Does resource recovery even make sense?
Overall approach

Need improved characterization of feedstock

Technologies informed by sounds science

End products driven by appropriate business models
Biorefining Waste to Commodities ($\text{think} > \text{CH}_4$)
Hydrolysis
Acidogenesis
Acetogenesis
Methanogenesis

'Biogas'

Hydrolysis
Acidogenesis
Acetogenesis

'Methanogenesis'

Hydrolysis
Acidogenesis
Acetogenesis

'VFA'

Building block chemicals

Adipic acid
Glycerol
Citrate
3-Hydroxypropionate
Butanol
Butanol
Malate
Succinate

'Sludge'
Potential for resource-recovery is immense, but…

… needs to address a higher objective
Sanitation needs

• ELIMINATE PATHOGENS
  • Eliminate safety concerns via handling
  • Reduce disease burden
  • Improve environmental safety

• OPERATE OFF GRID
  • Eliminate need for external inputs such as water and energy
  • Make portable and easy to install

• CONVEY LOW LIFE-CYCLE COSTS
  • Reduce need for pit emptying
  • Ensure a sustainable business model, including maintenance via service providers

• PRESENT MODULAR, ATTRACTIVE INTERFACE
  • Reduce / eliminate construction costs
  • Provide clean and dignified product
  • Eliminate odors and waste

The Reinvented Toilet is a modular, transformative technology that offers a non-sewered sanitation solution, eliminating the need for a piped collection system. The aim of the Reinvented Toilet is to: destroy all pathogens onsite and recover valuable resources, operate without sewer, water or electricity connections and cost less than $0.05/user/day in a sustainable business model.

Bill & Melinda Gates Foundation
Standards (PC 305) to drive resource recovery through policy change

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Justification</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Enteric Pathogens</td>
<td>Bacteria (E. coli as surrogate)</td>
<td>≤100 per liter</td>
</tr>
<tr>
<td></td>
<td>Virus (MS2 Coliphage)</td>
<td>≤10 per liter</td>
</tr>
<tr>
<td></td>
<td>Protozoa (Clostridium perfringens spores)</td>
<td>≤1 per liter</td>
</tr>
<tr>
<td>Helminth eggs</td>
<td>Helminth eggs are considered a major health burden in many developing countries (Ascaris suum ova - surrogate)</td>
<td>≤ 1 eggs per litre</td>
</tr>
<tr>
<td>COD</td>
<td>Standard environmental performance parameter</td>
<td>≤ 50 (Category A)</td>
</tr>
<tr>
<td></td>
<td>TSS Standard environmental performance parameter</td>
<td>≤ 150 (Category B)</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>Nitrogen is a pollutant for surface water and can cause eutrophication.</td>
<td>&gt; 70% reduction</td>
</tr>
<tr>
<td>Total phosphorous</td>
<td>Phosphorous is a pollutant for surface water and can cause eutrophication.</td>
<td>&gt; 80% reduction</td>
</tr>
<tr>
<td>pH</td>
<td>Too high or too low pH is harmful to biological life.</td>
<td>6-9</td>
</tr>
<tr>
<td>Odor</td>
<td>Indicator of pleasantness and comfort - Maximum percentage of observations reported as “unacceptable”</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>PM2.5 (μg/m³)</td>
<td>Air pollution indicator - Emission thresholds (1 h average)</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Noise</td>
<td>Noise pollution indicator over the course of 24h</td>
<td>≤ 70 dBA (L_{EX,24h})</td>
</tr>
</tbody>
</table>
Developing better strategies for FS management by opening up its black-box

What is missing?

- Microbial composition
- Chemical composition
- ‘Designed’ treatment and recovery strategies
Global Fecal Sludge Microbiome

Potential Applications

Enhanced Resource Recovery
Link to Human Health
Odor, GHG
Where do we stand now?

FS and other “+x” streams can offer attractive flexible prospects for resource recovery
Detailed understanding in conjunction with reductionist approaches needed to advance implementation

Wide variety of endpoints (chemicals, fuels..) possible
Disrupting sanitation as well as conventional agro- or fossil-based pathways

Links to other applications needed and possible
Resource efficient options for wastewater treatment and sanitation
Discussion

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