SUPERCritical WATER OXIDATION (SCWO)

The future of sanitation & waste treatment

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Treating **WET wastes** is one of civilization’s main global challenges today
Global Sanitation Crisis

Fecal slurry in developing countries is not being treated effectively & safely
▶ 2.3 billion people lack basic sanitation services (~ 32% of world pop)
▶ Diarrheal diseases are the 2nd leading cause of death of children under 5, killing about 350,000 children every year

In most developed countries, animal manure is only partially treated, resulting in widespread pollution and breeding of antibiotic resistant bacteria

Source: Joint Monitoring Program 2017 Update ~ World Health Organization & UNICEF
Biosolids Treatment Challenge

Most of our biosolids (secondary and digested sludge) are currently being buried in landfills or being land applied

- The city of New York is producing 36,000 tons (wet) per month of biosolids and ships it all the way to Alabama!
- These landfills contaminate the environment, aquifers and our drinking water
- Land application create severe odor nuisances and breeds antibiotic resistant bacteria
Hazardous & Industrial Waste Problem

Dilution or “safe storage” in hazardous waste landfills is not a solution

- There are growing concerns about emerging non-biodegradable pollutants (e.g., GenX, PAHs, pesticides, pharmaceuticals, microplastics, etc.).
- Traditional treatment methods are limited
- Current incineration practices are costly and centralized.
- Treatment require addition fossil fuel and generate secondary pollutants (NOx, SOx, dioxins)
Traditional Wastewater Treatment Is Energy and Space Intensive

US in 2018 ~ 17,000 municipal wastewater treatment facilities

- 3% of total US energy consumption
- 35% of the total energy consumed by municipalities
- Sludge management and disposal account for 60% of the WWTP OpEx
- +20% of the infrastructure is aging (needs upgrade/replacement)
- +100 million people aren’t connected to centralized sewer
- Traditional WWTP (Primary and Secondary) require 3.5 Acres per 1000 people
Market Trends

$202.5 B
US Market
(EPA projection for 2024)
Lack of infrastructure creates opportunities for private sector

$674 B
Global WWT Market

$300 B
WWTP Infrastructure

$97 B
Decentralized

Decentralization & On-site scalable solutions

72%
Growth
(WaterWorld projection for 2024)
Emphasis on water efficiency & reuse

Emerging pollutants, Antibiotic resistant bacteria, pharmaceuticals, GenX

This barrel is an 87 kWh worth of dump! A hot shower (15 liter) is about 0.4 kWh. Shifting the waste paradigm!
The Supercritical Water Oxidation Solution

SCWO converts organic waste into clean water, heat, electricity and CO$_2$ in seconds!
Supercritical Water – Water Phase Diagram

Below the critical parameters, two distinct phases exist.
The Duke’s SCWO Technology Key Benefits

A. Mixing Tee Configuration

• **Avoids fouling and limits corrosion** - Obviates slow heating of slurry through the subcritical and transition temperature region (280 - 374 °C)

• **High conversion rate/clean reaction** - Rapid heating to supercritical conditions, avoiding gasification

• **Safety** - Limiting temperature, avoid runaway reaction

B. Proven Reactor Design (Patent Pending)

• **Enable effective operation** at low solids % and flexible feedstock treatment

C. Integrated Energy Recovery System

• **Utilize an unique expander technology** - Optimized energy efficiency
SCWO Benefits

► Zero polluting emissions: no SO\textsubscript{x}, NO\textsubscript{x}, no odor
► Very fast reaction (seconds) - small footprint
► High treatment effectiveness - >99.95% conversion to CO\textsubscript{2} and clean water
► Can treat most hazardous industrial wastes (oil, chemical, pharma, etc.)
► Process does not require catalysts or additional chemicals
► Can treat non-biodegradable and concentrated feedstock
► Complete elimination of pathogens without any disinfection by-products (trihalomethane, etc.)
► Scalable and versatile

...at a game-changing competitive cost!
A fully functional prototype – not just blueprints

Industrial-scale prototype treats ~the fecal waste of 1000 people per day
Inside Prototype A
Progress to Date

2014
- Operating & safety procedures
- Construction
- Commissioning

2016
- Running with slurries
- New reactor design

2018
- Reliability testing prototype A
- Commercial development

2013
- Reactor design
- Electrical & control design
- Procurement

2015
- Liquids treatment
- Aspen Plus modeling
- Slurry handling

2017
- Energy recovery investigations
- New slurry pump
- Prototype B design
# Prototype A - Influent vs. Effluent

| Dewatered Secondary sludge | Dewatered Secondary sludge | Dry solids: 16%  
Ash: 20-24%  
Calorific value: 15 MJ/kg\textsubscript{dry} | Feed | Effluent | After settling |
|--------------------------|--------------------------|-------------------------------------------------|-------|------------|----------------|
| Dog feces                | Dog feces                | Dry solids: 20-30%  
Ash: ~27%  
Calorific value: 15.7 MJ/kg\textsubscript{dry} | | | |

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*Note: \textsubscript{dry} denotes dry weight.*
Prototype A in action
## Biosolids processed in prototype A

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Influent</th>
<th>Effluent</th>
<th>Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>214,000</td>
<td>70</td>
<td>99.97</td>
</tr>
<tr>
<td>Total N (mg/L)</td>
<td>10,875</td>
<td>200</td>
<td>98.2</td>
</tr>
<tr>
<td>NH$_3$ (mg/L)</td>
<td>443</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>NO$_3$ (mg/L)</td>
<td>183</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ (mg/L)</td>
<td>14.9</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>PO$_4^{-3}$ (mg/L)</td>
<td>4930</td>
<td>67.9</td>
<td>98.6</td>
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<tr>
<td>pH</td>
<td>6.8</td>
<td>7.02</td>
<td></td>
</tr>
</tbody>
</table>

**No trace** of ibuprofen, acetaminophen or triclosan in effluent when running feedstock-spiked experiments.
Fate of N and P and S during treatment

**N Forms**
- Organic
- Urea
- Ammonium
- Heterocycles

**SCWO Process**

**Gas**
- $N_2$ gas

**Exhaust**
- $<3$ ppm$_v$ NH$_3$
- $<5$ ppm$_v$ NO$_x$
- $<3$ ppm$_v$ SO$_x$

**P Forms**
- Organic
- Phosphate

**Solid minerals**
- Phosphate precipitates
  - $Ca_3(PO_4)_2$

**S Forms**
- H2S, COS
- Mercaptans

**Sulfate Hydrate**
- $CaSO_4$
Our vision – decentralized supercritical treatment facility

**Fecal sludge & Biosolids**
- Primary from pits or septic emptying
- Secondary sludge (Digested or undigested)

**Versatile applications**
- Industrial wastes
- WWTP capacity extender
- Water purifier
- Military
- Emergency responses

**Example SCWO treatment facility in 20 ft. container for 1000-3000 people**

**Mixed waste streams**
- Hazardous waste
- Fecal sludge
- Animal waste
- Septage
- Sewage

**40 ft. container for 6000 people**

**Return clean, hot water**

**Produce fertilizer**

**Energy**
- Minerals

**CO₂** (carbonation, capture, capture)

**Distilled water**
Funding & Support

➤ Current focus is on technology transfer and commercialization

➤ A spinoff company from Duke University will take a leading role in bringing the first units to the market by 2020
SCWO integration & synergies

Alternatives to Biosolids Landfilling

Contaminated Water

Drinking Water

Mixed Waste Treatment
Fecal sludge and hazardous waste/solvents

Mild Dewatering

Sewage Septage

WWTP Capacity Expander
Reduce COD/BOD load

Additional Revenues
Hot water (low grade heat)
Minerals, value added products (e.g., fertilizer, PCC)
CO₂ (carbonation, capture)

Shifting the waste paradigm