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Opportunities for Nano-Enabled Resource Recovery

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WATER SUSTAINABILITY
THROUGH NANOTECHNOLOGY

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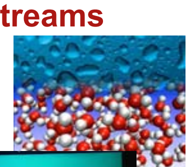
We Imagine…

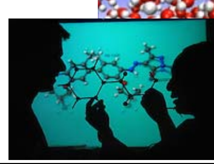
Reversing drought impacts through affordable desalination




Securing a sustainable food cycle through efficient resource recovery from waste streams



Developing new nanomaterials for water technologies at an unprecedented pace, accelerating innovation by decades



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What resources are available in waste?

Water

Energy

Nutrients

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[www.wikipedia.org] [www.watertechnology.net] [Cusick et al., *Appl. Microbiol. Technol.*, 2011] [www.pbs.org] [www.ostara.com]

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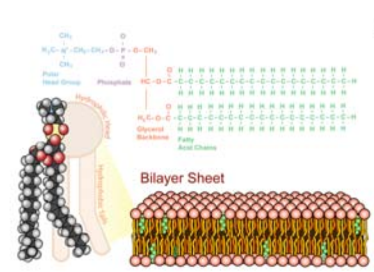
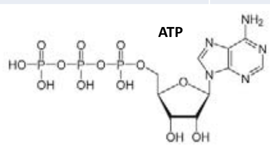
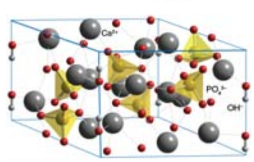
Phosphorus is essential for life

Biological component	P-content (% by mass)
Cell membrane – lipid bilayer	~4%
ATP/ADP/AMP	18% for ATP
DNA/RNA	~9%
Bone (tissue based on hydroxyapatite)	~12%

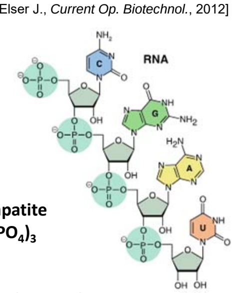
[Elser J., *Current Op. Biotechnol.*, 2012]







Hydroxyapatite
$Ca_5(OH)(PO_4)_3$



http://www.ck12.org/biology/Phospholipid-Bilayers/lesson/Phospholipid-Bilayers-BIO/ http://www.chemtube3d.com/solidstate/SShydroxyapatite.htm

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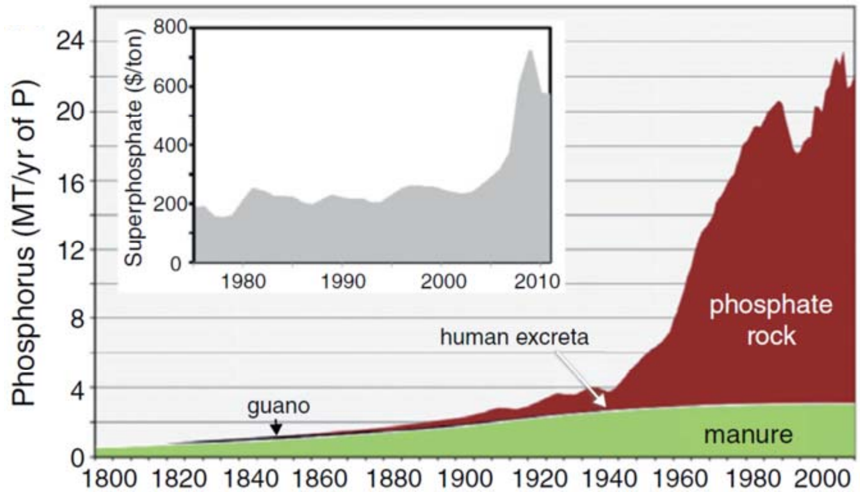
Phosphate rock reserves are finite and prices are not stable (but “peak P” not expected in next 20-25 years)



[Elser J., *Current Op. Biotechnol.*, 2012]

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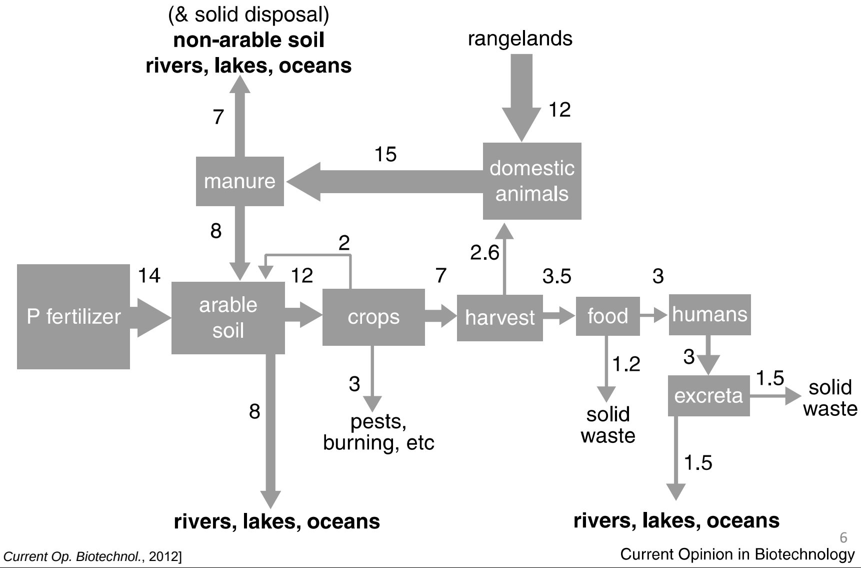
Most of the “lost” phosphate ends up in our waterways or in animal manure



[Elser J., *Current Op. Biotechnol.*, 2012]

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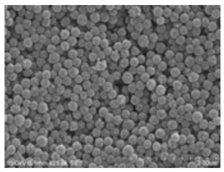
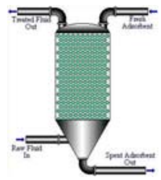
Closing the phosphorous loop to enable sustainable agriculture and protection of our waterways

Our Solution



1. Identify nanomaterial properties that enable effective P capture and release



2. Experimentally determine P removal using novel and existing nanosorbents

3. Apply our new materials to recover P from a variety of waste sources

4. Release recovered P for reuse in agriculture

[www.pbs.org] [www.wri.org] [www.uidaho.edu] [www.dtnw.de] [www.umich.edu] [www.wunc.org]

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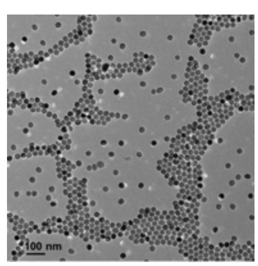
Heuristic approaches have introduced:

- Inorganic nanoparticles: CuO, TiO_2, various iron oxides and hydrated iron oxides, biogenic iron oxides
- Al, Ca, and Mg-based metals and oxides
- Organo-metallic complexes
- Clays
- Carbon nanotubes
- Polymer hydrogel supports
- Polymer supports



Other interesting materials at NC State:

- **Gao:** ***graphene, graphene oxide;***
- **Bradford:** ***long nanotubes;***
- **From CNR:** ***porous fibrous web structures, foams made from natural materials, natural super-absorbents***

http://www.sigmaaldrich.com/catalog/product/aldrich/747327?lang=en&region=US

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…but we need to develop

- *a systematic understanding of phosphate adsorption and sorbent material properties*
- *sorbents that can selectively recover phosphate from waste*
- *sorbents that can readily release sorbed phosphate?*

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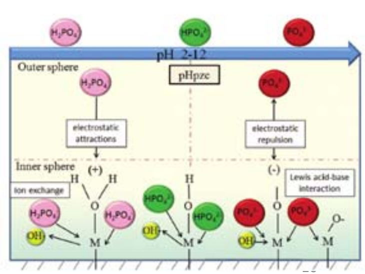
Our Approach

- Nanomaterial database
  - Commercially available
  - Available at NCSU (and beyond)
  - New nanomaterials (based on models developed in Thrust 1 – Functional materials by design)
- Assess P recovery and release
  - Single-solute experiments
  - Multi-solute experiments (assess matrix interference)
  - Identify uptake and release mechanisms
  - Feed information back to Thrust 1 to inform models



Li et al. *Env. Review* 2016

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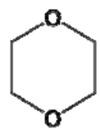
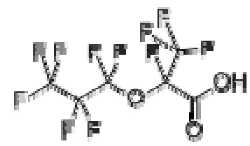
Outlook – Beyond Phosphorus…

- Resource recovery and separation
  - Rare earth elements (coal ash – Hsu-Kim)
  - Precious metals (biosolids)
- Removal of emerging contaminants
  - Industrial wastewater
  - Water reuse
  - Point-of-use treatment





- Integration of nanoparticles into water treatment technologies
  - Membranes
  - Electrochemical systems
  - Point-of-use filters