

Biological and Ecological Toxicity of Engineered Nanoparticles

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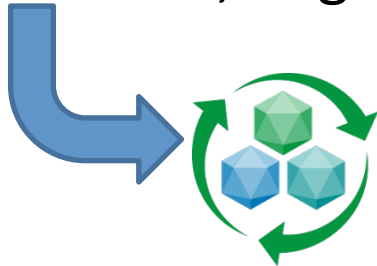


The Center for
Sustainable Nanotechnology



Research article

We take input from:
Occupational exposure to nanomaterials: Assessing the potential for cutaneous exposure to metal oxide nanoparticles in a semiconductor facility
materials chemists, physical/analytical chemists, computational chemists, freshwater biologists, soil scientists, engineers, industrial scientists



The Center for Sustainable Nanotechnology



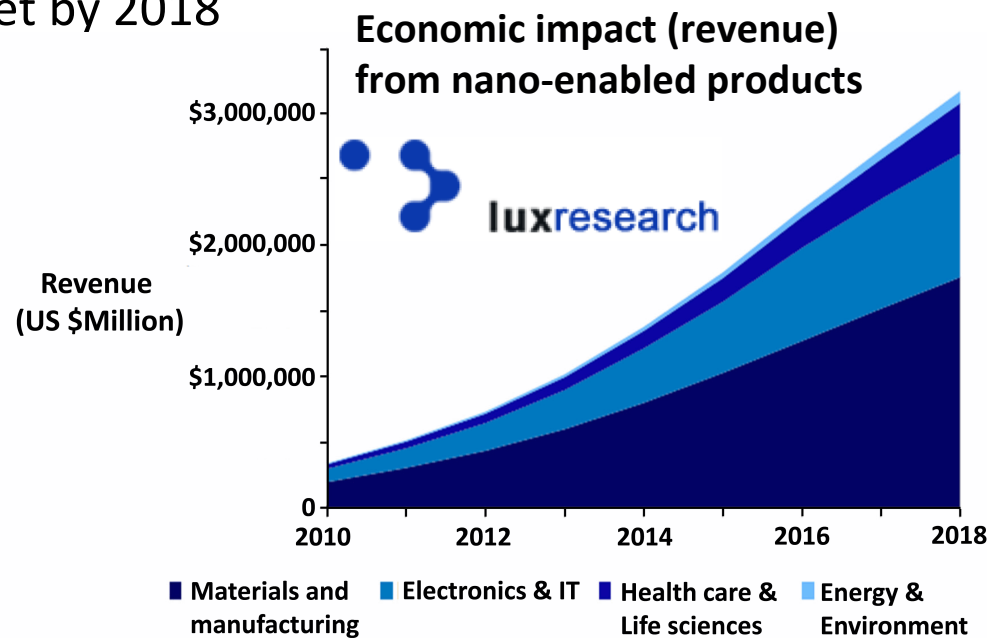
working to achieve “benign by design” nanoparticles

What can we learn from chemical health and safety experts?

Surge in Nanoscale Materials Use

An independent market study by Lux Research commissioned by NSF and NNCO found that:

- Governments, corporations, and investors invested **\$18.5 Billion** in nanotechnology in 2012
- Nano-enabled products, intermediates, and materials will be a **\$4.4 trillion** market by 2018



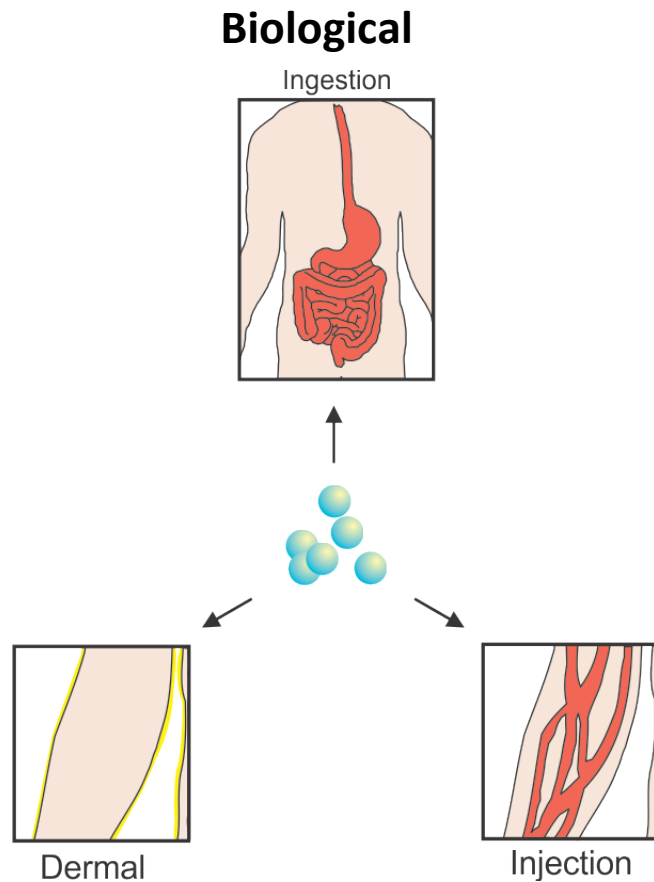
Human health and/or environmental impacts of nano-enabled products



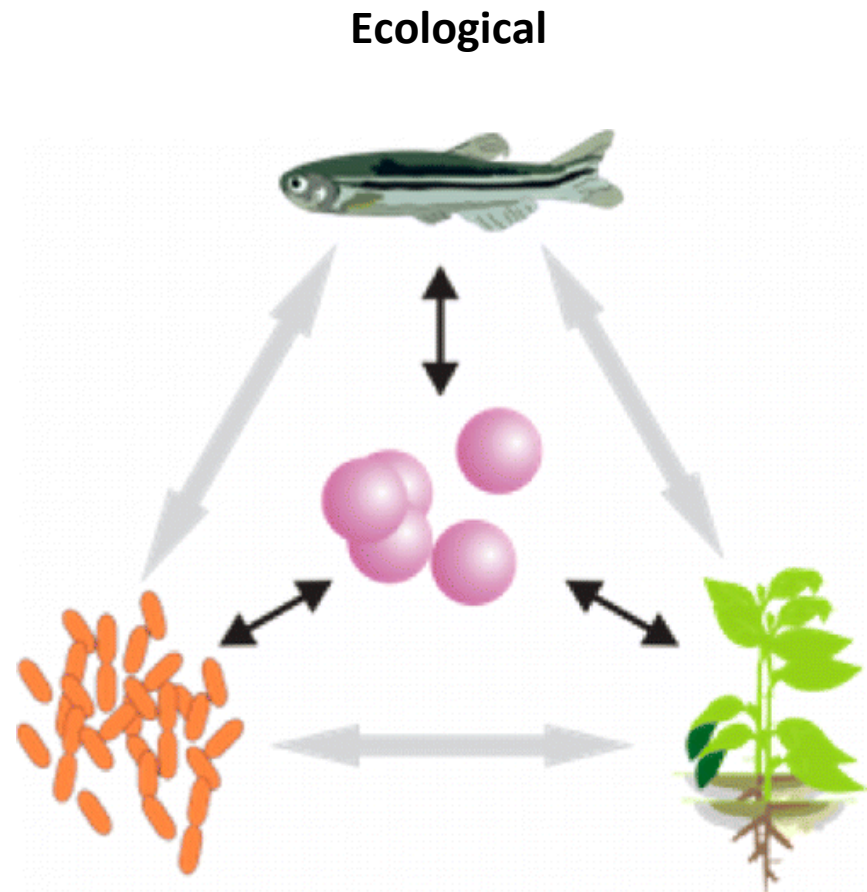
We are missing critical knowledge about the potential impacts of engineered nanomaterials that may limit future applications

Towards Safer Design Rules

Determine the impact of nanoparticles released within biological and ecological systems



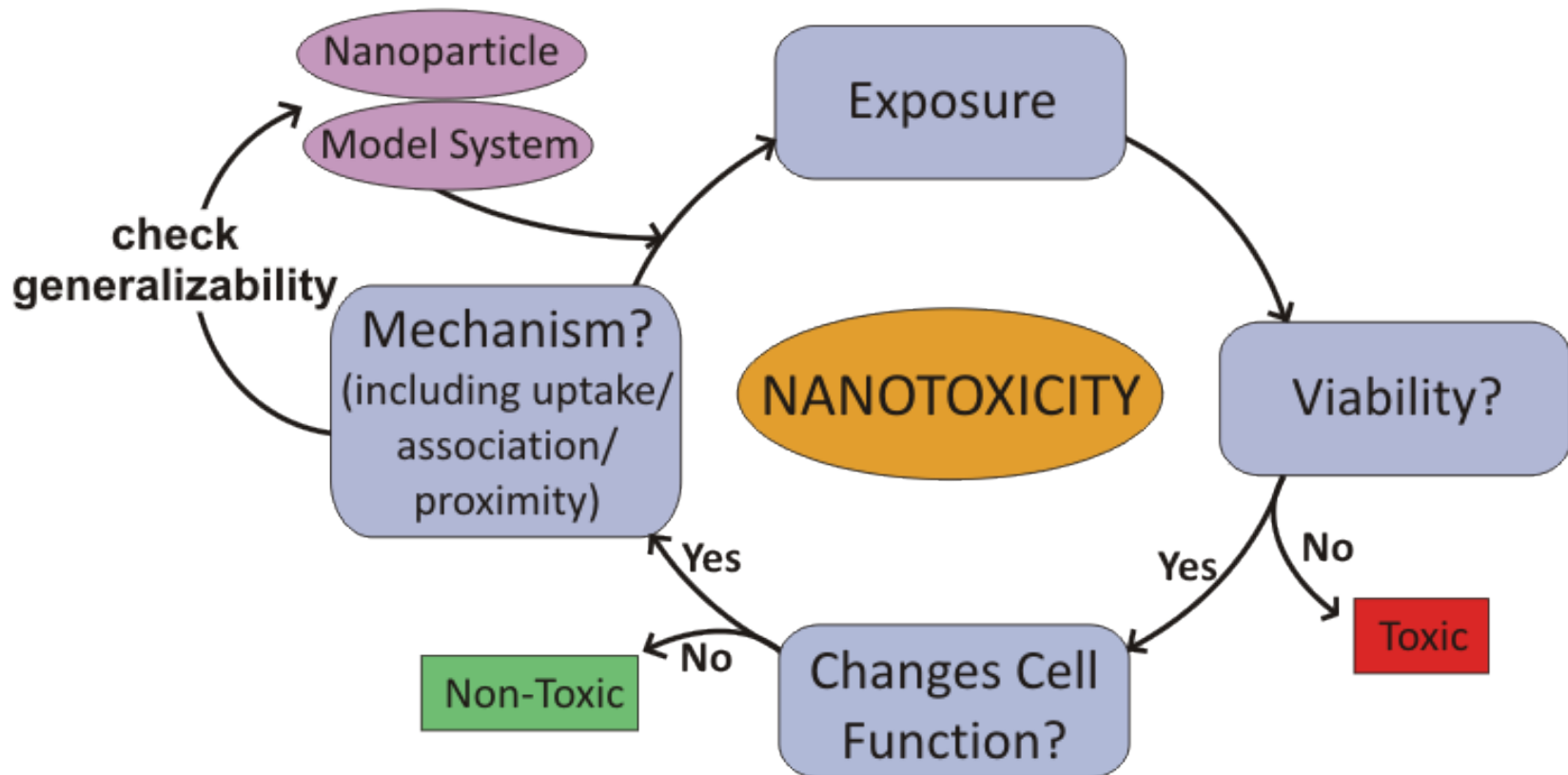
Assessing Nanoparticle Toxicity, Love, et al., *Ann. Rev. Anal. Chem.*, **2012**, 5, 181.



Toxicity of Engineer Nanoparticles in the Environment, Maurer-Jones, et al., *Anal Chem* **2013**, 85, 3036

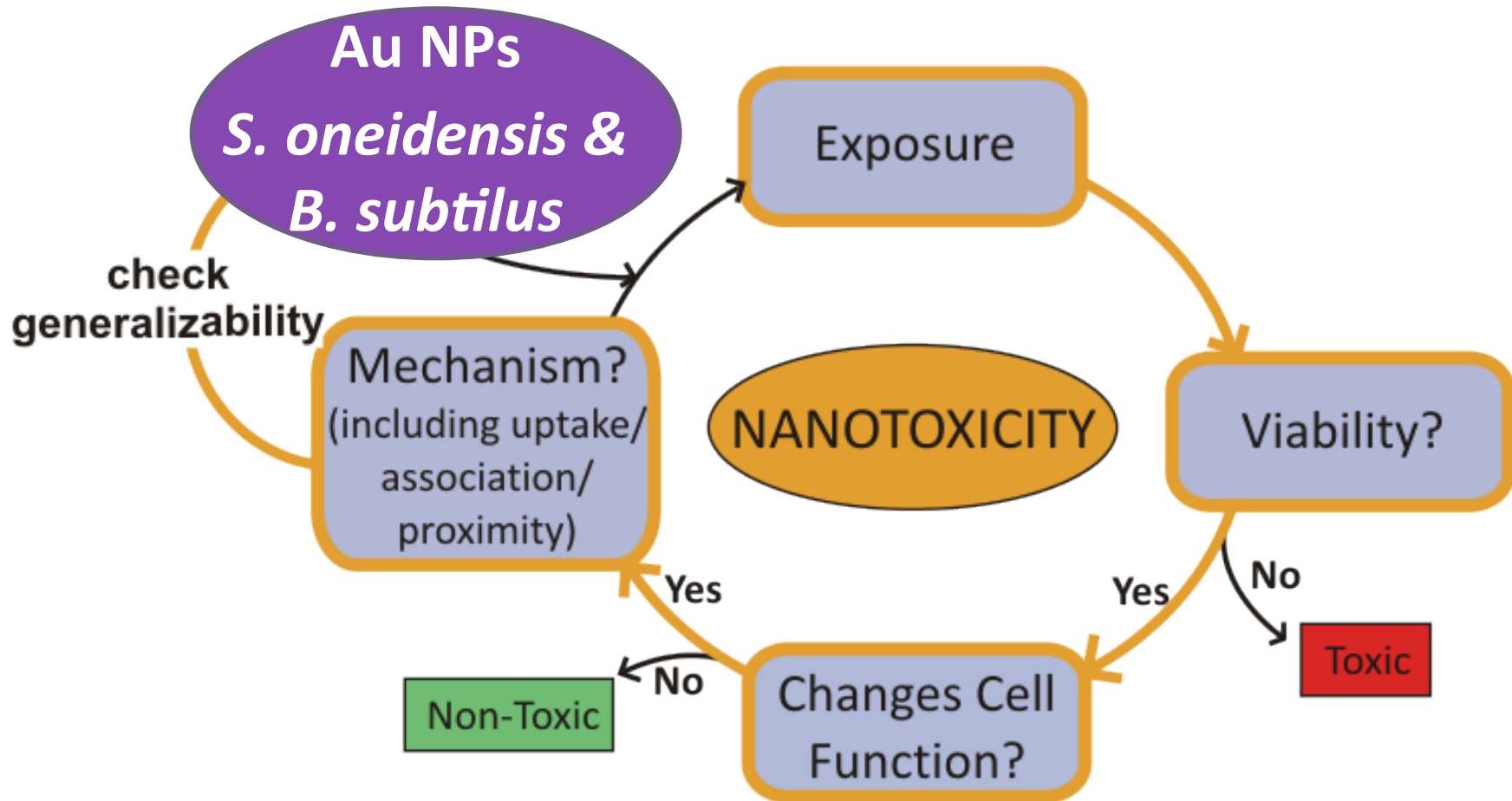
Iterative Approach

Determine the functional impact of nanoparticles on biological and ecological model systems



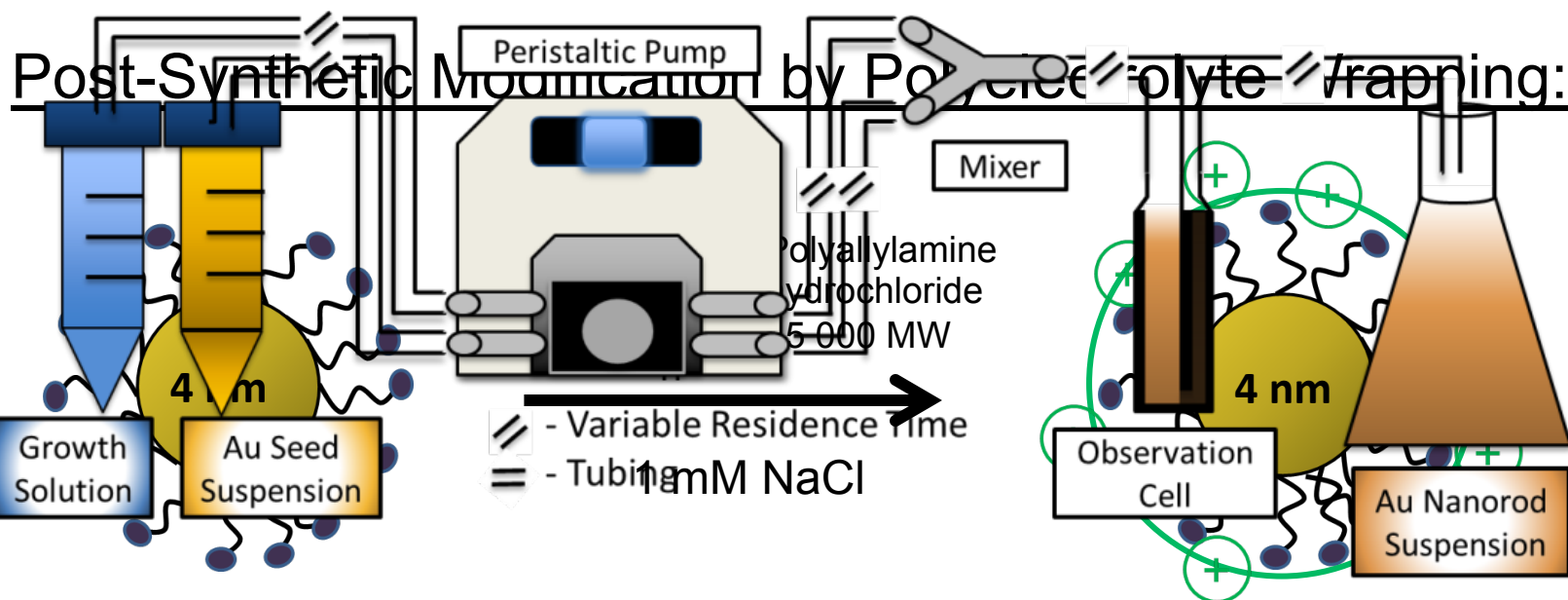
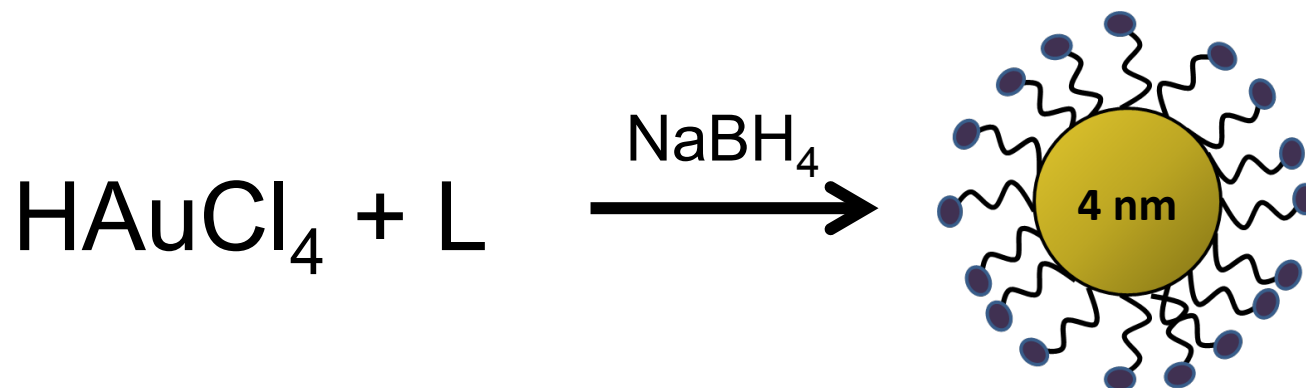
Beginning the Cycle – Econanotoxicity

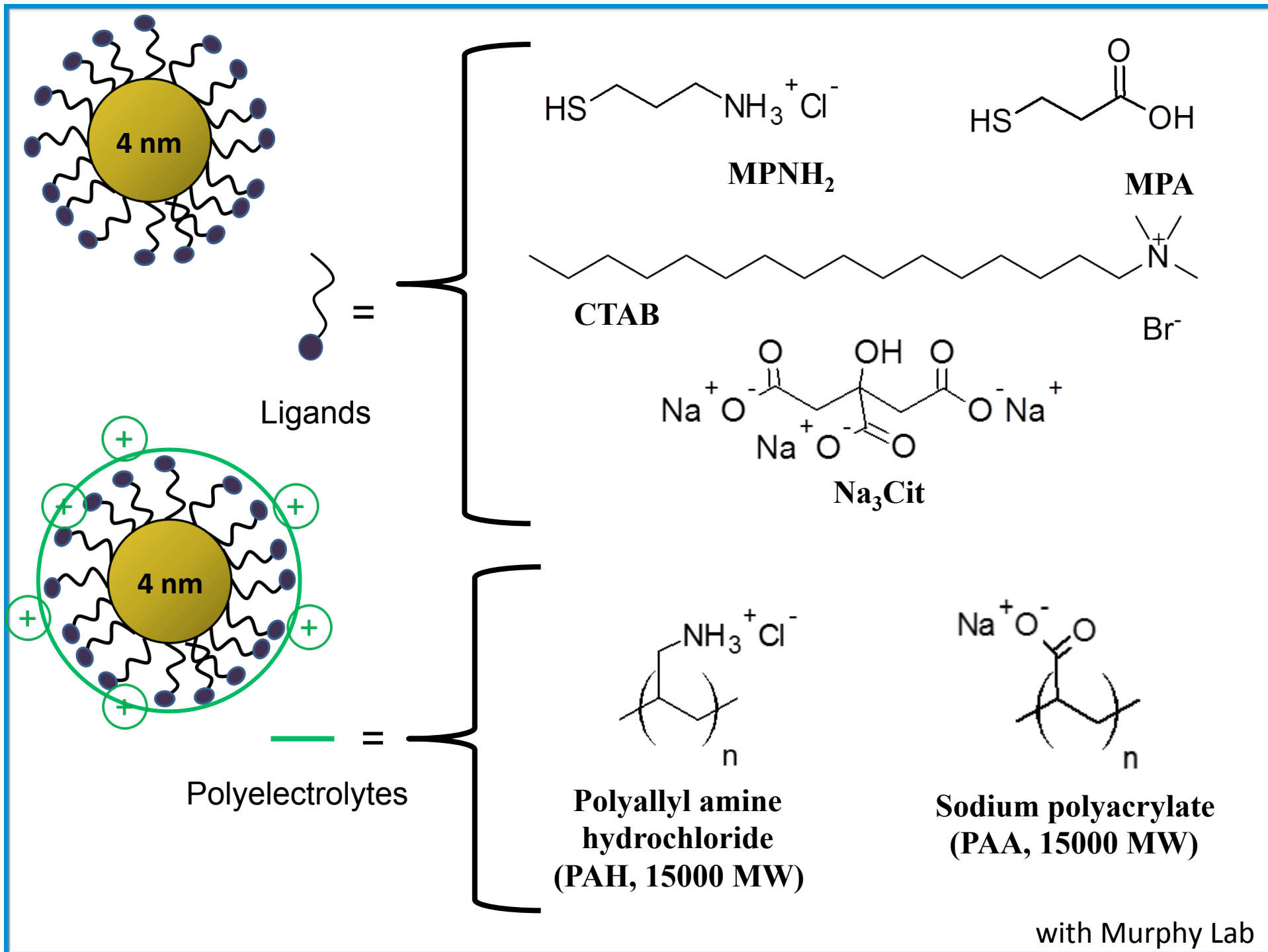
Quantitate changes in bacterial function and elucidate possible mechanisms of toxicity after exposure to nanoparticles



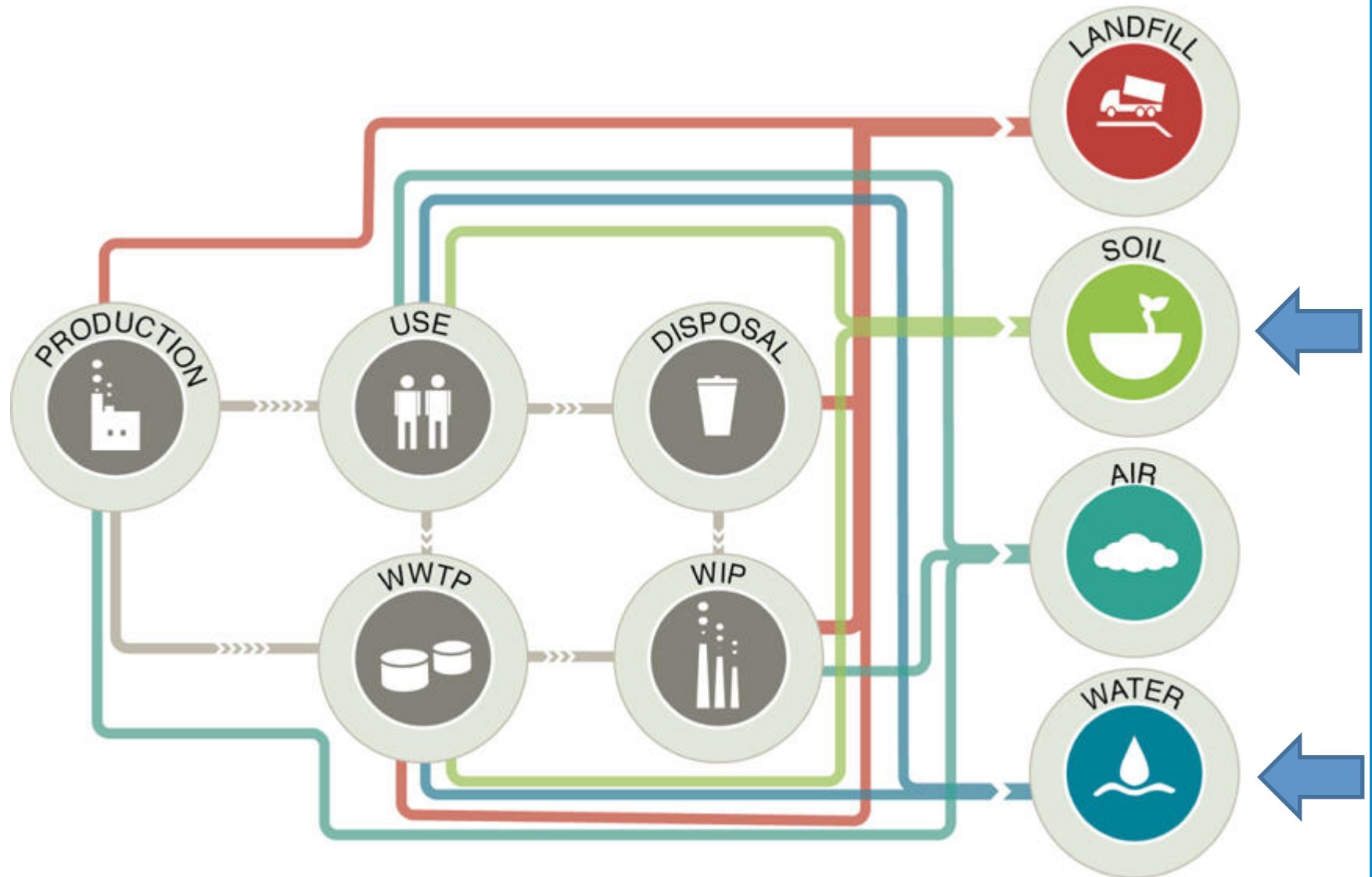
Au NP Synthesis

Direct Synthesis of Au NPs:





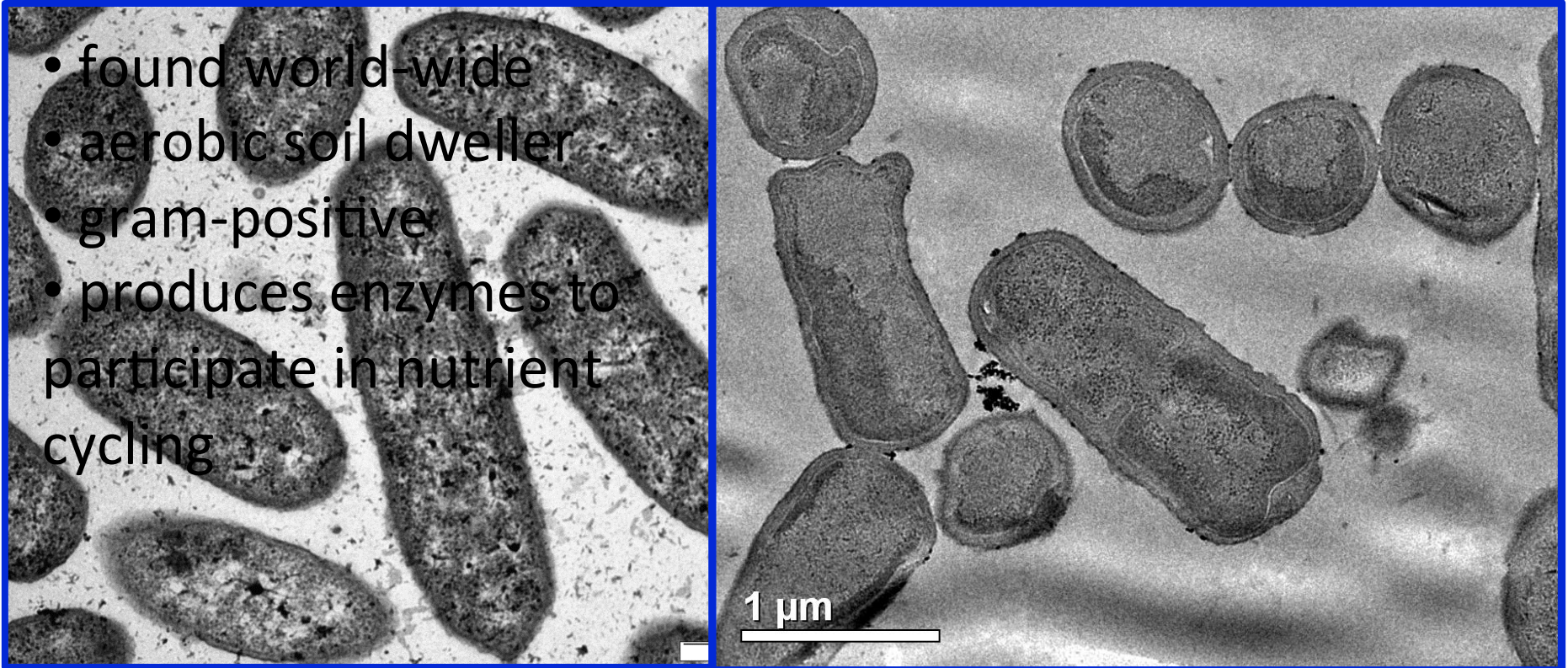
Life Cycle of Engineered NPs



Predicted Releases of Engineered Nanomaterials: From Global to Regional to Local, Keller, A.A. and Lazareva, A. *ES&T*, 1, 65-70 (2014).

Model Bacteria: *Shewanella oneidensis* and *Bacillus subtilis*

- found world-wide
- aerobic soil dweller
- gram-positive
- produces enzymes to participate in nutrient cycling

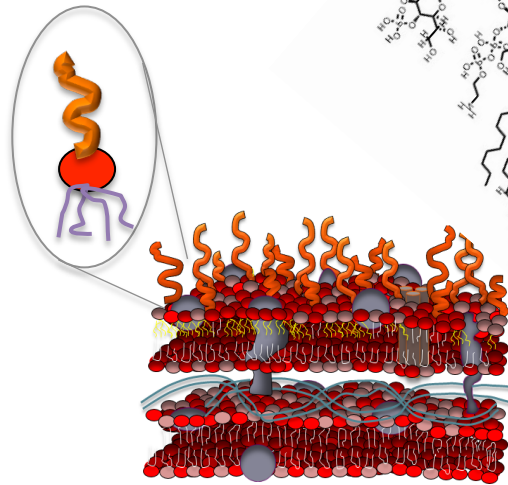
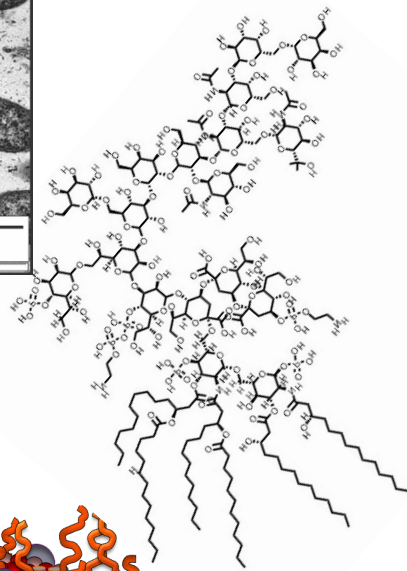
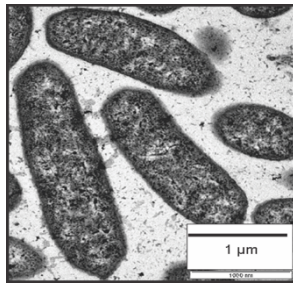


**S. oneidensis* was a generous gift from J. Gralnick (UMN Microbiology)

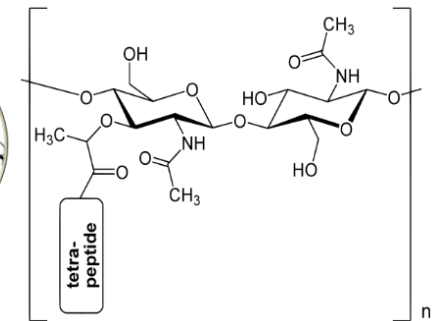
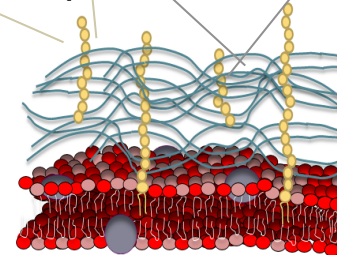
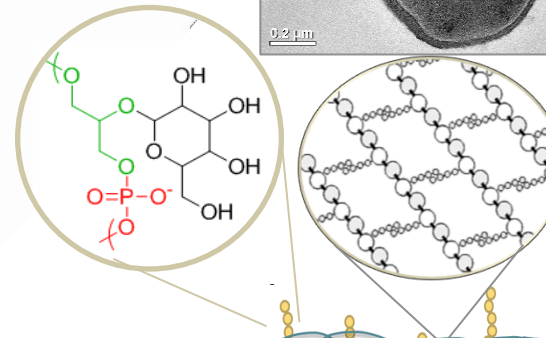
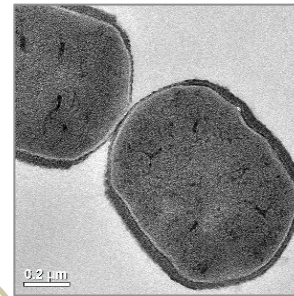
Determining the Role of the Chemistry of the Cell

Hypothesis: **Cell surface chemistry** plays significant role in nanomaterial-organism interaction.

Gram (-)
Shewanella

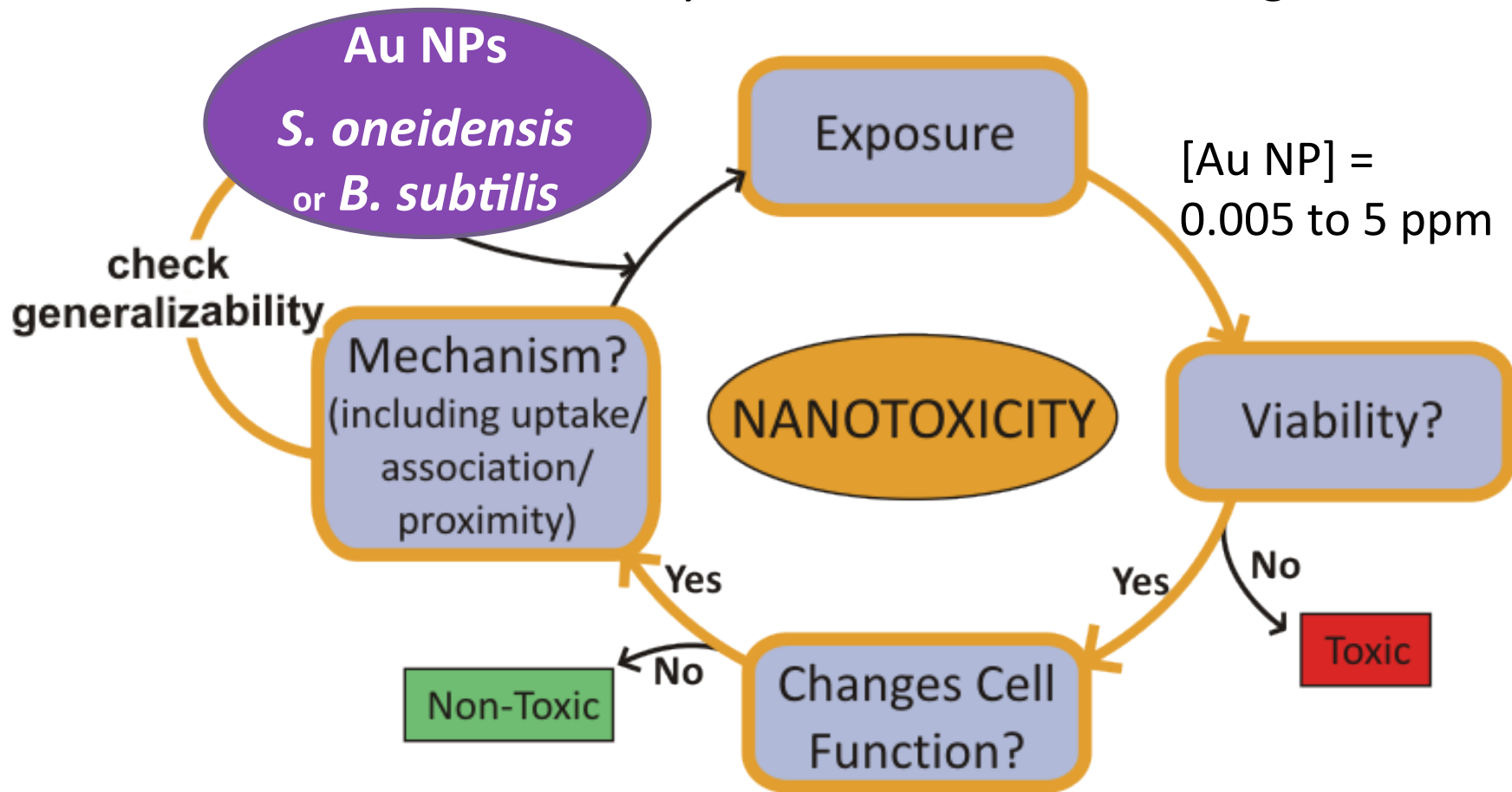


Gram (+)
Bacillus

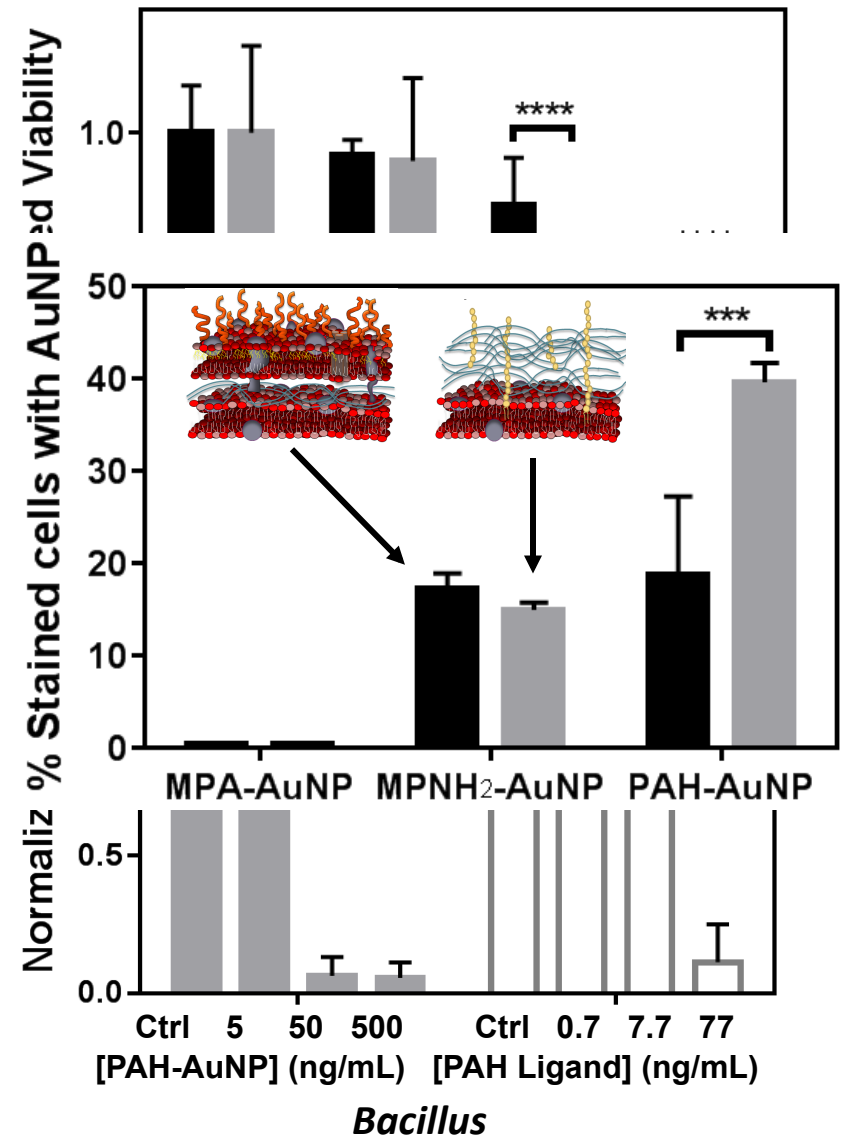
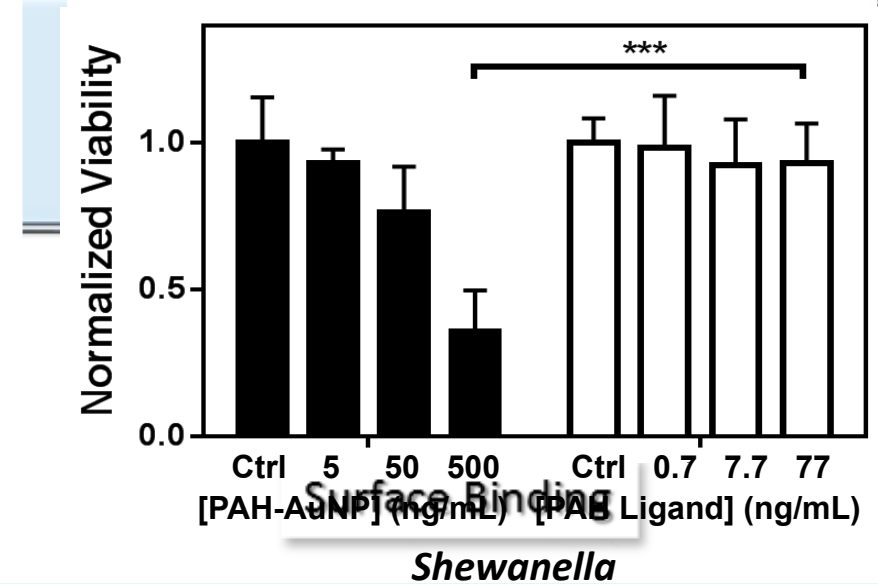
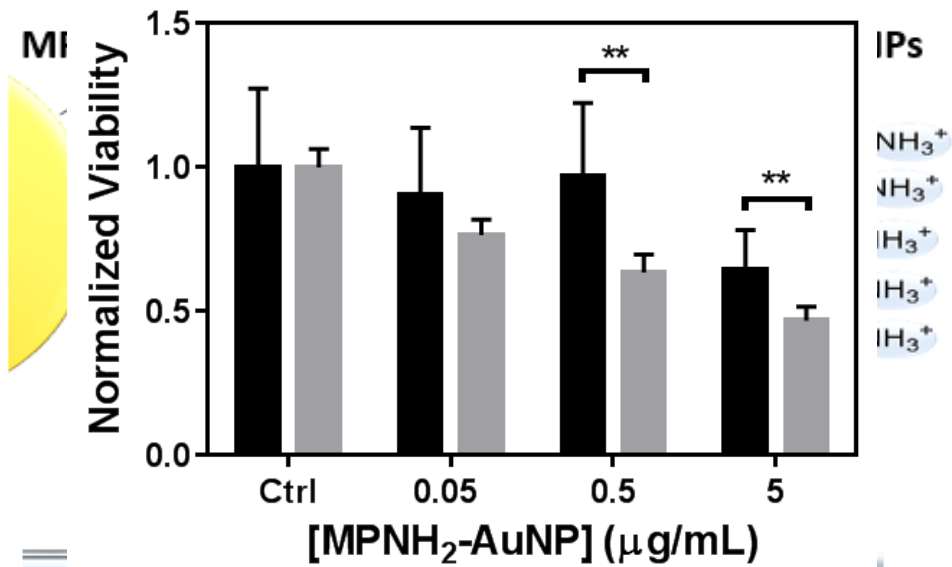


Exploring Nanoparticle Impacts

Goal: Develop and utilize a molecular-level understanding of nanomaterial-bacteria interactions to enable development of sustainable, societally beneficial nanotechnologies

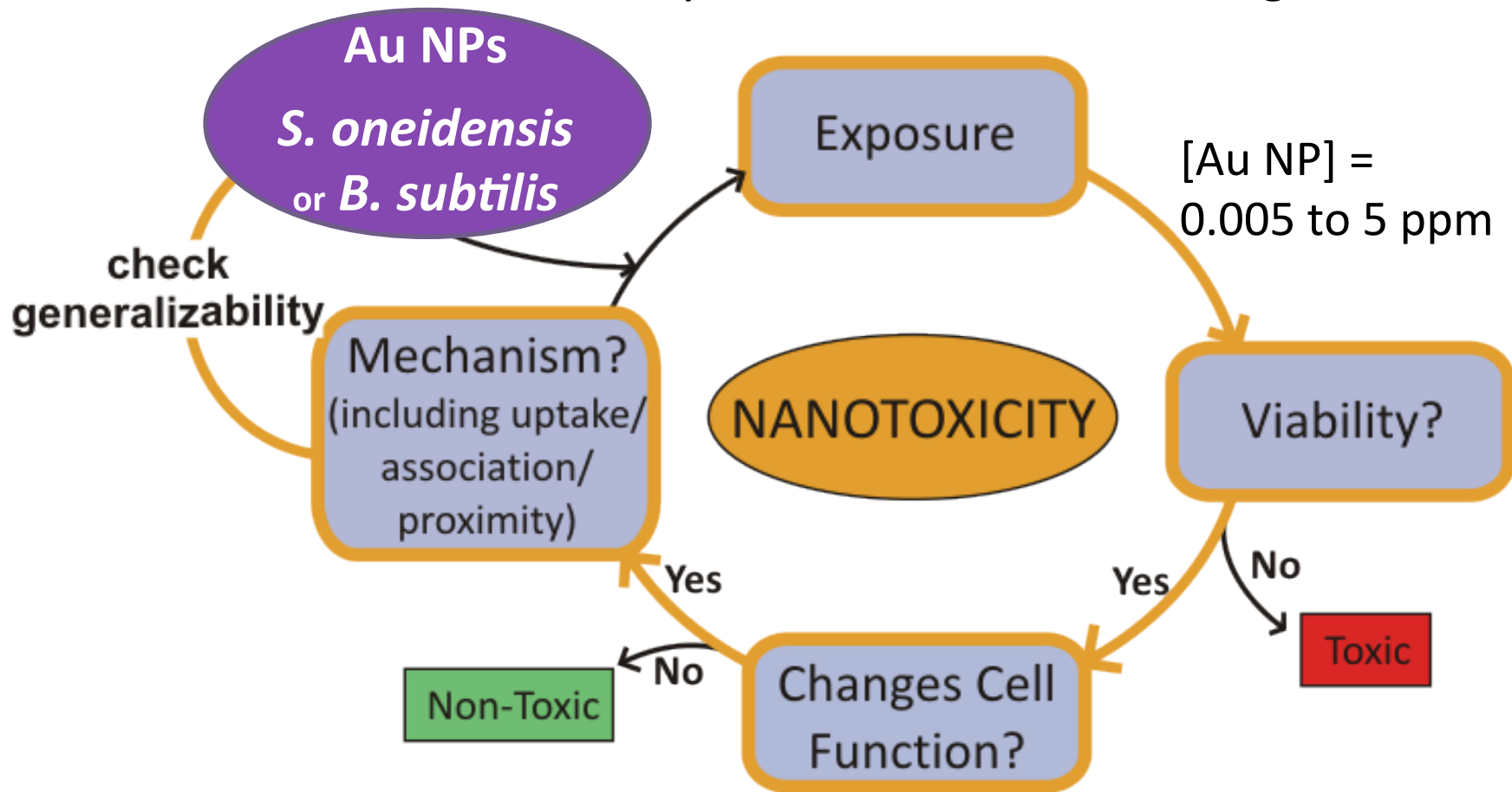


Viability of Gram-negative and Gram-positive Bacteria following AuNP Exposure



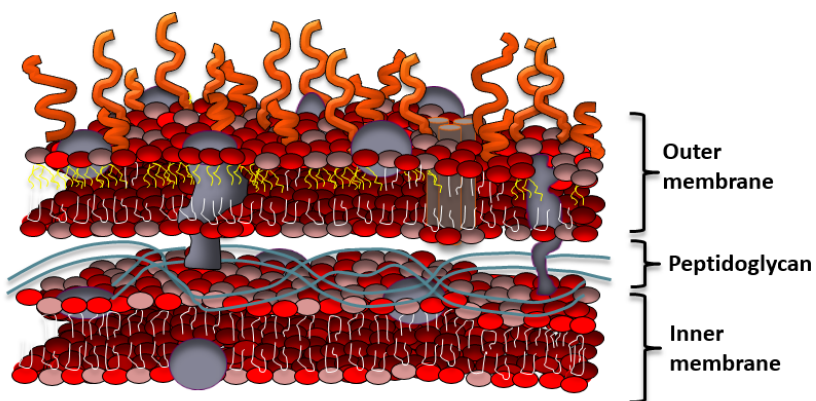
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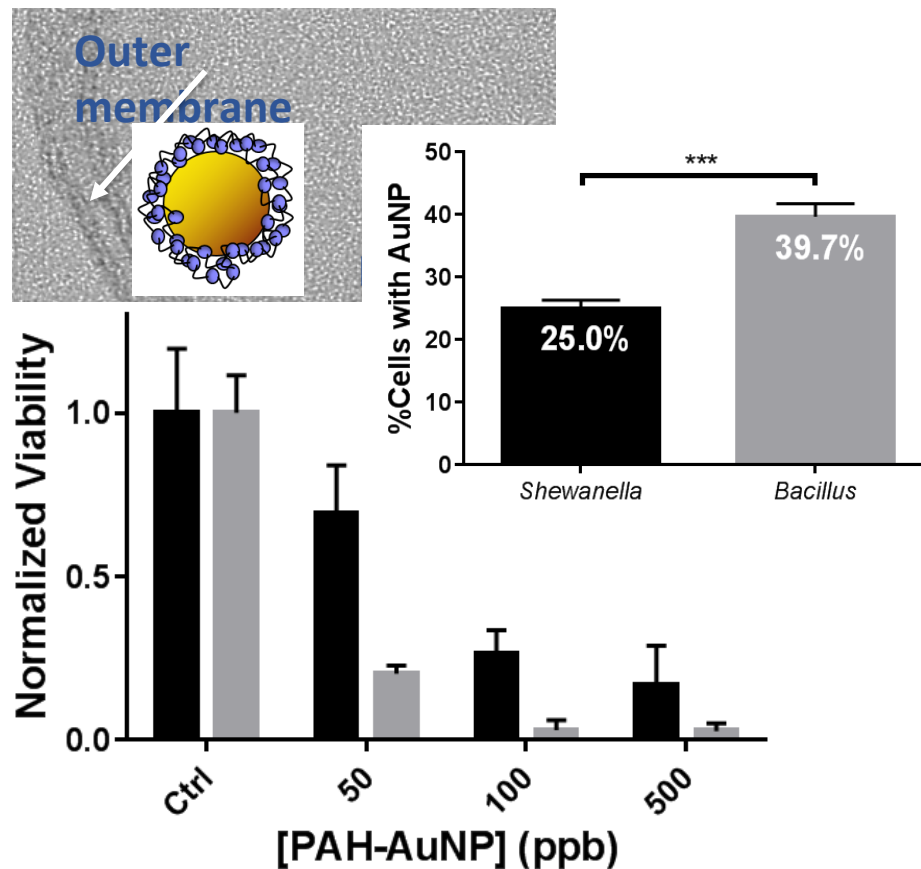
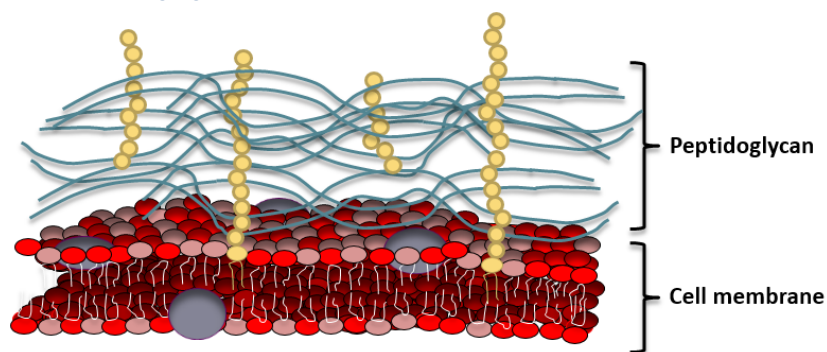


How do AuNPs associate with the bacteria?

Gram (-) *Shewanella*



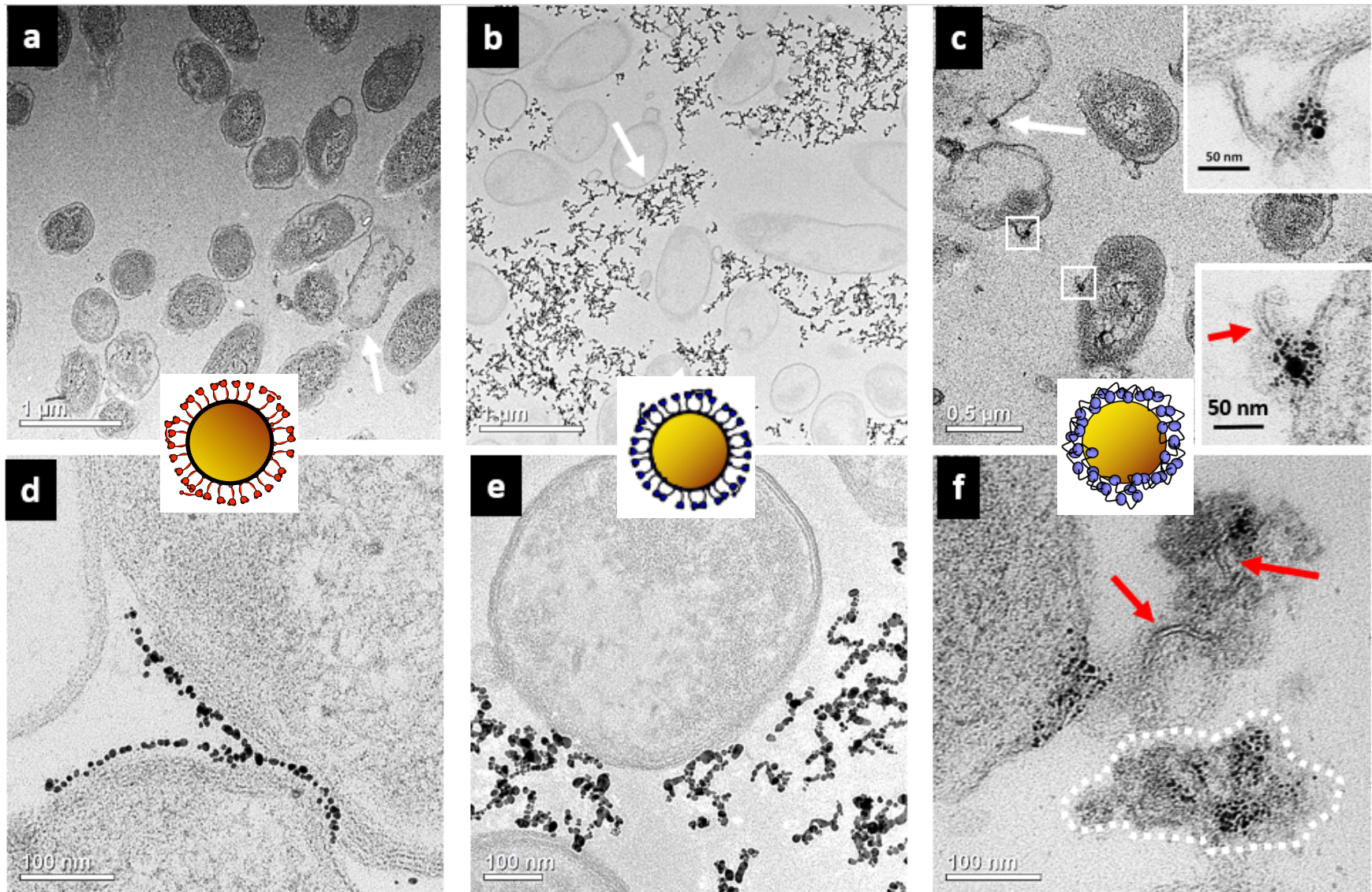
Gram (+) *Bacillus*



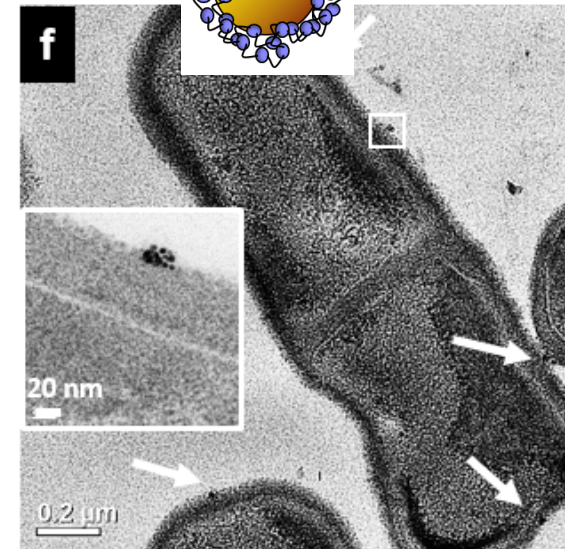
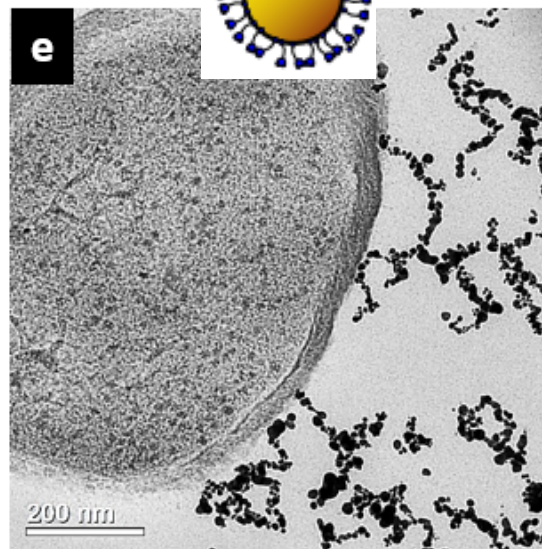
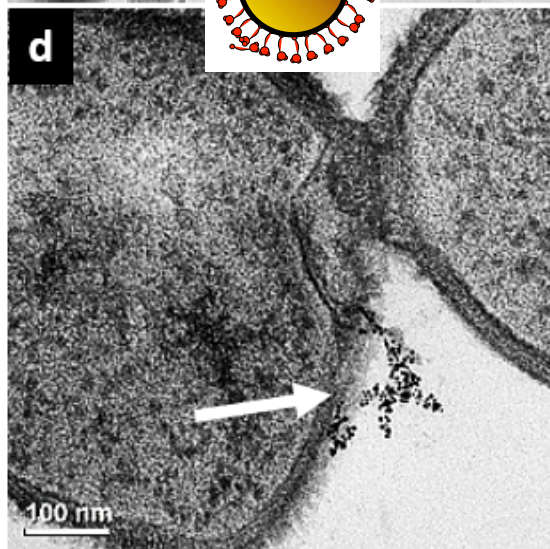
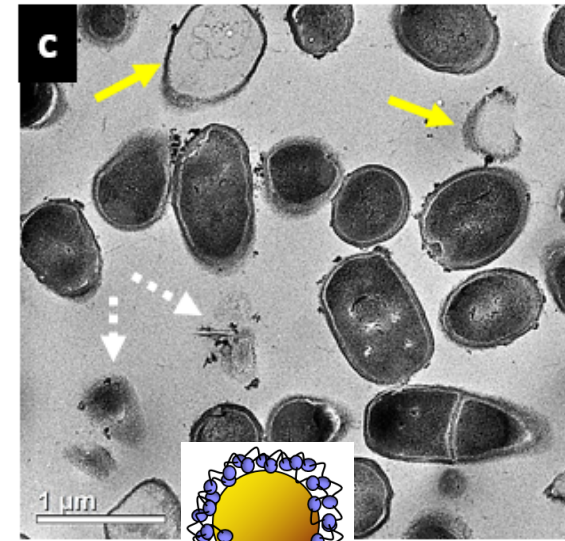
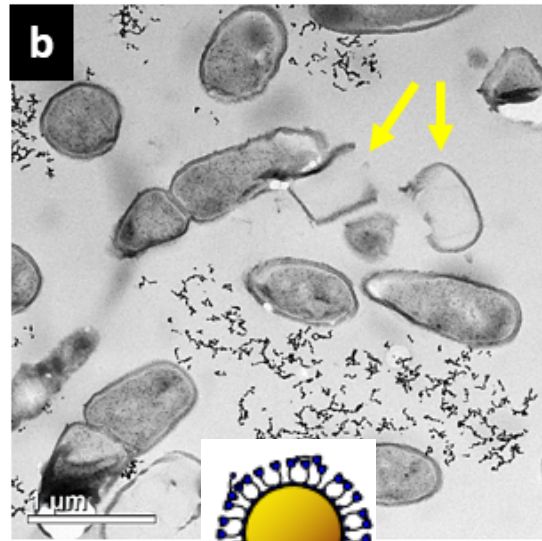
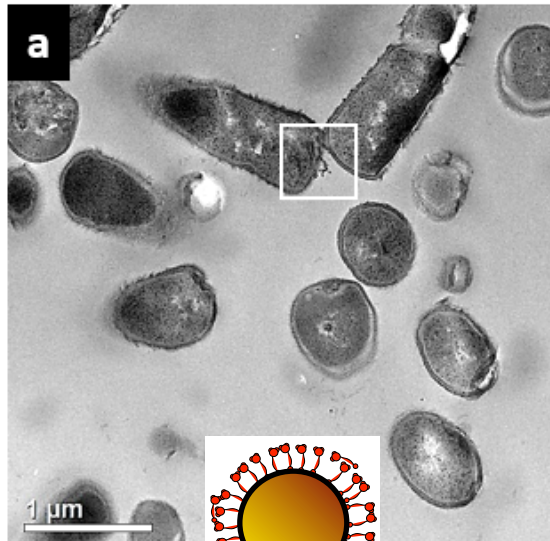
NPs have same core and same ligands, so distinct impacts must be attributable to NP/cell interactions



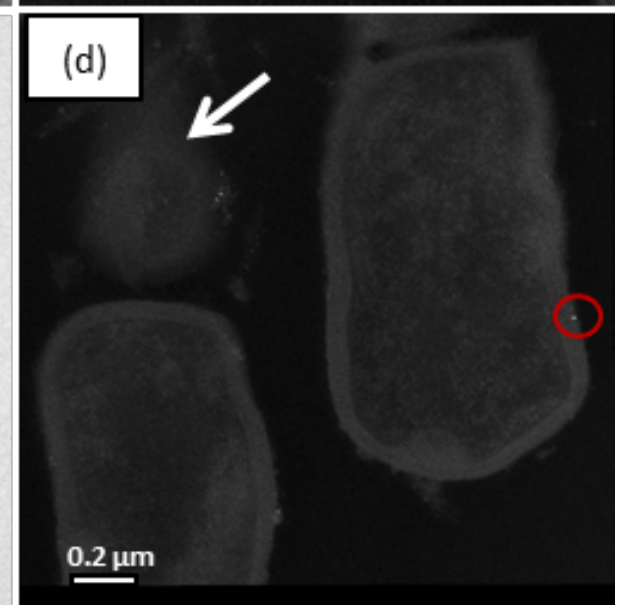
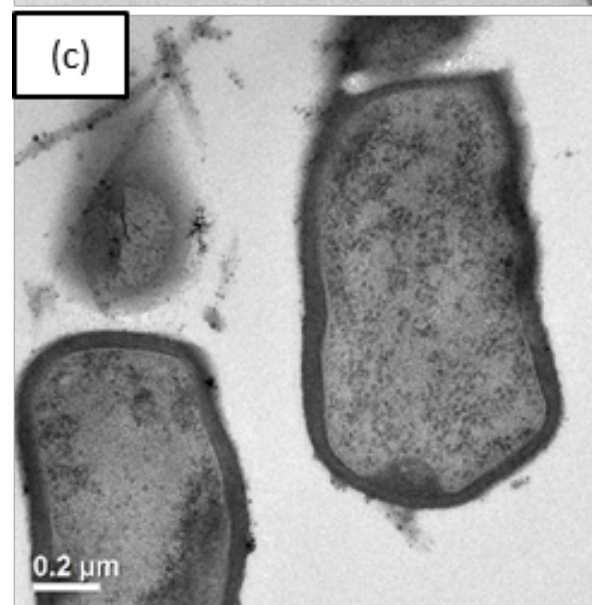
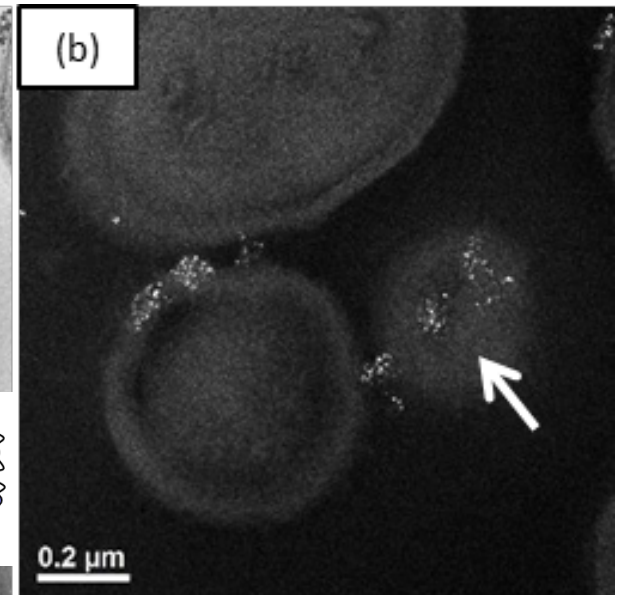
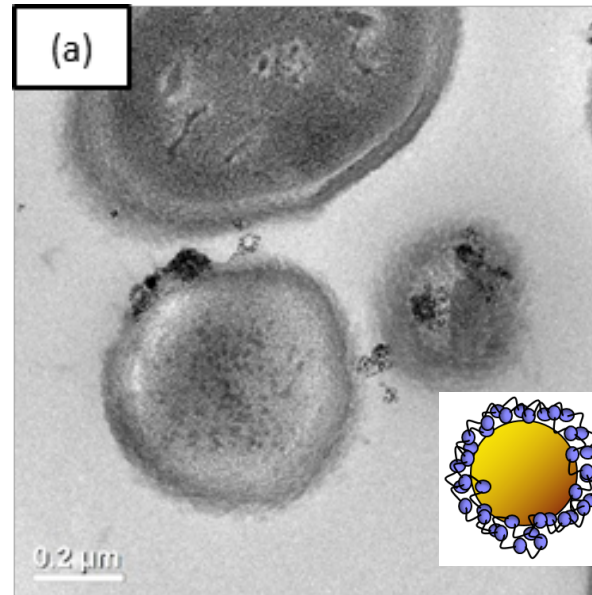
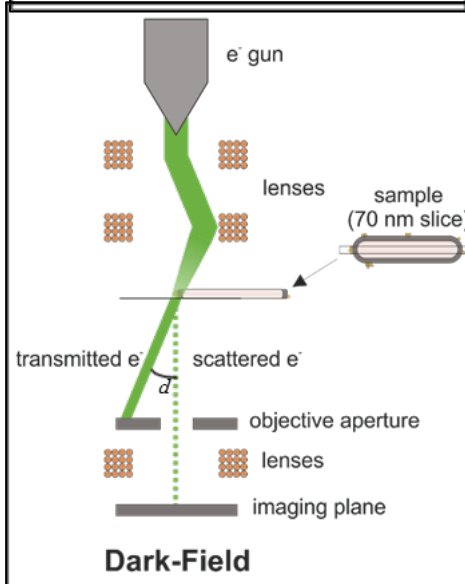
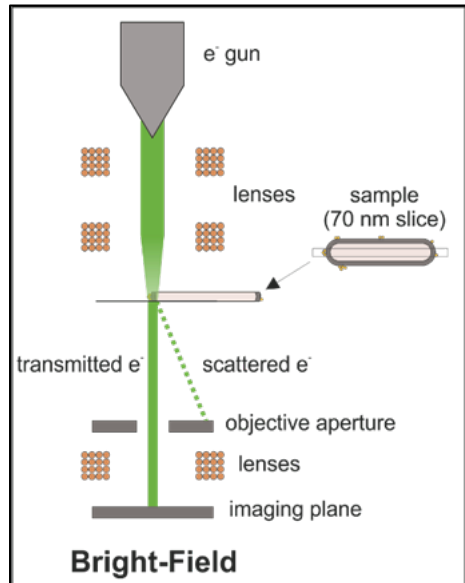
Visualizing AuNP Association with *Shewanella*



Visualizing AuNP Association with *Bacillus*

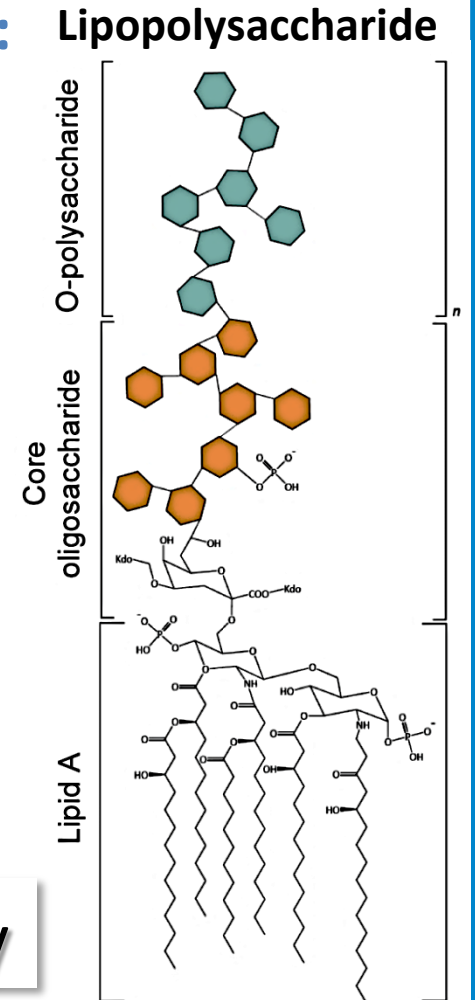
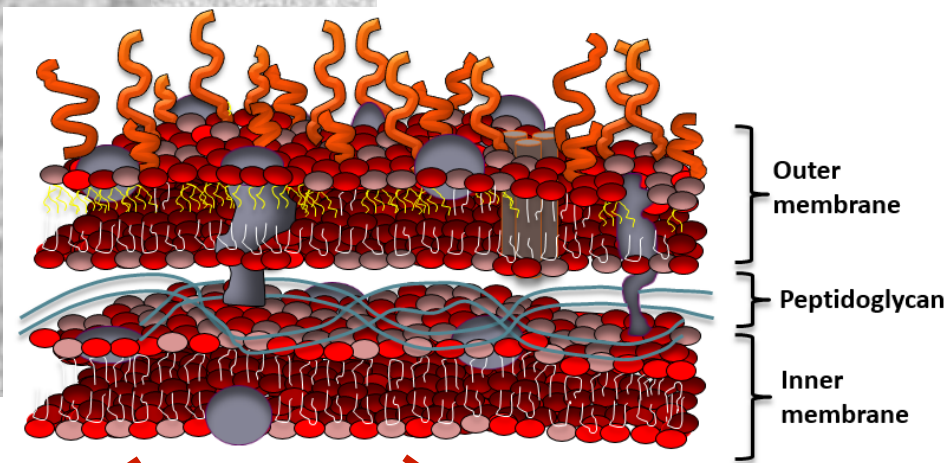
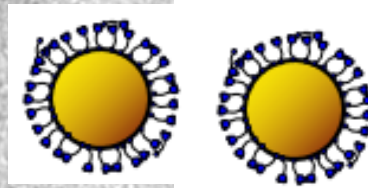
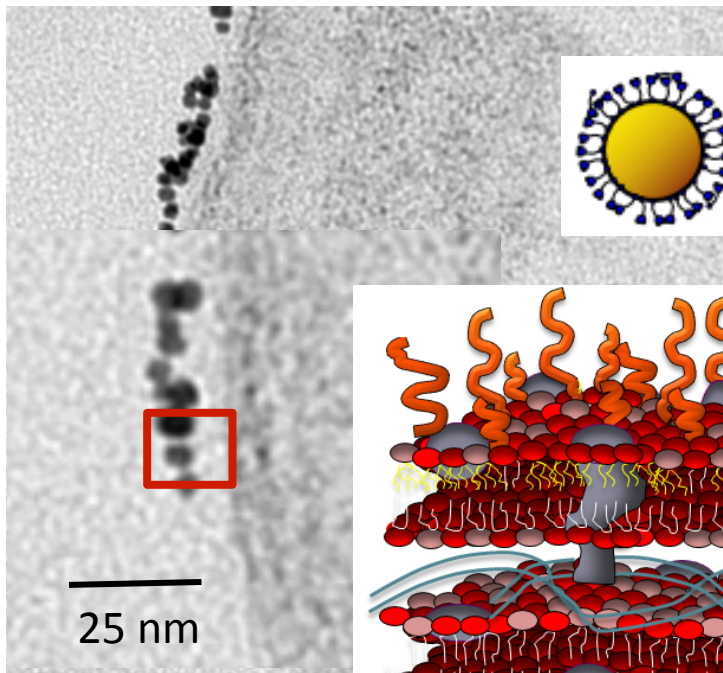


Dark Field TEM to Visualize AuNP Association with *Bacillus*



What drives NP interactions with *Shewanella* cell surfaces?

Hypothesis: Lipopolysaccharide



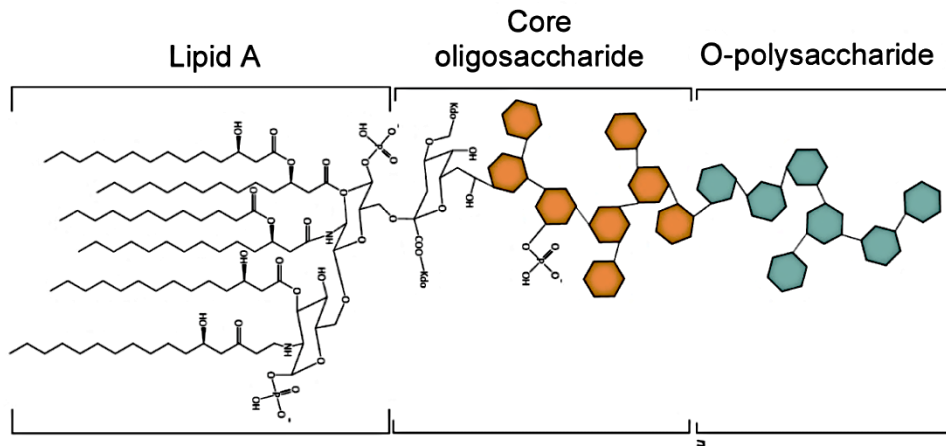
Whole Cell Study

Haynes, Orr

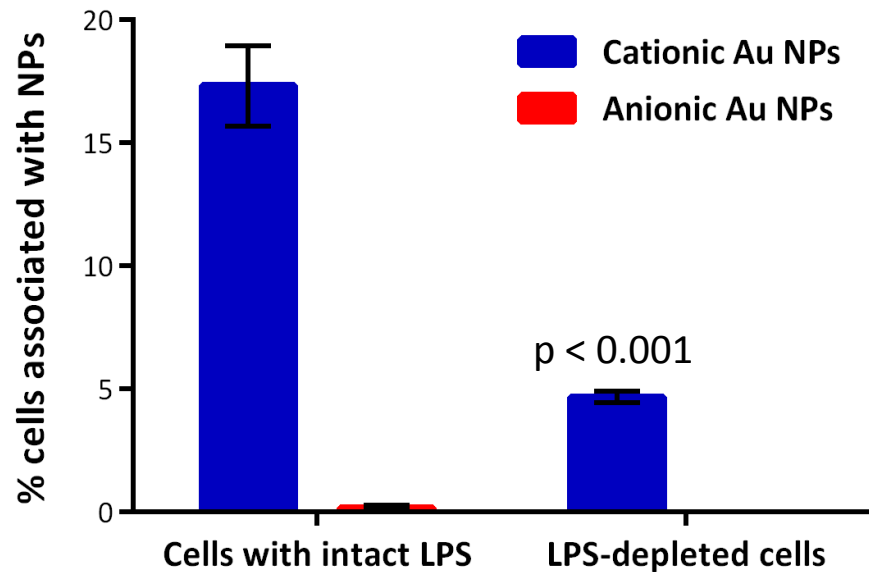
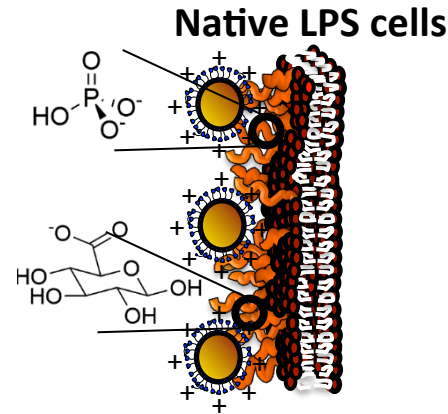
Model Membrane Study

Pedersen, Geiger

LPS Mediates Cell-NP Interactions



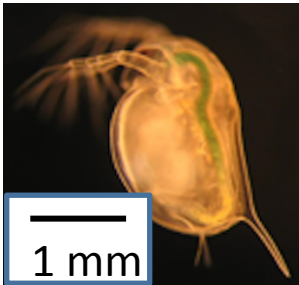
Proposed mechanism



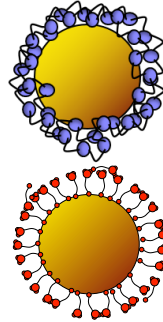
Lipopolysaccharides mediate the electrostatic interaction between AuNPs and gram-negative bacterial cells

Jacobson, Gunsolus, Kuech, Troiano, Melby, Lohse, Hu, Chrisler, Murphy, Orr, Geiger, Haynes, Pedersen, *ES&T*, in press.

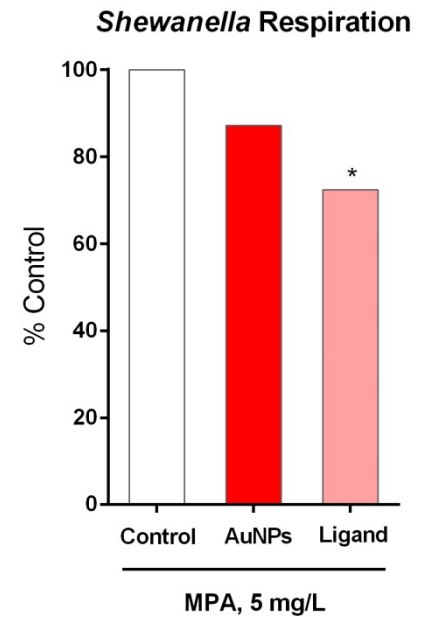
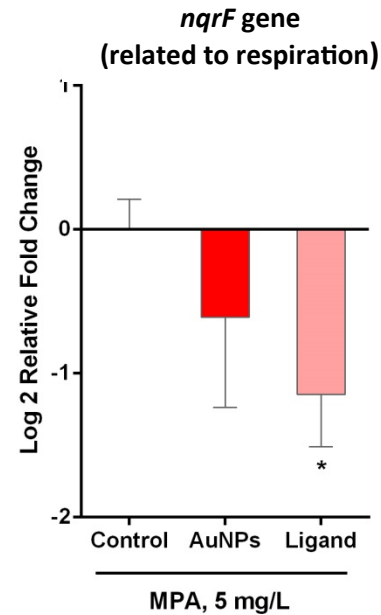
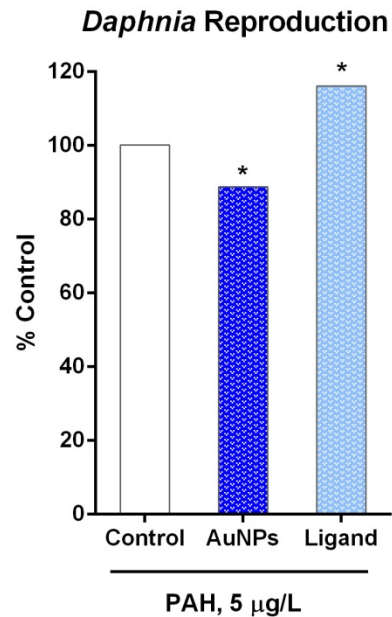
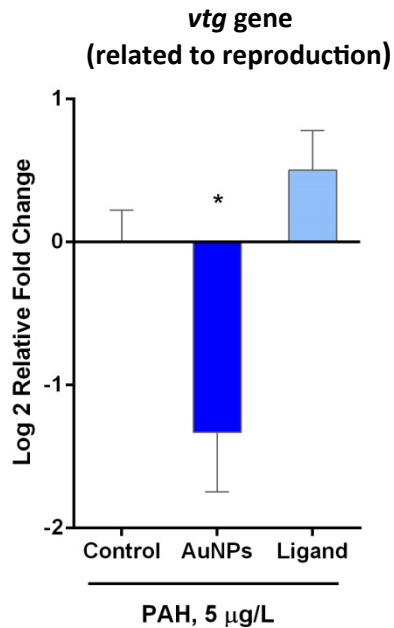
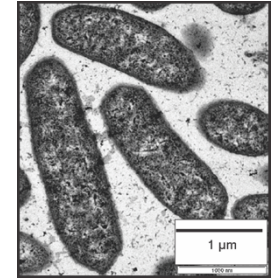
NP Impacts on Organisms with Distinct Surface Chemistries



- *Daphnia* showed more sensitivity to PAH-AuNPs, with a NP-specific effect.
- Link molecular pathway to *Daphnia* reproduction.



- In *Shew*, ligand contributed to most of the effects for both PAH- and MPA-AuNPs.
- Link molecular pathway to *Shewanella* respiration.



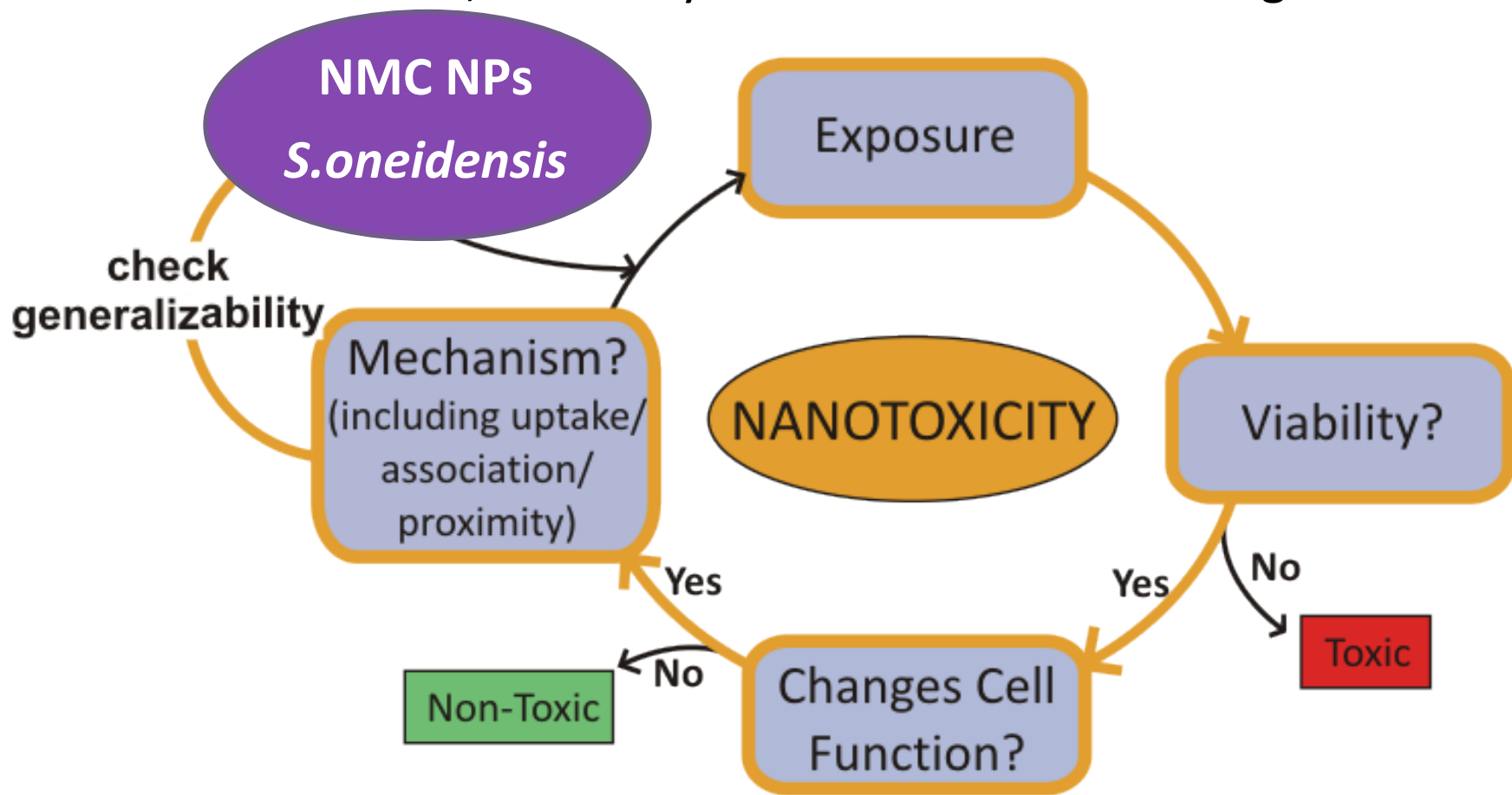
Two organisms with distinct cell surface chemistry respond differently to functionalized AuNPs in apical endpoints and molecular pathways.

Bozich, Klaper, Hamers, Murphy et al., 2014.

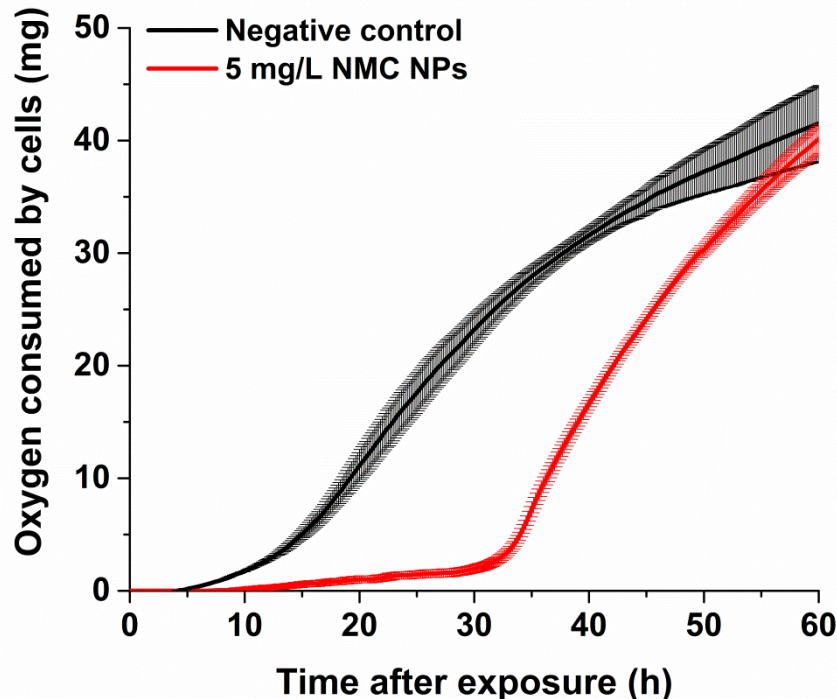
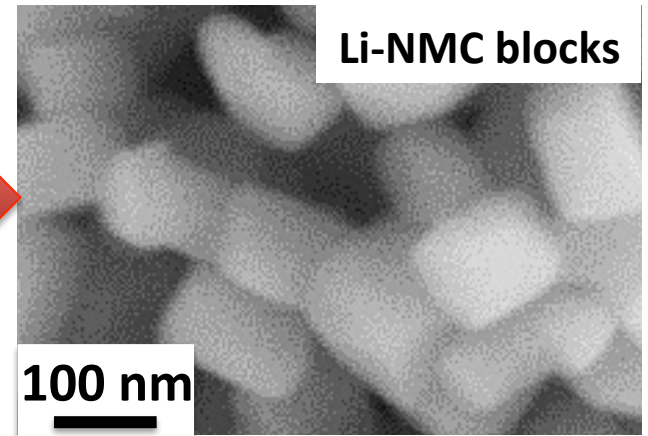
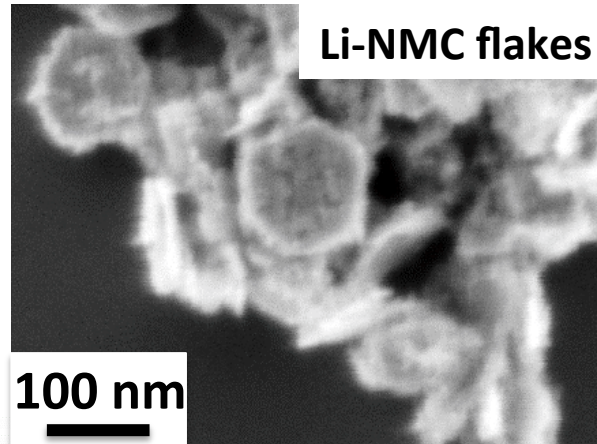
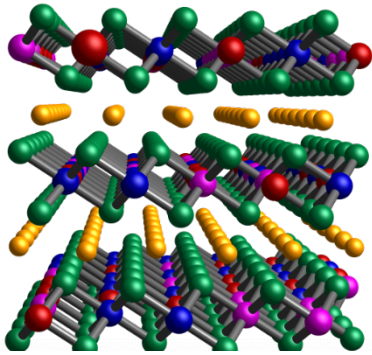
Qiu, Bozich, Murphy, Haynes, Klaper, *ES:Nano*, in press.

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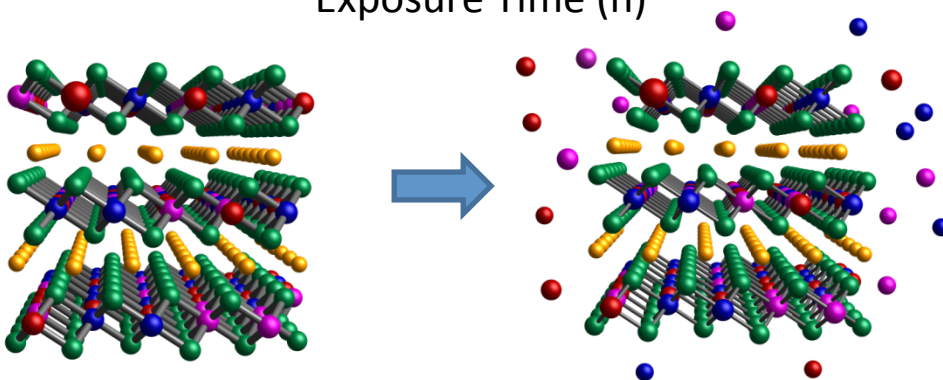
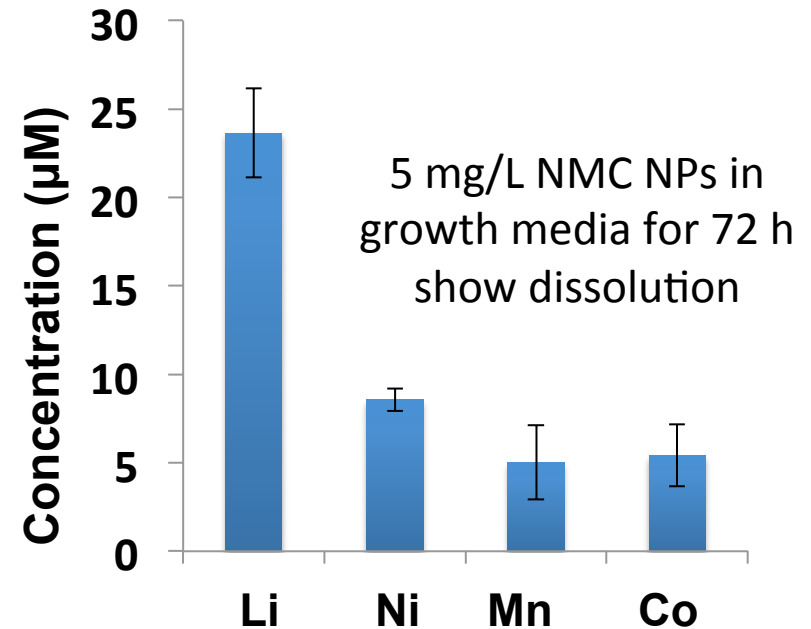
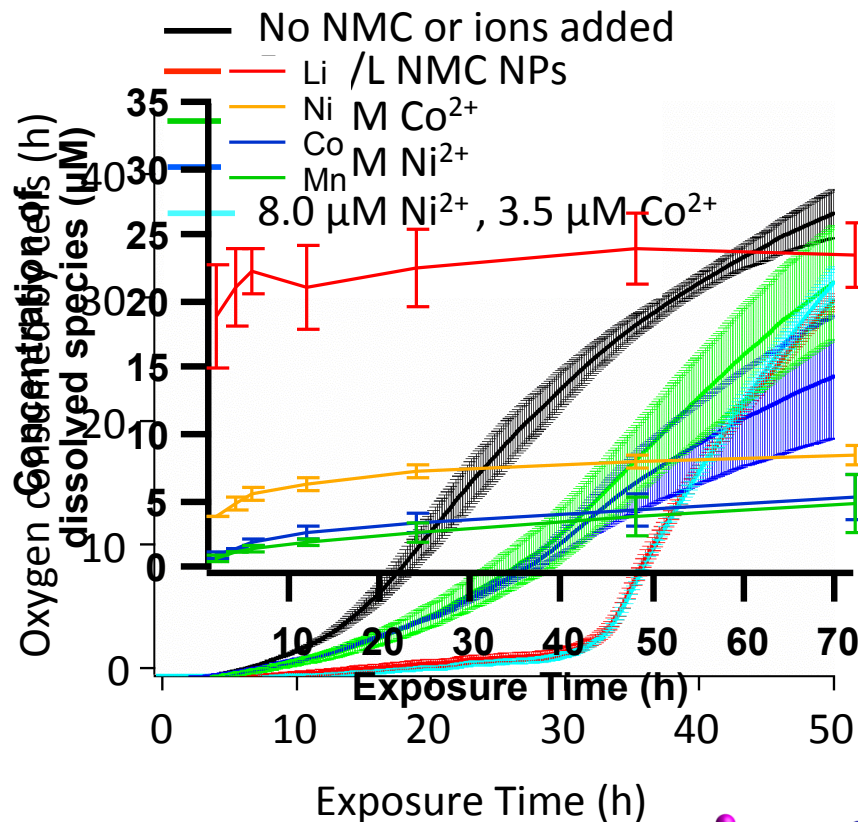
How does NMC impact bacteria?



Exposure to NMC produces much larger biological impact compared to Au NP exposure

What is the major route to the observed biological impact?

NMC Transformation Impacts Bacteria



- Biological response due to incongruent dissolution and release of metals, dominated by Ni²⁺ and Co²⁺

Lessons from Econanotox Studies

- Preliminary experiments show some nanoparticle-specific impacts on beneficial bacteria
- Nanoparticles considered to date do **not** enter healthy bacterial cells, but they **do** associate with the bacterial membrane
- Nanoparticle **transformations** in aqueous media can influence their toxicity
- To predict nanoparticle toxicity, one must consider **both the nanoparticle and organism surface chemistry**

Acknowledgements



The Center for
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<http://susnano.chem.wisc.edu/>

<http://sustainable-nano.com/>

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