Decentralised Wastewater Treatment and Reuse: New Trends, Technologies and Opportunities

2017 AOWMA Convention and Trade Show
Ephesus, Turkey (100 BC)
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Centralized System Cost

Collection = 70%

Treatment = 30%
Why decentralised?

- Can achieve excellent treatment
- Lower cost for rural, suburban communities
- Allows more flexibility
- Saves energy
- Opportunities for water and solids reuse
- Reduces public health and environmental risks
- Plan growth around community goals, not infrastructure
Barriers

- Perceived risk with unfamiliar technologies
- Engineers are unfamiliar alternative technologies
- More planning is required
- Regulatory framework is complex
- Harder to secure financing
- Public perception that bigger is better
Town of Manotick, ON
A community unlike any other.

Located just 5 km from Ottawa, Mahogany will spring from the beauty of the Manotick landscape. This new community will represent the highest standards of quality excellence that Minto has to offer, surrounded by the topography that has been here for eons. This unprecedented combination of craftsmanship and land stewardship means Mahogany will be a place unlike any other, and a place you feel you naturally belong.

At home in Manotick

Museums/Tourist Attractions:

- Dickinson Square
- Watson's Mill
- Mahogany Harbour

Restaurants:

- The Miller's Oven and Tea Room
- French Café
- Black Dog Bistro
- Main Street Cellar
Drivers for change

- Impossibility of maintaining the status quo
- Population increase
- Environmental pollution
- Deteriorating water infrastructure
- The need to rebuild/retrofit
- New technologies
- Climate change
- Increasing water scarcity

Circular economy
Resource recovery

- Water
- Organic carbon
- Nutrients (N and P)
- Energy
- Value added material
Water recovery

Source separation
- Black water – fecal matter
- Yellow water – urine
- Gray water – laundry, bath, kitchen

Reuse opportunities
- Irrigation
- Nutrient recovery
- Toilet flushing
- Flow augmentation
- Cooling
- Groundwater recharge
Nutrient (N and P) recovery

- Nitrification (aerobic)
- Denitrification (anoxic)
- Phosphorus (anaerobic – aerobic)
- Chemical precipitation of phosphorus
- Struvite (magnesium ammonium phosphate)
Energy recovery

- Biogas from anaerobic digestion
- Hydrogen gas produced by fermentation of organic matter in microbial fuel cells or hydrogen fuel cells
- Direct electricity production in microbial fuel cells
- Heat and cooling energy recovered by heat pump from warmer effluents
- Geothermal, wind and solar energy
Advanced onsite treatment systems

- Aerobic treatment units (suspended, attached, combined)
- Sequential use of aerobic/anoxic/anaerobic
- Media filters (sand, peat, foam, textile)
- Natural systems (wetlands, greenhouse)
- Waterless toilets and graywater systems
- Disinfection systems (UV, chlorination and dechlorination)
Septic systems

- Effluent screens
- Mixing
- Aeration
- Grinding
- Heating
- Enzymes
- Multiple chambers
- Attached growth
- Membranes
- Soil absorption system
Microaeration

Fig. 4 Profiles of the total COD (tCOD: solid lines) and soluble COD (sCOD: dashed/dotted lines) during the batch reactor tests with raw primary sludge treated with micro-aeration (tCOD: $p = 0.00535$, sCOD: $p = 0.00029$)
Small diameter gravity systems

**Effluent Sewer System**
- Flow: 50 gpd/person
- BOD$_5$: 140 mg/L
- TSS: 30 mg/L
- FOG: 15 mg/L

**Conventional Gravity System**
- Flow: 120 gpd/person
- BOD$_5$: 187 mg/L
- TSS: 209 mg/L
- FOG: 68 mg/L

Data from tables 4-12 and 4-16, Small and Decentralized Wastewater Management Systems, Crites/Tchobanoglous.
Rotating biological contactors (RBCs)
Sequencing batch reactors (SBRs)
Lagoons
MBBR post treatment of lagoon effluent at 1 °C

Almomani et al., 2014
The “Living Machine”
Microalgae based wastewater treatment

Different species identified in wastewater cultivated with mixed algal culture: (A) Tribonema and Chlorella, (B) Ulothrix, (C). Left: Oscillatoria, Right: Tribonema, (D) Stigeoclonium, (E) Oedogonium and (F) Aphanocapsa

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary</th>
<th>Secondary</th>
<th>Centrate</th>
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<tbody>
<tr>
<td>COD</td>
<td>40.1</td>
<td>40.1</td>
<td>64.9</td>
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<tr>
<td>Total Nitrogen</td>
<td>60.2</td>
<td>50.7</td>
<td>63.2</td>
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<tr>
<td>Total Phosphorus</td>
<td>34.8</td>
<td>32.4</td>
<td>70.0</td>
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<tr>
<td>COD</td>
<td>20.9</td>
<td>38.3</td>
<td>41.0</td>
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<tr>
<td>Total Nitrogen</td>
<td>30.5</td>
<td>14.1</td>
<td>36.1</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>16.0</td>
<td>9.5</td>
<td>19.4</td>
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20 °C

8 °C
Freeze-thaw treatment of sludge
Issues of concern

- Nanoparticles
- Emerging contaminants
- Pathogens
- Heavy metals
- Stability and odors
Nanoparticles

- Rapid development and commercialization of nanomaterials
- High surface area to volume ratio makes them reactive and physiochemically dynamic
- Transformations (e.g. reactions, aggregation, dissolution) change the fate, transport and toxicity of nanomaterials
- Fate through treatment? After land application?
- Do they pose a significant risk?
Impact of AgNPs on soil microorganisms

![Graph showing the impact of AgNPs on soil microorganisms over time. The graph is a bar chart with the x-axis representing time in days (0, 15, 30, 45, 60, 75, 105) and the y-axis representing log10 relative CCE. The bars are color-coded to represent different bacterial groups: Protobacteria, Firmicutes, Bacteroidetes, Actinobacteria, and Acidobacteria.](image-url)
Emerging contaminants/trace organics

- Adverse impacts on aquatic ecosystems well-known
- Preference to partition to solids
- No significant impacts from biosolids
- Biological processes are more effective than physical/chemical processes
- Aerobic processes are particularly effective
- Compound specific measurements vs bioassays, bioindicators
- Risks due to prolonged exposure at low concentrations
EU REACH Regulation

- Adopted to protect human health and environment from risks posed by chemicals
- REACH applies to all chemical substances
- REACH places the burden of proof on companies
- Companies must identify and manage the risks linked to the substances they manufacture and market in the EU
- Companies must demonstrate how the substance can be safely used and communicate the risk management measures to the users
- Authorities can restrict the use of substances
- Biocidal Products Regulation (2012)

Source: EU REACH
The SIN (Substitute it Now!) List is a globally used database of chemicals likely to be banned or restricted in a near future.

The chemicals on the SIN List have been identified by ChemSec as Substances of Very High Concern (SVHC) based on the criteria established by the EU chemicals regulation REACH.

Out of all SVHC’s regulated under REACH today, ChemSec named 94 percent of them well ahead of the authorities.

The aim of the SIN List is to spark innovation towards products without hazardous chemicals by speeding up legislative processes and giving guidance to companies and other stakeholders on which chemicals to start substituting.

Source: ChemSec
Pathogens

- Bacteria, viruses, protozoa, helminth ova
- New organisms of concern
- Lack of standard methods for detection and enumeration
- Limitations of using indicator bacteria: short survival times & origins other than fecal source
- Fate and transport in soil and water
Fig. 1. Schematic diagram illustrating the range of approaches used in the assessment of bacterial viability.
DNA can survive long after the death of a cell

qPCR counts intracellular and extracellular DNA

Propidium monoazide (PMA) is a photoreactive dye that selectively modifies DNA from dead cells

Source: Biotium
### Chlorine

<table>
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<tr>
<th></th>
<th>MUG</th>
<th>qPCR</th>
<th>PMA-qPCR</th>
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<tr>
<td><strong>Wastewater</strong></td>
<td>7.52</td>
<td>7.51</td>
<td>7.12</td>
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<tr>
<td><strong>1 mg/L Cl</strong></td>
<td>4.17</td>
<td>7.64</td>
<td>6.92</td>
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<td><strong>2 mg/L Cl</strong></td>
<td>1.70</td>
<td>7.53</td>
<td>5.70</td>
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<tr>
<td><strong>3 mg/L Cl</strong></td>
<td>1.48</td>
<td>7.67</td>
<td>5.93</td>
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<td><strong>4 mg/L Cl</strong></td>
<td>0.38</td>
<td>7.59</td>
<td>6.31</td>
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</table>
High Concentrations of Disinfectants

<table>
<thead>
<tr>
<th>Condition</th>
<th>MUG</th>
<th>qPCR</th>
<th>PMA-qPCR</th>
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<tr>
<td>Wastewater</td>
<td>7.63</td>
<td>7.60</td>
<td>7.54</td>
</tr>
<tr>
<td>7mg/L Cl</td>
<td>0.00</td>
<td>7.33</td>
<td>6.74</td>
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<tr>
<td>10 mg/L PAA</td>
<td>1.34</td>
<td>7.49</td>
<td>4.45</td>
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<tr>
<td>150 mg/L Fe</td>
<td>2.00</td>
<td>7.77</td>
<td>3.98</td>
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Opportunities – First Nations

Neegan Burnside, 2011
Opportunities – India and China
Opportunities – FSM in Africa
Conclusions

• Decentralised treatment systems can provide high-quality wastewater treatment at a smaller-scale and lower-cost for many communities

• Use of decentralised systems to treat, recycle and reuse wastewater with minimum collection will be the method of choice for wastewater treatment

• We have excellent technologies for treatment and dispersal of treated effluent

• It is critical that the infrastructure for operation and management of these technologies and the regulatory framework are established
Acknowledgment

• James Diak, Zainab Abdulsada, Fares Almomani, Natalie Linklater from Ormeci Lab

• NSERC, CRC, CFI, ECCC
Thank you.

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Banu.Ormeci@Carleton.ca
## Hypothetical EPA rural community technology costs

<table>
<thead>
<tr>
<th>Technology option</th>
<th>Total capital cost</th>
<th>Annual O&amp;M* cost</th>
<th>Total annual cost (annualized capital plus O&amp;M)</th>
<th>Average monthly cost per household</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized systems</td>
<td>$2,585,600 – $4,176,590</td>
<td>$33,110 – $44,830</td>
<td>$241,480 – $381,410</td>
<td>$149 – $235</td>
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<tr>
<td>Alternative SDGS** collection and small cluster systems</td>
<td>$666,040</td>
<td>$8,120</td>
<td>$61,800</td>
<td>$38</td>
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<tr>
<td>Onsite systems</td>
<td>$567,940</td>
<td>$14,920</td>
<td>$60,690</td>
<td>$37</td>
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</tbody>
</table>

Note: The rural community consists of 450 people in 135 homes.

*O&M means operation and maintenance

** SDGS stands for small-diameter gravity sewers

(Adapted from the Environmental Protection Agency, 1997—extrapolated to year 2000 costs)
Selection of phyla

Composition of the bacterial community in soil (Siles, et al., 2014)
Future outlook

- Circular economy
- Resource recovery and reuse
- Regulatory framework
- Novel technologies
- Low-energy systems
- Contaminants of concern
- Growing markets in India, China, Africa, South America
Total DNA

[Graph showing the change in DNA concentration over time for different treatments, with error bars indicating variability.]