State of the Technology

On-site wastewater treatment (OWTS)

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Hazen and Sawyer
Objectives

• Provide an overview of existing technology options for nitrogen removal from on-site systems
• Identify knowledge gaps and opportunities
• Rank technology to prioritize R&D efforts
• Summary of CCWT efforts
Methodology

• Reviewed manufacturer information, research literature, past technology reviews
• Met with practitioners, researchers in the field, other stakeholders
• Engaged Hazen and Sawyer to compile existing information and develop a technology assessment
Conventional OWTS in Suffolk County

• Basic treatment for single-family homes (1972 standards) consist of septic tank and precast leaching pools

Source: http://104cliffroadeast.com/?page_id=955
Innovative/Advanced OWTS

Alternative and innovative systems add a component between the septic tank and drainfield.

Source: http://104cliffroadeast.com/?page_id=955
Onsite nitrogen reduction technologies

Onsite Nitrogen Reduction Technologies Classification

- Source Separation
  - Urine Recovery
  - Wastestream Segregation
- Biological Processes
  - Single Sludge BNR
  - Two Sludge, Two Stage BNR
- Physical / Chemical Processes
  - Membrane Separation
  - Ion Exchange
  - Evaporation
- Soil, Plant And Wetland Processes
  - Soil Treatment Unit Modification
  - Vegetative Uptake / Evapo-Transpiration
  - Constructed Wetlands
Single Sludge BNR: single reactor carries out nitrification & denitrification

**Process:**
Suspended growth or fixed film utilizing aeration process for nitrification and possibly nitrified effluent recycle for denitrification using WW carbon

**Pros:**
- Relatively simple installation

**Cons:**
- More complex operation
- Higher energy use

**Diagram:**
- WW → Septic Tank → Aerobic/Anoxic Reactor → Eff
- N2
- Nitrified Effluent Recycle
Two sludge, two-stage BNR

**Process:**
Two separate bacteria populations for nitrification and denitrification, requires electron donor from external source for denitrification.

**Pros:**
Performance  
Reliability  
Lower energy use

**Cons:**
Capital costs  
Footprint  
Experience

- WW → Septic Tank → Nitrification Biofilter → Denitrification Biofilter → Anoxic Reactor (Denitrification) → Electron Donor Source → Effluent Dispersal
- Septic Tank: Computes $\text{NH}_4^+ \rightarrow \text{NO}_3^-$  
- Nitrification Biofilter: Computes $\text{NO}_3^- \rightarrow \text{N}_2$  
- Anoxic Reactor (Denitrification): Computes $\text{N}_2$
# Biological process summary

<table>
<thead>
<tr>
<th>Process</th>
<th>Single Sludge Sequential BNR</th>
<th>Single Sludge with Preanoxic Nitrified Effluent Recycle BNR</th>
<th>Two Sludge, Two-Stage BNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Donor</td>
<td>Organic carbon from bacterial cells</td>
<td>Organic carbon from influent wastewater</td>
<td>External electron donor (Organic carbon; Lignocellulose; Sulfur; Iron, Other)</td>
</tr>
<tr>
<td>Typical N Reductions</td>
<td>40 to 65%</td>
<td>45 to 75%</td>
<td>70 – 96%</td>
</tr>
<tr>
<td>Typical Technologies</td>
<td>Extended aeration, Pulse aeration, Porous media biofilters, Sequencing batch reactors, Membrane bioreactor</td>
<td>Extended aeration with recycle back to septic tank, Recirculating media biofilters with recycle back to septic tank, Moving bed bioreactor</td>
<td>Nitrification followed by: Heterotrophic suspended growth denite, Heterotrophic porous media fixed film denite, Autotrophic porous media fixed film denite</td>
</tr>
<tr>
<td>Phase I - Suffolk Co. Demo Program</td>
<td>Norweco Singulair TNT, Busse</td>
<td>Norweco Hydro-Kinetic, Hydro-Action, AdvanTex AX 20 and AX-RT</td>
<td>CCWT pilot at MASSTC, CCWT Phase II Suffolk County Demo Program</td>
</tr>
</tbody>
</table>

**Stony Brook University**
Future possibility, deammonification process

Process:
Conversion of ~50% of the influent ammonia into nitrite by ammonia oxidizing bacteria using nitritation, followed by the simultaneous removal of ammonia and nitrite by anammox bacteria.

Pros:
- Lower energy use

Cons:
- No OWTS experience
- Performance reliability

Source: Hazen (2016)
Soil, Plant and Wetland Processes

- Soil Treatment and Infiltration
  - Heterotrophic / Autotrophic
  - Nitrification / Denitrification
  - Anammox

- Vegetative Uptake / Evapotranspiration

- Constructed Wetlands
  - Free Surface
  - Submerged
Soil, plant and wetland processes - soil treatment unit (STU)

**Process:**
Utilize physical, chemical and biological processes that occur naturally in the soil and/or plant

**Pros:**
- OWTS Experience
- Simple operation
- Lower energy use

**Cons:**
- Performance
- Footprint
Nitrogen removing biofilter (NRB)

**Process:**
Engineered media layers for nitrification and denitrification using external source for electron donor

**Pros:**
- Performance
- Footprint
- Simple operation
- Lower energy

**Cons:**
- Experience
- Construction complexity
**Constructed wetlands**

**Process:**
Engineered wetlands typically consist of submerged rock bed planted with wetland vegetation. Providing aeration typically increases TN removal.

**Pros:**
- Lower energy use
- Mechanical reliability

**Cons:**
- Footprint
- Performance
- Capital costs
- Construction complexity

Source: Kadlec and Knight (1996)
Physical/chemical processes

- Physical / Chemical Nitrogen Reduction Processes
  - Membrane Separation
    - Examples: Reverse Osmosis, Nano Filtration
  - Ion Exchange
    - Cation Exchange (Ammonium)
    - Anion Exchange (Nitrate)
  - Evaporation
    - Incineration
    - Solar
    - Distillation
Membrane bioreactors

Process:
Integration of a permeable membrane material to facilitate solid-liquid separation and potentially support biofilm growth.

Cons:
- Fouling
- High energy use
- Membrane cost

Pros:
- Versatile
- Small footprint

http://www.lenntech.com/
Microbial fuel cells

Process:
Application of an electrical potential between two electrodes causes an electric current to pass through the solution, which in turn causes a migration of cations toward the negative electrode and a migration of anions toward the positive electrode. Ionic components are separated through the use of semipermeable ion-selective membranes.

Cons:
- No OWTS experience
- High energy use

Source: Lu et al. (2015)
Source separation

- Source Separation
  - Urine Recovery
  - Wastestream Segregation
    - Greywater
      - Phys, Chem, or Bio. Treatment
    - Black Water
      - Composting
      - Incineration
      - Holding Tank / Hauling Offsite
    - Irrigation
    - Disinfection
    - Toilet Flushing
Urine separating toilets

Source: www.no-mixtoilets.com
Source: www.treehugger.com
Source: www.wateronline.com
Source: http://richearthinstitute.org
Domestic Wastewater: Volumetric Flow

**Urine = 1%**

Domestic Wastewater: Nitrogen Load

**Urine = 75%**

**Direct Application**

**Precipitation**

**Sorption & Ion Exchange**

**Aeration/Stripping**

- **Urine** → **Stripping Unit** → **Air**
- **Air, ammonia** → **Absorber Unit**
- **Sulfuric acid** → **Air, ammonium sulfate**

**Nitrification & Distillation**

**Membrane Filtration**

**Electrolysis & Microbial Fuel Cells**

Source: http://richearthinstitute.org
Source: www.sswm.info
Source: www.eawag.ch
Source: https://dspace.library.colostate.edu
Source: www.rsc.org
Urine disposal options

- Transport to WWTP
- Direct Land Application
- Treated to create fertilizer/soil amendment

Source: www.npr.org  Source: www.mdpi.com
Nitrogen Reduction Technology Ranking Assessment

• A simple numerical ranking system was developed to prioritize available nitrogen reduction systems based on twelve selected criteria

<table>
<thead>
<tr>
<th>Effluent nitrogen concentration</th>
<th>Restoration of performance</th>
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<tbody>
<tr>
<td>Performance consistency</td>
<td>Operation complexity</td>
</tr>
<tr>
<td>Construction cost</td>
<td>Energy requirement</td>
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<tr>
<td>CBOD/TSS effluent concentration</td>
<td>Construction complexity</td>
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<tr>
<td>Mechanical reliability</td>
<td>Local resources</td>
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<tr>
<td>Land area required</td>
<td>Climate resiliency</td>
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• A weighting factor was applied to each criterion based on the results of a Technology Weighting Factor Workshop
Nitrogen reduction biological technology ranking summary

- Top ranked single sludge BNR = rotating biological contactor

- Top ranked two sludge, two-stage BNR

Source: www.klar-environnement.com
Nitrogen reduction soil, plant and wetland processes technology ranking summary

- Top ranked = nitrogen removing biofilter (NRB)
Urine source separation approaches ranking summary

Direct land application

Transport to WWTF

Source: www.no-mixtoilets.com
Source: http://ricearthinstitute.org
Source: www.npr.org
<table>
<thead>
<tr>
<th>Natural Systems</th>
<th>Biological</th>
<th>Physical/Chemical</th>
<th>Source Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promising systems</td>
<td>Passive NRBs</td>
<td>Two sludge, two-stage BNR</td>
<td>Membrane bioreactor technology</td>
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<tr>
<td>Opportunities</td>
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<tr>
<td>• low cost</td>
<td>• Effective media</td>
<td>• novel materials</td>
<td>• resource recovery</td>
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<tr>
<td>• effective</td>
<td>• replacement</td>
<td></td>
<td></td>
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<tr>
<td>• PRBs and wetlands</td>
<td>• novel pathways</td>
<td>resource recovery</td>
<td></td>
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<tr>
<td>Knowledge gaps</td>
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<td></td>
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<tr>
<td>• media longevity, replacement</td>
<td>• media longevity</td>
<td>• fouling</td>
<td>• public acceptance</td>
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<tr>
<td>• design</td>
<td>• PPCPs design</td>
<td>• longevity</td>
<td>• beneficial use</td>
</tr>
<tr>
<td>• PPCPs</td>
<td></td>
<td>• nitrogen removal</td>
<td>• PPCPs</td>
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<td>CCWT efforts</td>
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<td></td>
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<tr>
<td>• white paper</td>
<td>• white paper</td>
<td>• cellulose MBR</td>
<td>• Planning</td>
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<tr>
<td>• pilot-testing</td>
<td>• pilot-testing</td>
<td>novel materials</td>
<td>stage</td>
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<td>• design guidance</td>
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