Nitrogen Removal 3.0: Integration of Anammox into Sidestream and Mainstream BNR Processes

Charles B. Bott, Ph.D., P.E., BCEE
Hampton Roads Sanitation District
History

• 1925 – Dept of Health condemns a large oyster producing area
  – 30 million gallons per day of raw sewage discharged into Hampton Roads

• 1940 – HRSD was created by the VA General Assembly to eliminate sewage pollution in the Chesapeake Bay
Hampton Roads Sanitation District

- Created in 1940
- Serves 1.6 million people
- Includes 17 jurisdictions – 3,100 square miles
- 9 major plants, 4 small plants
- Capacity of 249 MGD
Outline

• Overview of BNR Upgrades at HRSD
• Conventional Nitrogen Removal Processes
  Aside: Centrate Treatment
  Aside: York River DEMON Process Upgrade
• Chesapeake-Elizabeth – Conventional Upgrade
• Chesapeake-Elizabeth – Pilot Study

Please stop me with questions...
The VIP® Process

- It was developed and patented by HRSD and CH2M Hill Engineers
- Biologically removes Phosphorus and Nitrogen
- It's free for anyone to use...
Current HRSD R&D Efforts in BNR

• Supplemental carbon for denitrification (chemicals)
  – AOB conversion of methane to methanol
  – Reduced S compounds
  – Ethanol used for fuel blending
• Ammonia-based DO control systems (energy)
• Organic nitrogen sources and fate
• Cost effective Chemically Enhanced Primary Treatment (chemicals)
• Algae-based nutrient removal (chemicals, energy)
• Centrate treatment – anammox (chemicals, energy)
• Nitrite accum. and excessive chlorine demand (chemicals)
• IFAS process development and modeling (concrete, energy)
• Nitrification inhibition (concrete)
• BNR process reliability and stochastic methods (concrete)
• Improvement of BNR process models (chemicals, energy, concrete)
• Urine separation (source separation)
HRSD’s Bubble Permit - 2011

- **James River**
  - 6,000,000 lbs/yr TN
  - 573,247 lbs/yr TP

- **York River**
  - 288,315 lbs/yr TN
  - 33,660 lbs/yr TP

- **Rappahannock River** (one plant)
  - 1,218 lbs TN
  - 91 lbs/yr TP
Chesapeake Bay TMDL & VA WIP

• Nitrogen – James River
  – 2011 – 6.0 million pounds/year
    • Major upgrades ongoing at Nansemond, James River, Williamsburg, Army Base,
    • Upgrade at Boat Harbor (minimal N removal)
  – 2017 – 4.4 million pounds/year
    • VIP - biological process upgrade for improved denitrification
    • Small upgrade at Williamsburg possible
  – 2021 – 3.4 million pounds/year
    • Upgrade Chesapeake-Elizabeth (full plant)

• Nitrogen – York River ---- No change?
  – Rapid upgrade to add denite filters for 2011 compliance
  – Additional upgrade needed for cost-effective BNR and reliability
Motivation for this Discussion

- Nitrogen removal upgrade required by 2021 to meet TN of approximately 5 mg/L
- Capital Cost = $125-150M (conventional process)
- Operating costs will increase dramatically:
  - Incremental Energy for aeration and pumping = $1.0 M/yr
  - Incremental chemicals (caustic and carbon) = $1.0 to 2.0 M/yr
  - Labor & supplies?
- Limited land available
  - Nutrient Removal
  - Biosolids
Wastewater Treatment 101 – Liquid Processes

Raw Sewage
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abbreviation</th>
<th>Units</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Flow rate</td>
<td>gpd/capita</td>
<td>50-100</td>
<td></td>
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<tr>
<td>Biochemical Oxygen Demand</td>
<td>BOD</td>
<td>mg/L</td>
<td>120-350</td>
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<tr>
<td>Chemical Oxygen Demand</td>
<td>COD</td>
<td>mg/L</td>
<td>250-800</td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>TSS</td>
<td>mg/L</td>
<td>120-350</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>TKN</td>
<td>mg/L</td>
<td>30-50</td>
</tr>
<tr>
<td>Total Ammonia Nitrogen</td>
<td>NH4-N</td>
<td>mg/L</td>
<td>25-40</td>
</tr>
<tr>
<td>Nitrate –N + nitrite-N</td>
<td>NOx-N</td>
<td>mg/L</td>
<td>0</td>
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<tr>
<td>Total Phosphorus</td>
<td>TP</td>
<td>mg/L</td>
<td>4-10</td>
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<tr>
<td>ortho-Phosphate as P</td>
<td>OP</td>
<td>mg/L</td>
<td>3-8</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>FC</td>
<td>No./100 mL</td>
<td>10^5-10^8</td>
</tr>
</tbody>
</table>
Wastewater Treatment 101 – Liquid Processes

- **Screening**
- **Grit Removal**
- **Primary Clarification**
- **Biological Treatment** Typically - Activated Sludge
  - **BOD and TSS Removal**
- **Secondary Clarification**
  - **RAS**
  - **Tertiary Treatment**
    - **Filtration**
    - **More Nutrient Removal**
- **Disinfection**
  - **Chlorine**
  - **UV**
- **Reaeration**

**Raw Sewage** → **Landfill** → **Influent Pumping** → **Landfill** → **Primary sludge & Waste Biomass to Biosolids Treatment Processes and Disposal** → **Disinfection** → **Reaeration**
Digestion Plant Example

Waste Activated Solids (WAS)

Gravity Belt Thickener (or DAF)

Sidestream Recycles to head of plant

Anaerobic Digesters (First Stage)
Mixed

Biogas

Anaerobic Digesters (Second Stage)
Unmixed

Polymer

Centrifuge

Primary Solids

Gravity Thickener (or None)

Land Application of Liquid Biosolids Product (Class B)
Incineration Plant Example

- Waste Activated Solids (WAS)
  - Gravity Belt Thickener (or DAF)
  - Polymer
  - Sidestream Recycles to head of plant

- Primary Solids
  - Gravity Thickener (or None)

- Centrifuge

- Air Pollution Controls (scrubbers)
  - Stack

- Multiple Hearth Incinerator
  - Natural Gas or Fuel Oil

- Plant NPW

- Ash Disposal
Forms of Nitrogen

- Total ammonia nitrogen (TAN) = $\text{NH}_4^+\text{-N} + \text{NH}_3\text{-N}$
- $\text{NO}_2^- = \text{nitrite}$
- $\text{NO}_3^- = \text{nitrate}$
- Organic Nitrogen (protein, nucleic acid, etc)
  - Soluble/dissolved
  - Particulate
- TKN = Total Kjeldahl Nitrogen = TAN + Org N
- $\text{NO}_x\text{-N} = \text{NO}_2\text{-N} + \text{NO}_3\text{-N}$
- TN = Total Nitrogen = TKN + $\text{NO}_2\text{-N} + \text{NO}_3\text{-N}$
  (everything is expressed on an “as N” basis)
- Raw Sewage – TKN = TN = 30 to 45 mg/L
- Raw Sewage – $\text{NO}_x\text{-N} \sim 0 \text{ mg/L}$
BNR-N consists of three processes:

1. **Ammonification**
   - Influent Seq: Org-N → NH₄-N

2. **Nitrification**
   - Org-N + NH₄-N → NH₄-N → NO₃-N
   - Air-Oxygen (energy)
   - Alkalinity (caustic)

3. **Denitrification**
   - NO₃-N → N₂
   - Carbon
   - Sludge
   - Some Alkalinity

**Aerobic**

**Anoxic**
Conventional Nitrification-Denitrification

**Nitrification**
- Autotrophic Bacteria
- Aerobic Environment
- 1 mole Ammonia (NH$_3$ / NH$_4^+$)
- 25% O$_2$ (energy)
- 75% O$_2$ (energy)
- ~100% Alkalinity

**Denitrification**
- Heterotrophic Bacteria
- Anoxic Environment
- 1 mole Nitrite (NO$_2^-$)
- 40% Carbon (BOD)

Ammonia Oxidizing Bacteria (AOB)

Nitrite Oxidizing Bacteria (NOB)

1/2 mol Nitrogen Gas (N$_2$)

60% Carbon (BOD)
MLE Process (N Removal)

Primary Effluent

BOD + NH₄

Anoxic

BOD Rem. by Denitrification

Nitrate/Internal Recycle (IMLR) = Nitrate Recycle (NRCY)

Aerobic

Nitrification & Residual BOD Removal

TN ~ 8-12 mg/L

RAS

SC

WAS

air
4-Stage Bardenpho (Better N Removal)

Nitrate Recycle (NRCY)

BOD + NH₄

Anoxic

Aerobic

Carbon (Methanol?)

Anoxic

Aerobic

Primary Effluent

RAS

SC

WAS

TN ~ 3-5 mg/L
Let’s save a little energy and carbon...
Some New Vocabulary....

Autotrophic Bacteria
Aerobic Environment

Heterotrophic Bacteria
Anoxic Environment

Nitrification

1 mole Ammonia
(NH₃ / NH₄⁺)

Nitrite Oxidizing Bacteria (NOB)

1 mole Nitrite
(NO₂⁻)

Denitrification

1½ mol Nitrogen Gas
(N₂)

Ammonia Oxidizing Bacteria (AOB)

1 mole Nitrite
(NO₂⁻)

Nitrification

1 mole Nitrate
(NO₃⁻)

Nitrite Oxidizing Bacteria (NOB)
Nitritation-Denitritation = “Nitrite Shunt”

**Advantages:**
- 25% reduction in oxygen demand (energy)
- 40% reduction in carbon (e⁻ donor) demand
- 40% reduction in biomass production
Can we implement this in the plant liquid stream?

Simultaneous Nitrification/Denitrification (SND)

Process has not been purposefully implemented in larger plants...

- Large aeration tank volume required
- Sophisticated instrumentation & controls
- Uncertain design
- Uncertain operation
- Risk of poor mixed liquor settling
Let’s now move to another part of the treatment plant...
1% of Total Plant Influent Flow
- Rich in Nitrogen & Phosphorus
- 15 to 25% of the Total Plant TN load
- Ammonium Conc. 800 to 1,500 mg-N/L
- Temperature 30 - 38°C
- Alkalinity insufficient for complete nitrification
- Insufficient carbon for denitrification

For a Bio-P plant with no iron addition:
- Centrate TP = 200-800 mg/L
Centrate Treatment Options

**Biological - N**
- Nitrification / Denitrification & Bioaugmentation
  - With RAS & SRT Control
  - With RAS
  - Without RAS
- Nitritation / Denitritation
  - Chemostat
  - SBR
  - Post Aerobic Digestion
- Deammonification
  - Suspended Growth SBR
  - Attached Growth MBBR
  - Upflow Granular Process

**Physical-Chemical – N&P**
- Ammonia Stripping
  - Steam
  - Hot Air
  - Vacuum Distillation
- Ion-Exchange
  - ARP
- Struvite Precipitation
  - Ostara Process
  - PhosPaq Process
Conventional Nitrification-Denitrification

Autotrophic Bacteria
Aerobic Environment

1 mole Ammonia
(NH$_3$ / NH$_4^+$)

75% O$_2$ (energy)
~100% Alkalinity

1 mole Nitrite
(NO$_2^-$)

25% O$_2$ (energy)

1 mole Nitrate
(NO$_3^-$)

Nitrite Oxidizing Bacteria (NOB)

Ammonia Oxidizing Bacteria (AOB)

1 mole Nitrite
(NO$_2^-$)

40% Carbon (BOD)

Heterotrophic Bacteria
Anoxic Environment

1/2 mol Nitrogen Gas
(N$_2$)

60% Carbon (BOD)
InNitri Process was the First Bioaugmentation Concept

PC → Activated Sludge Tank → Sec. Effluent

RAS

WAS

Nitrifiers
NO$_3$-N

Nitrification Reactor
~25°C

Centrate (NH$_3$-N)

Expected bioaugmentation benefit not fully realized
Temperature change
Poor capture of recycle stream nitrifiers
Predation

Peter Kos
M2T Tech License
Bioaugmentation is achieved better with this process.
### Centrate Treatment Options

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- Nitrification / Denitrification & Bioaugmentation
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  - Ostara Process
  - PhosPaq Process
Nitritation-Denitritation = “Nitrite Shunt”

**Nitritation**
- 75% O₂ (energy)
- ~100% Alkalinity
- 1 mole Ammonia (NH₃/ NH₄⁺)

**Autotrophic Bacteria**
- Aerobic Environment

**Denitritation**
- 40% Carbon (BOD)
- ½ mol Nitrogen Gas (N₂)

**Heterotrophic Bacteria**
- Anoxic Environment

**Advantages:**
- 25% reduction in oxygen demand (energy)
- 40% reduction in carbon (e⁻ donor) demand
- 40% reduction in biomass production
Nitritation (SHARON) - Denitrification

Centrate NH₄⁺ → AOB
\[ \text{NH}_4^+ + \text{O}_2 \rightarrow \text{NO}_2^- \]

Alkalinity

Air

Methanol or other carbon source

Mostly NO₂⁻

NO₂ Denitration

Centrate with low Effluent NH₄⁺ and NOₓ

Centrate with high NO₂⁻ to headworks for odor control?
Centrate Treatment Options

Biological - N
- Nitrification / Denitrification & Bioaugmentation
  - With RAS & SRT Control
  - With RAS
  - Without RAS
- Nitritation / Denitritation
  - Chemostat
  - SBR
  - Post Aerobic Digestion
- Deammonification
  - Suspended Growth SBR
  - Attached Growth MBBR
  - Upflow Granular Process

Physical-Chemical – N&P
- Ammonia Stripping
  - Steam
  - Hot Air
  - Vacuum Distillation
- Ion-Exchange
  - ARP
- Struvite Precipitation
  - Ostara Process
  - PhosPaq Process
The N-Cycle

Denitrification

$\text{NO}_3^-$ \rightarrow $\text{NO}_2^-$ \rightarrow Anammox \rightarrow NH_4^+$

N-fixation

$\text{N}_2$ \rightarrow $\text{NO}_3^-$

E. Broda (1977): „missing lithotroph“ … „might have existed or still exists“

free enthalpy -360 kJ/mol
Partial Nitritation-Anammox = “Deammonification”

ANAMMOX
“Anaerobic” Ammonia Oxidation - (New Planctomycete - Strous et al, 1999)

\[ \text{NH}_4^+ + 1.32 \text{NO}_2^- + 0.066 \text{HCO}_3^- + 0.13 \text{H}^+ \rightarrow \]

\[ 0.26 \text{NO}_3^- + 1.02 \text{N}_2 + 0.066 \text{CH}_2\text{O}_{0.5} \text{N}_{0.15} + 2.03 \text{H}_2\text{O} \]

Autotrophic Bacteria
Aerobic Environment

- 0.5 mole Nitrite (NO_2^-)
- 1 mole Ammonia (NH_3 / NH_4^+)
- 37% O_2 (energy)
- ~50% Alkalinity

Ammonia Oxidizing Bacteria (AOB)

Autotrophic Anoxic Environment

- ½ mol Nitrogen Gas (N_2)
- a little bit of nitrate (NO_3^-)

Advantages:
- 63% reduction in oxygen demand (energy)
- Nearly 100% reduction in carbon demand
- 80% reduction in biomass production
- No additional alkalinity required
Partial Nitritation – Anammox

- Two Step Anammox Process
  - Dokhaven, Rotterdam (NL)
One-Step Centrate Deammonification

- **CANON - Paques Granular Sludge**
  - Olburgen, Netherlands

- **SBR-Type Process (DEMON)**
  - Strass, Austria + ~18 others

- **Attached growth process**
  - Hattingen, Germany
    - Deammon
  - Veolia Pilot- Malmo, Sweden
    - AnitaMox

Partial Nitritation and Anammox - combined in a single reactor
Deammonification SBR – the DEMON™ Process

 DEMON™ at Strass WWTP, Austria

Flow, Q
Dissolved Oxygen, DO
pH
Side Water Depth, SWD

Cyclone for selecting for DEMON® Granules

- Mixed Liquor
- Overflow
- Underflow

Activity [%]

MLSS  Overflow  Underflow

Mixed Liquor  Overflow  Underflow
**Deammonification Experience: DEMON® Process**

Operational:
- Strass, Austria
- Glarnerland, Switzerland
- Thun, Switzerland
- Plettenberg, Germany
- Heidelberg, Germany
- Apeldoorn, Netherlands

Several under construction:
- Croatia
- Austria
- Germany

- By 2011 more centrate Demon facilities (>20) than conventional Nitrification/Denitrification
- Cyklar-Stulz & Grontmij providing turnkey services and now World Water Works in US
Sidestream Deammonification (Anammox)  
What’s the benefit?

• Remove about 20% of the N load to the plant by treating the centrate separately

• Do it with:
  – No chemicals (caustic & methanol)
  – < 40% of the energy cost
  – (as compared to traditional nitrification-denitrification)

• Risks:
  – Slow process startup (US plant)
  – Requires robust process control
  – Process has been adequately demonstrated in Europe
  – We need just one in North America (anywhere)…
ASA, UOSA, DCWater – Universal SBR

- Flexible SBR process for centrate treatment
  - Nitrification (+ Alkalinity)
  - Nitritation (+ Alkalinity)
  - Nitrification-Denitrification (with carbon + Alkalinity)
  - Nitritation-Denitritation (with carbon + Alkalinity)
  - Partial Nitritation-Anammox (DEMON)

(Daigger et al, 2011)
HRSD York River WWTP - DEMON

• World Water Works, Inc. now has an exclusive license from Cyklar-Stulz to market DEMON in the US

• WWW offered to install DEMON at no cost to HRSD:
  – Decanter, aeration upgrades, instrumentation and controls, DCS hardware, other modifications
  – Anammox seed sludge transported from Europe

• Installation occurring now

• Startup expected January 2012
Now let’s discuss the Ches-Eliz TP
Chesapeake-Elizabeth Treatment Plant

- 24 MGD design, 15-21 MGD operating
Traditional BNR Alternative by 2021

• Construct primary clarifiers
• Construct:
  – 5-stage Bardenpho (+9 MG) & Filters
  – MLE or VIP + Denite Filters
• Incinerator scrubber blowdown treatment
  – Sidestream biological treatment of cyanide
• Thickening improvements
• Full Distributed Control System (DCS)

• Approximate $125-150M capital cost
• Operating costs will increase dramatically:
  • Incremental energy for aeration and pumping = $1.0 M/yr
  • Incremental chemicals (caustic and carbon) = $1.0 to 2.0 M/yr
  • Labor & supplies?
BNR Pilot Testing at the Chesapeake-Elizabeth Treatment Plant
Ches-Eliz Nutrient Removal Pilot Study

- 4 year study
- Collaboration through Water Environment Research Foundation (WERF) project:
  - DCWater
  - One Swiss and one Austrian wastewater utility
  - American Water
  - Developers of the DEMON process
  - ODU, Virginia Tech, Columbia University (NY), University of Innsbruck (Austria)
  - Two US engineering firms – HDR and Black & Veatch
  - Several other US wastewater utilities
Concepts for Pilot Testing

1. Two stage “A/B” process:
   – A stage – high rate activated sludge for 60-70% COD removal
   – B stage – MLE in SND mode (N removal 2.0)

2. Two or Three stage process:
   – activated sludge for COD removal
   – partial nitritation – Anammox (Deammonification) (N removal 3.0)

3. Two or Three stage process (energy positive):
   – Anaerobic treatment (CH₄ gas generation) for COD removal
   – partial nitritation – Anammox (Deammonification) (N removal 3.0)
Chesapeake – Elizabeth WWTP
Potential Benefits – Compared to Baseline BNR Alternative

1. Two stage “A/B” process:
   - Reduced capital cost and footprint
   - Increased sludge production
   - Similar energy use
   - Slightly increased chemical use

2. Two or Three stage process with Deammonification:
   - Potential reduction in capital cost
   - Similar sludge production
   - Footprint uncertain
   - Significant reduction in chemical and energy use
   - Potentially energy neutral

3. Two or Three stage process with Anaerobic Treatment & Deammonification:
   - Energy positive treatment
   - Minimal chemicals
   - Minimal sludge production
   - Significant O&M cost savings
   - Likely increased capital cost and footprint requirement
Mainstream Deammonification

• Very challenging....
• Primary objective: Eliminate competition for NO$_2^-$
• Selective retention of Anammox bacteria is critical
• Risk is high that this process will not work, but reward is very high...
  – Reduce capital cost by ~$20-40M
  – Reduce chemical cost by $1-2M/yr (no increase above current conditions)
  – Reduce energy cost by ??? (depends on A-stage)
Mainstream Deammonification Status – Worldwide

• Strass, Austria – ~10 MGD
  – Full-scale conversion complete and testing in progress

• Glarnerland, Switzerland - ~15 MGD
  – Full-scale testing of one train in progress
  – Not designed as currently envisioned
  – Testing has been moderately successful
STRASS WWTP DEMONSTRATION (Full-Scale)
A-Stage HRAS
B-Stage MLE
B-Stage Deammonification
Ideal Configuration...

Raw Wastewater → Screening → Grit Removal → Anaerobic MBR or Biokinetic Process → Partial Nitritation → Anammox → Tertiary Filtration → UV Disinfection → Discharge to Chesapeake Bay

Energy Generation → FeCl₃ → CH₄ → Waste Sludge → WAS → Gravity Thickener → Centrifuge → Multiple Hearth Incinerators → CH₄ → ASH
If this works...

• Capital cost may be about the same - $125-150M

• Reduce chemical cost by $1-2M/yr (no increase above current conditions)

• **Energy positive plant with TN removal is possible:**
  – Current energy use at Ches-Eliz = $1.25M/yr (electricity and natural gas)
  – Projected increase with conventional BNR ~ $1.0M/yr
  – Savings ~ $2.25M/yr
  – Energy production??
Questions?

Charles Bott

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Source Separation in the HRSD Main Office
New HRSD Operations Center Complex
What is Source Separation?

- Separation of concentrated urine stream from gray and black water
- Urine contains >70% of the TKN and >60% of the TP in <1% of raw sewage flow
- Management of urine separate from sewage:
  - Separate high strength urine treatment $\rightarrow$ biologically convert NH$_4$ to N$_2$, precipitate OP using FeCl$_3$ or alum
  - NH$_4$ recovery – stripping and production of (NH$_4$)$_2$SO$_4$ or NH$_4$NO$_3$ fertilizer
  - Recover OP using lime – apatite or hydroxyapatite solids
  - Evaporation
  - Electrodialysis + ozonation
  - Best - Recover NH$_4$ and OP by struvite precipitation (MgNH$_4$PO$_4$·6H$_2$O)
Motivation for Source Separation

• This is a truly sustainable solution for the wastewater industry and nutrient removal
  – Environmental benefits
  – Financial benefit for wastewater utility

• This has not been done in the US – demonstration or otherwise
Source Separation and Treatment of Anthropogenic Urine

by:
Kimberly LeMonde Fewless
Sybil Sharvelle (PI)
Larry A. Roesner (Co-PI)
Colorado State University

2011
Examples from Around the World

• EAWAG, Switzerland

Welcome to Novaquatis

**Novaquatis – a cross-cutting Eawag project.** The transdisciplinary research project Novaquatis is concerned with urine source separation as a new element in wastewater management. The goals are to improve water pollution control by reducing inputs of nutrients and micropollutants, and to close nutrient cycles.

From 2000 to 2006, this cross-cutting project explored the potential of urine source separation – also known as NoMix technology. Novaquatis comprises **nine work packages**, largely organized around the various stages of a nutrient cycle. Participating in the project were researchers from the fields of sociology, economics, natural sciences and engineering. They worked closely together with the sanitary technology industry, local authorities and an emerging country – China.

The main results of Novaquatis are presented on this homepage and in the final report "NoMix – A new approach to urban water management."
Examples from Around the World

- Several tall buildings in Japan + struvite recovery
- Stockholm suburban development – 160 people
  - Swedish Goal: 60% of P recycled from wastewater by 2015
Examples from Around the World

• German Technical Cooperation (GTZ) - Sustainable Sanitation- ECOSAN

• Office building with 56 No-mix toilets + 25 waterless urinals \( \rightarrow \) 8000 L/week urine

• Struvite production

**Figure 2-15 Struvite Produced from Urine at GTZ Headquarters (M. Winker, 2010). Reprinted with permission from GTZ.**

**Figure 2-16 MAP (Struvite) Reactor at GTZ Headquarters (M. Winker, 2010). Reprinted with permission from GTZ.**
Examples from Around the World

- International Space Station...
Examples from Around the World

- Direct use of urine as a fertilizer in developing countries – promoted by Swedish Water Institute
urine → fertilizer

DIY KIT
LEED Certification

• Currently no credit for source separation

• All water-related criteria providing LEED points either provide no benefit to the wastewater utility or make treatment more difficult & expensive

• Discussion ongoing with USGBC
The Concept for the Operations Center Building

- Install waterless urinals in male bathrooms
  - Install separate drain line from urinals to collection tank located outside mechanical room with valve (?) allowing redirection to main sewer

- Install separate “yellow water” and ”black water“ drain lines in female bathrooms
  - Install normal toilets for now – yellow water line connected to main sewer for now
  - Flush toilets with reclaimed gray water or stormwater

- “Test Drive” one urine separating toilet
The Concept for the Operations Center Building

- Size collection tank to contain 2-4 weeks of urine (men) with provisions to expand for women
- pH control system & $\text{H}_2\text{SO}_4$ feed
- GAC or acid trap odor control for tank ($\text{NH}_3$)
- Pump and truck load out station
- Ability to offload truck into centrate tanks at Nansemond Plant – Ostara process
Back of the Envelope – Ops Center

• 100 adult men in building for 8 hours/day
• 0.75 L/day/person ➔ 75 L/day = 600 gal/month
• Urine characteristics:
  – 4300 mg/L NH$_4$-N
  – 1000 mg/L OP
• Assume 80% conversion of OP in urine to struvite
  – ~1.0 lb/day struvite produced
• Future ➔ Follow Ostara by Anammox centrate treatment process for NH$_4$ removal....
Back of the Envelope – 10,000 people

• 1 MGD sewage flow & 5000 gpd urine

• Raw sewage:
  – Normal BOD & COD
  – TKN = 8-12 mg/L
  – TP = 1-2 mg/L

• BNR is probably not required at the WWTP – borderline & depends on TN and TP limit

• Urine characteristics:
  – 4300 mg/L NH\(_4\)-N
  – 1000 mg/L OP

• Assume 80% conversion of P in urine to struvite
  – 230 lbs/day struvite produced

• Follow struvite recovery process by Anammox treatment and precipitate remaining OP with FeCl\(_3\) or alum....
Other Issues

• **Public acceptability...**
• If WW utility personnel can’t deal with this, there is no hope...
• This gives us a clear mechanism to demonstrate the cost of nutrient removal...
• Of course, scale-up and residential collection are big challenges...
• Potential to eliminate the need for BNR and provide a potentially valuable fertilizer product
• This project is clearly a demonstration project and R&D platform
  – K⁺ recovery potential? K-struvite?
  – Impact of elevated K⁺ on Ostara process?
  – Microconstituents – estrogens and pharmaceuticals concentrated in urine
  – Odor, pipe scale, urea hydrolysis
HRSD Current R&D Efforts in BNR

• Supplemental carbon for denitrification (chemicals)
  – AOB conversion of methane to methanol
  – Reduced S compounds
  – Ethanol used for fuel blending
• Ammonia-based DO control systems (energy, chemicals)
• Organic nitrogen sources and fate
• Cost effective CEPT (chemicals)
• Algae-based nutrient removal (chemicals, energy)
• Centrate treatment – anammox (chemicals, energy)
• Nitrite accum. and excessive chlorine demand (chemicals)
• IFAS process development and modeling
• Nitrification inhibition
• BNR process reliability and stochastic methods
• Improvement of BNR process models
• Urine separation (source separation)