Biosolids Management in the WWTP of the Future

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Presentation Outline

- Background
- Brief review of energy recovery
- Nutrient recovery
  - Why
  - Technology life cycle
  - Technology review
- Conclusion
WWTP of the Future
What is the Problem We are Trying to Solve?

Population Growth + Urbanization + Consumption + “Linear System”

Linear System = Take + Treat + Use + Treat + Waste

Integrated Water and Resource Management

= Water Stress + Resource Consumption + Nutrient Dispersal
1950

World Cities exceeding 5 million residents

Data source: U.N. Population Division
Development of World Cities

2000

World Cities exceeding 5 million residents

Data source: U.N. Population Division
Development of World Cities

2015

World Cities exceeding 5 million residents

Data source: U.N. Population Division
Population Explosion

- Population, Billion
- Year
- 7 Billion (2010)
- 9 Billion (2050)
Can a System That Serves:

- Global Population < 2 Billion
- Mostly Rural
- Lacking Modern Technology

Be the Solution When:

- Global Population ~ 10 Billion
- Mostly Urban
- Experiencing Greater Resource Constraints?
1. Redefines wastewater treatment plants as water resource recovery facilities (WRRFs)
2. Affirms that energy derived from WRRFs is a renewable energy source
3. States that biosolids should be recognized as biomass under all applicable government and commercial definitions
4. Asserts that state and federal agencies should fully endorse all renewable energy associated with WRRFs
5. Encourages WRRFs to set a goal of becoming energy neutral or net energy producers
6. Encourages more research into emerging technologies on energy recovery from wastewater
7. Encourages continued participation by water sector in traditional energy conservation and recovery at WRRFs

NBP Webcast, 7 Dec. 2011
WWTP of the Future in a Resource and Energy Constrained World

- Water Conservation
- Distributed Stormwater Management
  - Low Impact Development
  - Rainwater Harvesting
- Water Reclamation and Recycling
- Energy Neutral or Energy Positive
- Carbon Sequestration for Energy Production
- Nutrient Recovery
- Source Separation
- Decentralized treatment
  - Distributed liquid treatment
  - Centralized solids treatment
WERF Optimization Challenge

Energy Management

Resource Recovery

Process Optimization

Solids Volume Reduction
General Energy Balance for WRRF

Sources of Energy from Waste (Btu/lb Dry):
- Biosolids: 6,000-9,000
- Fats, Oils & Grease: 16,700
- Food Wastes: 1,500 -3,000

WRRF

Use to reduce fossil fuel source energy at plant or process steam

- Solar
- Algae
- Wind
- Hydro

Use for residential or commercial power
Produce electrical energy off-site
Provide “green” fuel for other uses

Compare to other fuels (Btu/lb Dry):
- Coal: 7,000 to 11,000
- Wood: 1,500 to 3,000
- Natural Gas: 7,000-9,000
The Future of Nutrient Recovery
Influences and Drivers

- Minimize use of chemicals
  - Chem.-P to Bio-P removal

- Struvite scaling

- Impact of phosphorus scarcity
  - Increased cost
  - Security

- Viability of continued land application
  - Availability of suitable land
  - Phosphorus limitation

- Nitrogen cycle disruption
The Future of Nutrient Recovery Influences and Drivers

- Highly marketable end-product
- Fertilizer industry greenhouse gas emissions
- Future regulations (favorable)
  - Sweden: 60% of P recycled from wastewater by 2015
- Nutrient recovery an integral component of sustainable WWTP of the future
- Decentralized treatment with centralized sludge treatment
The Future of Nutrient Recovery

Barriers

- Economics
- Competing priorities
- Lack of regulatory drivers
- Lack of knowledge
- Followers rather than leaders
- Lack of adequate full scale experience
- Averse to adding new processes
  - Staffing constraints
- Lack of public support
- Vague timeline (50 - 100 years?)
The Importance of Phosphorus

- Essential element of all life forms:
  • Genetic material, ATP, Bones
- A primary nutrient required for plant growth
- Detergents, crop protection, pharmaceuticals, flame retardant, etc.

An average human body contains 650g of Phosphorus.
Phosphorus is a Precious Element

• Essential – no substitutes, natural or synthetic
• Non-Renewable
Phosphorus Reserves and Production Worldwide

Together with nitrogen and potassium, phosphorus is a crucial ingredient in fertilizer. It is extracted from phosphorus-rich rock in the form of phosphate. Morocco, China, South Africa, and the U.S. hold 83 percent of the world's easily exploitable phosphate rock and contribute two-thirds of the annual phosphorus production (circles, below). At current rates of extraction (bars, below), known U.S. reserves are projected to last 49 years. Globally about 90 years’ worth of phosphorus remains.

Once the resource starts running out, less economical supplies may have to be tapped, which could result in higher prices and market disruption. Early production has been declining despite the increase in prices (graph, right); last year the price spiked up in line with supply and increased demand.

Phosphate Rock Reserves (thousands of metric tons)

- China: 4,300,000
- Morocco: 570,000
- South Africa: 1,500,000
- U.S.: 100,000

2008 Mine Production (thousands of metric tons)

- China: 28,000
- Morocco: 11,000
- South Africa: 600
- U.S.: 900

U.S. Production in Decline as Price Soars

- 1993 price: $21.38 per ton
- 2008 price: $120.00 per ton
- 2008 production: $713.00 per ton
- 2008 output: 560,000 tons

Vaccari, 2009
Current Phosphorus Use Profile

Fertilizer use expected to increase due to

• Rapid population growth
• Increased intensive agriculture
The Phosphorus Crisis

- Phosphorus resources are declining both in quality and accessibility

  Availability of high quality P:
  - 100 years globally
  - 40 year in the US

- Poor quality sources have increasing amounts of contaminants (Cd, U, Ni, Cr, Cu, Zn)
  - Higher cost of recovery

- Global response:
  - Sweden: 60% of P recycled from wastewater by 2015
  - China: 135% export tariff
  - Use of special urine separation toilets (Japan and Europe)
Is There Really a Loss of Phosphorus?

- Human
- WWTP
- Agriculture
- Rivers, Oceans
- Sediments
- Phosphate rock
- Weathering
- Tectonic uplift
- Sedimentation
- Runoff
- Discharge
- Mining
- Fertilization
- Detergent

Cornel et al (2009)
Phosphorus Distribution in Domestic Waste

400,000 tons/year of phosphorus in US sewage

Cornel et al (2009)
Nitrogen is Essential to Life

Contained in our DNA

- Present as $N_2$ gas in the atmosphere – infinite source
- Unusable by most organisms
- Need to convert to Reactive N (Nr)

Nr = Nitrogen bonded to carbon (C), oxygen (O) or hydrogen (H) atoms; e.g. $\text{NH}_3$

Natural conversion of $N_2$ gas to Nr:
- Lightening
- N-Fixation

Inadequate to sustain life - need human intervention
Global Nr Production

Fritz Haber
Nobel Prize - 1918

Carl Bosch
Nobel Prize (joint) - 1931

www.nobelprize.org
Global Nr Production

Haber – Bosch Process

\[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]

N source = air
H source = natural gas

450°C, 250 atm
Global Nr Production

Adapted from Barton and Atwater (2002) and Galloway et al (2008)
The Fate of Reactive Nitrogen (Nr)

"new" Nr used for food production

- entering human mouth - 15%
- lost to environment - 85%

Environment is also the sink for all of the Nr created by fossil fuel combustion.

"new" Nr entering human mouth

- used by body - 5%
- lost to environment - 95%

adapted from Galloway et al (2004)
Impact of Global Nitrogen Imbalance

Nitrogen loss = Increased synthetic fertilizer production:

• High energy demand = 12 kWh / kg ammonia N (Phillips et al, 2011)
• High embedded GHG emissions = 1.4 to 2.6 kg CO$_2$e / kg ammonia N (Wood and Cowie, 2004)

Canadian GHG Emissions

adapted from Environment Canada (2008)
Continuing Business as Usual will:

- Continue to alter the global nitrogen balance
- Result in nitrogen accumulation in the environment causing environmental & health impacts.

Estimated social damage costs of environmental Nr emissions to European Union countries (mid-range values)

Adapted from Sutton et al (2011)
Human Intervention Needed to Minimize the Impact on Global N Balance

Wastewater management is one of the intervention points.

Conversion to $N_2$ via treatment

Recovery
Technology Life-Cycle Model

Technology development is a 100 to 10 to 1 game!

Knowledge vs. Time

Level of Innovation & Application

Acclimation
Growth
Stability (Maturation)
Lag
Loss of Technology
Next Generation

10 Years (average)
<table>
<thead>
<tr>
<th>Technology</th>
<th>Life Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity Belt Thickening</td>
<td></td>
</tr>
<tr>
<td>Rotary Press</td>
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<tr>
<td>Belt Filter Press</td>
<td></td>
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<tr>
<td>Vacuum Filter</td>
<td></td>
</tr>
<tr>
<td>Centrifuge Dewatering</td>
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<tr>
<td>Recuperative Thickening</td>
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<tr>
<td>Acid-Gas Digestion</td>
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<tr>
<td>Temperature Phased Anaerobic Digestion</td>
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<tr>
<td>Co-Digestion</td>
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<tr>
<td>Dual Digestion</td>
<td>✓</td>
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<tr>
<td>Auto-thermal Aerobic Digestion</td>
<td>✓</td>
</tr>
<tr>
<td>Thermal Hydrolysis</td>
<td>✓</td>
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<tr>
<td>Thermal Drying</td>
<td>✓</td>
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<tr>
<td>Class A Heat Treat System</td>
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</tr>
<tr>
<td>Sludge Disintegration</td>
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<tr>
<td>Microsludge™</td>
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<td>Open Cel™</td>
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<td>Ostara™</td>
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<tr>
<td>Co-generation</td>
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<td>Fuel Cell</td>
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<td>Solar Photovoltaics</td>
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<tr>
<td>Gasification</td>
<td>✓</td>
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<tr>
<td>Biosolids Composting</td>
<td>✓</td>
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</tbody>
</table>
Phosphorus Recovery Alternatives

- Precipitation
- Crystallization
- Struvite
- Apatite
- Adsorption
- Sorption
- Ion Exchange
- Chemical desorption
- Magnetic separation
- Solids Separation
Potential Locations for P Recovery
# Proven P Recovery Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Feed Stream</th>
<th>Product</th>
<th>External Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalactor</td>
<td>RAS</td>
<td>CaPO$_4$</td>
<td>Lime, sand</td>
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<tr>
<td>PhoStrip</td>
<td>RAS</td>
<td>CaPO$_4$</td>
<td>Lime</td>
</tr>
<tr>
<td>Ostara</td>
<td>Centrate, filtrate</td>
<td>Struvite</td>
<td>MgCl, NaOH</td>
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<tr>
<td>Ostara</td>
<td>WAS</td>
<td>Struvite</td>
<td>MgCl, NaOH</td>
</tr>
<tr>
<td>Multiform Harvest</td>
<td>Centrate, filtrate</td>
<td>Struvite</td>
<td>MgCl, NaOH</td>
</tr>
<tr>
<td>Procorp</td>
<td>Centrate, Filtrate</td>
<td>Struvite</td>
<td>MgCl, NaOH</td>
</tr>
</tbody>
</table>
Fluidized Bed Reactor

Crystalactor

Centrate Influent → Pellet Discharge

→ Treated Effluent

Reagent

Ostara

CHEMICAL DOSING

CENTRATE INFLUENT

→ TREATED CENTRATE EFFLUENT

→ RECYCLE LINE

CRYSTAL GREEN® PRODUCT
Struvite Recovery Installations

Ostara
- Operational
  - Gold Bar, Edmonton
  - Durham WWTP, Portland, OR
  - York, PA
  - Nansemond, HRSD, VA
- Under construction
  - Rock Creek, Portland, OR
  - Saskatoon, Calgary, Winnipeg
  - Madison

Multiform Harvest
- Under Construction
  - Boise, ID

Procorp
- Under design - 1
Adsorption Technology

Raw Water (Municipal Wastewater Secondary Effluent)

Pre-treatment (Filtration)

Adsorption

Adsorption Treated Effluent

Recovered Phosphorus (apatite-type calcium phosphate)

Alkaline Aqueous Solution

Precipitation

Solid-Liquid Separation

Ca(OH)$_2$

Recovered Phosphorus Products (Fertilizer), Phosphorus Material

Neutralization

Acid

Drain

Desorption

Recovery

Drying / Granulation

Refine

deBarbadillo, 2011
# Other P Recovery Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Origin</th>
<th>Feed Stream</th>
<th>Product</th>
<th>External Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>KREPO</td>
<td>Sweden</td>
<td>Primary sludge</td>
<td>Ferric Phosphate</td>
<td>Heat, pressure, H₂SO₄, NaOH</td>
</tr>
<tr>
<td>Seaborne</td>
<td>Germany</td>
<td>Digested sludge</td>
<td>Struvite</td>
<td>Heat, H₂SO₄, NaOH, Mg(OH)₂</td>
</tr>
<tr>
<td>Kemicond</td>
<td>Sweden</td>
<td>Primary sludge</td>
<td>Ferric Phosphate</td>
<td>H₂SO₄, H₂O₂, polymer</td>
</tr>
<tr>
<td>BioCon</td>
<td>Denmark</td>
<td>Incinerator ash</td>
<td>H₃PO₄</td>
<td>H₂SO₄, ion-exchange</td>
</tr>
<tr>
<td>SEPHOS</td>
<td>Germany</td>
<td>Incinerator ash</td>
<td>AlPO₄, Ca₃(PO₄)₂</td>
<td>H₂SO₄, NaOH, Ca²⁺</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Japan</td>
<td>Effluent</td>
<td>Ca₃(PO₄)₂</td>
<td>Acid, NaOH, Ca²⁺</td>
</tr>
</tbody>
</table>
Nitrogen Recovery Alternatives

- Stripping
  - Air
  - Steam
- Adsorption
- Sorption
- Ion Exchange
- Precipitation
- Struvite
Ammonia Recovery Process (ARP)

- Ammonia in centrate removed by ion exchange adsorption
- Zinc sulfate & sulfuric acid used to regenerate media
- Regeneration solution vaporized to crystallize ammonium sulfate
Conclusion

- Population explosion and rapid urbanization is forcing us to go from a comfortable position of abundant resources to a stressful position of scarcity.

- Biosolids management of the future will continue to remain true to its core principles of public health and environmental protection.

- However, in order to remain sustainable, current practices must evolve to cope with the practical realities of the 21\textsuperscript{st} century and beyond.

- Rebranding to better define the role of WWTP of the future – Resource Recovery Facility with focus on recovery of nutrients, energy & water.
A President Understood the Looming Phosphorus Crisis Over 70 years Ago

“\textit{I cannot overemphasize the importance of phosphorus not only to agriculture but also the physical health and economic security of the people of the nation.”} 

Franklin D. Roosevelt, 1938
Questions

Planning **Always** Avoids Problems!