
# Anaerobic Digestion 101

**November 2, 2017**

**1:00 – 3:00 pm Eastern**

**WEF Plant Operations and Maintenance Committee**

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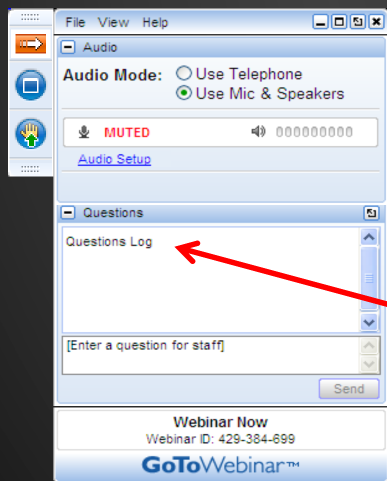
# How to Participate Today




- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select “Use Telephone” and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

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# Today’s Moderator

Fred Edgecomb
Gilbert Neely Wastewater Reclamation Facility
Project Manager

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# Today's Speakers

Matthew Higgins, Ph.D.
Professor, Civil and
Environmental Engineering
Bucknell University

Matt Van Horne, P.E.
Hazen and Sawyer

Peter Loomis, P.E.
CDM Smith

Dave Parry, Ph.D.
C2HM

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# Anaerobic Digestion 101

Matthew Higgins, Ph.D.
Claire W. Carlson Chair
in Environmental Engineering
Bucknell University
Lewisburg, PA 17837

Bucknell UNIVERSITY

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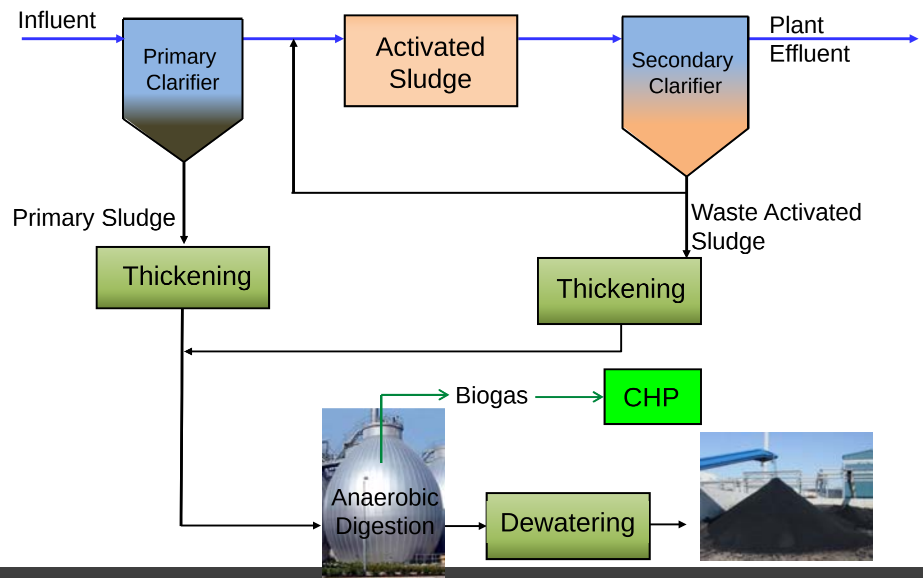
# Big Picture






# Why Anaerobic Digestion?

One of the approaches to meeting EPA 503 Requirements for biosolids:

1. Vector Attraction Reduction (VAR) requirements

   -reduces the organics in the sludges so it is 'stable'

2. Reduces pathogens

   -Meets EPA Requirement as

   "Process to Significantly Reduce Pathogens"

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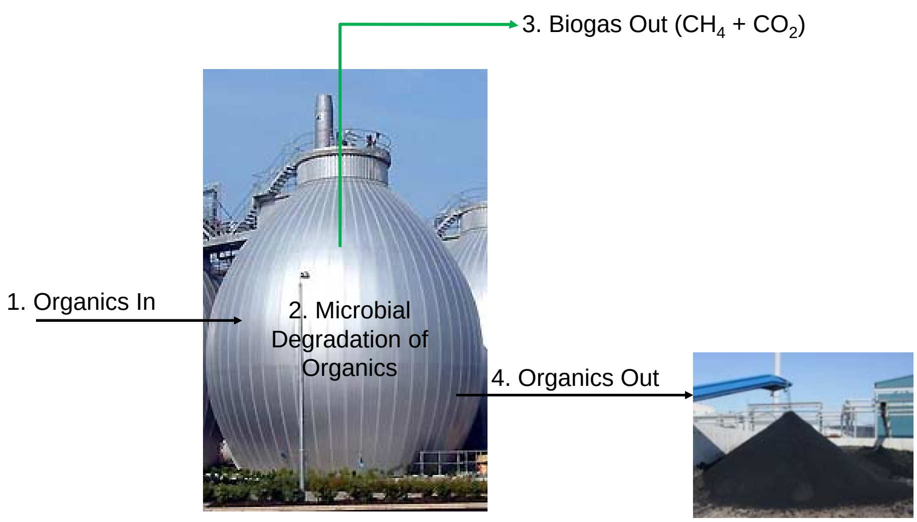
# Why Anaerobic Digestion?

3. Produces a renewable energy source – biogas (55-70% methane) uses:
   - -Combined heat and power systems (CHP)
   - -Digester heating
   - -Vehicle fuel
   - -Put into natural gas grid
4. Produces a excellent soil amendment product, rich in:
   - -carbon
   - -nitrogen
   - -phosphorus
   - -micronutrients



# Big Picture of Anaerobic Digestion Process

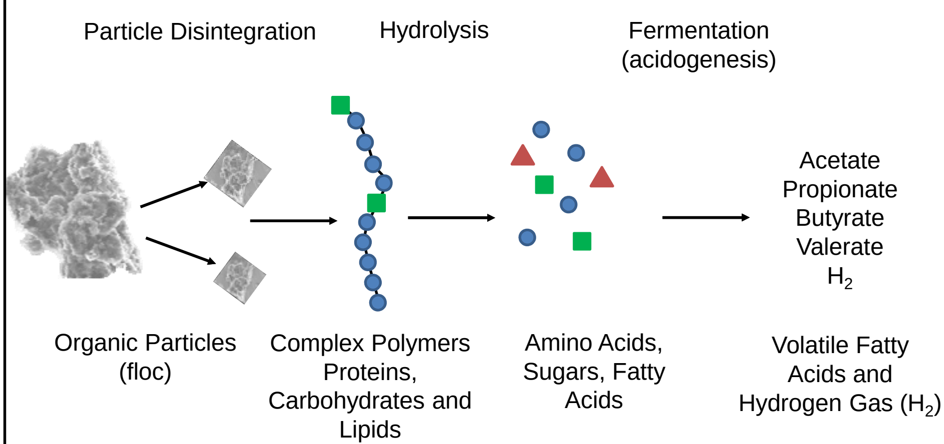


# Organics In

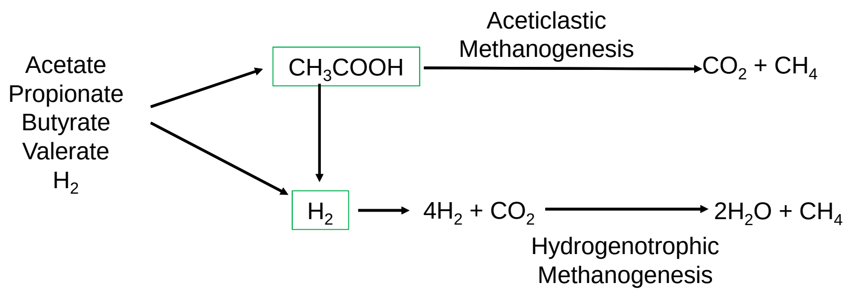
| Feed Stocks | Typical Feed Total Solids Concentrations |
|---|---|
| Waste Activated Sludge (WAS) | 4-6% |
| Primary Sludge (PS) | 4-6% |
| Primary/Secondary Blends | 4-6% |
| Food Wastes | 5-15% |
| Fats, Oils and Grease (FOG) | Highly variable |
| Lots of other organic wastes | variable |



# Microbial Conversions



# Microbial Conversions

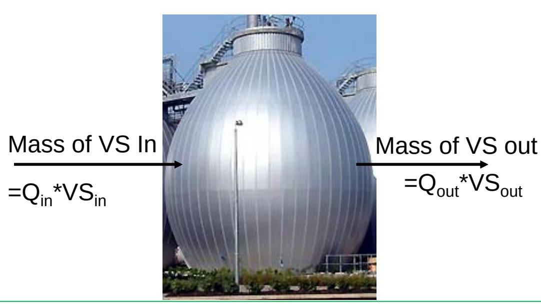





# Microbial Degradation

<u>Typical Parameters for Expressing Degradation</u>

1. Volatile Solids Reduction (VSR)
2. Chemical Oxygen Demand Reduction (CODR)




$$\text{VSR} = 100 * \left( \frac{Mass\ of\ VS_{in} - Mass\ of\ VS_{out}}{Mass\ of\ VS_{in}} \right)$$

## Microbial Degradation

VSR by Van Kleek Equation

$VSF_{in} = \frac{VS_{in}}{TS_{in}}$

$VSF_{out} = \frac{VS_{out}}{TS_{out}}$

- Van Kleek assumes inert solids are constant in and out of the digester, no settling of grit
- Inert Solids = TS – VS (also called 'fixed' solids or ash')
- Equation uses the volatile solids fraction (VSF) = $\frac{VS}{TS}$

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## Microbial Degradation

Volatile Solids Reduction by Van Kleek Equation

$VSF_{in} = \frac{VS_{in}}{TS_{in}}$

$VSF_{out} = \frac{VS_{out}}{TS_{out}}$

VSR by Van Kleek = 100 * $\left(\frac{VSF_{in} - VSF_{out}}{VSF_{in} - (VSF_{in} * VSF_{out})}\right)$

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# Typical VSRs

| Feed Stocks | VSR |
|---|---|
| Waste Activated Sludge (WAS) | 25-40% |
| Primary Sludge (PS) | 40-65% |
| Food Wastes | 75-85% |
| Fats, Oils and Grease (FOG) | 80-95% |

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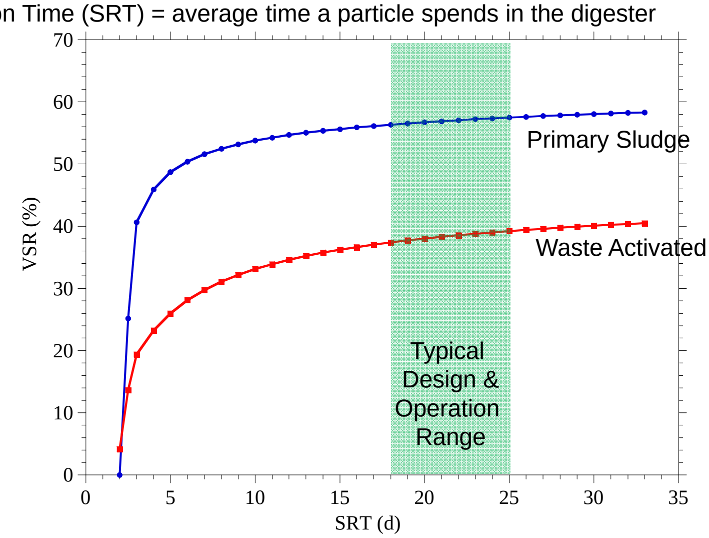
# Operational Parameters Affecting VSR - SRT

Solids Retention Time (SRT) = average time a particle spends in the digester

$$SRT = \frac{\text{Volume (gal)}}{\text{Flowrate }(\frac{gal}{d})}$$

$$= \frac{V}{Q}$$

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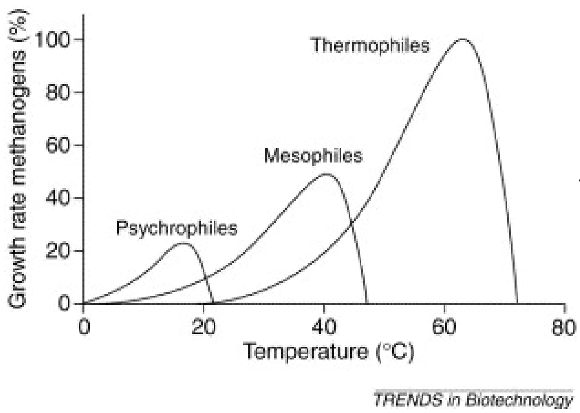
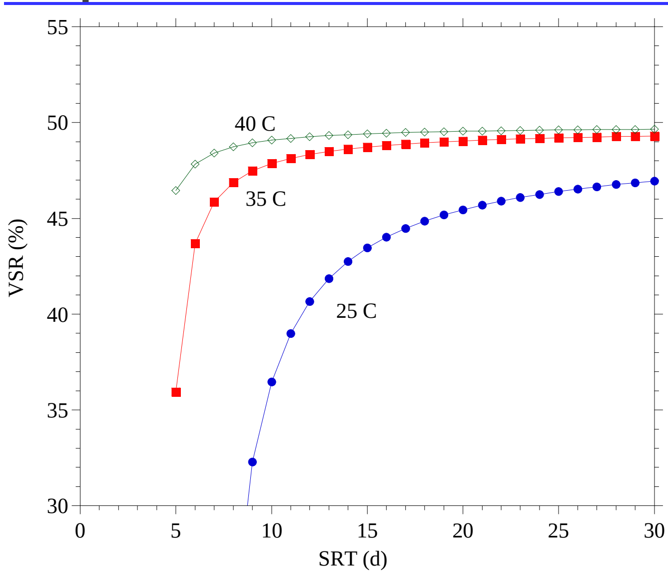
## Operational Parameters Affecting VSR - Temperature




Mesophilic Range: 25-45 °C
Thermophilic Range: 50-65 °C



## Operational Parameters Affecting VSR - Temperature




Typical Mesophilic Operating Temperature 35-38 °C

## Digester Operational Parameters
## Organic Loading Rates

Volatile Solids Loading Rates = mass of VS fed per day per unit volume of digester.

Typical “Textbook” Values:

a. kg $VS_{in}$ per day per cubic meter of digester volume (1-3 kg VS/d-$m^3$)

b. lb $VS_{in}$ per day per cubic ft of digester volume (0.06-0.30 lb VS/d-$ft^3$)

$\frac{\text{Kg } VS_{in}}{d - m^3}$

<u>OLR don’t consider</u>:

a. What is in your digester
b. Nature of wastes
c. Operational conditions

Higher OLRs can be readily achieved with good operations



## Digester Operational Parameters
## Specific Organic Loading Rates

Specific Organic Loading Rate considers ‘biomass’ in digester

= grams of $COD_{in}$ per day, per gram of VS in digester

Current Guideline:

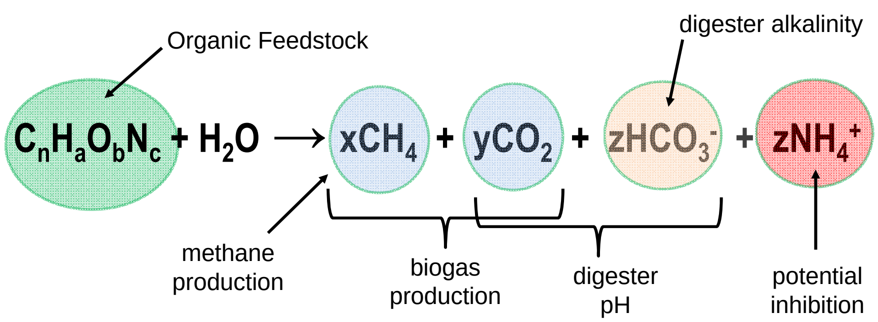
$$\text{SOLR} = \frac{g\ COD_{in}}{d \cdot g\ VS\ in\ digester} < 0.3$$

## Anaerobic Digestion Operational Parameters

| Parameter | Importance | Stable Operating Ranges |
|---|---|---|
| pH | Master variable for digester operation | 6.7-7.8 |
| Alkalinity | Helps buffer pH changes | >1000 mg/L as $CaCO_3$ |
| VFAs or VAs | Increase in concentrations an indicator of potential upset | <300 mg/L |
| VA/Alkalinity | Ratio of Volatile Fatty Acids to Alkalinity Ratio, increases mean process changes | <0.2 |
| Biogas Composition ($CH_4/CO_2$ Ratio) | Decreases in $CH_4$ content can mean process changes and inhibition | >55% |

## Stoichiometry of Anaerobic Digestion

### Theoretical General Equation (Buswell, 1952)




$$C_nH_aO_bN_c + H_2O \longrightarrow xCH_4 + yCO_2 + zHCO_3^- + zNH_4^+$$

x, y and z are a function of n, a, b, and c

## Stoichiometry of Anaerobic Digestion

| Type | Formula | Source |
|---|---|---|
| Waste Activated | $C_{6.6}H_{12}O_{2.4}N$ | Bucknell Data (average of 8 plants) |
| Primary Sludges | $C_{17}H_{31}O_{7.2}N$ | Bucknell Data (average of 5 plants) |
| Food Waste | $C_{17}H_{30}O_{6}N$ | Bucknell Data (average of 3 different FWs) |
| Fats | $C_{16}H_{32}O_{2}$ | Rittman and McCarty |
| Carbohydrate | $C_{6}H_{10}O_{5}$ | Rittman and McCarty |
| Protein | $C_{16}H_{24}O_{5}N_{4}$ | Rittman and McCarty |

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## Biogas Production

| Feed Stock | Methane Yield $\left(\frac{\text{L CH}_4}{\text{kg VS}_{\text{destroyed}}}\right)$ | Methane Yield $\left(\frac{\text{L CH}_4}{\text{kg VS}_{\text{fed to digester}}}\right)$ | VSR |
|---|---|---|---|
| Primary Sludge | 660 | 360 | 55% |
| Waste Activated | 625 | 250 | 40% |
| Food Waste | 650 | 560 | 80% |
| FOG (Fats, Oil, Grease) | 980 | 880 | 90% |
| Sugars | 440 | 400 | 90% |
| Protein | 580 | 520 | 90% |

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## Notes on EPA Regulatory Requirements

Class B Biosolids:

- assumes pathogens are present
- site restrictions are used for land application to ensure public safety
- product is stable, vector attraction reduction is met

Several Options for Demonstrating Class B Requirements

1. VSR > 38% for vector attraction reduction
2. Monitor fecal coliforms: < 2 million per gram dry solids
3. Demonstrate digestion meets time and temperature requirement = 15 days at > 35 $^{o}$C




## Notes on EPA Regulatory Requirements

Class A Biosolids:

- pathogens levels below detection
- no site restrictions for beneficial reuse
- stable product that meets vector attraction reduction

Several Options for Demonstrating Class B Requirements

1. >38% VSR for vector attraction reduction
2. Monitor fecal coliforms: < 1000 per gram dry solids
3. Monitor Salmonella: < 3 MPN/gram dry solids


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## Summary

Anaerobic digestion is a sustainable approach to treating organic wastes:

- produces renewable energy
- produces a product that recycles organics and nutrients
- can be used to meet EPA requirements for biosolids
- stable operations require regular monitoring and good practices



Hazen

## Matt Van Horne, PE

- 14 years experience
- Specializes in biosolids, energy management and wastewater treatment facilities
- Principal Investigator for WE&RF project on the operational impacts of co-digestion

# Agenda

- What is co-digestion?
- Why consider co-digestion?
- System configuration
- System control
- Lessons learned



# What is Co-Digestion?

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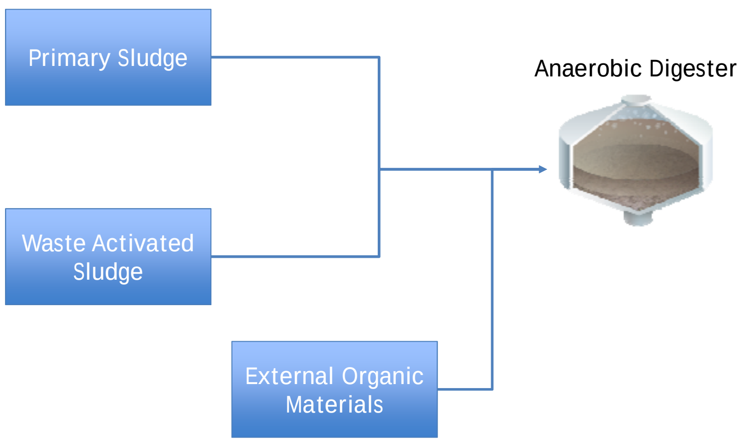
# Co-Digestion at a WRRF

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# What Are Possible External Sources of Material?

- Fats/oils/grease (FOG)
- Pre-consumer food waste
- Post-consumer food waste
- Industrial waste organics

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# What Are Possible External Sources of Material?

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# Why Consider Co-Digestion?

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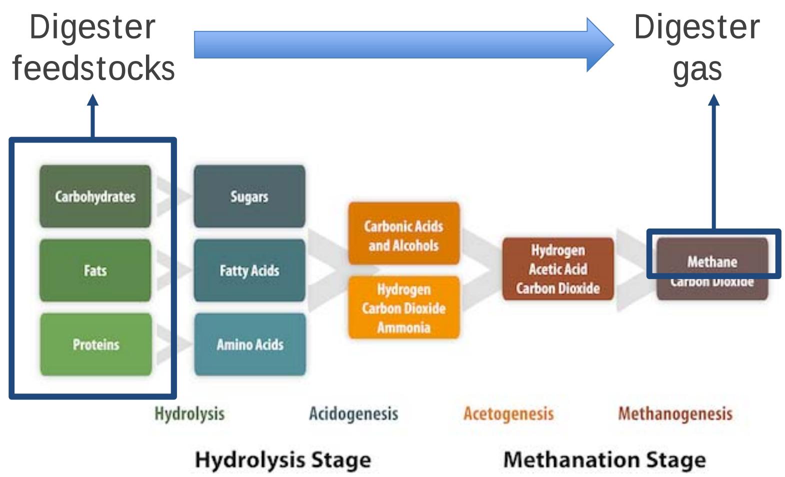
# First Lets Take a Step Back…






# Increasing Gas Production

- More incoming organics can result in more digester gas produced
- More change the economics of beneficial utilization

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# Increase Utility Revenue

- Tipping fees
- More biosolids to sell
- More energy to sell externally



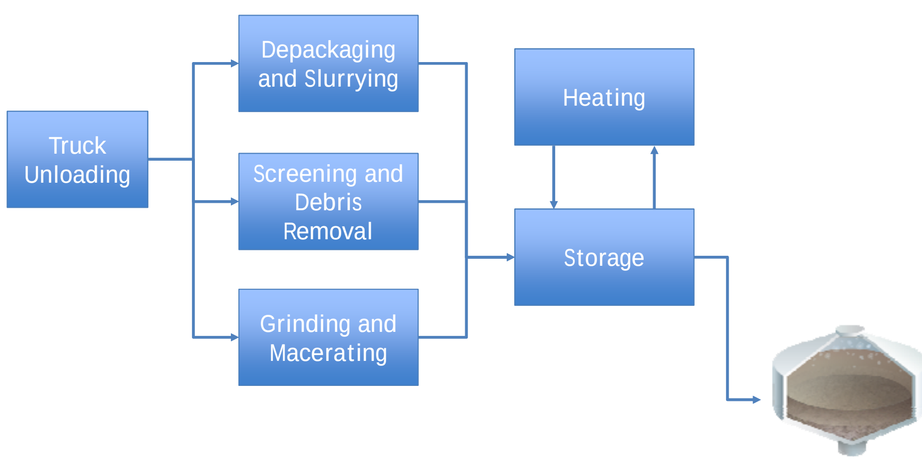
# Collection System Benefits

- Remove problematic materials (FOG) from collection system with appropriate outlet

# System Configuration



# Overall System Components

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# Truck Unloading



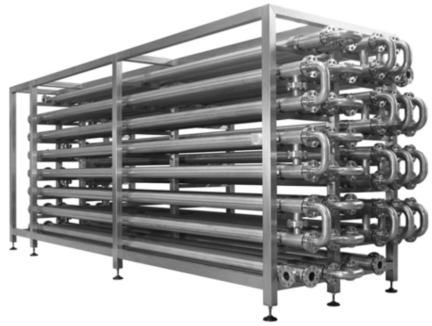

# Depackaging/Slurrying

# Screening/Debris Removal



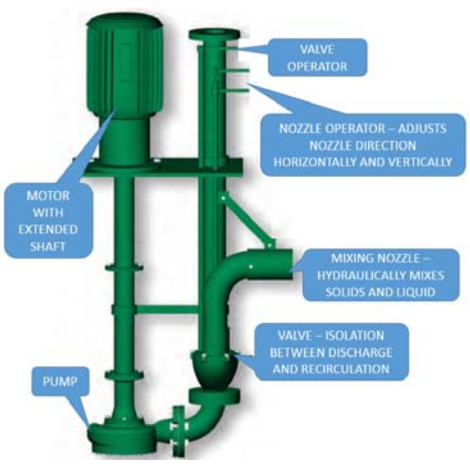
# Grinding/Macerating

# Heating

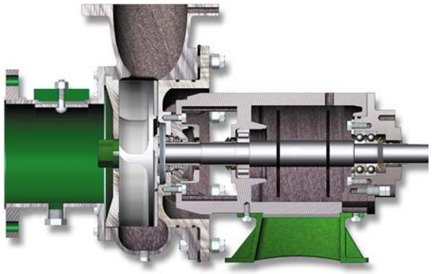




# Storage




# Feeding

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# Sample FOG Facility

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# Sample FOG Facility



# Sample FOG Facility

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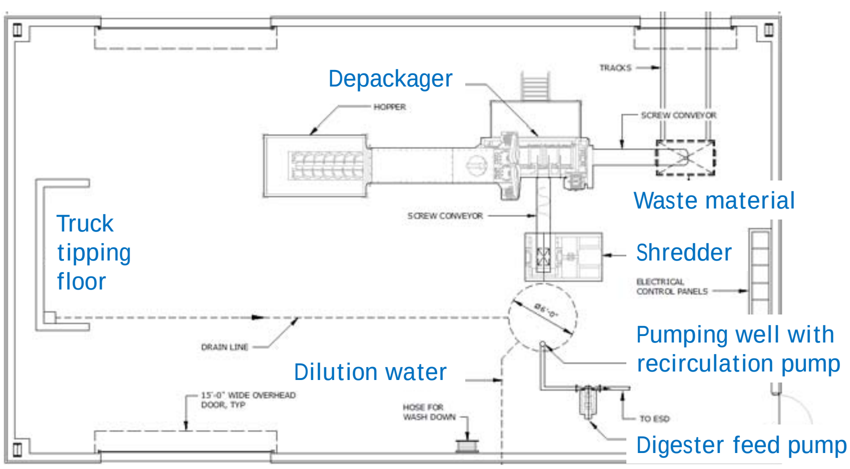
# Sample FOG Facility



# Sample Food Waste Facility



## Digester Considerations

- Increased solids content – mixing
- Increased organic loading – gas handling and foaming/RVE control
- Digested solids production

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## Key Points

- Can be many new steps
- Harsh characteristics of material
- Odor management
- Design for reliability
- Design for maintenance access

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# System Control

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## What Are We Really Trying to Control?

- Digester performance is key
  - Loading rates
  - Quality of materials for digestion
  - Mixing system performance

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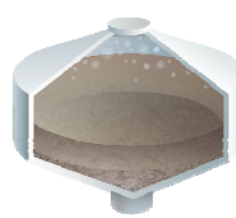
# How Do We Monitor and Control This?

- Feedstock monitoring
  - pH
  - Total solids
  - Volatile solids
  - Toxicity
- Take samples from each batch received!



# How Do We Monitor and Control This?

- Digester monitoring
  - pH
  - Volatile acid concentrations
  - Alkalinity
  - Foaming
  - Temperature
  - Feed rates
  - Volatile solids



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## But What Does This Really Mean?

- Continue normal digester monitoring and sampling
  - Maybe small expansion of parameters
- Become familiar with received materials
  - Understand how the digesters react to different materials
  - Can be simple flow rate control



## Lessons Learned

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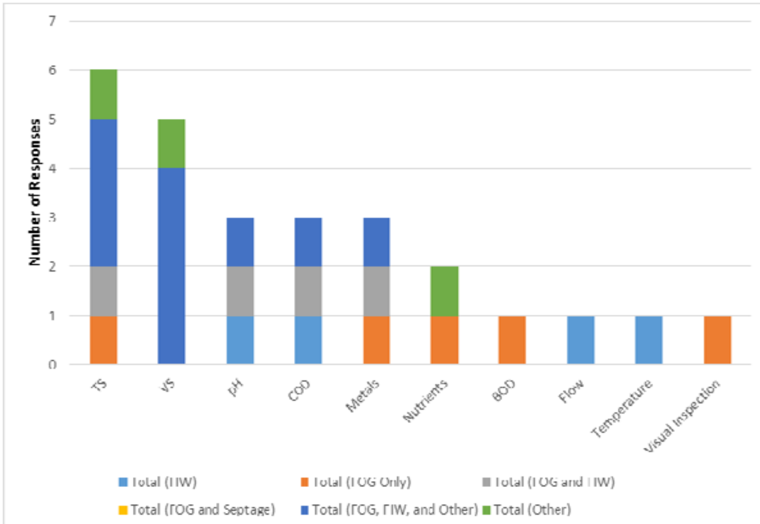
# WE&RF Has a Significant Research Program on Co-Digestion

| Ongoing Projects | | Number |
|---|---|---|
| Energy Balance and Reduction Opportunities, Case Studies of Energy-Neutral Wastewater Facilities and Triple Bottom Line (TBL) Research Planning Support | | ENER1C12 |
| Identification of Barriers to Energy Efficiency and Resource Recovery at WRRFs and Solutions to Promote these Practices | | ENER7C13 |
| Developing Solutions to Operational Side Effects Associated with Co-Digestion of High Strength Organic Wastes | | ENER8R13 |
| Low Energy Alternatives for Activated Sludge - Advancing Anaerobic Membrane Bioreactor Research | | ENER4R12 |
| Research to Advance Energy Production and Recovery from Wastewater and Solids | | ENER5C12 |
| State of the Science and Issues Related to Heat Recovery from Wastewater | | ENER10C13 |
| Guidelines for Utilities Wishing to Conduct Pilot Scale Demonstrations | | ENER11R13 |
| Co-digestion of Organic Waste – Addressing Operational Side-effects | | ENER9C13 |
| Co-digestion of Organic Waste – Addressing Operational Side-effects | | ENER12R13 |



# Detailed Survey

# What Do Plants Monitor?

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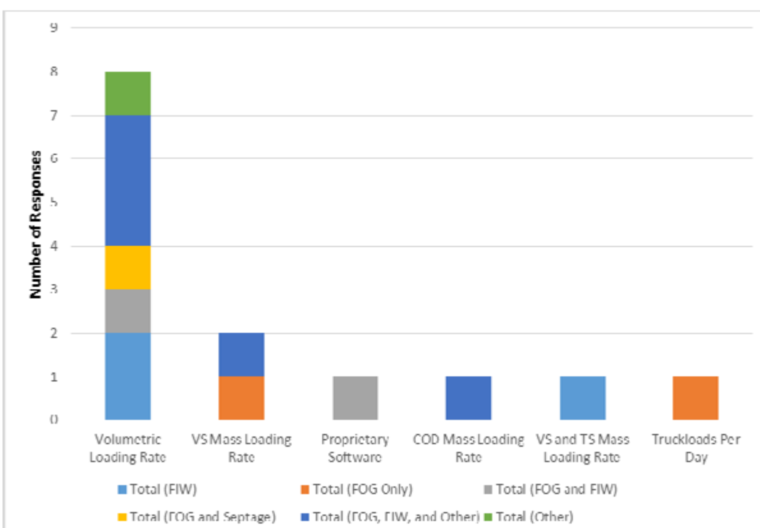
# How is Digester Feed Controlled?

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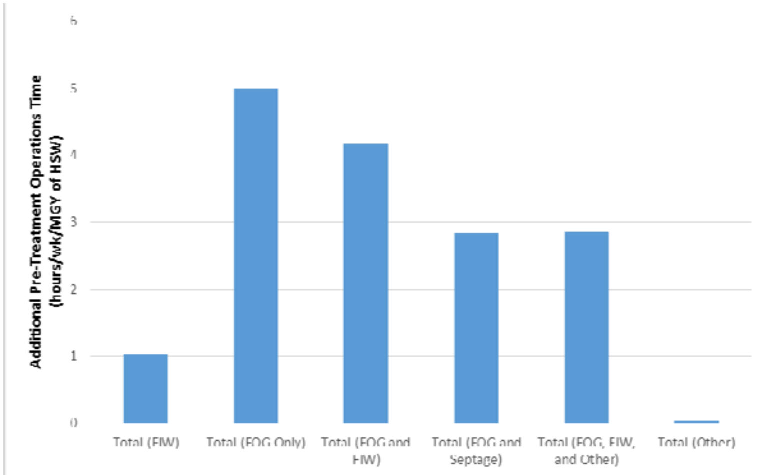
# Additional Operator Time At Pre Treatment

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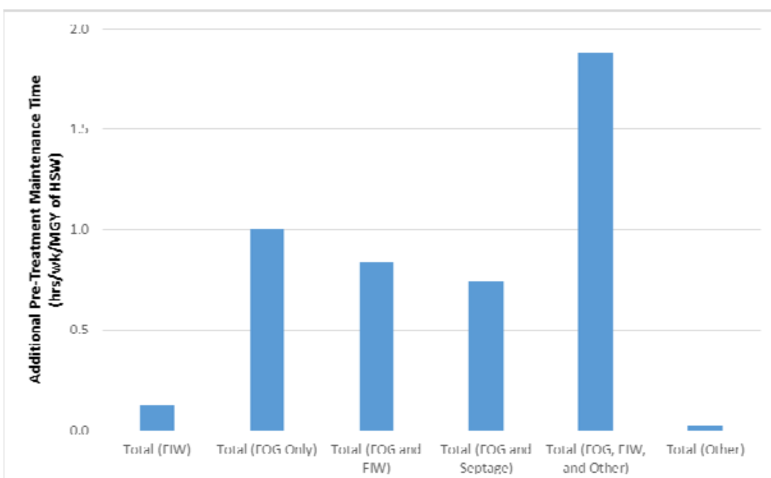
# Additional Maintenance Time at Pre Treatment

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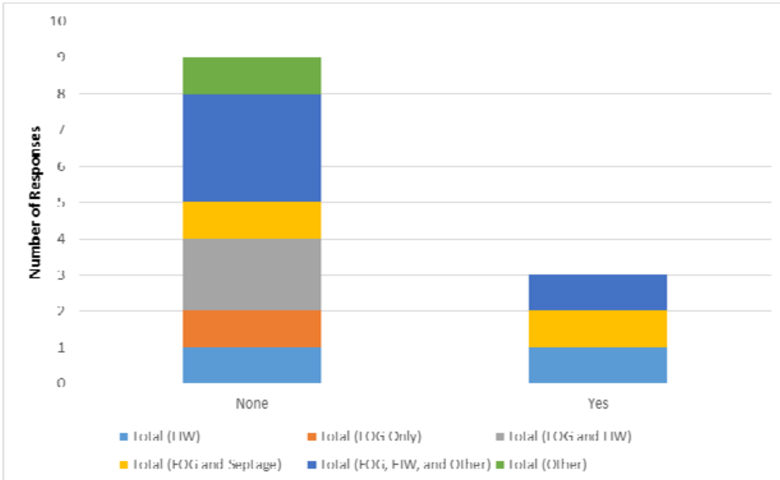
# Additional Time Spent at Digestion






# Future Work Efforts for Co Digestion

- There is no standard approach to monitoring co-digestion systems;
- Operational impacts vary widely based on the type and quantity of material co digested;
- Few major operational impacts were reported; and,
- The industry would benefit from additional guidance for how to best manage operations of co-digestion facilities.

# Questions and Answers

**Matt Van Horne, P.E.**
mvanhorne@hazenandsawyer.com
**703-267-2738**

# Thermal Hydrolysis Operating Considerations

**Peter Loomis, PE**

- 29 years experience in wastewater and biosolids
- Led commissioning, startup and 2 years of operations at Blue Plains for TH/Digestion
- Oversaw installation/commissioning of Ringsend TH/Digestion expansion in 2008

# Thermal Hydrolysis Operating Considerations

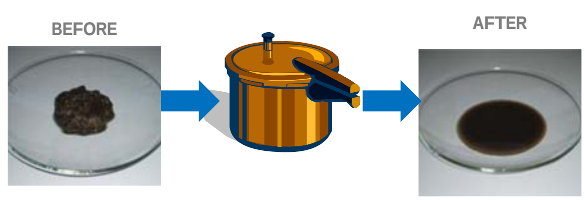
**Agenda**

1. Thermal Hydrolysis – Background and History
2. Operations at DC Water
3. TH/Digestion Operating Results
4. Lessons Learned



# Thermal Hydrolysis – Background and History

Thermal Hydrolysis (THP) is a process by which sludge is heated and pressurized with the purpose of reducing organic solids to make them more readily biodegradable….
In other words, it's a pressure cooker.

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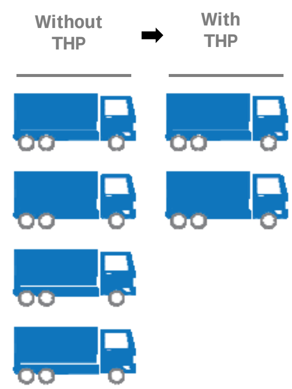
# Why THP?

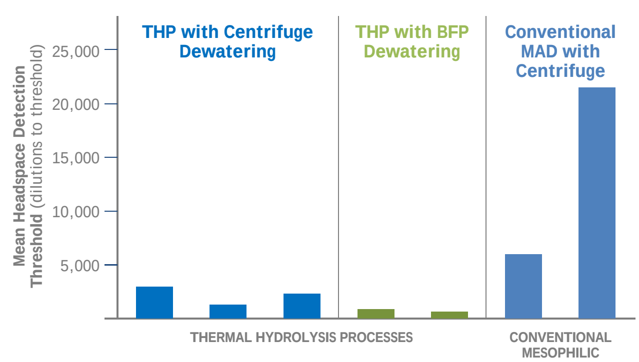
- Class A biosolids
- Increased downstream processing capacity
- Increased VSR      biogas
  - Projected 10–15% VSR increase
  - Reduced digested solids production
  - Potential energy neutrality
- Increased cake solids content
  - 10% increase
- Reduced digester foaming

**…and reduced odor**



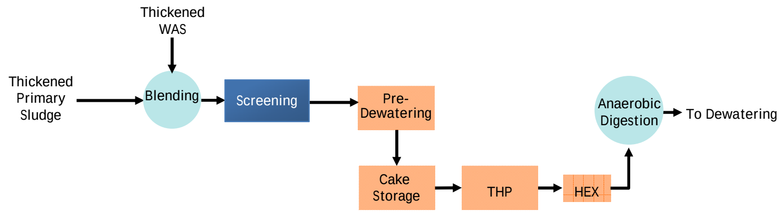



# Lower Odor of THP Biosolids Could Open Product Use Opportunities




Source: Murthy, 2012

# THP System Overview






# THP Background - History

- First full scale THP system commissioned in 1995 by Cambi
- HIAS plant Lillehammer, Norway
- Original vessels are still in operation
- Kruger/Veolia 1st pilot plant 2004 (Biothelys) full scale ~2009.
- Kruger/Veolia 1st Exelys plant 2014
- First US Installation – DC Water Operational October 2014 (Cambi)
- 8 US THP Facilities in planning/design/construction

## THP Background - Manufacturers

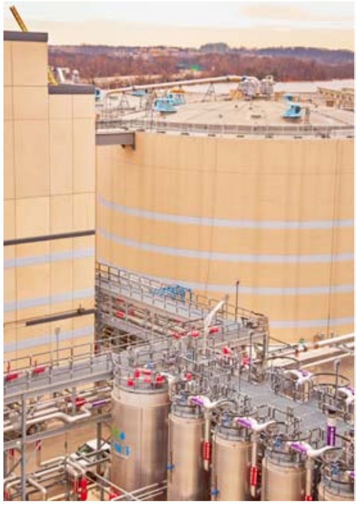
- Cambi ~50 facilities. 1 in US. 8 Additional in US in next 3 years.
- Veolia/Kruger 2 types
  - Biothelys – continuous batch ~7 facilities + 1 US pilot
  - Exelys – continuous 2 facilities + 1 demonstration
- Sustec – 2 full scale, 3 pilot
- Haarslev – 2 pilot scale plants



## DC Water: First Operating THP Facility in North America

# DC Water: Operations

- Implemented THP/digestion with seeding beginning in October 2014
- Full throughput in February 2015
- Full acclimatization in late 2015
- Temporary approval for Class B land application February 2015
- Approval for Class A land application in May 2016





# DC Water: Operations Controls

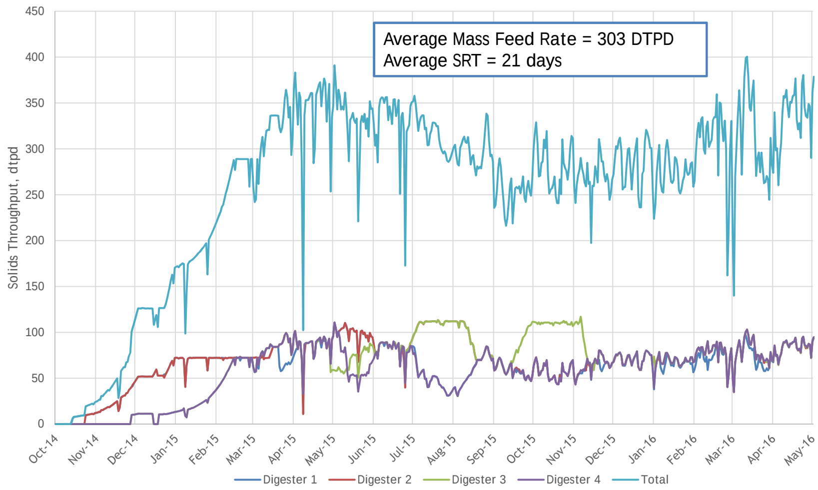
- Key Control Issues
  - Feed Concentration
  - THP Feed Rate
  - Reactor Temperature
  - Dilution Control
  - Digester Temperature Control
  - Steam Pressure

# DC Water: Biosolids Operating Results

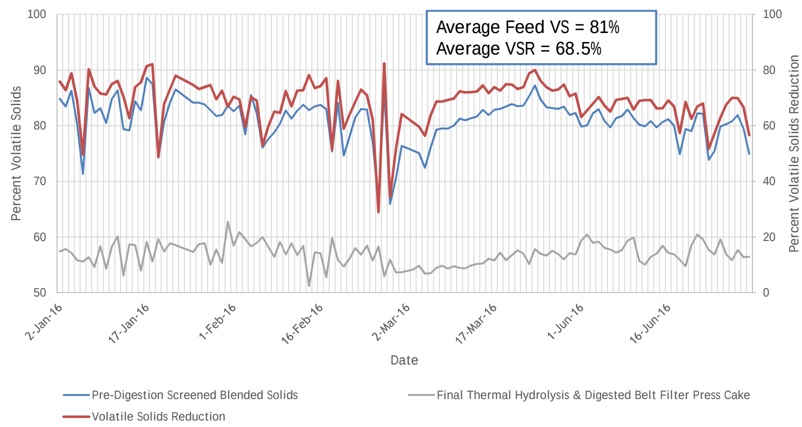
- VSR 65% to 70% (January to June 2016)
- SRT/HRT at ~20 days
- Fecal coliforms <5 MPN/Gram
- Approximately 500 wet tons per day produced
- Generating 8 to 10 MW of power
- Waste heat from power generation providing steam



# DC Water: Daily Feed Rates

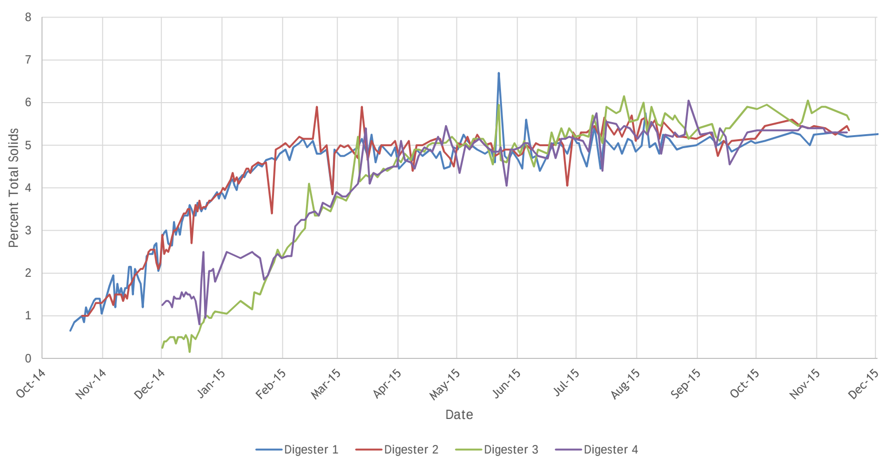


# DC Water: Volatile Solids Reduction






# DC Water: Solids Concentration in Digesters

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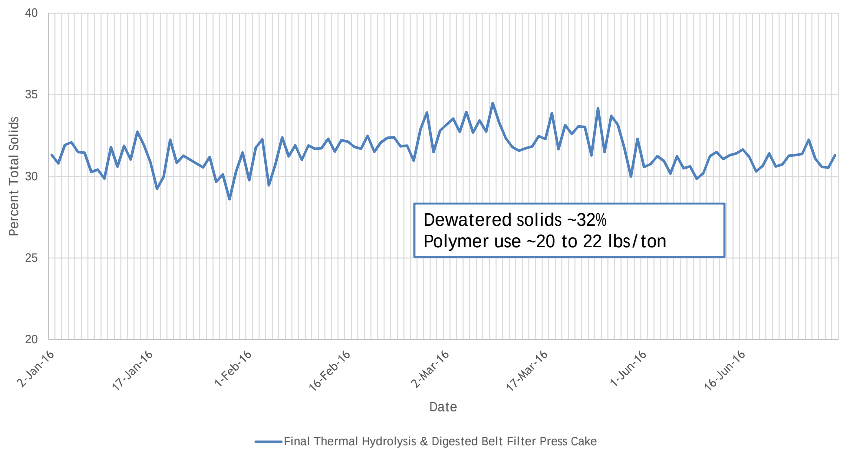
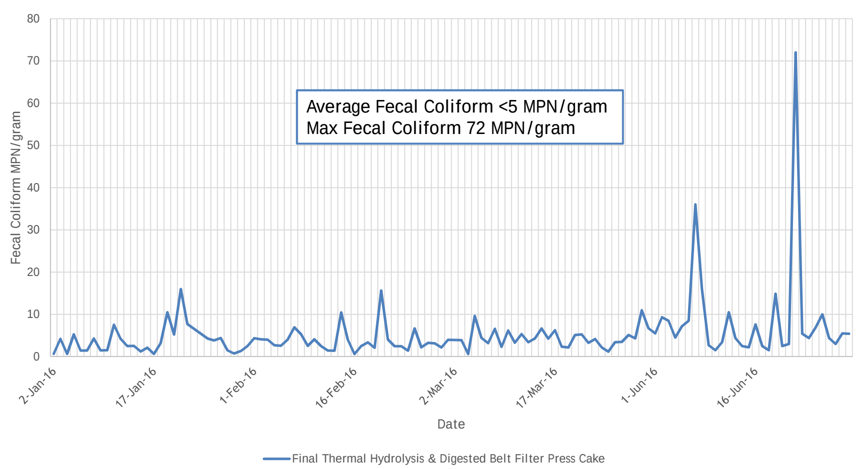
# DC Water: Dewatered Solids Concentration

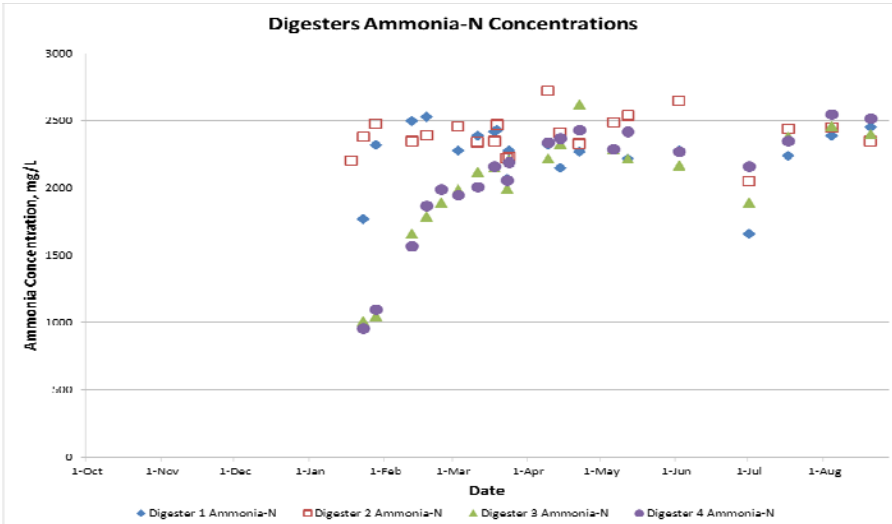





# DC Water: Meeting and Exceeding Class A Requirements

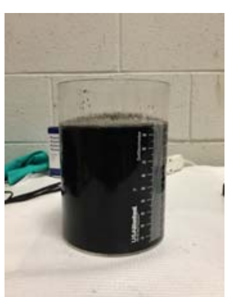


# Digester Ammonia






# Digester Settling

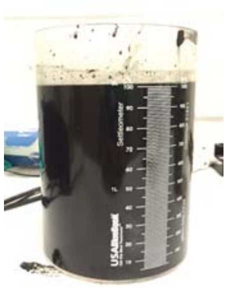


1 minute

90 minutes

4 hours

# Hydrolyzed Sludge Settling



1 minute

90 minutes

28 hours



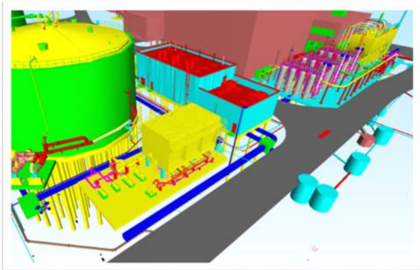
# Sludge Cooling

**DC Water**

- Approach
  - 2 Cooling HEX & 1 Tuning HEX per digester
  - Cooling HEX cools incoming solids
  - Tuning HEX provides "trim" cooling of digesting solids
- Results
  - Cooling HEX Maintain Digester Temperatures
  - Tuning HEX loses significant heat in winter

# Cooling Water

- DC Water
  - Plant Effluent (10 MGD Pump Station)
  - Maximum Water Temp. of 81°F
  - Chlorine addition to prevent bio-fouling
  - Apparent precipitate fouling of water side
  - Microbially Induced Corrosion

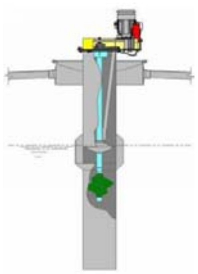


**Lesson Learned:**
Cooling water supply is critical for conceptual design



# Digesters

- Draft Tube Mixing
- Rapid Rise Control via overflow to ground
- No supplemental gas storage
- No Field Analysis Capabilities



# DC Water: Operating Issues

- Mechanical Issues
  - Rotary Lobe Pumps
  - Cake Bin Gates
  - Centrifuge Solids Control
  - Wear on Mechanical Equipment
- Process Issues
  - Vivianite
  - Grit
  - Foam
  - Odors
- Support Equipment Issues
  - Steam Pressure
  - Flare Exhaust Results
  - Dilution Control

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# DC Water: Results and Observations Summary

Solids throughput approximately doubled standard mesophilic digesters

Concentration in digesters exceeds 5%

Little or no foam with reactors at 165°C

Digesters resilient to feed changes

At 50% Primary/50% Secondary Solids VSR improved by 20% to 30% (50% VSR to 65% VSR)

Gas yield proportionally higher with VSR

Digested solids release water better

Low odor from digested/dewatered solids after 24 to 48 hours

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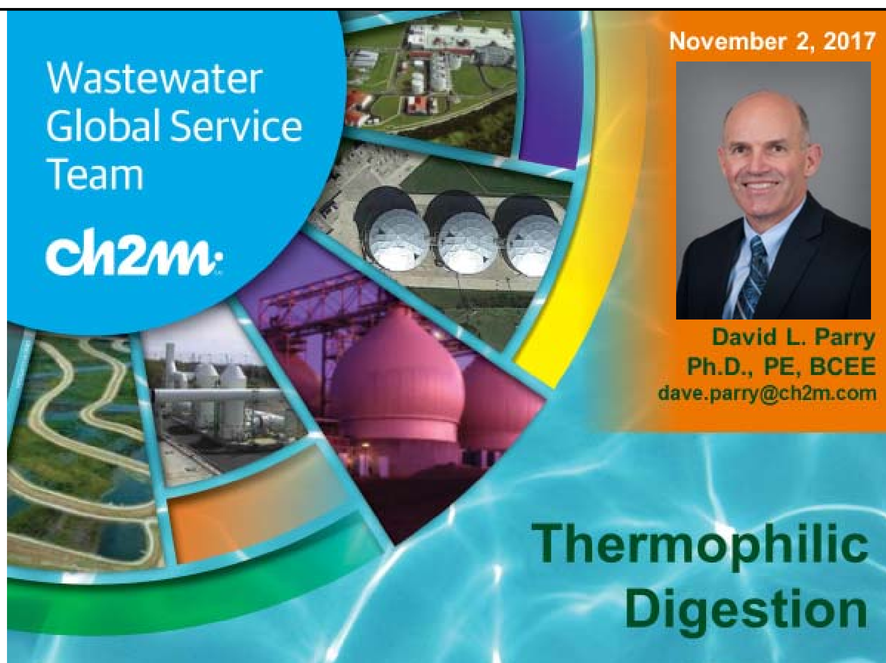
# Questions?

**Peter M. Loomis, PE**
703.691.6442
loomispm@cdmsmith.com

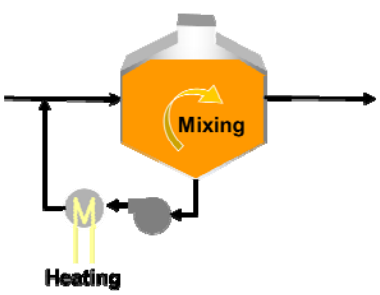




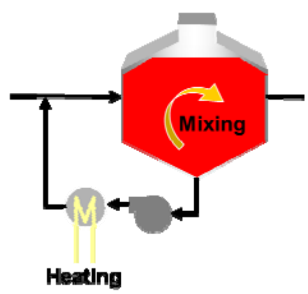
# Why Thermophilic Digestion?

- Increased digester capacity
- Class A Biosolids when time temperature requirement is met
- Cost savings from fewer digesters
- Meet site constraints

# What is Thermophilic Digestion?

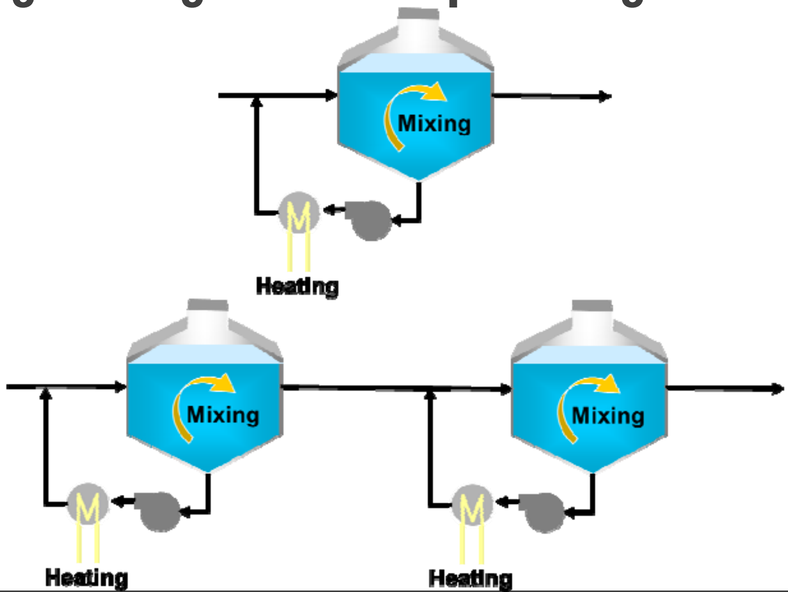



**Mesophilic**
**95 to 98 °F**
**(35 to 37 °C)**




**Thermophilic**
**125 to 140 °F**
**(52 to 60 °C)**

# Single-Stage or Multiple-Stage

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# Continuous versus Batch Thermophilic Digestion

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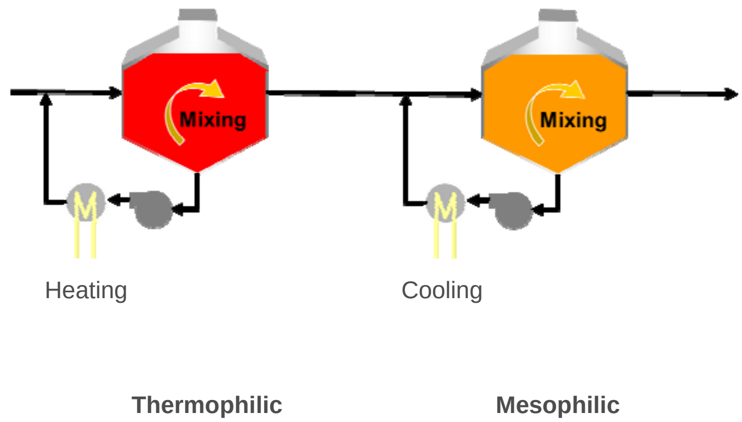
## Temperature-Phased Anaerobic Digestion (TPAD)






# Thermophilic Compared to Mesophilic Anaerobic Digestion

***Advantages***

- Increased digester capacity
- Increased solids destruction
- Greater biogas production
- Possible decrease in hydrogen sulfide in biogas
- Improved biosolids quality
- Class A biosolids with batch process

***Disadvantages***

- Higher operating temperatures
- Increased heat demand
- Requires more heat exchangers
- Possible increase in siloxanes in biogas
- Increased odor at dewatering

## Converting from Mesophilic to Thermophilic

- Digesters must be able to structurally handle thermophilic temperatures
- Additional heat exchangers are required for sludge heating
- Heat recovery exchangers may be added for energy efficiency
- Digester heating system must be able to supply more heat at a higher temperature




## Targeted Parameters for Digester Monitoring

| Parameter | Target Range |
|---|---|
| pH | 6.8 to 7.7 |
| Temperature | Mesophilic 35 deg C (95 deg F)<br>Thermophilic 55 deg C (130 deg F) |
| Volatile Solids Reduction | greater than 50% |
| Volatile Acids (VA) | less than 1,000 mg/L |
| Alkalinity (ALK) as $CaCO_3$ | Mesophilic: greater than 1,000 mg/L<br>Thermophilic: greater than 2,000 mg/L |
| Ammonia | less than 2,000 mg/L $NH_3$-N |
| VA/ALK Ratio | less than 0.2 or declining<br>(preferred under 0.1) |
| $CO_2$ in Digester Gas | less than 40% by volume |
| $CH_4$ in Digester Gas | greater than 60% by volume |
| Specific Biogas Production | greater than 0.9 $Nm^3$/kg_VSR<br>(15 scf/lb_VSR) |
| Foaming | little or none |

## Examples of Thermophilic Digestion Operations

- Los Angeles, CA
- Oakland, CA
- San Francisco, CA
- St Joseph, MO
- Duluth, MN
- Columbus, GA
- Vancouver, BC
- Tel Aviv, Israel



## Dan Region WWTP (SHAFDAN)

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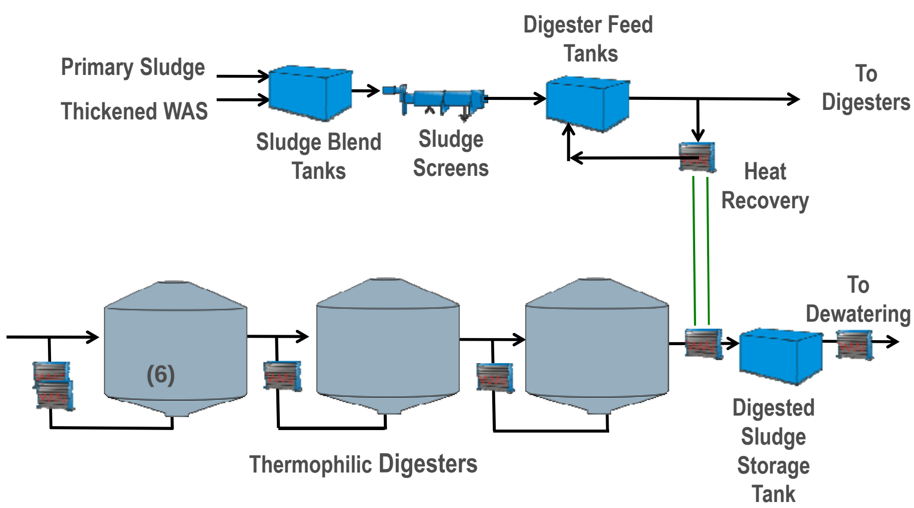
# Multi-Staged Thermophilic Digestion






# Thermophilic Heat Supply: 11 MW Cogeneration System with Eight 1.4 MW Packaged Units

- Heat supply system designed for thermophilic temperatures and engine heat recovery
- Boilers provide heat for startup and backup heat

Dan Region Shafdan WWTP, Tel Aviv, Israel,

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# Thermophilic Digestion Summary

- Advantages for capacity, Class A, cost savings, tight site
- Anaerobic digestion at 125 – 140 degrees F (50 – 60 degrees C)
- Differences between thermophilic and mesophilic digestion
- Same key control variables as mesophilic digestion
- Mesophilic digesters can be converted to thermophilic digesters
- Examples of thermophilic digestion systems

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# Questions?

**David L. Parry**
**Ph.D., PE, BCEE**
**dave.parry@ch2m.com**



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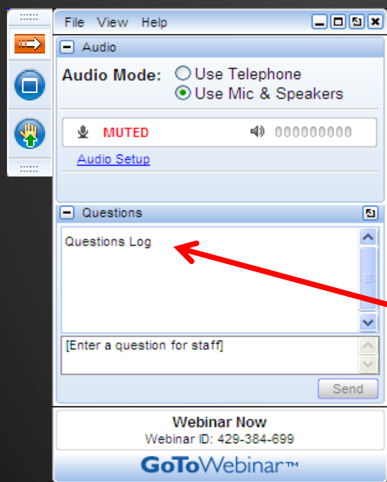
# Questions? How to Participate Today




- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**