ASU BIODESIGN INSTITUTE
ARIZONA STATE UNIVERSITY

Center for Environmental Biotechnology

Recovering the Lost P in Used Water

Bruce E. Rittmann

Regents' Professor of Environmental Engineering

Director of the Swette Center for Environmental Biotechnology

Biodesign Institute at Arizona State University

Multiple Major Resources

- Energy – in the BOD

- Nutrients – the P and N

- Clean Water

Enhancing environmental and economic value propositions

Multiple Major Resources

- Energy – in the BOD

- **Nutrients – the P and N**

- Clean Water

Enhancing environmental and economic value propositions

Phosphorus Recovery -- Need

- Globally, only about 16% of mined P ends up in human food. Most of the rest is lost along the way to agricultural run off (46%) and animal wastes (40%).

Simplified Summary of the Global P Flows According to the Estimates of Cordell et al. (2009)

Flow of P	% of Mined Input
Mined Input	**100**
Phosphate Fertilizer Production	85
Phosphate Fertilizer Applied to Arable Soil	80
Soil Erosion & Runoff Losses	**46**
Crops Harvested	40
Animals Produced from fertilized crops	15
Animal Wastes	**40**
Into Human Food	23
Consumed and Excreted by Humans	16
Sewage P Discharged to Waters	**8**
Sewage solids	**7**

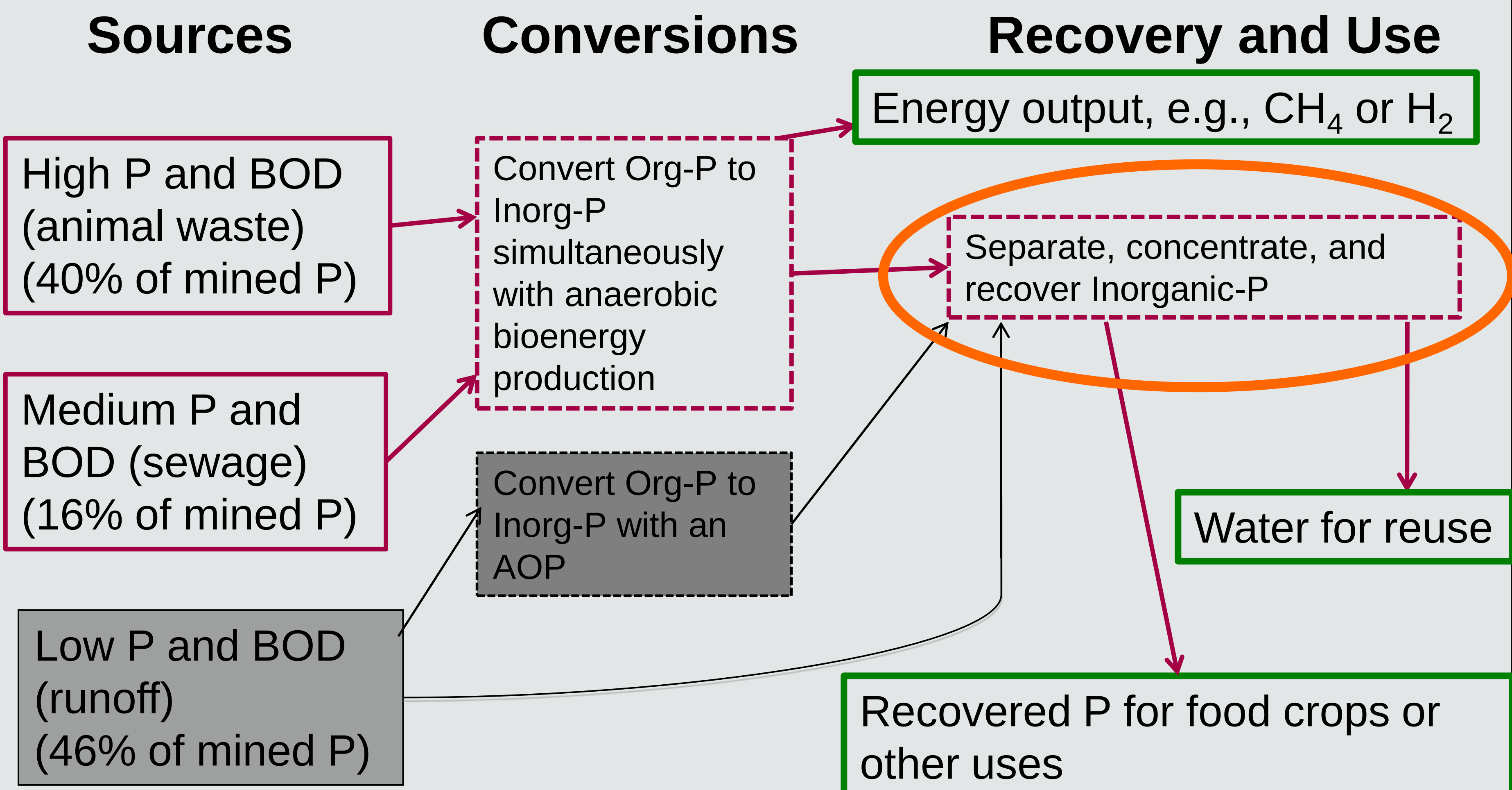
Phosphorus Recovery -- Need

- Globally, only about 16% of mined P ends up in human food. Most of the rest is lost along the way to agricultural run off (46%) and animal wastes (40%).
- Major P reserves are present in only five countries, and "cheap" reserves will deplete in a few decades.
- We must recover the "lost P" in order to sustain modern agriculture, as well as protect water quality from eutrophication.

Phosphorus Recovery – Opportunity

- P recovery from high-strength organic streams is naturally linked to energy recovery.
  - Hydrolysis, fermentation, and oxidation of organic matter releases inorganic P (ortho-PO_3^{3-})
- Generation of a concentrated and mobile P supply provides a new revenue stream → improving the value proposition.

Energy- and P-reborn Strategy



What has been the holdup with methanogenesis?

- Slow-growing methanogens
  - Need excellent biomass retention
- Inadequate effluent quality for BOD
- Dissolved CH_4
  - Loss of CH_4 energy
  - Greenhouse gas emission
- Sulfate reduction
  - Odors and loss of CH_4 energy
- Minimal N and P removals

P-Recovery Options

- Must yield a P product that is available in agriculture.
- Fe-phosphate solids are not available!
- Thus, the usual P-removal approach is not useful for P recovery.

Precipitation of Struvite

- Struvite (magnesium ammonium phospha hexahydrate, $MgNH_4PO_4 \cdot 6H_2O$) has multiple commercially available configurations, including PHOSNIX, Rem-Nut, and Ostara processes.
  - Struvite precipitation occurs readily once phosphate reaches 100

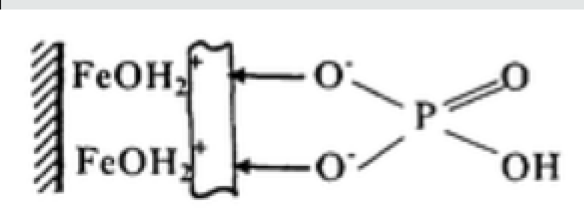
Current dilemma: high cost, but with a low-value output.

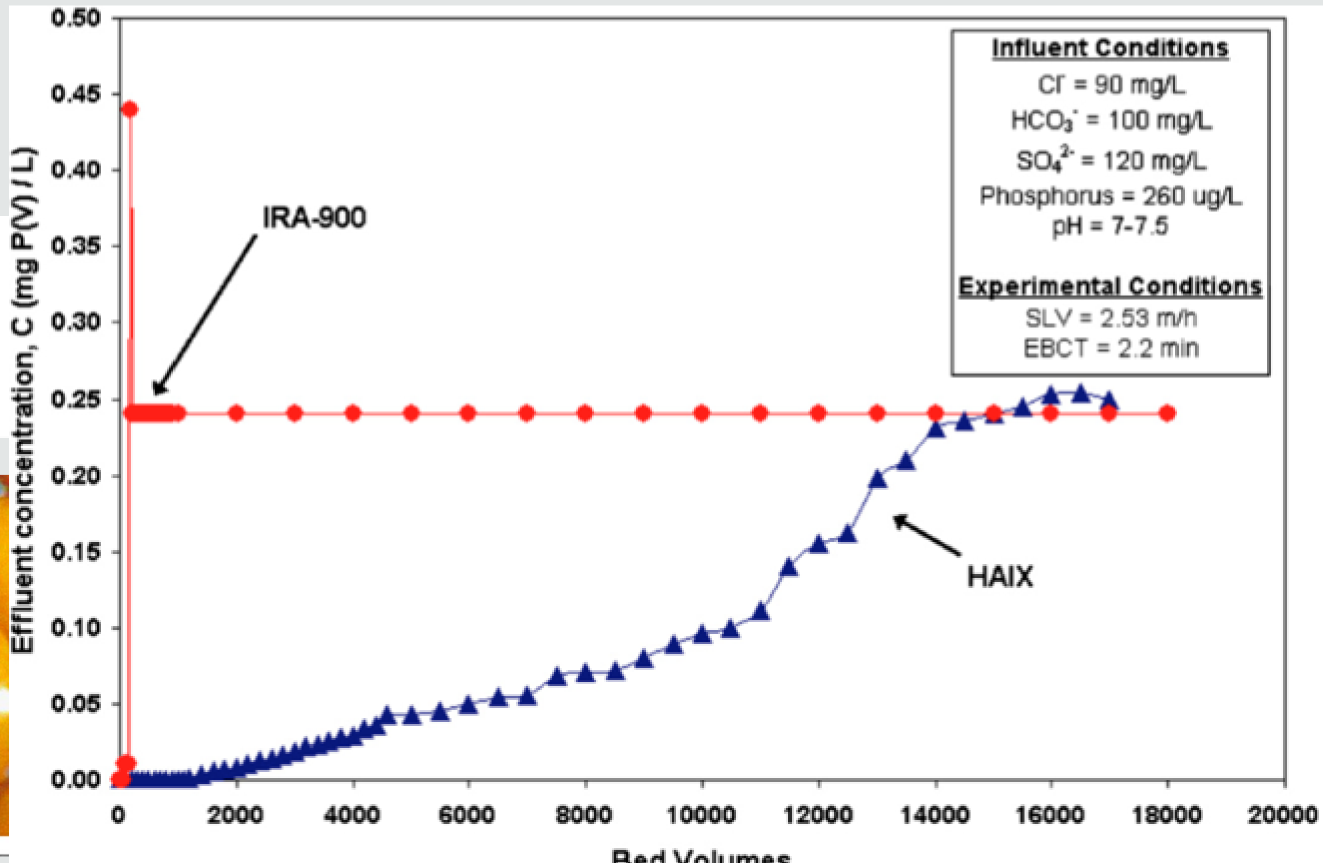
- Hydroxyapatite ($Ca_5(PO_4)_3OH$) requires the presence of Ca^{2+} and high pH (typically ≥ 10). Another alternative is $CaNH_4PO_4 \cdot H_2O$, which is a slow-release fertilizer.
  - To make P more bioavailable, it may be necessary to acidify the product and/or add chelating agents (e.g., EDTA)

Hybrid Ion-Exchange (HAIX)

Anion exchange resin beads impregnated with hydrated ferric oxide (HFO) nanoparticles

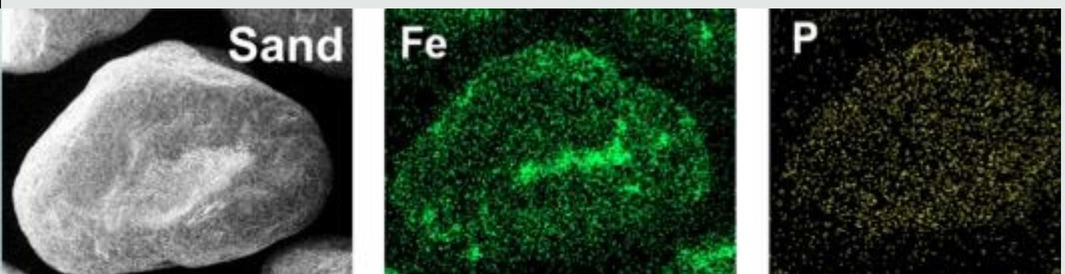
PhosX^{np}
(Lehigh U.)

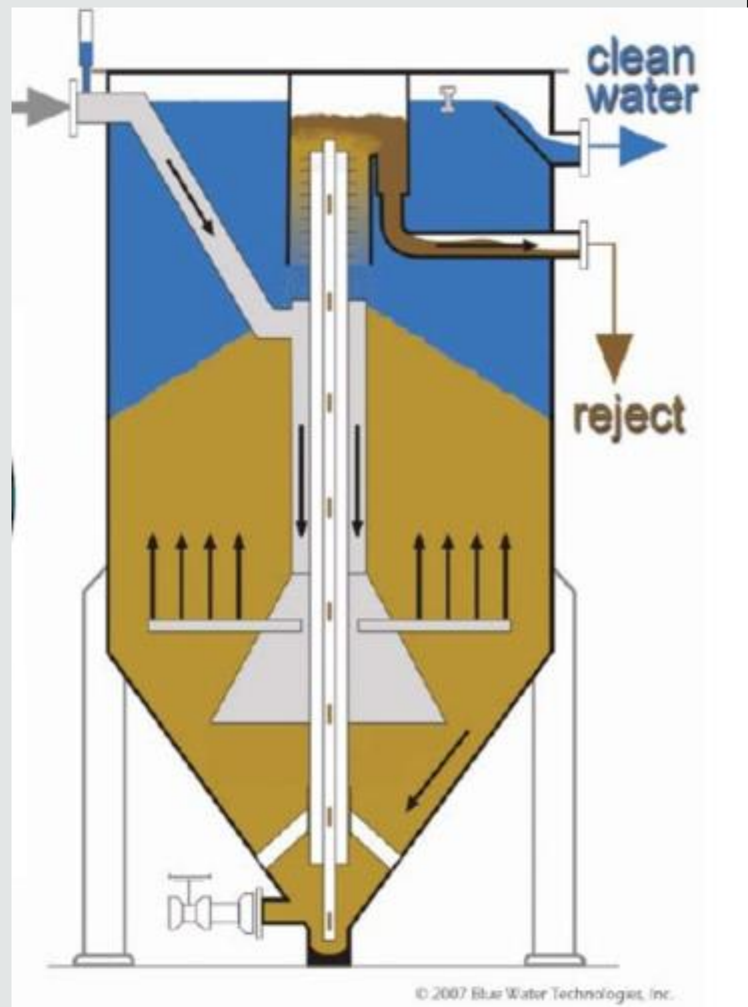




Hydrous Ferric Oxide Filter

BluePRO® technology from Blue Water Technologies





Other Promising Options

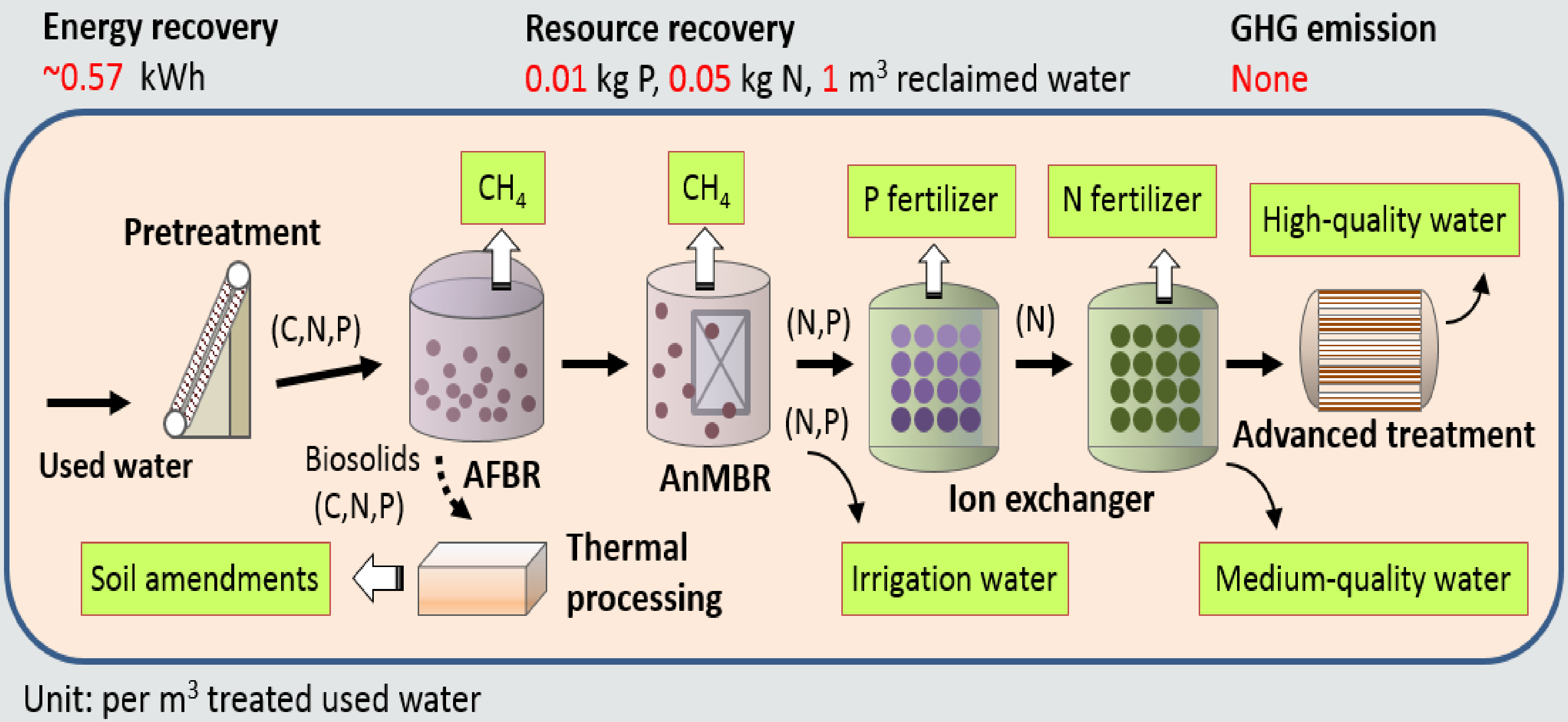
- PO_4^{3-}-selective sorbents based on Al or Ti oxides.
- Sub-micron-sized biochar that is added to the liquid stream and works as a single-use sorbent after separation via flotation.
  - Can be synthesized inexpensively from a wide array of agricultural waste products.
  - Can be chemically synthesized in large quantities in ways similar to graphene.
  - Sub-micron-sized materials have high external surface area to maximize sorption potential and short intra-particle paths that lead to rapid sorption mass transfer kinetics.
  - Their surface chemistry can be engineered to enhance N & P sorption.

Multiple Major Resources

- Energy – in the BOD
- Nutrients – the P and N
- **Clean Waters**

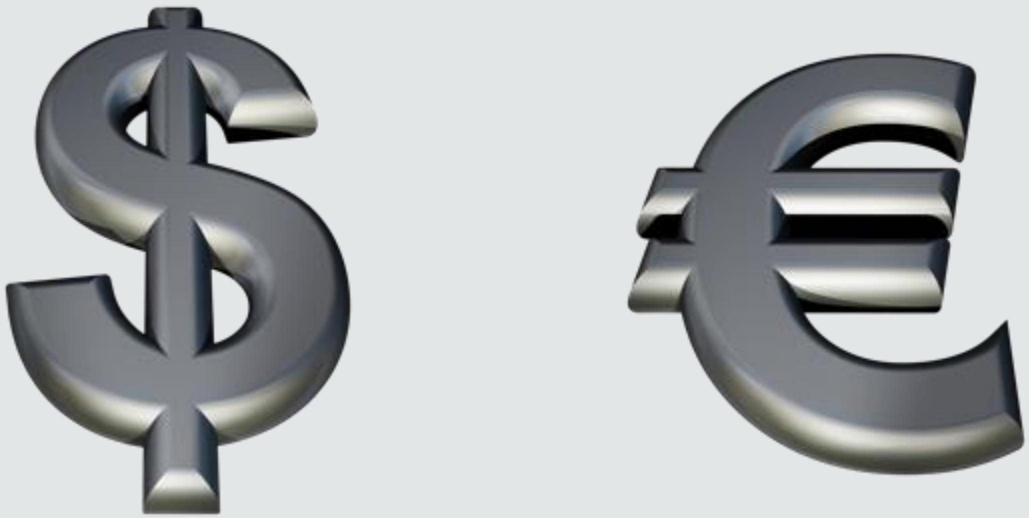
Enhancing environmental and economic value propositions

An example resource factory for domestic wastewater

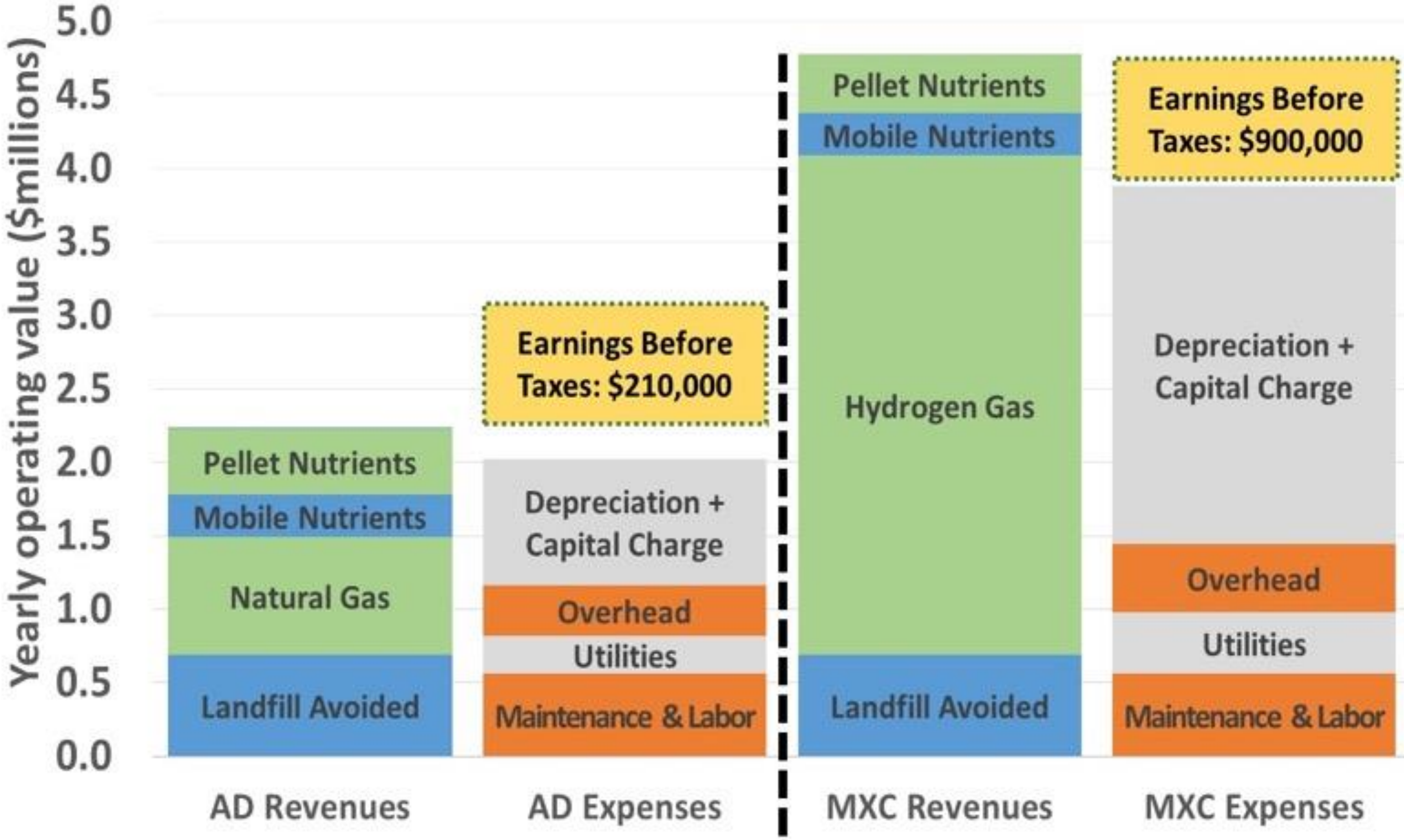


From: Li, W.-W., H.-Q. Yu, and B. E. Rittmann (2015). Reuse water pollutants. *Nature* 528: 29 – 31.

Economic Value Proposition

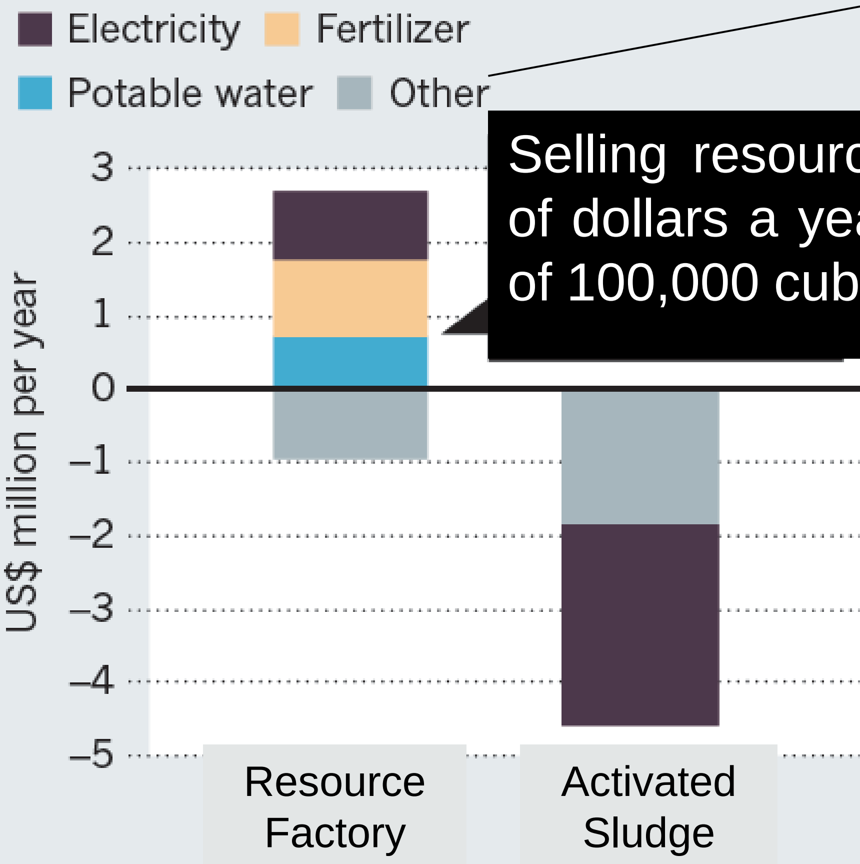


Techno-economics comparison, AD vs MXC annual operations revenue & expenses 6,500 dairy cow scenario



WATER WORKS

Capturing energy, nitrogen, phosphorus, and water can turn wastewater treatment from a major cost into a source of profit.



Chemicals consumption and biosolids disposal

Selling resources could make millions of dollars a year for a wastewater flow of 100,000 cubic meters per day.

Take-home Lessons

We also can **capture P** (and N)

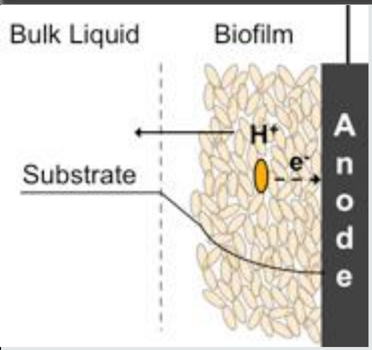
–We will need the P for agriculture

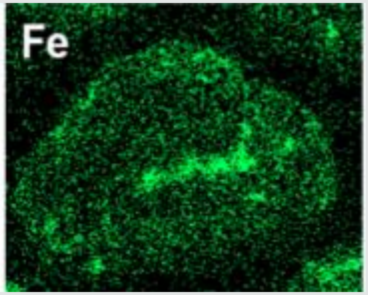
–It turns an apparent treatment liability into a resource benefit

–Mature and emerging methods are available

BIODESIGN INSTITUTE
ARIZONA STATE UNIVERSITY

Center for Environmental Biotechnology





Recovering the Lost P in Used Water

Bruce E. Rittmann

Regents' Professor of Environmental Engineering

Director of the Swette Center for Environmental Biotechnology

Biodesign Institute at Arizona State University

Rittmann@asu.edu

http://environmentalbiotechnology.org