Agenda

- Why the focus on Phosphorus?
- Struvite – What does it mean for me?
- Phosphorus Management and Harvesting
- Take Away
Why the focus on Phosphorus?
Phosphate Rock: Non-renewable resource

Phosphate production has steadily increased

Phosphorus Production

World Phosphate Rock Production (metric tons)

Phosphate production has steadily increased.
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 40 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 disruptions. Already production has been declining despite the incentive of increasing prices (graph, right); last year the price spiked up because of tight supply and increased demand.
Resource Nexus: The Environmental Challenge of the 21st Century
WEF believes that wastewater treatment plants are NOT waste disposal facilities, but rather water resource recovery facilities that produce **clean water**, **recover nutrients** (such as phosphorus and nitrogen), and have the potential to reduce the nation’s dependence upon fossil fuel through the production and use of **renewable energy**.
Struvite – What does it mean for me?
Struvite is a phosphate mineral with formula: \( \text{NH}_4\text{MgPO}_4\cdot6\text{H}_2\text{O} \)

**Crystallization:**
Higher concentrations, higher temperatures

**Solubility:**
Decreases at high pH values
Struvite Formation

Precipitation Occurs

- Increase pH
- Increase concentrations
Struvite – should I be concerned?

- Operate a bio-P facility?
- Operate an anaerobic digester?
- Recycle filtrate from dewatering?
- Interested in Phosphorus recovery?
- Master planning for future solids handling?
- Future regs for land app will become more stringent?
Struvite Harvesting

Primary Clarifiers → Aeration Basins → Final Clarifiers

Mg$^{2+}$, NH$_4^+$, P

Digestion
Struvite Harvesting

Primary Clarifiers → Aeration Basins → Final Clarifiers

Mg$^{2+}$ P NH$_4^+$

Digestion

P Mg$^{2+}$ NH$_4^+$

P Mg$^{2+}$ NH$_4^+$
Struvite Harvesting

Struvite production limited by:
- Mg$^{2+}$
- pH
Struvite Harvesting

Primary Clarifiers → Aeration Basins → Final Clarifiers

Mg$^{2+}$, P, NH$_4^+$

Release Tank → Digestion

P, Mg$^{2+}$, NH$_4^+$

P, Mg$^{2+}$, NH$_4^+$
Sidestream Impacts

**Impact**
- Increased effluent phosphorus
- Decreased dewaterability
- Detrimental struvite maintenance

**Mitigation**
- Bind phosphorus
- Polyphosphate binding + cation balance?
- Bind phosphorus
# Sidestream Impacts

## Increased Effluent Phosphorus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent flow rate</td>
<td>10.8 mgd</td>
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<tr>
<td>Total COD</td>
<td>387 mg/L</td>
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<tr>
<td>TKN</td>
<td>40 mg/L</td>
</tr>
<tr>
<td>Total P</td>
<td>4.5 mg/L</td>
</tr>
<tr>
<td>TSS</td>
<td>200 mg/L</td>
</tr>
<tr>
<td>VSS</td>
<td>120 mg/L</td>
</tr>
<tr>
<td>cBOD5</td>
<td>200 mg/L</td>
</tr>
<tr>
<td>Magnesium</td>
<td>20 mg/L</td>
</tr>
</tbody>
</table>

Increased effluent phosphorus
Sidestream Impact – Phosphorus Performance

Increased effluent phosphorus

<table>
<thead>
<tr>
<th>Day</th>
<th>All Data</th>
<th>BFP OFF</th>
<th>BFP ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
<td>5.1</td>
<td>5.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Monday</td>
<td>7.8</td>
<td>5.4</td>
<td>7.8</td>
</tr>
<tr>
<td>Tuesday</td>
<td>5.3</td>
<td>4.9</td>
<td>8.2</td>
</tr>
<tr>
<td>Wednesday</td>
<td>5.9</td>
<td>4.8</td>
<td>7.9</td>
</tr>
<tr>
<td>Thursday</td>
<td>7.3</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>Friday</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturday</td>
<td>3.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dewatering Impact with Bio-P

Decreased Dewaterability

BFP Solids (%)

RBC  AS - Chem P  AS - Bio-P
Dewatering Impact with Bio-P

Lime-Stabilization Solids Handling Facility

Chem-P => Initial Bio-P
Ok, Is This Real or Not???

- Others Are Also Seeing This, Including:
  - Hampton Roads Sanitary District
    - Atlantic & Nansemond Plants
  - Madison, WI Metropolitan Sewerage District
  - Met Council Environmental Services
    - Empire & Blue Lake Plants
  - Metro Denver, CO
  - Sheboygan, WI
  - A number of European plants
MCES Empire Plant

Conversion from 2 Sludge to 1 Sludge System

Anaerobic Basins On-Line

Cake Solids (%)

Effluent Total P (mg/l)

Jan-05 Apr-05 Aug-05 Dec-05 Mar-06 Jul-06 Nov-06 Feb-07

Belt Press Cake Total Solids

Plant Effluent Total Phosphorus
Phosphates: stabilizers in processed meat, bind water
Most Sludge Floc Surfaces Are Anionic
Common Cations in Wastewater

Monovalent – Single Plus (+) Charge:
  Sodium
  Potassium

Divalent – Double Plus (++) Charge:
  Magnesium
  Calcium
  Iron
DVC Theory, in a Nutshell

Anion Dominated Solution Keeps More “Interstitial Water” in Sludge

Basis – Unlike Charges Attract/ Like Charges Repel
Can’t forget about detrimental struvite formation

- Clogged pipes
- Accumulation in digesters
Sidestream Impacts

- Glass-Lined Piping
- Increased pumping pressures
- Equipment / Process Downtime
- Labor
- Chemical Use

Detrimental struvite maintenance
Phosphorus Management and Harvesting
Alternative 1: Chemical Precipitation

Addition to digester

Addition to dewatering filtrate
Alternative 1: Chemical Precipitation

- Initial estimate: alum assumed
  - Binds phosphorus
  - Dewaterability improvements (more so with FeCl3 or Sorb-X)

180 gpd
$130k annual
$5k solids
Alternative 2: Struvite Harvesting

\[ \text{Struvite Harvesting System} \]

\[ \text{MgCl}_2 \quad \text{(non-limiting)} \]

\[ \text{P} \]
\[ \text{Mg}^{2+} \]
\[ \text{NH}_4^+ \]

\[ \text{NaOH} \quad \text{(pH adjustment)} \]

\[ \text{Harvested Struvite} \]
\[ \text{NH}_4^+ \]

\[ \text{P} \]
\[ \text{Mg}^{2+} \]
\[ \text{NH}_4^+ \]
Struvite Harvesting from Filtrate

Ostara

- Struvite Harvesting on Filtrate or Centrate
  - After Digested Sludge Thickening or Dewatering
Struvite Harvesting from Filtrate
Struvite Harvesting from Filtrate

Sorting, product Storage and bagging

Dewatering and Drying

3 - 500 kg/day fluidized bed reactors

Hampton Roads Sanitation District – Charles Bott
Struvite Harvesting from Biosolids

Forms/Removes Struvite Before Thickening or Dewatering
Struvite Harvesting from Biosolids

AirPrex®- Process Overview

1. Aeration to strip CO₂ out + recirculate sludge
2. Addition of Magnesium Chloride (MgCl₂)
3. MAP- Crystallisation and sedimentation
4. MAP- Separation and washing
Struvite Harvesting from Biosolids

Throughput: 30,000 GPD digested sludge @ 3.8% DS
## Economics – Struvite Production

<table>
<thead>
<tr>
<th></th>
<th>Alt 1 – Chemical Precipitation</th>
<th>Alt 2a – From Filtrate (Ostara)</th>
<th>Alt 2b – From Biosolids (Airprex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Removed</td>
<td></td>
<td>95%</td>
<td>80%</td>
</tr>
<tr>
<td>P Removed (ppd)</td>
<td></td>
<td>105</td>
<td>62</td>
</tr>
<tr>
<td>Struvite produced (ppd)</td>
<td></td>
<td>459</td>
<td>270</td>
</tr>
<tr>
<td>Percent Capture</td>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Product produced (ppd)</td>
<td></td>
<td>459</td>
<td>270</td>
</tr>
<tr>
<td>Product value ($/ton)</td>
<td></td>
<td>$400</td>
<td>$100</td>
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<tr>
<td>Product income ($/year)</td>
<td></td>
<td>$33,485</td>
<td>$4,935</td>
</tr>
<tr>
<td>Magnesium (gpd)</td>
<td>85</td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>Magnesium cost ($/year)</td>
<td>$23,269</td>
<td></td>
<td>$23,269</td>
</tr>
<tr>
<td>Sodium Hydroxide (mg/L feed)</td>
<td>75</td>
<td></td>
<td>0</td>
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<tr>
<td>Sodium Hydroxide (DST/year)</td>
<td>11</td>
<td></td>
<td>0</td>
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<tr>
<td>Sodium Hydroxide ($)</td>
<td>$5,995</td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td>Power (kwh/d)</td>
<td>374</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Power ($)</td>
<td>$10,921</td>
<td></td>
<td>$4,380</td>
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<tr>
<td>STRUVITE HARVESTING COST</td>
<td>$0</td>
<td>$7,203</td>
<td>-$22,714</td>
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</table>
# Economics – Chemical Precipitation

<table>
<thead>
<tr>
<th></th>
<th>Alt 1 – Chemical Precipitation</th>
<th>Alt 2a – From Filtrate</th>
<th>Alt 2b – From Biosolids</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Removed (ppd)</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al Required (ppd)</td>
<td>89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum Required (gpd)</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Produced (ppd)</td>
<td>434</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearly acreage increase</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual chemical (gal/yr)</td>
<td>65,849</td>
<td></td>
<td></td>
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<tr>
<td>Annual chemical cost</td>
<td>$131,000</td>
<td></td>
<td></td>
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<tr>
<td>Annual Solids Cost</td>
<td>$4,000</td>
<td></td>
<td></td>
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<tr>
<td>Total Annual Cost</td>
<td>-$135,000</td>
<td>$0</td>
<td>$0</td>
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</tbody>
</table>
## Economics – Nitrification

<table>
<thead>
<tr>
<th></th>
<th>Alt 1 – Chemical Precipitation</th>
<th>Alt 2a – From Filtrate</th>
<th>Alt 2b – From Biosolids</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH3 Load (ppd)</td>
<td>405</td>
<td>197</td>
<td>344</td>
</tr>
<tr>
<td>AOR (ppd)</td>
<td>1,852</td>
<td>901</td>
<td>1,570</td>
</tr>
<tr>
<td>scfm/AOR (based on existing aeration)</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>Airflow (scfm)</td>
<td>981</td>
<td>477</td>
<td>832</td>
</tr>
<tr>
<td>Energy (scfm\hp) (based on existing blowers)</td>
<td>23.00</td>
<td>23.00</td>
<td>23.00</td>
</tr>
<tr>
<td>Energy (hp)</td>
<td>43</td>
<td>21</td>
<td>36</td>
</tr>
<tr>
<td>Energy (kwh/yr)</td>
<td>278,829</td>
<td>135,618</td>
<td>236,413</td>
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<tr>
<td>Power cost ($)</td>
<td>-$22,306</td>
<td>-$10,849</td>
<td>-$18,913</td>
</tr>
</tbody>
</table>
## Economics – Biosolids Reuse

<table>
<thead>
<tr>
<th></th>
<th>Alt 1 – Chemical Precipitation</th>
<th>Alt 2a – From Filtrate</th>
<th>Alt 2b – From Biosolids</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Removed from solids (ppd)</td>
<td></td>
<td>105</td>
<td>62</td>
</tr>
<tr>
<td>P Removed from solids (t/yr)</td>
<td></td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>Acres Required per year</td>
<td>1,200</td>
<td>892</td>
<td>1,018</td>
</tr>
<tr>
<td>Biosolids Reuse Cost – Assuming P limitation for application</td>
<td>-$654,000</td>
<td>-$483,000</td>
<td>-$551,000</td>
</tr>
<tr>
<td>Biosolids Reuse Cost – Based on cake solids concentration</td>
<td>-$654,000</td>
<td>-$575,000</td>
<td>-$575,000</td>
</tr>
</tbody>
</table>
Economic Comparison

Relative Savings & Revenue
Filtrate Struvite Harvesting

Product value has the smallest economic impact

Relative Savings & Revenue
Biosolids Struvite Harvesting

Biosolids Reuse - Improved Cake Concentration
Chemical Precipitation
Nitrification Power Cost

Biosolids Reuse - Improved Cake Concentration
Chemical Precipitation
Nitrification Power Cost
Economic Comparison

Cost in Millions (2014$)

- Chemical Precipitation: Capital $0.00, Annual $1.02
- Ostara Struvite Harvesting: Capital $5.90, Annual $0.65
- Airprex Struvite Harvesting: Capital $2.55, Annual $0.67

20-Year TPW in Millions (2014$)

- Chemical Precipitation: $18.07
- Ostara Struvite Harvesting: $15.93
- Airprex Struvite Harvesting: $13.02

Airprex: lowest 20-year cost
Economic Comparison

Cumulative Cost ($M)

Years after Installation

- Chemical Precipitation
- Ostara Struvite Harvesting
- Airprex Struvite Harvesting

Airprex: 7 year payback
Not for everyone (at least not right now)
- Need (Bio-P, Digestion, ... maybe Dewatering)

When considering: Identify your drivers/costs/risk
- Don’t assume all the claims will hold true

Revenue will not offset capital investment, payback likely to be based on cost savings rather revenue generation

Technology:
- Options have different nuances
- Pilot study and evaluate on a case by case basis
- Technology market is rapidly developing

Future nutrient demands will drive the need for change
Any questions

Mike Harvey, PE
Donohue & Associates | 312.405.7965 | mharvey@donohue-associates.com

Thank you!