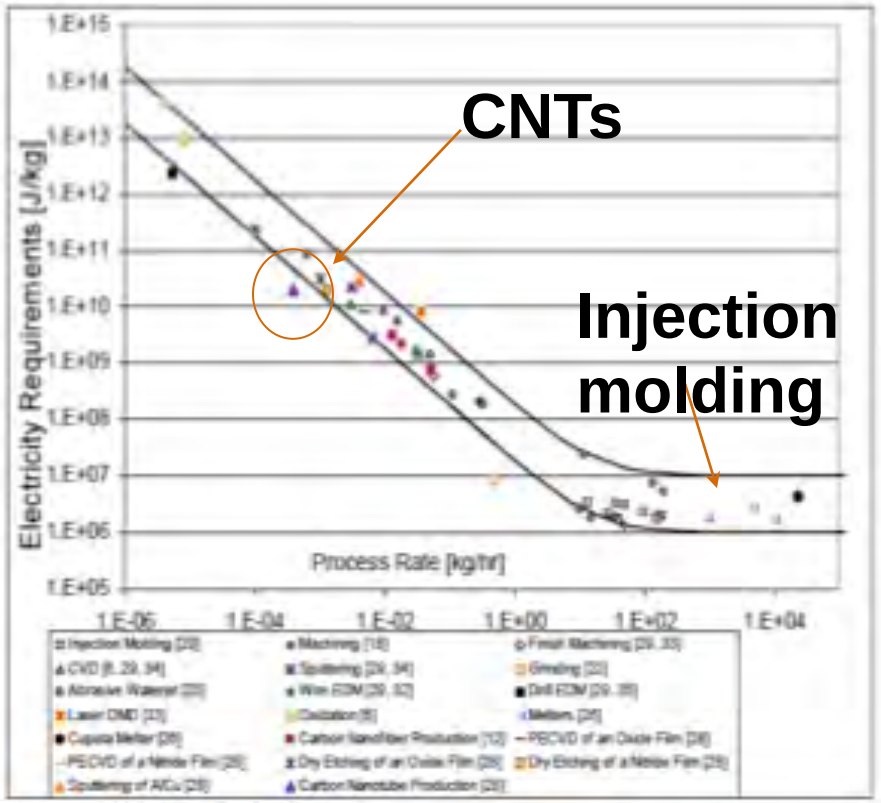
Energy use has environmental consequences



Artwork: cityscape I & II by Grace Grothaus, The monster footprint of digital technology. Low-tech Magazine, June 16, 2009



Minimum Exergy Requirements for the Manufacturing of Carbon Nanotubes

Timothy G. Gutowski, John Y. H. Liow, Dusan P. Sekulic

IEEE, International Symposium on Sustainable Systems and Technologies, Washington D.C., May 16-19, 2010

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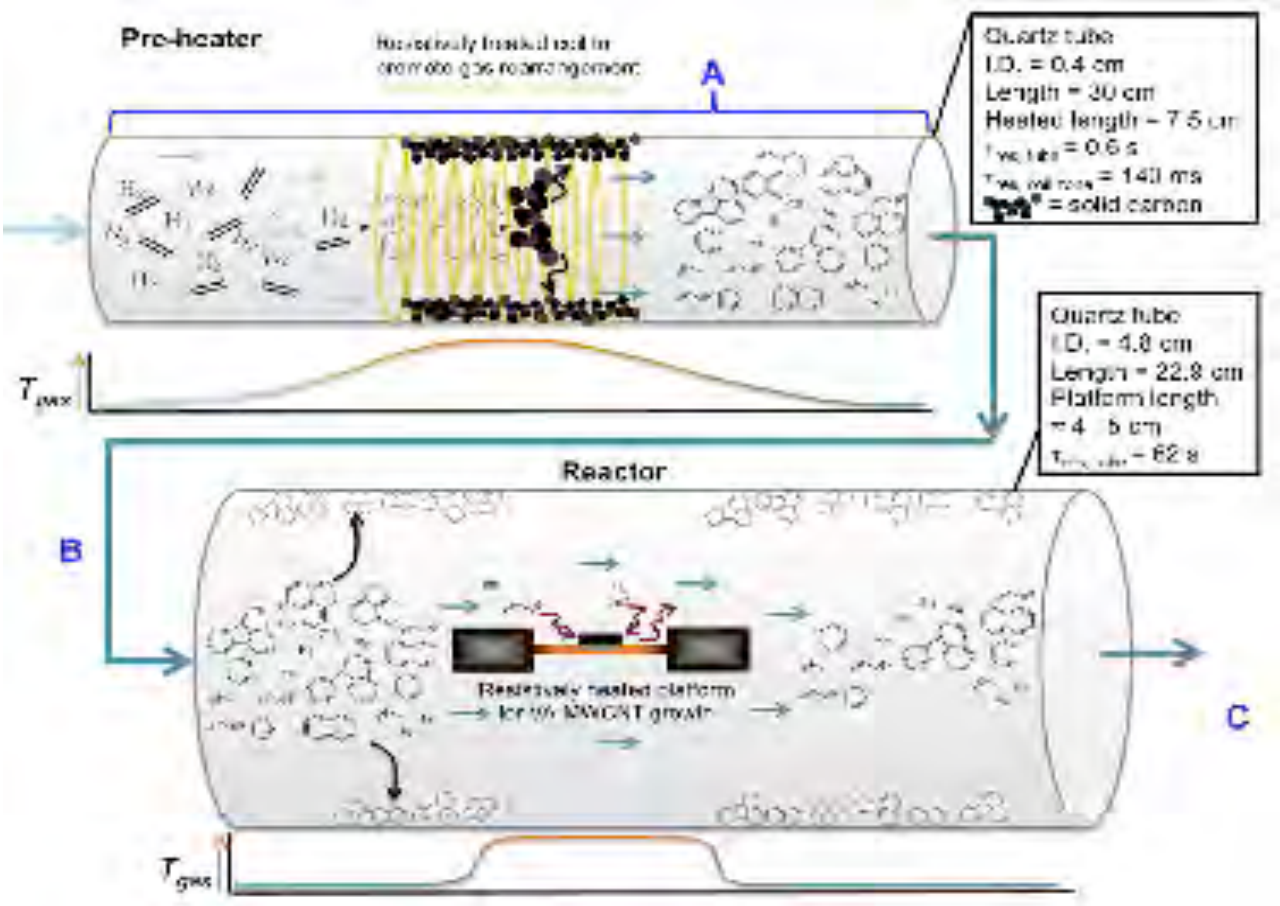
Wastes generated (CNTs)



Desiree Plata and co-workers 2009

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Thank You

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