Anaerobic Digestion
The New Frontier

HAZEN AND SAWYER
Environmental Engineers & Scientists

Ohio WEA
Biosolids Specialty Workshop
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Outline

- Process Basics
- Digester Component Parts
- Anaerobic Digester Process Configurations
- 21st Century Paradigm Shift
- Case Study

Anaerobic Digester Process Basics

The Big Idea…

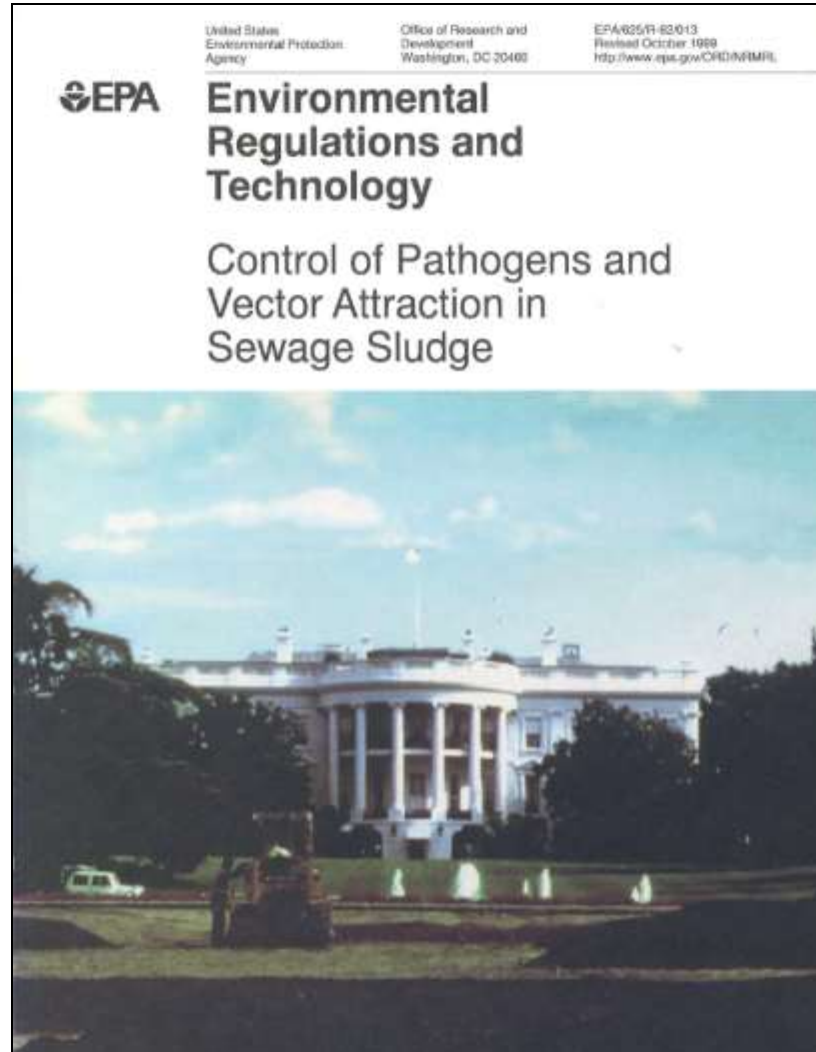
Anaerobic digestion is the biological conversion of degradable particulate mass into a gas through multiple steps in the absence of oxygen

There are a number of potential benefits of anaerobic digestion, including:

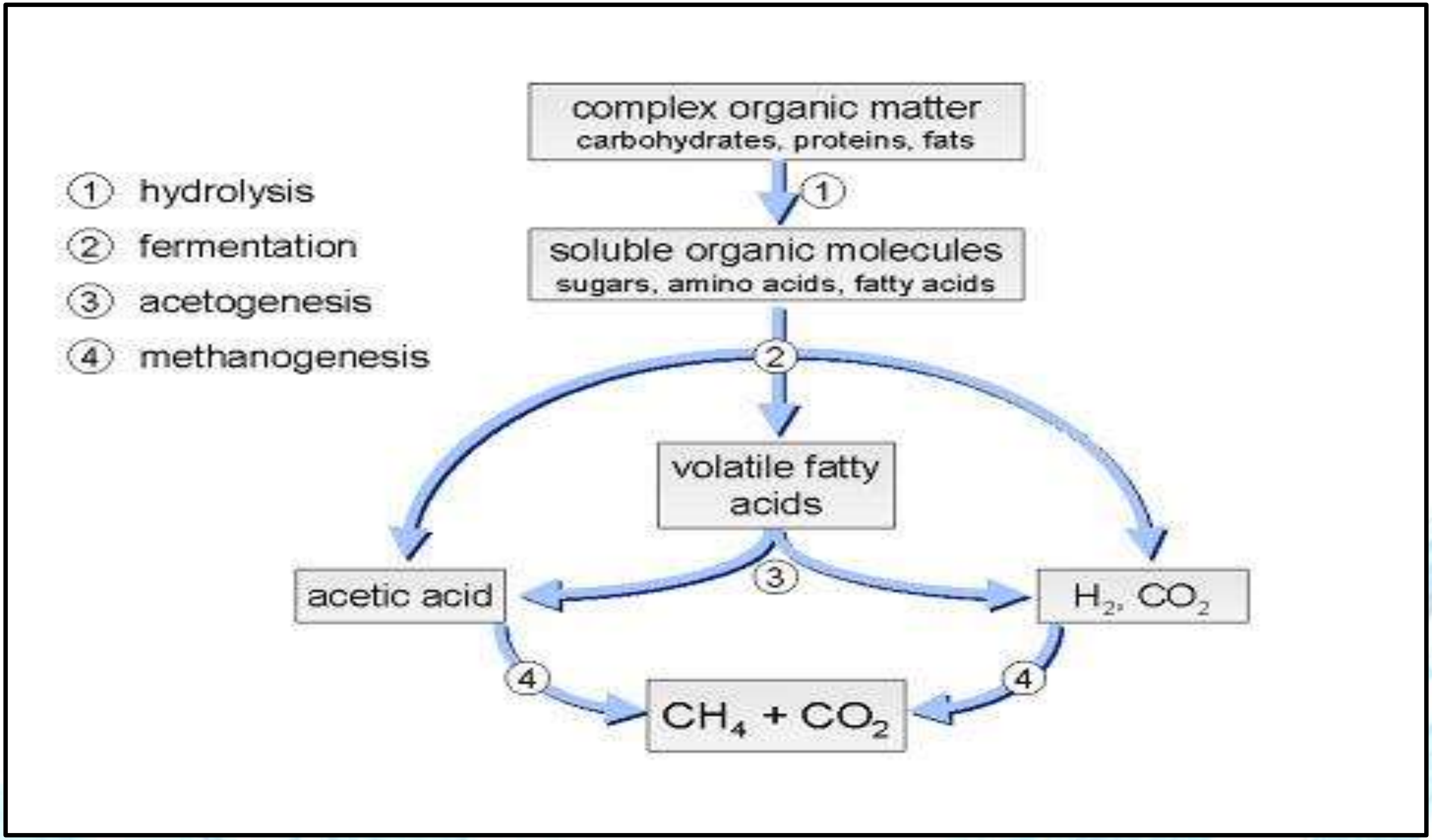
- **Mass and volume reduction of feed solids**
  - Reduce downstream processing costs for handling residuals
- **Reduction of pathogens and stabilization of organics**
  - Reduce odor potential of final residuals products
- **Production of energy containing biogas**
  - Used for process heating demands and other beneficial use (e.g., engine generators, boilers, thermal drying)
- **Phosphorus release from sludge**
  - Nutrient recovery and P reduction in final biosolids

40 CFR Part 503 Regulations

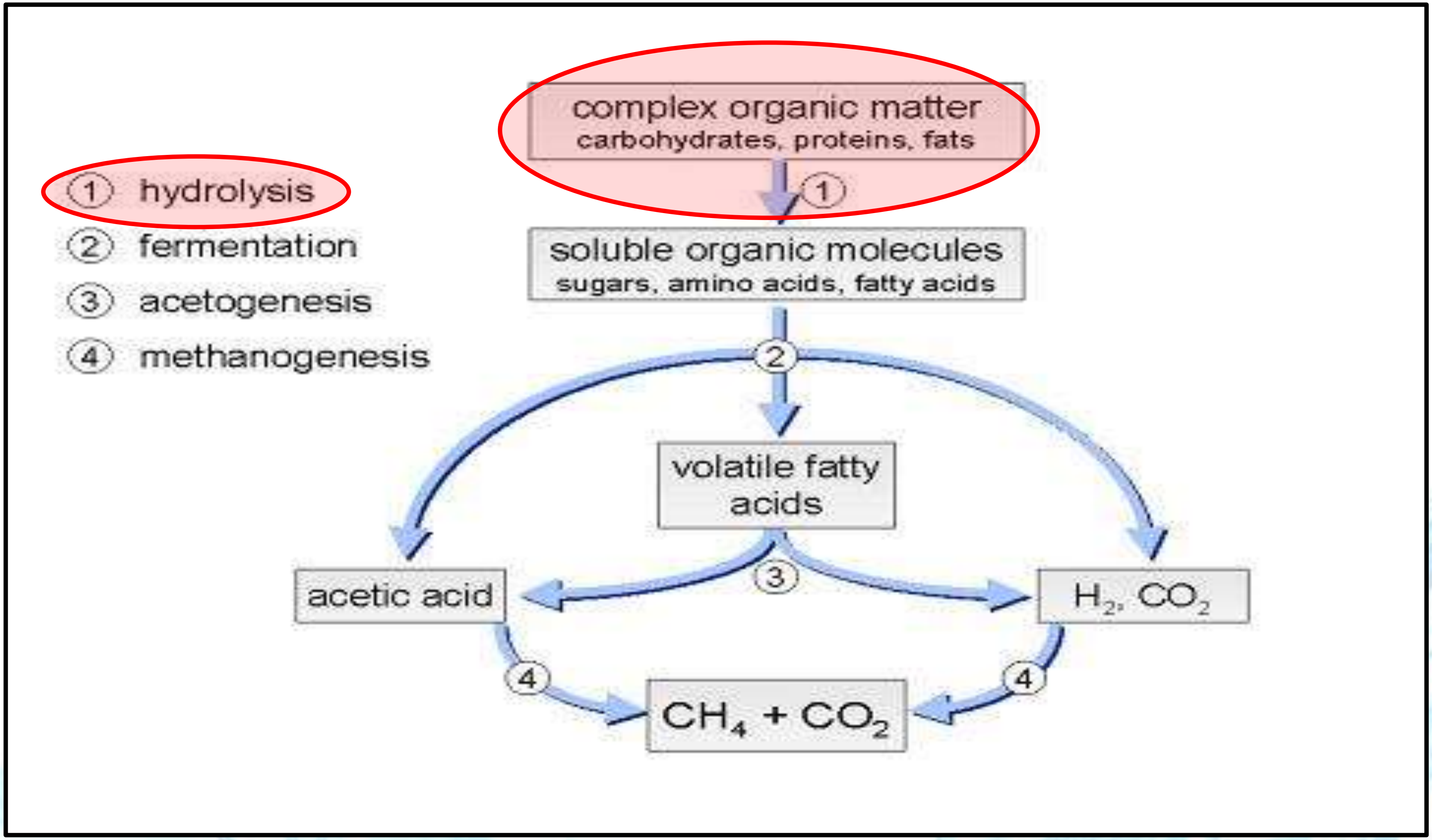
- **Class B Land Application**
  - **Pathogen Reduction**
    - **PSRP**
    - **> 15-days MCRT @ 35°C to 55°C or > 40-days MCRT @ 20°C**
  - **Vector Attraction Reduction**
    - **≤ 38% volatile solids reduction**
    - **Testing**
- **Class A Land Application**
  - **Time and Temperature Requirements**



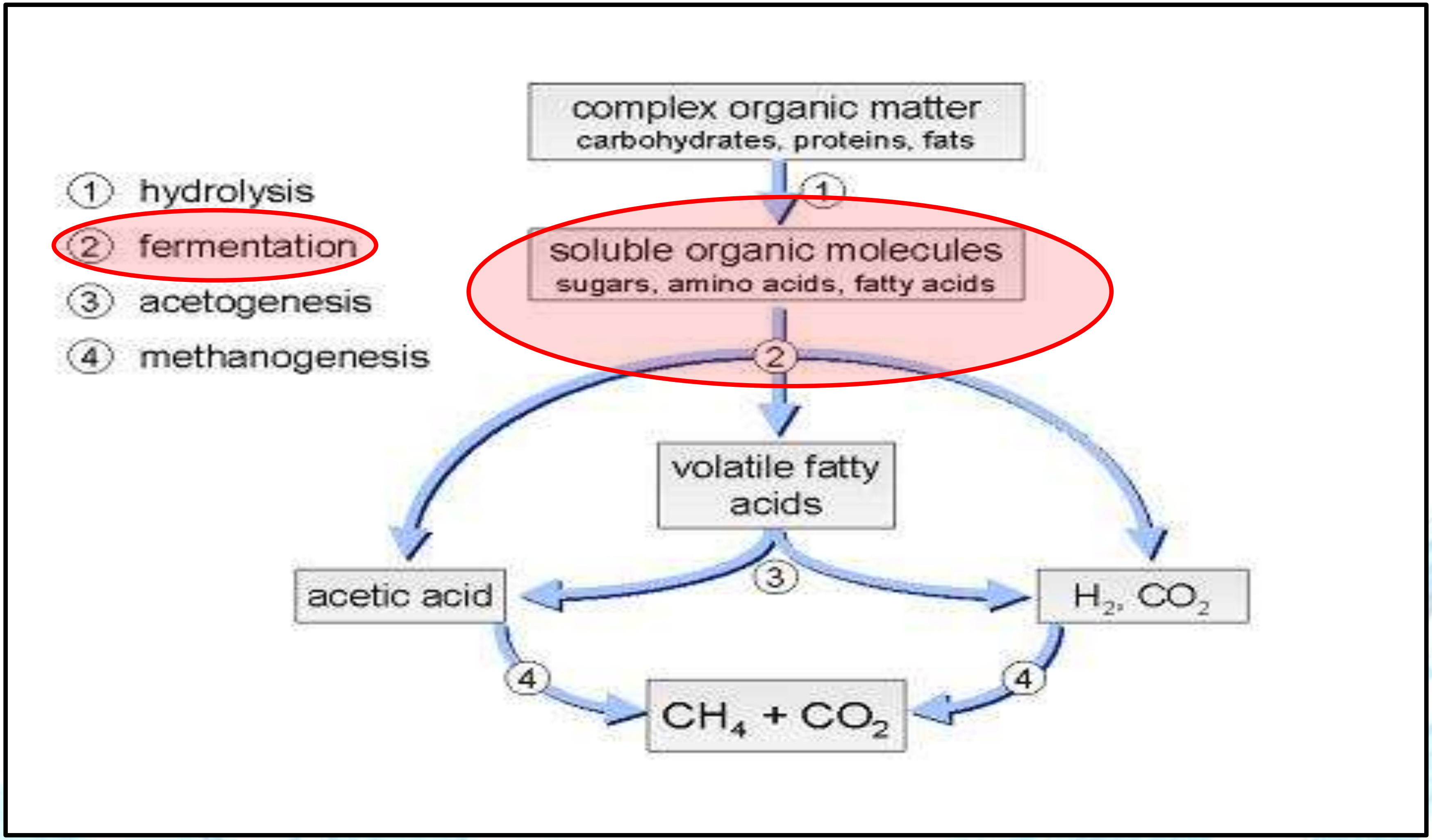
Anaerobic digestion is a process with several “steps” converting solid material into a gas



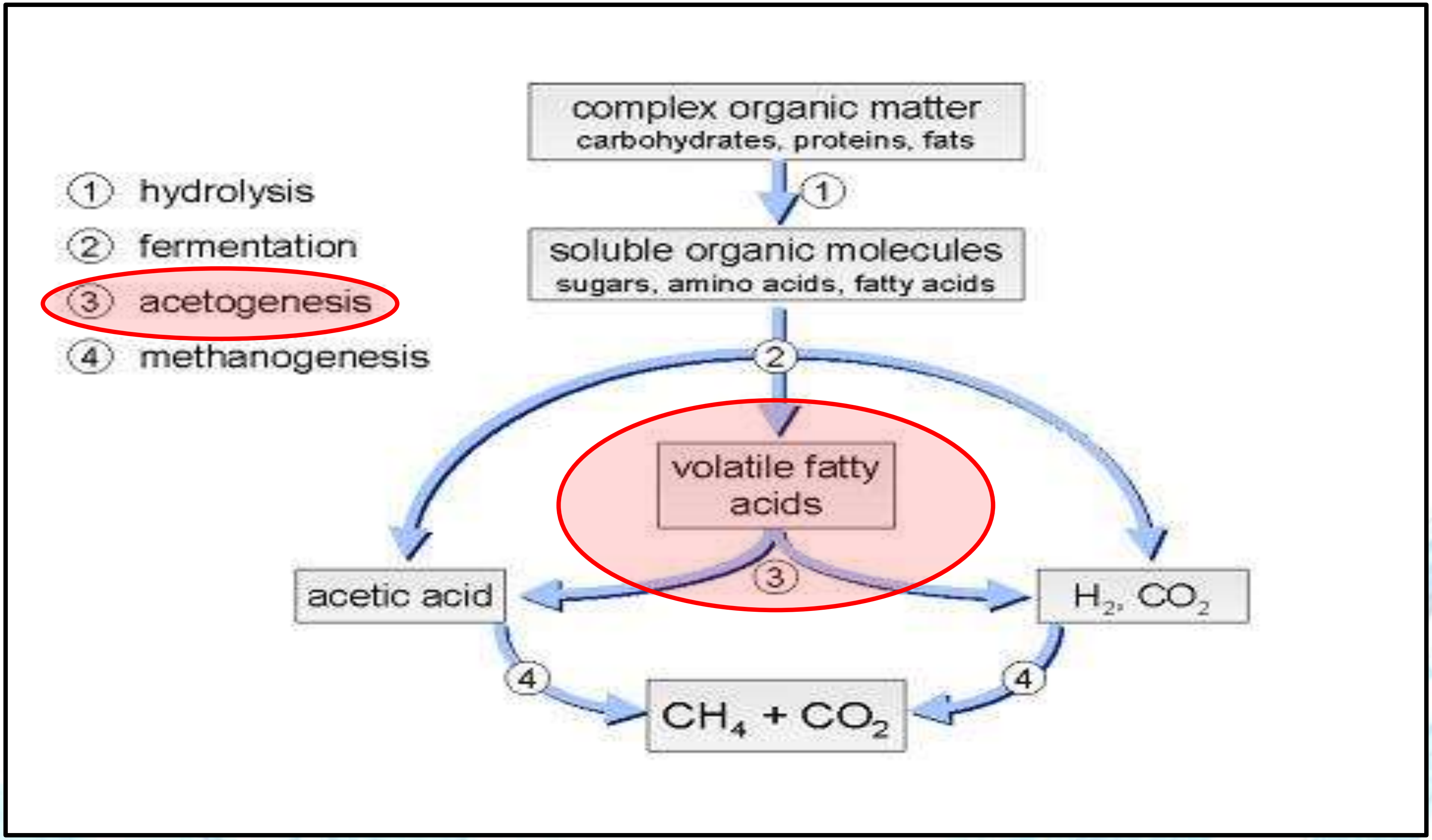
Hydrolysis is the first step in converting solids into soluble organic molecules



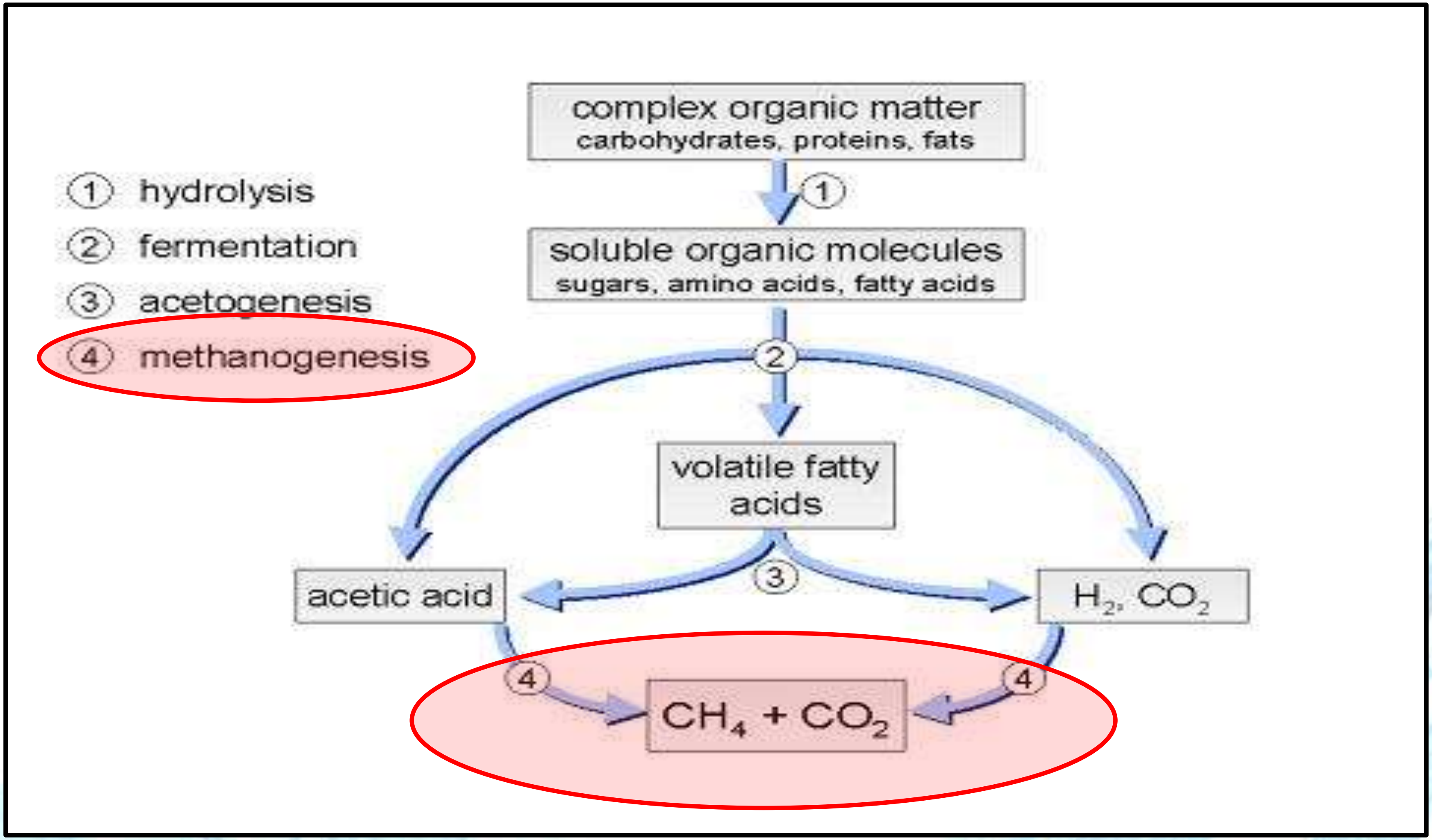
Soluble organics are fermented into simple and complex volatile fatty acids (VFAs).



Complex VFA are converted to acetic acid (simplest form of VFA) in acetogenesis.



Acetic acid and hydrogen can be converted biologically to methane via methanogenesis.



The Big Idea…

Creating the right operating environment will be critical to maintaining stable digester operations

Digester Sizing Considerations

Hydraulic retention time is an important factor in digester sizing

$$HRT = \frac{Digester\ Tank\ Volume}{Volumetric\ Feed\ to\ Digester}$$

Where:

Volumetric Feed to the Digester= gallons/day

Digester Tank Volume = gallons

HRT = Hydraulic Retention Time, days

Typical HRT/SRT ≥ 15 days

Volatile solids organic loading rate (VSLR) is one measure to track digester loading.

$$VSLR = \frac{Volatile\ Solids\ Feed\ to\ Digester}{Digester\ Tank\ Volume}$$

Where:

Volatile Solids Feed to the Digester = lb(VS)/day

Digester Tank Volume = 1,000 cubic feet

VSLR = Volatile Solids Loading Rate, lb(VS)/day-1000ft^3

Typical VSLR **< 150 lbs(VS)/day-1000ft^3**

Range **100-400 lbs(VS)/day-1000ft^3**

Digester Component Parts

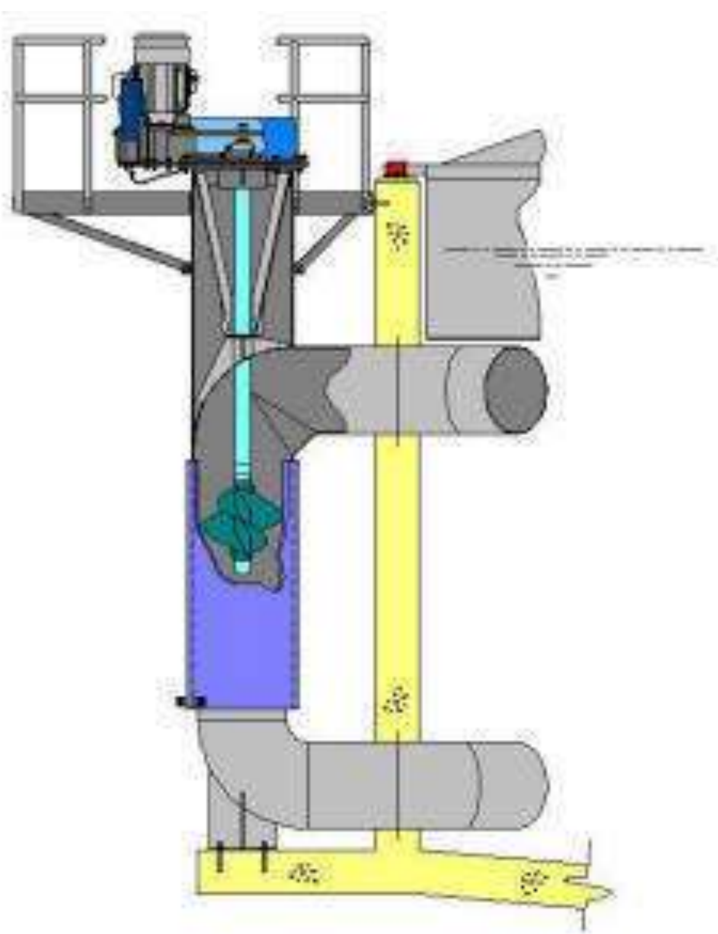
The anaerobic digester system has several major supporting systems

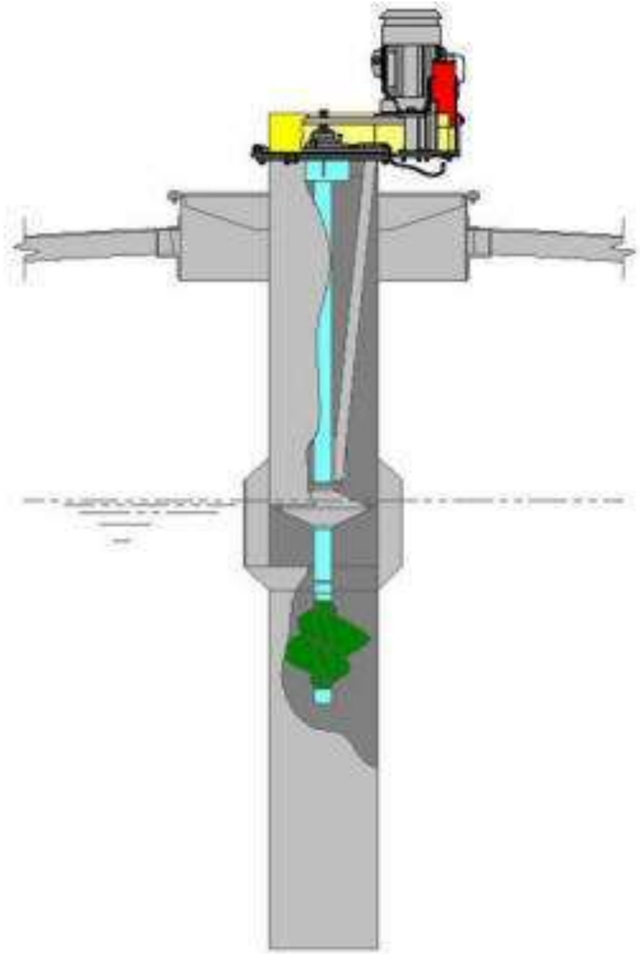
- **Mixing**
- **Heating**
- **Covers**
- **Gas Handling & Treatment**

Digester Mixing Systems

- **Draft Tubes**
- **Pumped Mixing Systems**
- **Gas Mixing Systems**
- **Linear Motion Mixer**

Draft tube mixers can be side mounted or cover mounted



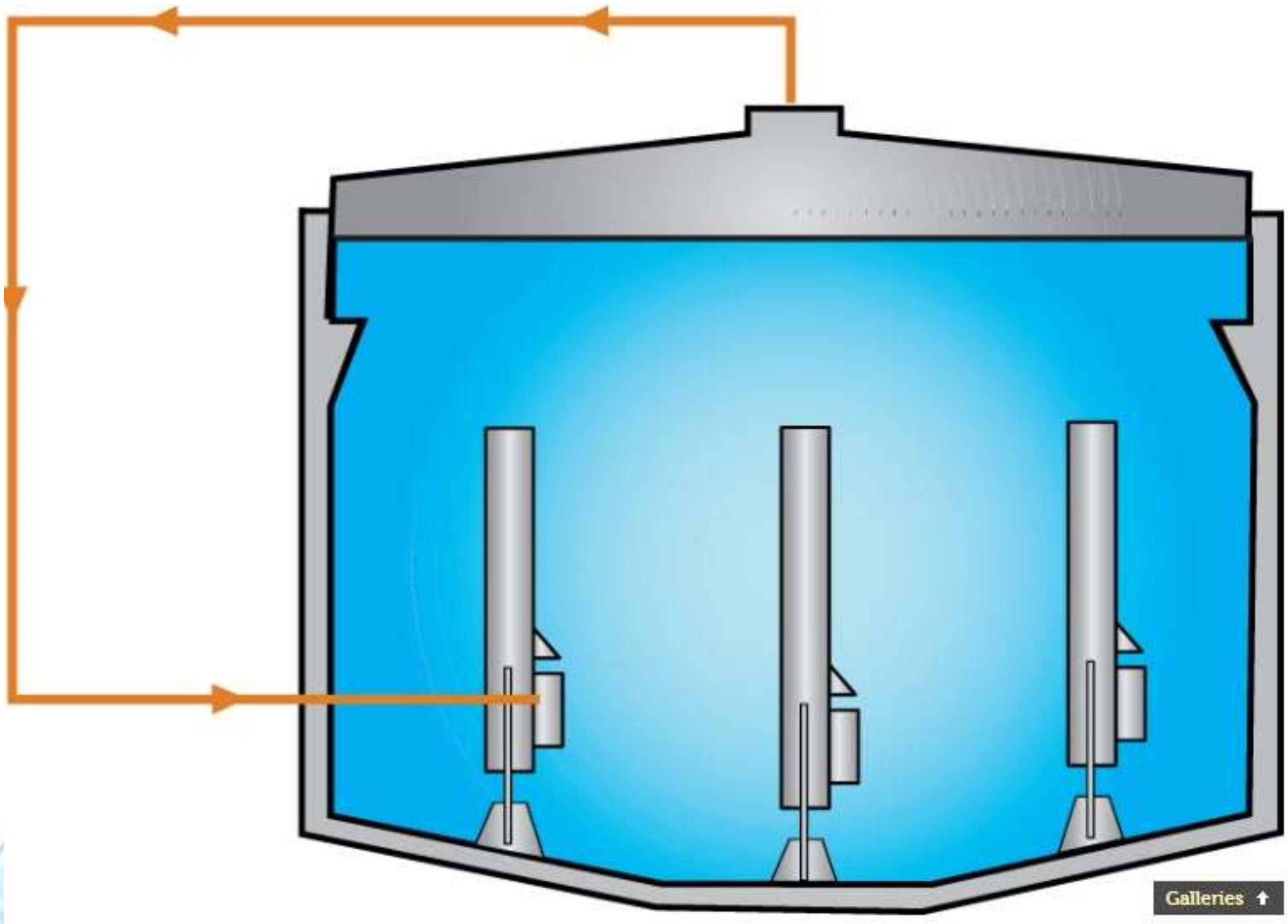


Courtesy: Olympus Technologies, Inc.

Pumped mixing systems from Vaughan and Siemens JetMix use nozzles.

Pumped mixing systems from Vaughan and Siemens JetMix use nozzles.

“Cannon” are floor mounted inside the digester and gas is recirculated



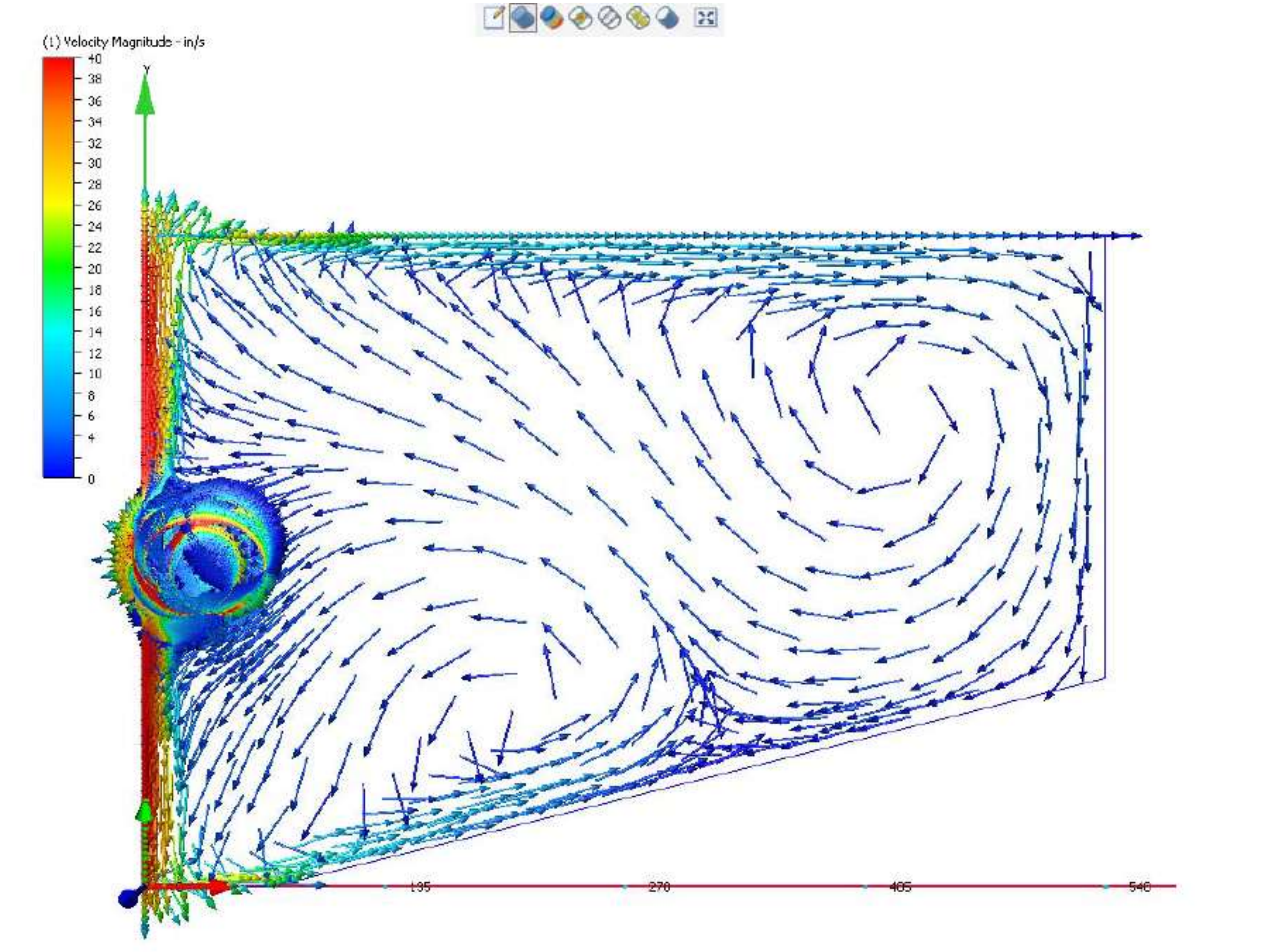
Courtesy: Infilco Degremont Industries

Gas cannon mixing systems have a gas compressor and distribution header

Linear motion mixers are relatively new to the market for digester mixing

Courtesy: OVIVO

Linear Motion Mixer Velocity Profile

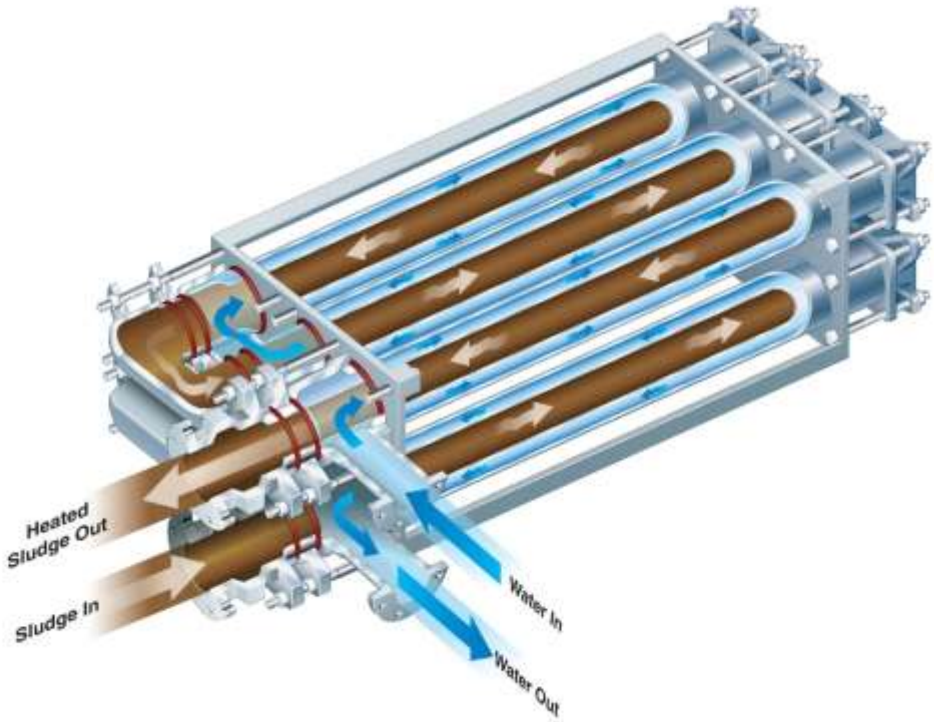


Courtesy: Ovivo

Heating

- **Heat Exchangers**
- **Hot Water Boilers**
- **Combination Boiler / HEX Systems**
- **Mesophilic Temperature**
  - 95-98°F
- **Thermophilic Temperature**
  - 130-135°F

Tube-in-Tube heat exchangers are among the most commonly applied HEX units.



Courtesy: Walker Process

Spiral heat exchangers have also been used for digester heating

Courtesy: Alfa Laval

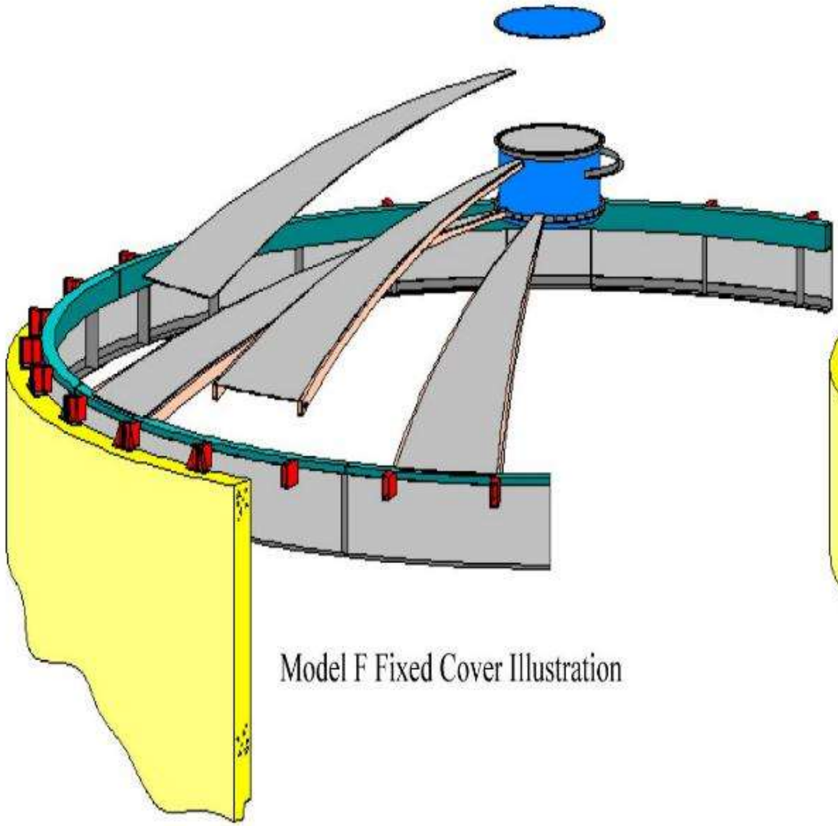
Dual fuel capable fire tube style boilers can be used for hot water heating.

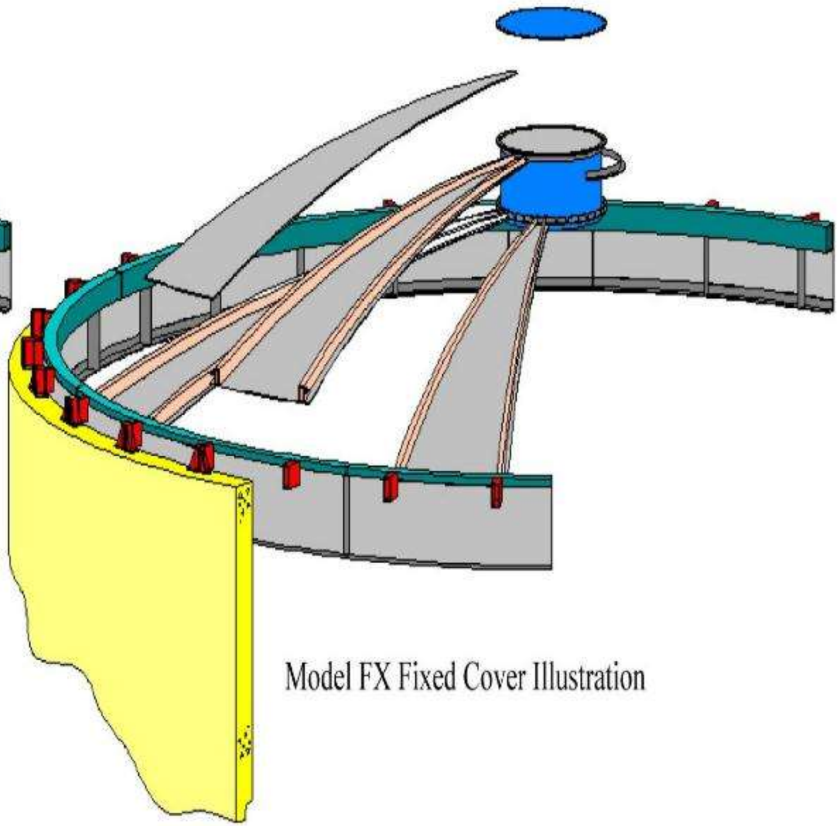
Combination hot water boiler and heat exchanger units can also be found.

Covers

- **Fixed Covers**
- **Gas Holder Covers**
- **Steel Truss Floating Covers**
- **Membrane**

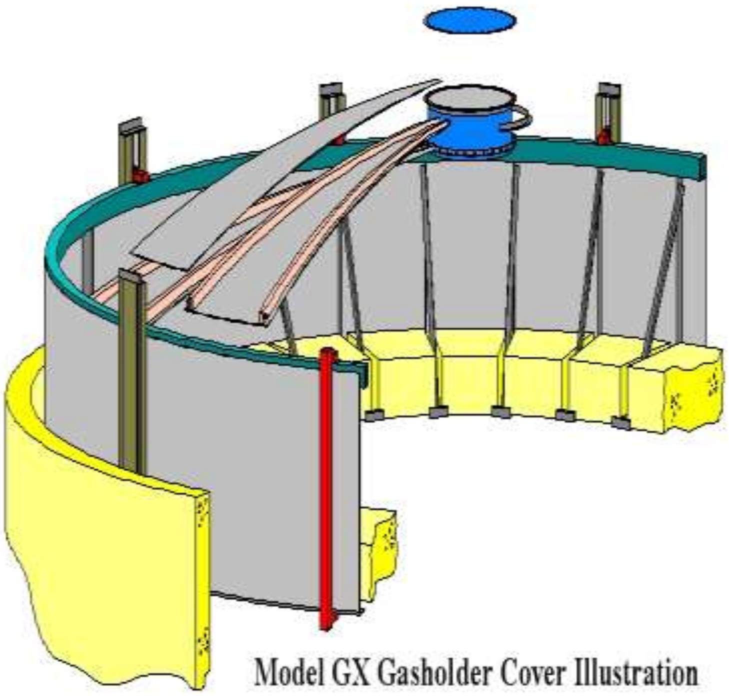
Fixed covers are the least costly but have special operating considerations.

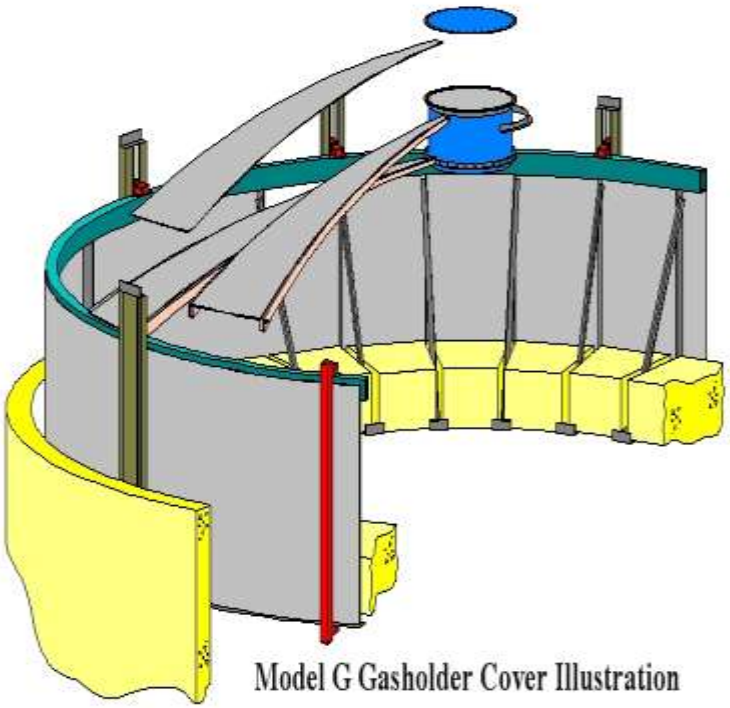




Courtesy: Olympus Technologies, inc.

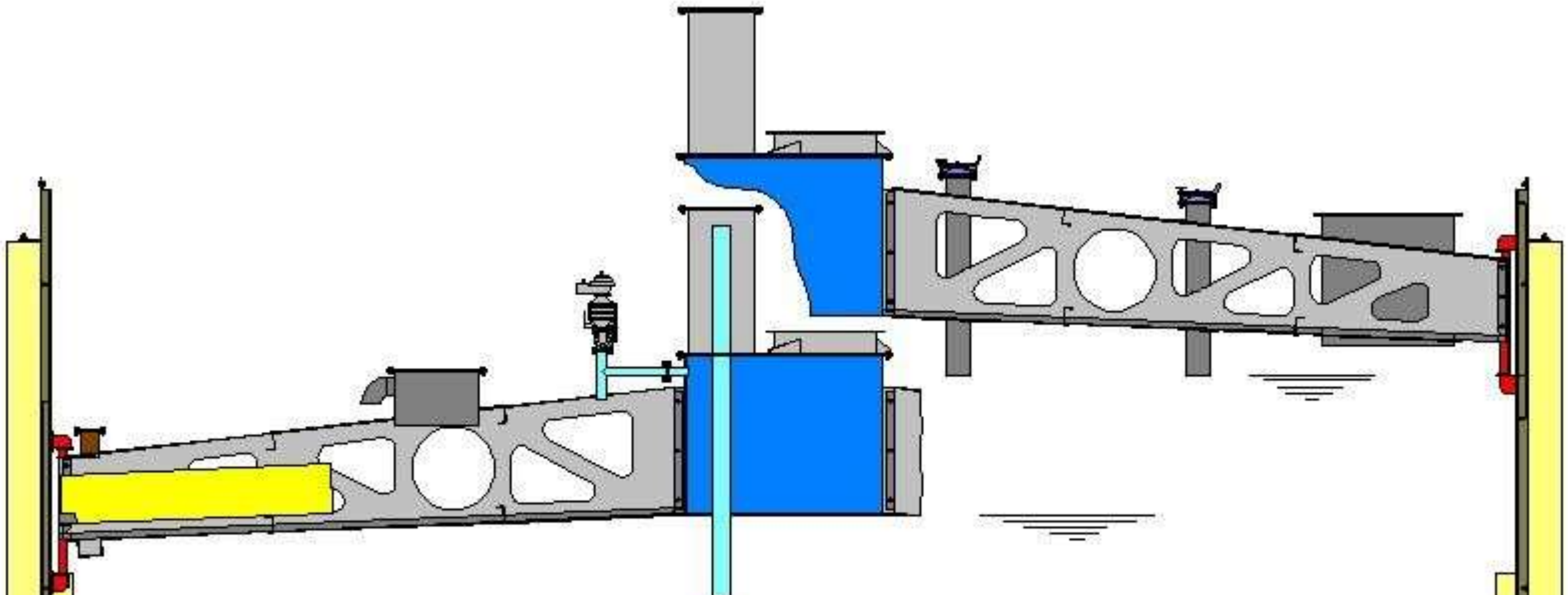
Floating covers are ballasted and can provide for some gas storage capacity.





Courtesy: Olympus Technologies, inc.

Truss style covers are typically more costly to manufacture and assemble.



Structural Truss Floating Cover

Courtesy: Olympus Technologies, inc.

Membrane covers can provide high gas storage volume

Gas Handling and Treatment

- **Condensate and Moisture Removal**
- **Sulfide Removal**
- **Siloxane Removal**
- **Gas Storage**
- **Waste Gas Flaring**

Gas handling equipment for condensate removal

Gas handling equipment for moisture removal

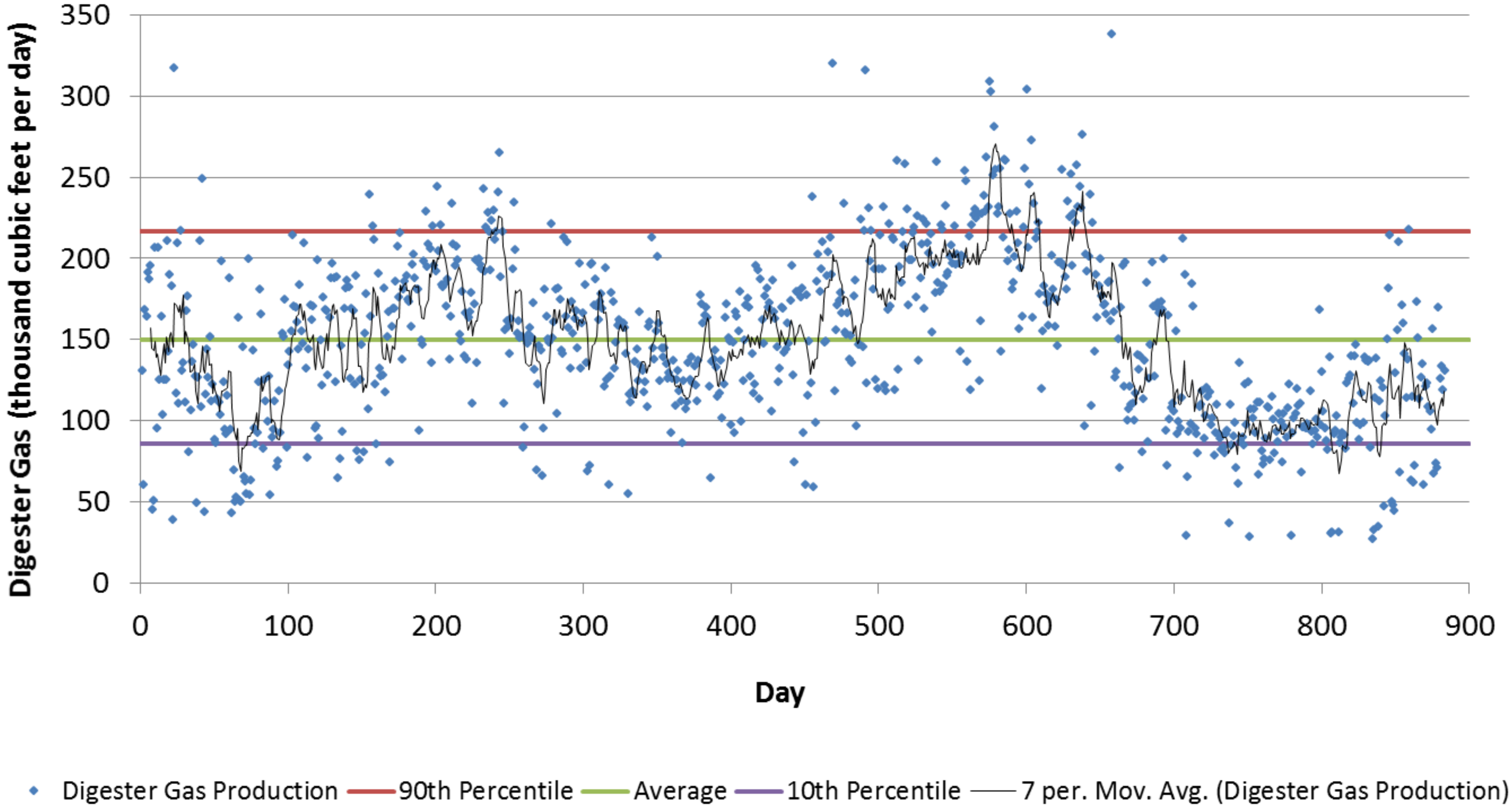
Iron sponge can be used for sulfide removal from digester gas

Activated carbon treatment and be utilized for siloxane removal

Gas storage can be provided in several different ways within the facility.




Digester gas production varies daily and seasonally



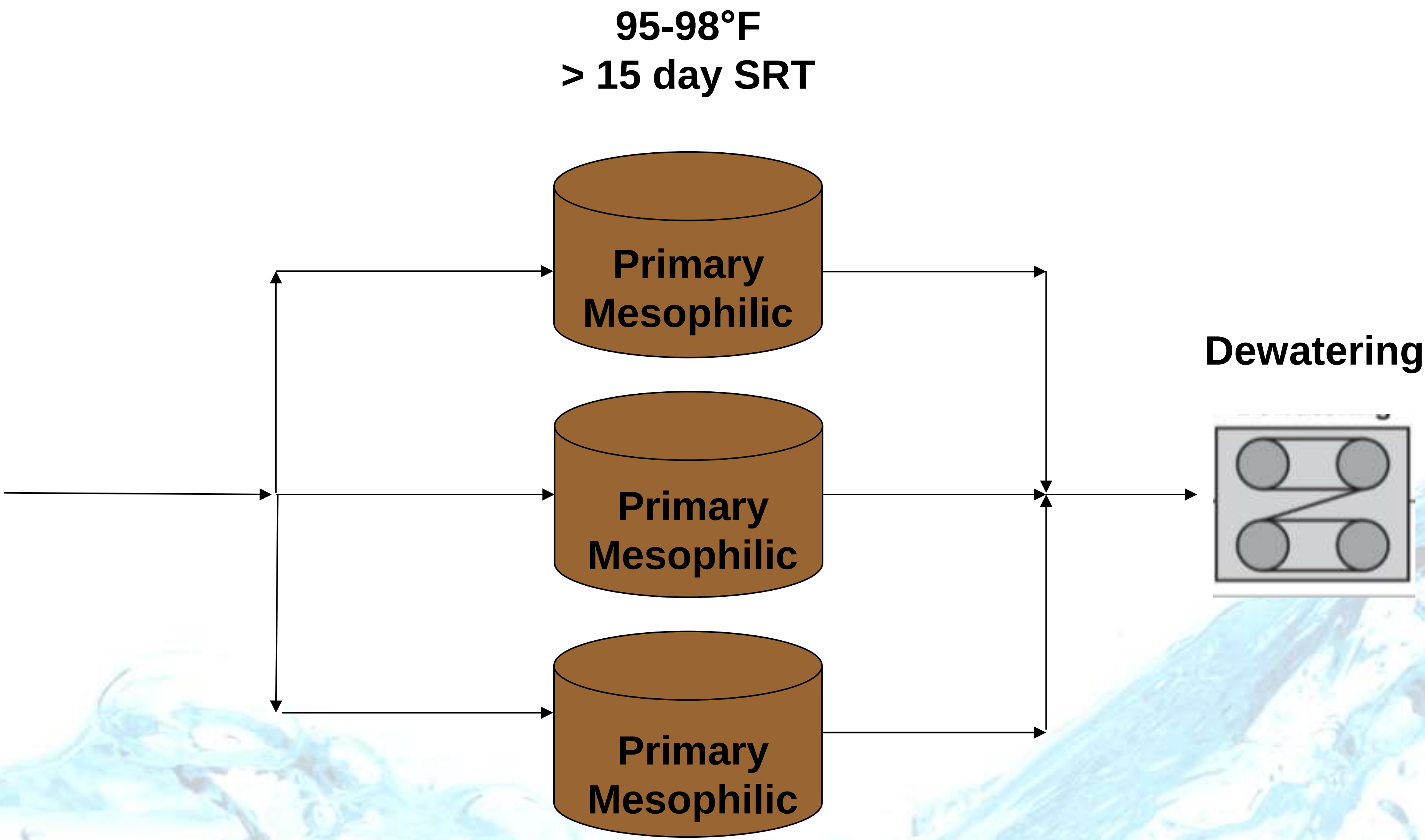
Waste gas flare for burning excess digester gas

Digester Process Configurations

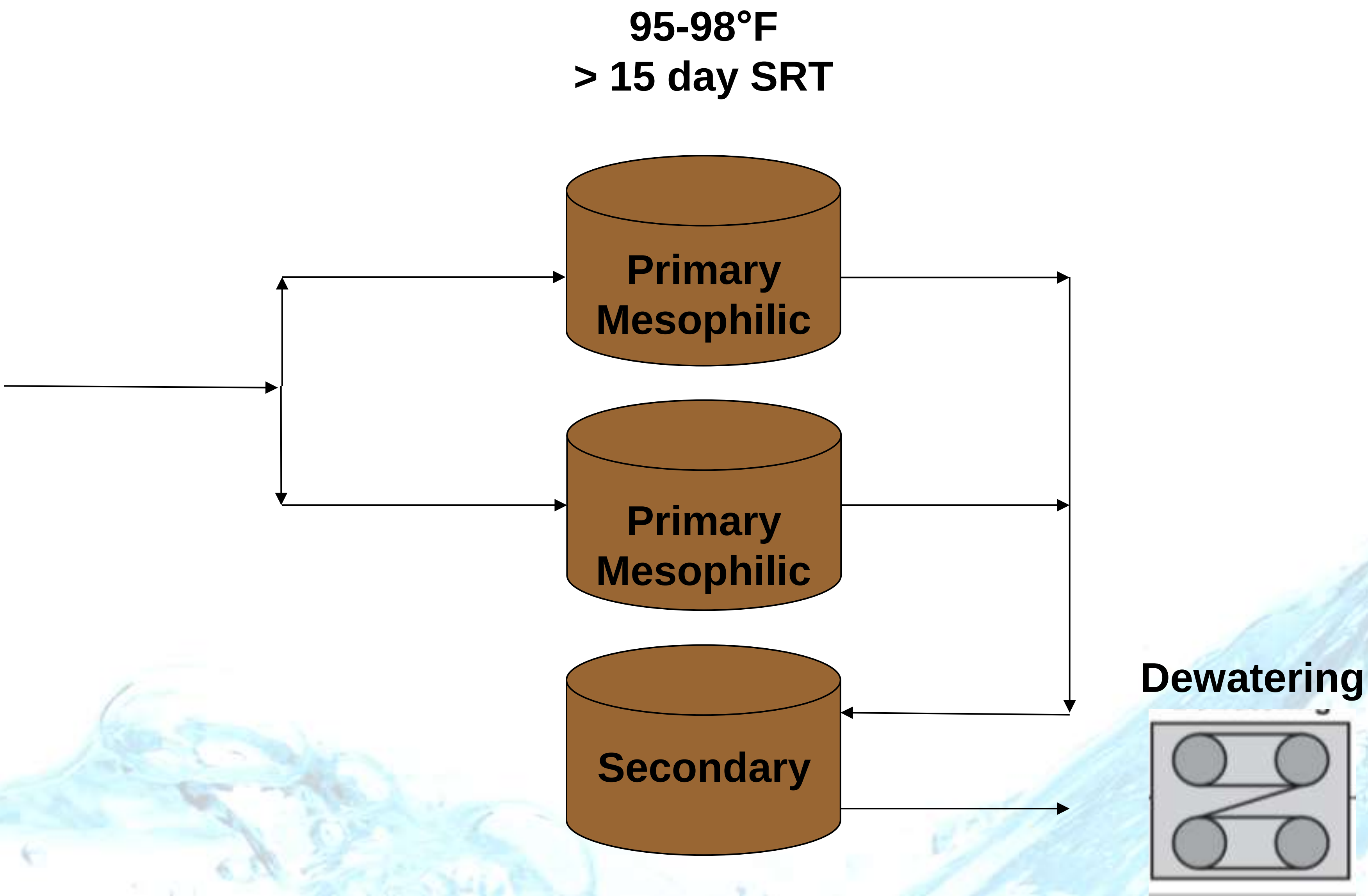
Digesters can be operated in different process configurations

- Primary – Heat and Mix
- Primary + Secondary
- Temperature Phased
  - Thermophilic + Mesophilic
- Acid-Gas Phased
- Combination Phased
  - AGMM
  - AGTM
- Class A – (TPBAD)
  - Temperature Phased Batch Anaerobic

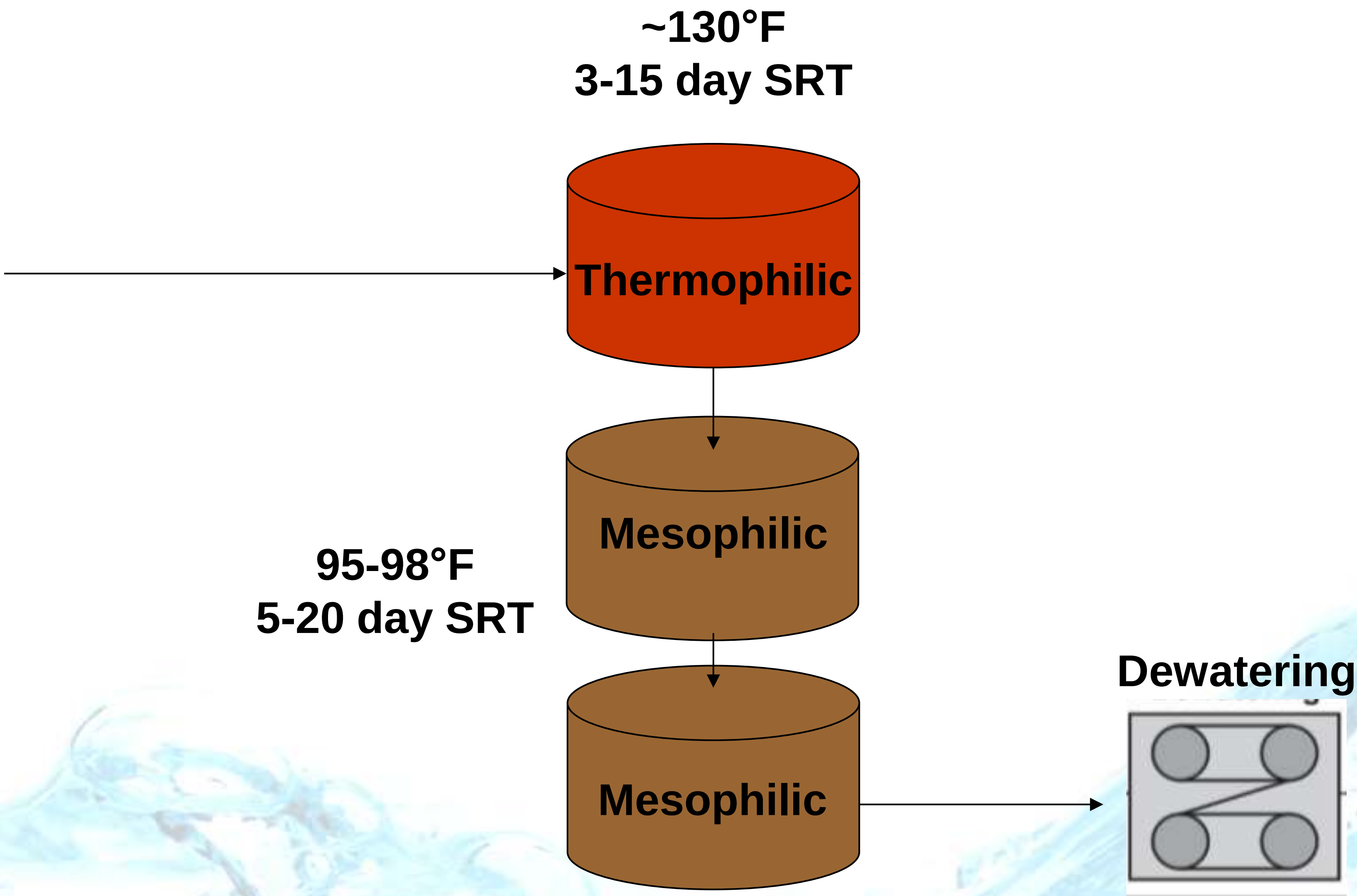
Primary Digesters – Parallel Operation



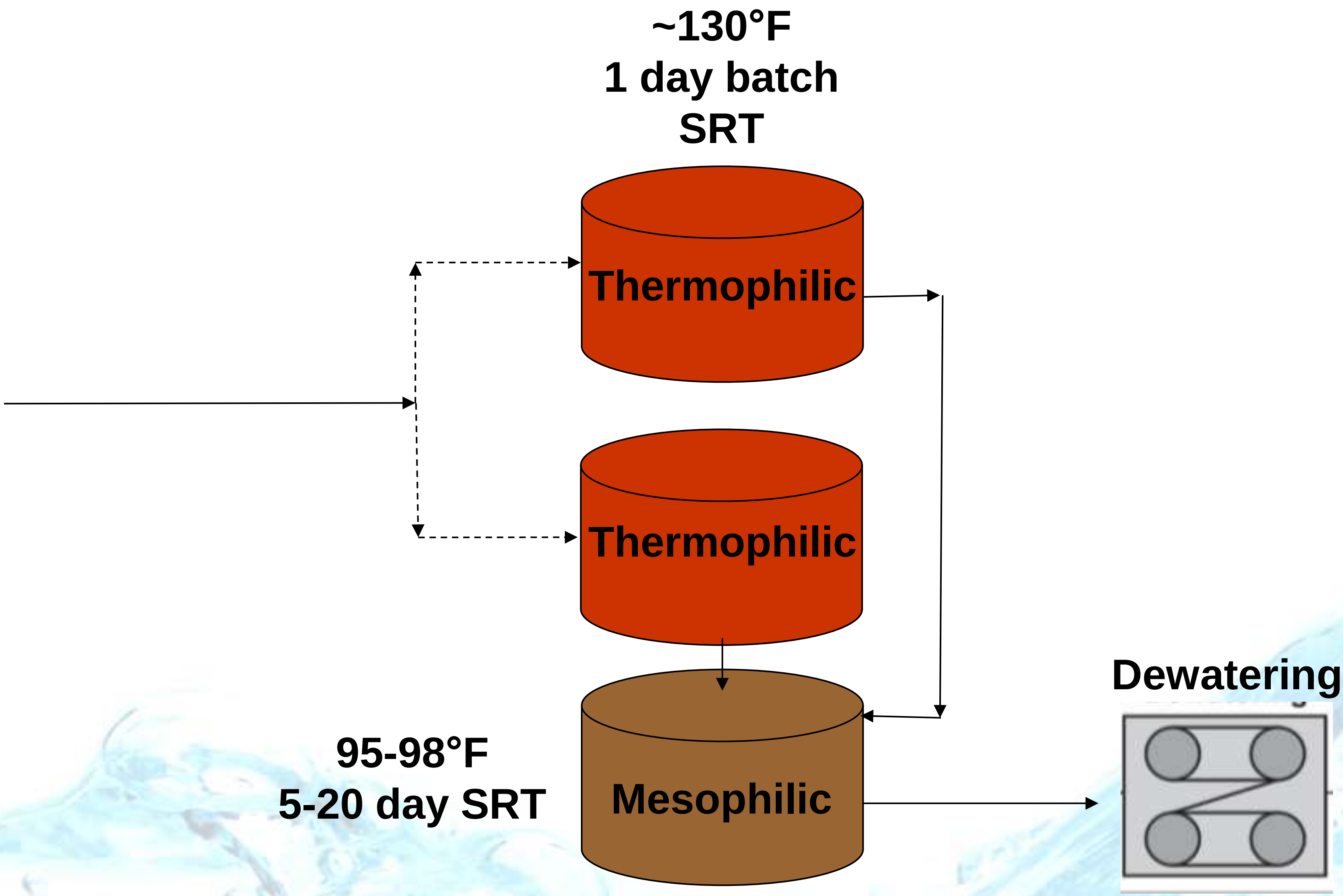
Primary and Secondary Digesters



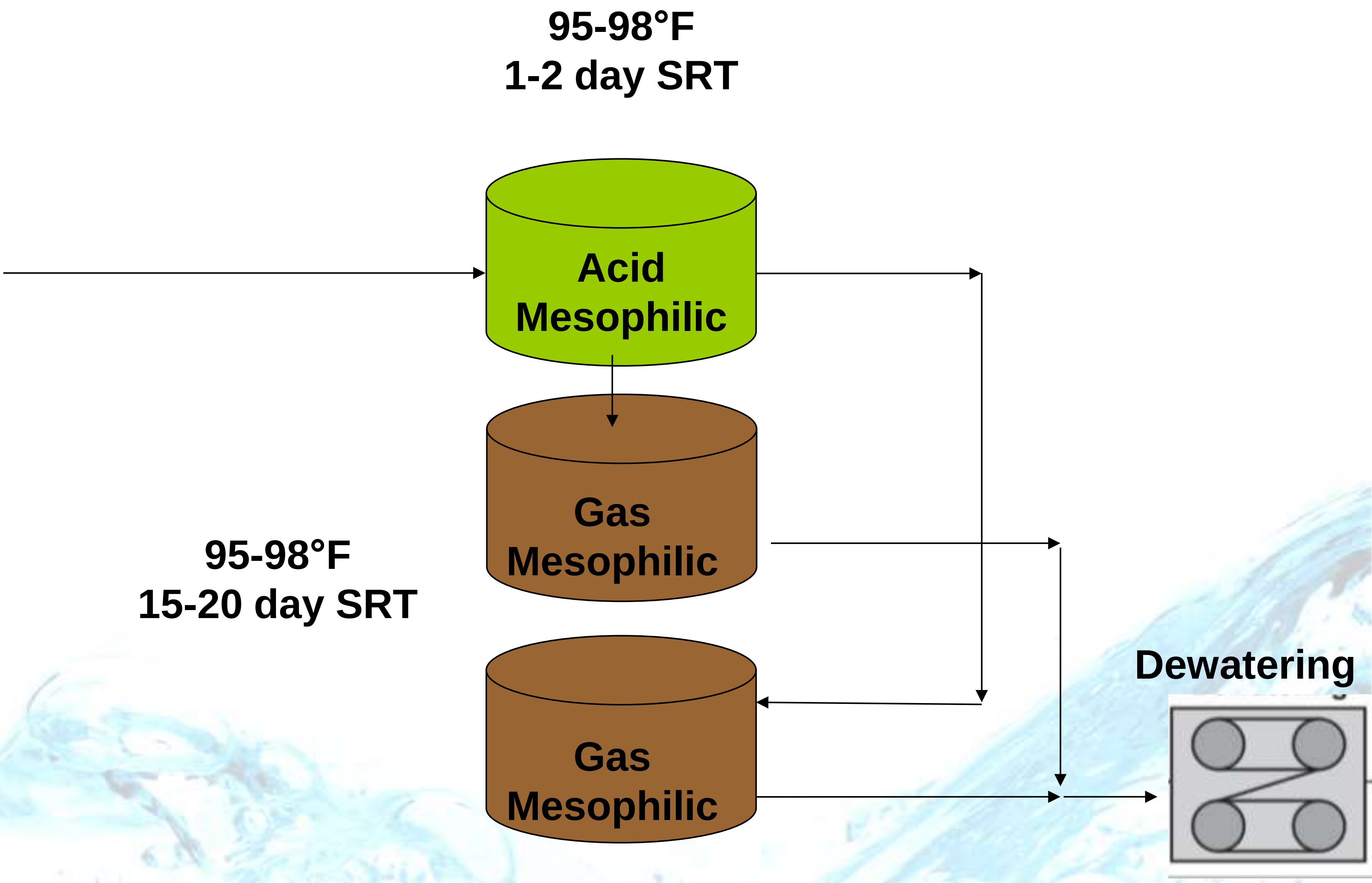
Temperature Phased Anaerobic Digestion



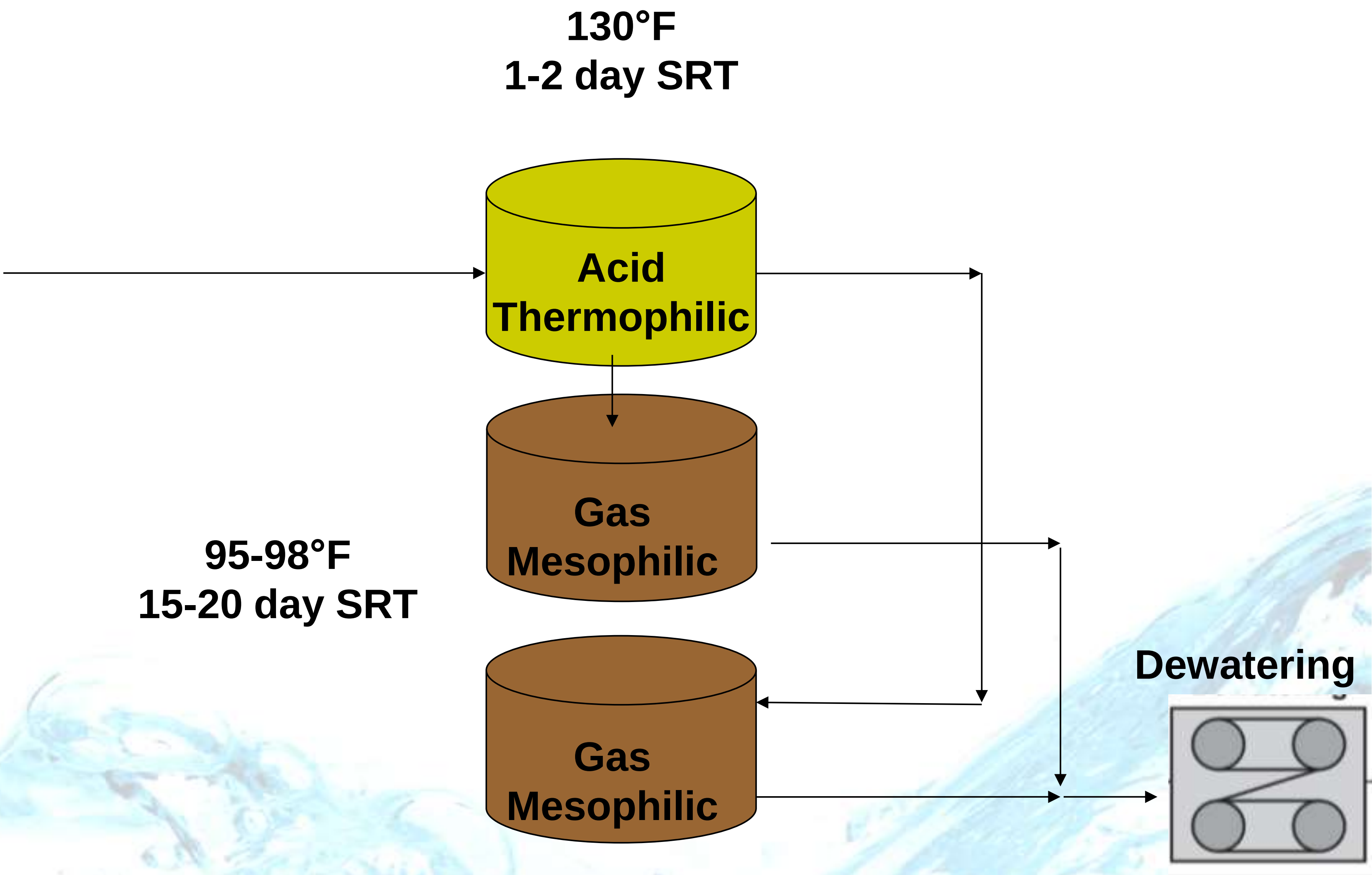
Temperature Phased Batch Anaerobic Digestion



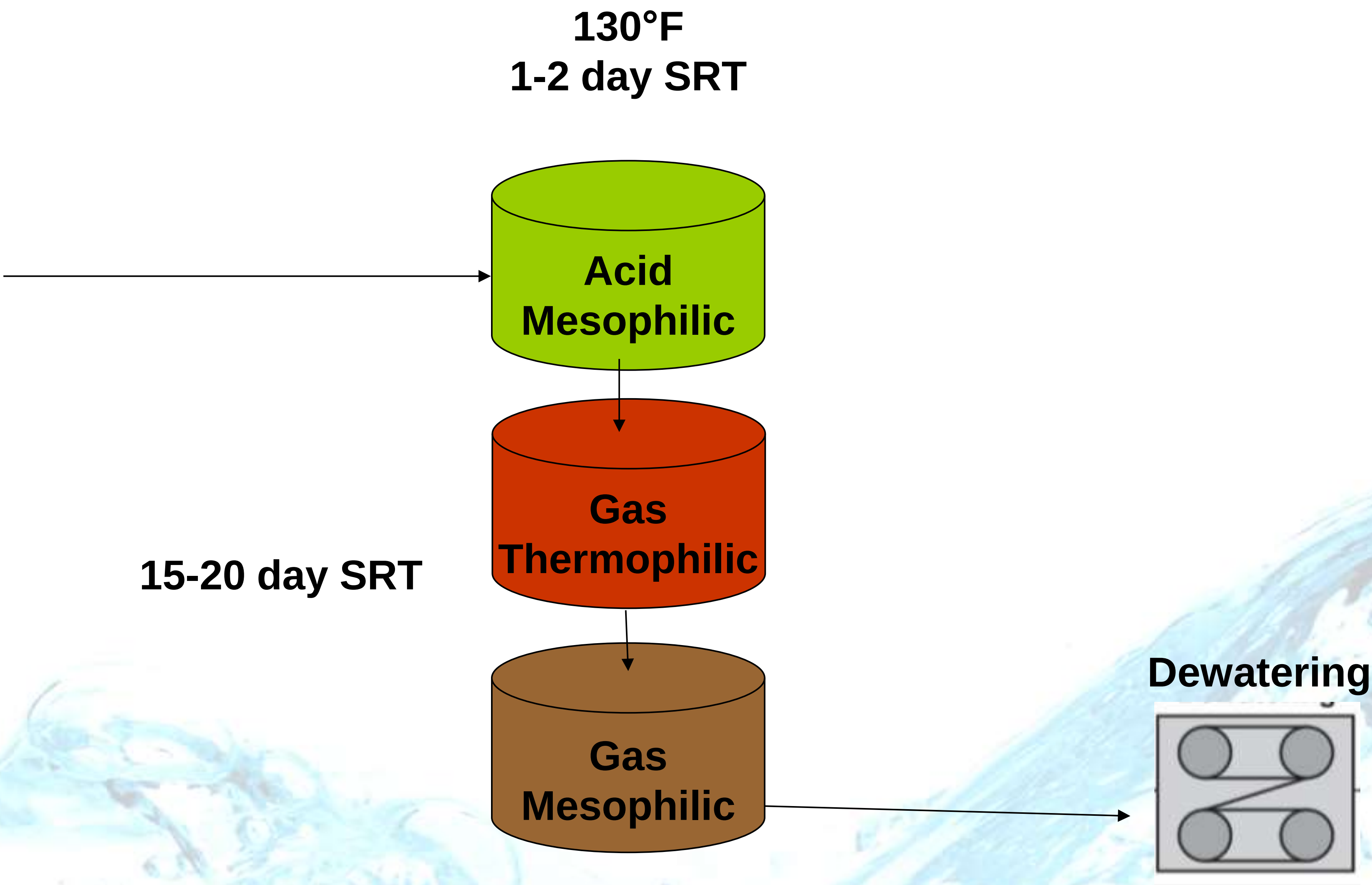
Acid / Gas Phase Meso-Meso



Acid / Gas Phase Thermo-Meso



Acid / Gas Phase Meso - Thermo



Digester Process Control Monitoring

Process monitoring should be done for each of the feedstock streams

- **Daily Volumetric Feed Rate (gallons/day)**
- **Raw Feed Total Solids (mg TSS/L or %TS)**
- **Raw Feed Volatile Fraction (VS/TS Ratio)**
- **Raw Feed Temperature (°F)**

Volatile solids reduction effectiveness can be estimated using the VanKleek Equation

$$\%VSR = \frac{\%VS_{raw} - \%VS_{digester}}{\%VS_{raw} - \left(\%VS_{raw} \times \%VS_{digester}\right)}$$

Where:

%VSR = Volatile Solids Reduction Rate

$\%VS_{raw}$ = Feed Volatile Solids Fraction

$\%VS^{digester}$ = Digested Sludge Volatile Solids Fraction

Failure indicators to be on the look out for in your process control monitoring.

- **Volatile fatty acids (VFA) concentration increases rapidly**
- **Bicarbonate alkalinity decreases rapidly**
- **Reactor pH declines below 6.8 std. units**
- **Gas production rate decreases relative to the volatile loading to the reactor**
- **Carbon dioxide in the digester gas increases significantly**

Keep VFA/ALK in the proper balance for good digester “health”

- **Typical VFA/ALK = 0.02 to 0.05 (2% to 5%)**

- **High VFA/ALK = 0.08 to 0.10 (8% to 10%)**

- **If VFA/ALK gets to high:**
  - **VFA production exceeds VFA consumption**
  - **Organic overloading risk**
  - **Buffering capacity may be compromised**
  - **pH could drop in the reactor below 6.8**
  - **pH shift can further compromise methanogenesis**

<u>UNIFORMITY</u> and <u>CONSISTENCY</u> – will aid operations significantly.

- **UNIFORMITY**
  - **Strive for uniform loading rates across time**
  - **Avoid intermittent slug load feeding**
  - **Continuous feed or near continuous feed**
  - **Mixing helps provide uniformity in the reactor**

- **CONSISTENCY**
  - **Strive for consistent blend of sludge feedstocks**
  - **Maintain temperature with minimal variation in reactor.**

Transitioning to a sustainability paradigm for the 21st century

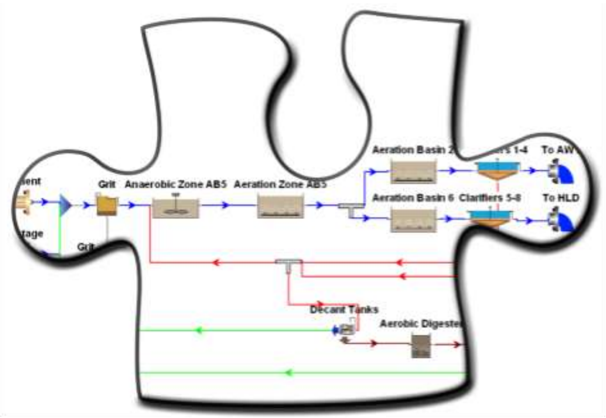
We now have a new acronym (and paradigm) to consider in wastewater treatment.

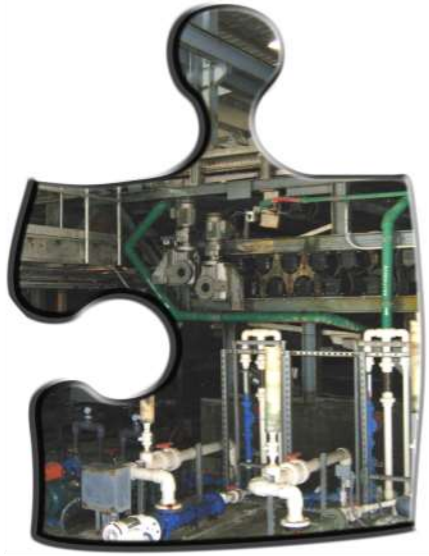
Nutrient Energy Recovery Facility is becoming the new expectation from our former WWTPs.

Shifting expectations will require getting out of the "silos" and looking at "wholistic" solutions.

Working in the new paradigm will require thinking about treatment facilities in a WHOLE new way that integrates the liquid, solids and recycle streams into a single system to provide superior solutions

The new paradigm will require getting the pieces of your plant to work together seamlessly.



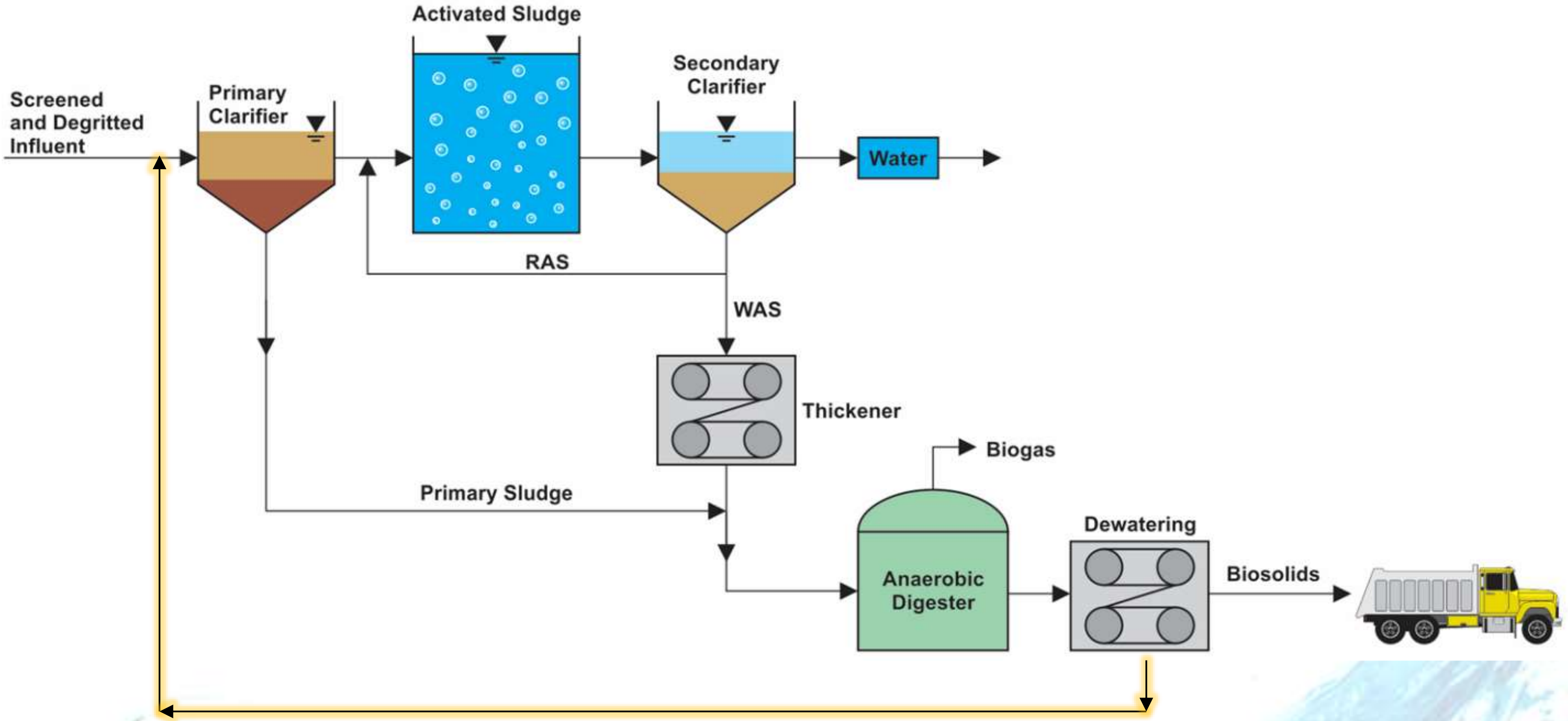


Liquid Treatment

Sidestream Treatment

Solids Treatment

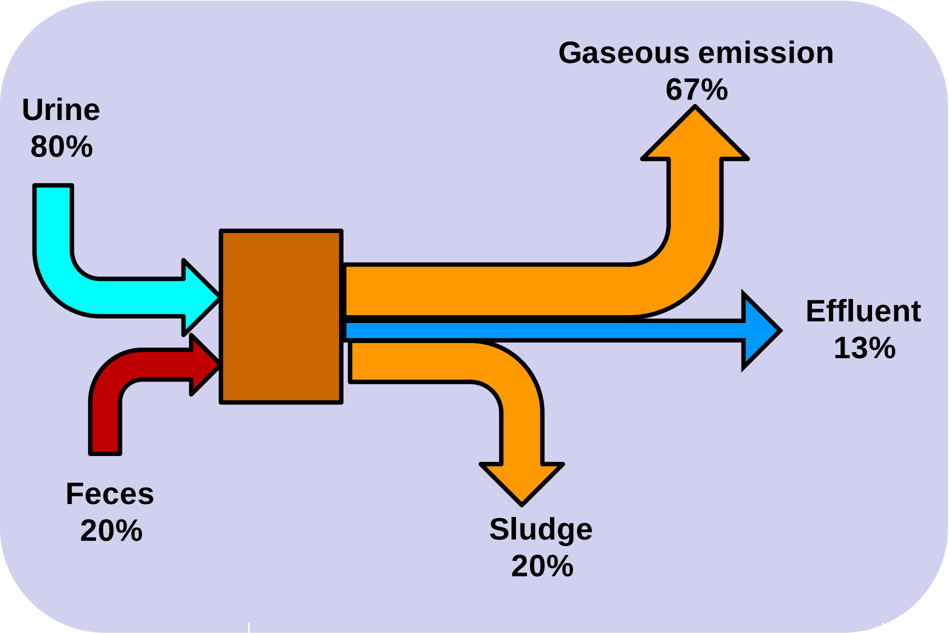
Solids treatment cannot remain isolated from liquids treatment



Nutrient harvesting and recovery from residuals and sidestreams

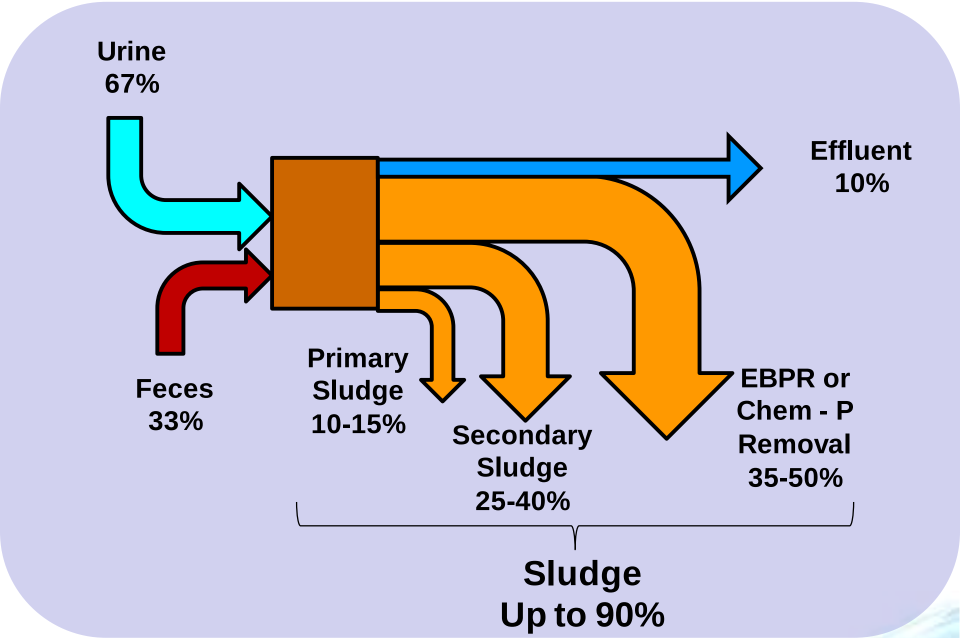
Wastewater treatment facilities are in reality nutrient recovery and capture facilities.

N mass balance in WWTP



From Phillips *et al.*, (2011) and Jonsson et al., (2006)

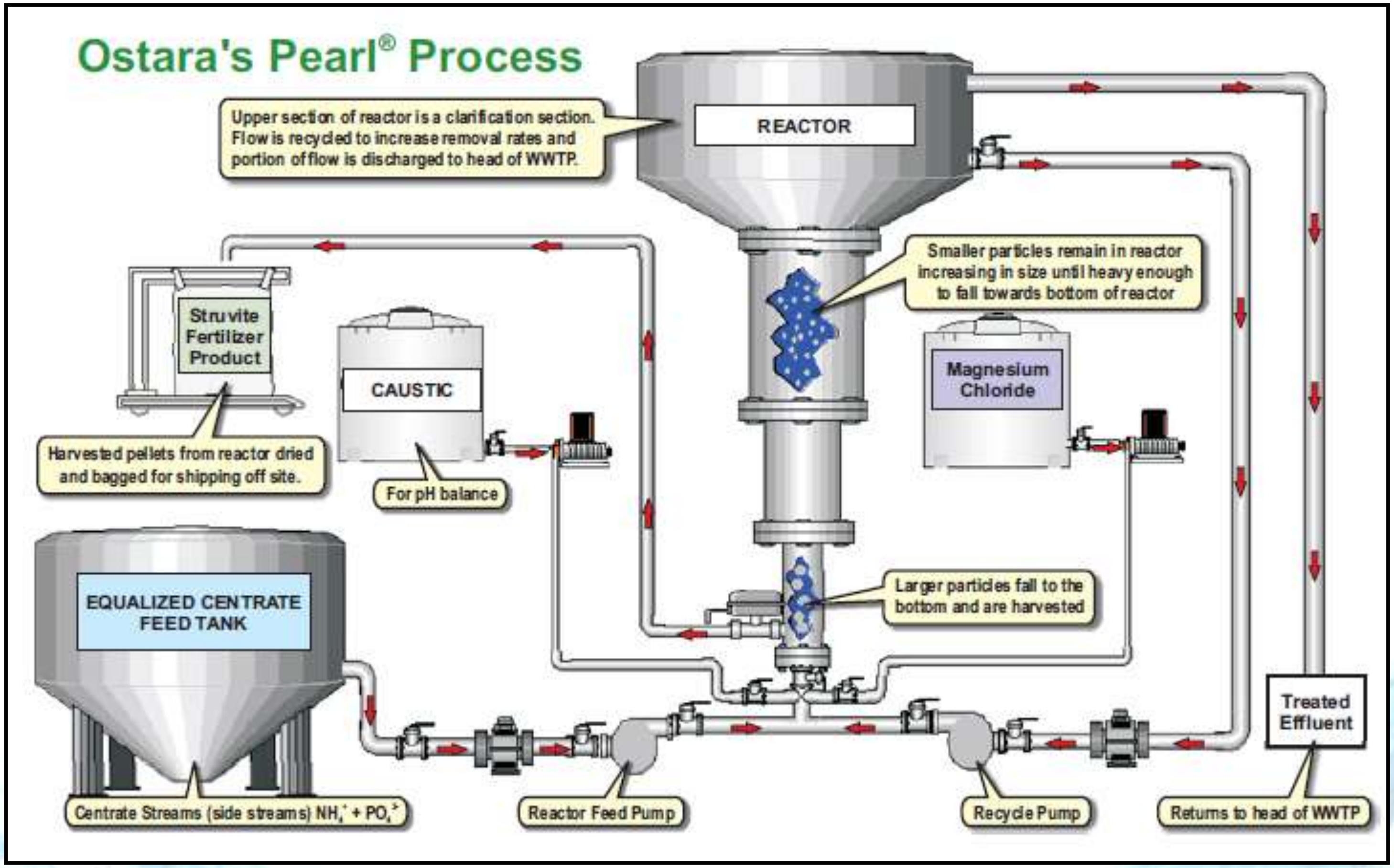
P mass balance in WWTP



From Cornel *et al.* (2009)

- The solids treatment process affects the nutrient content of the biosolids produced

Nutrient recovery can offer opportunities to harvest phosphorus into a beneficial use product.



$NH_4MgPO_4 \cdot 6H_2O$

Final product quality may differ depending on the technology utilized for struvite recovery.

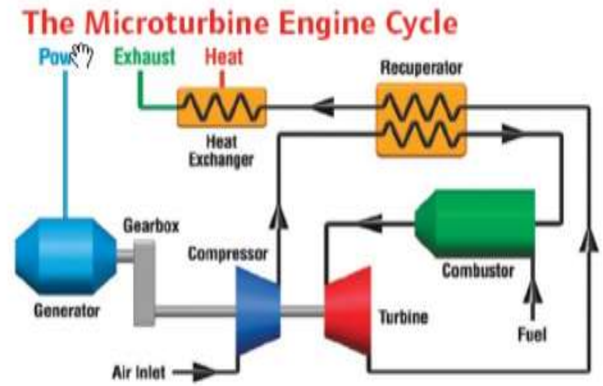
Slow Release Fertilizer

5-28-0 :: N-P-K + 10% Mg

Recovered struvite is sold as a fertilizer product for its nitrogen and phosphorus content.

Capturing energy imbedded in residuals and pushing toward “net zero”

Energy recovery, and energy neutrality, become topics of interest and consideration.



Energy recovery, and energy neutrality, become topics of interest and consideration.

Co-digestion and importing selected waste streams can be a path to increased energy.

New technologies which provide for a major “sea change” in residuals handling

Emerging technologies offer opportunities which can impact residuals management options.

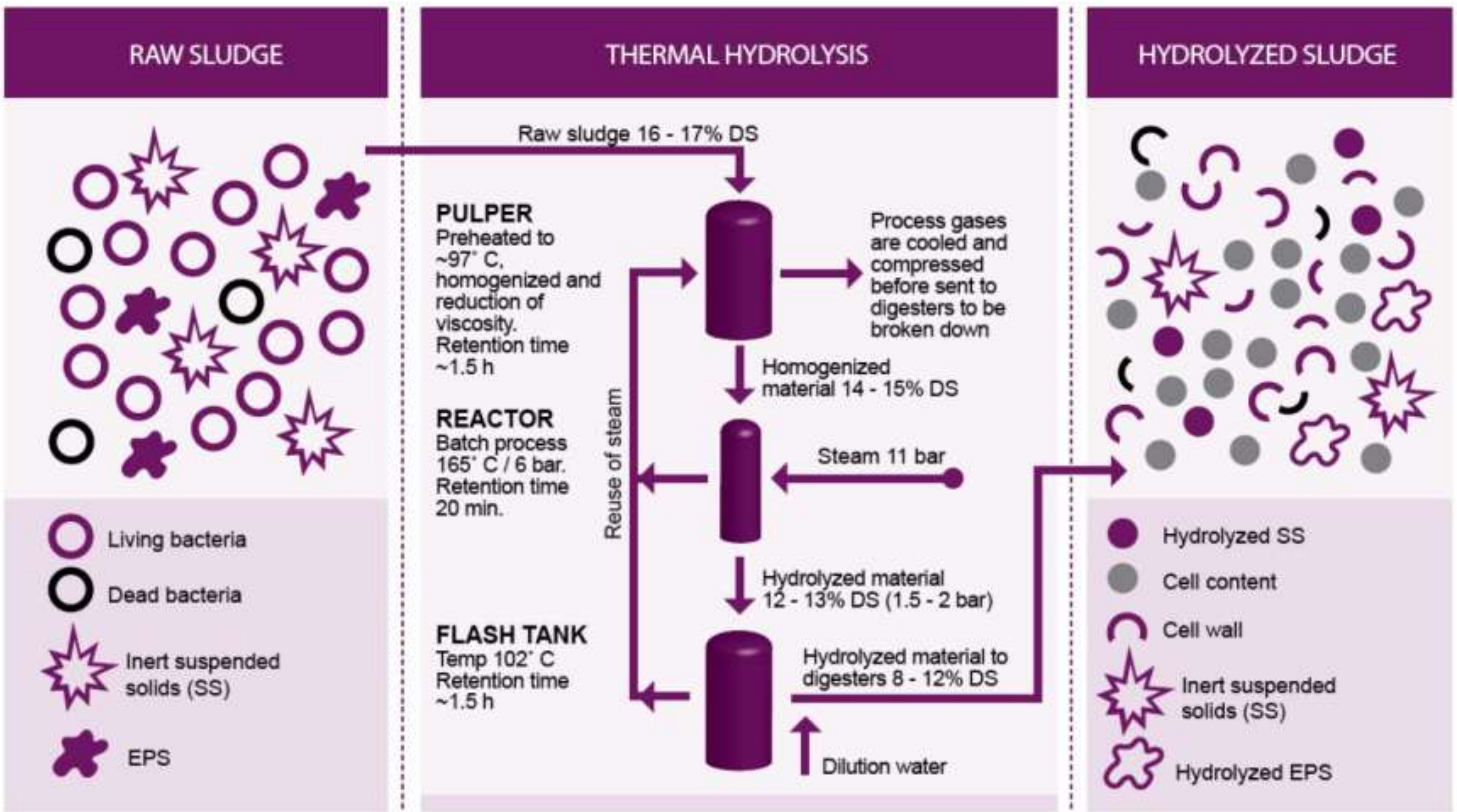
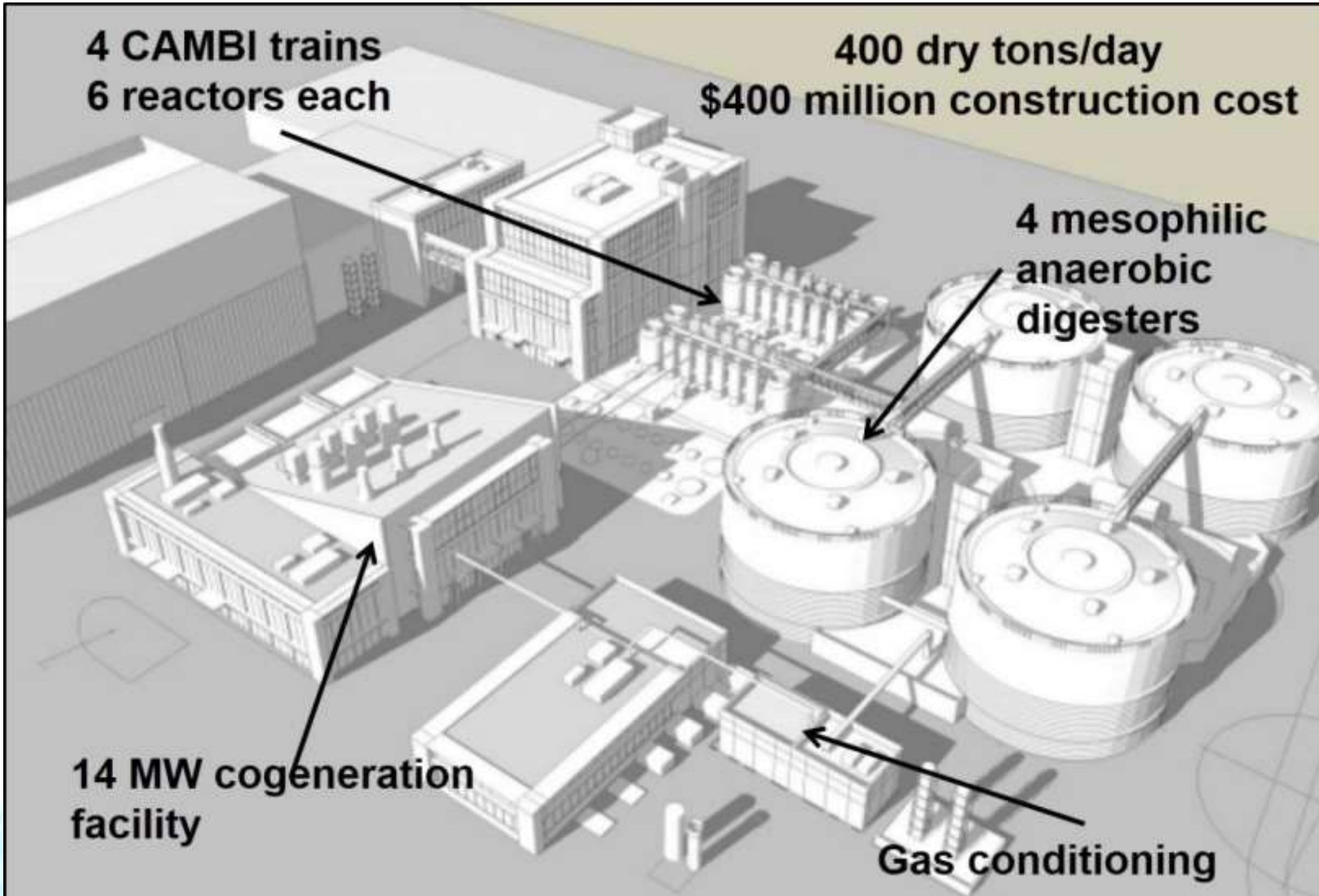


Image: provided from Cambi

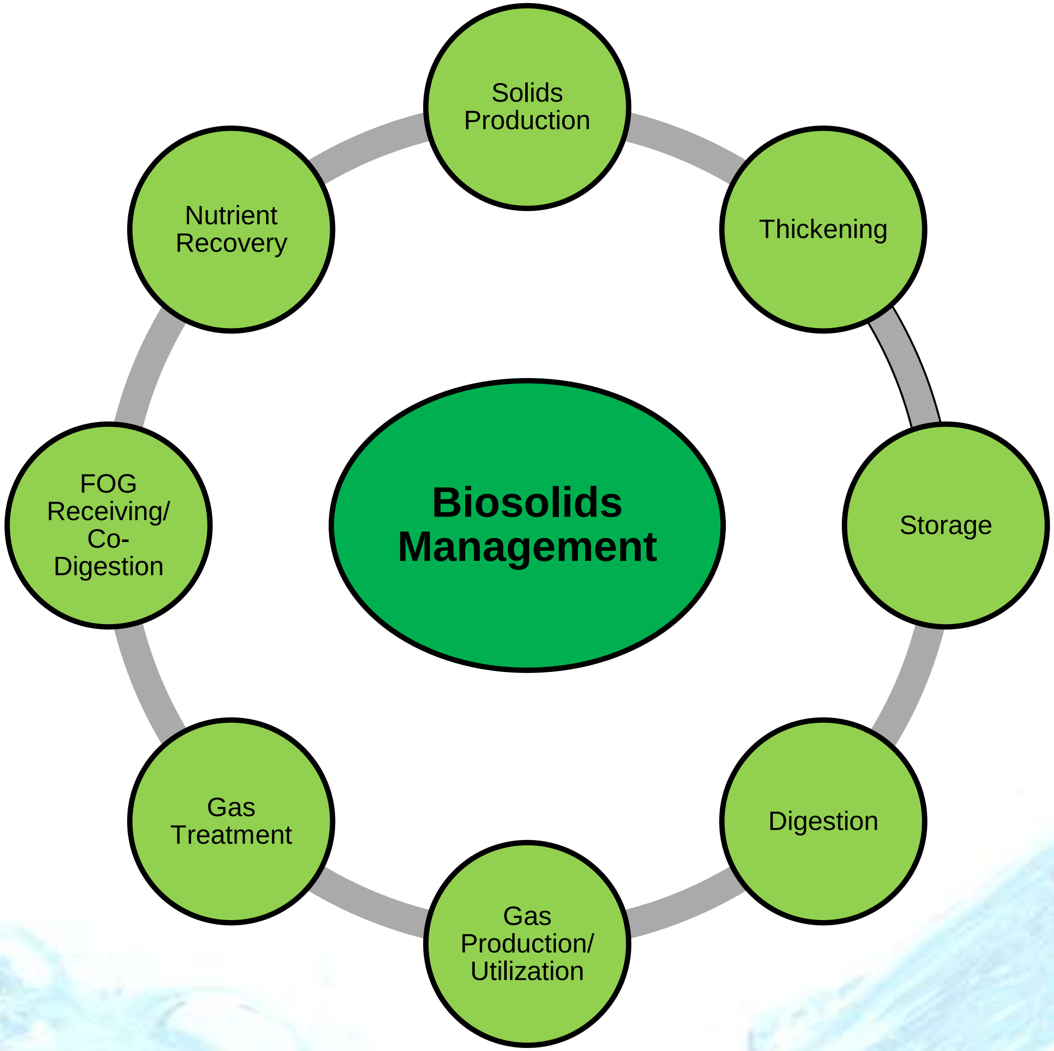
DCWATER is going in a new direction with the largest CAMBI plant in the world.



A selected utility case study looking at wholistic facility optimization

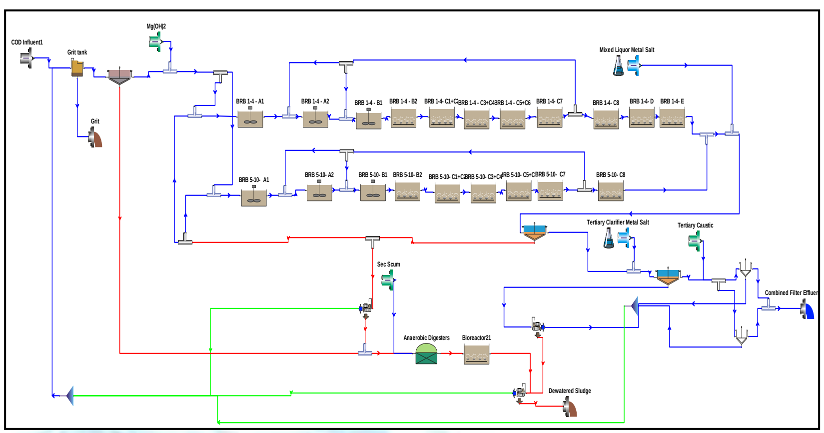
The 60-mgd capacity F. Wayne Hill WRF is operated by Gwinnett County near Atlanta, GA.

This involved a comprehensive look into their whole process for a synergistic solution.



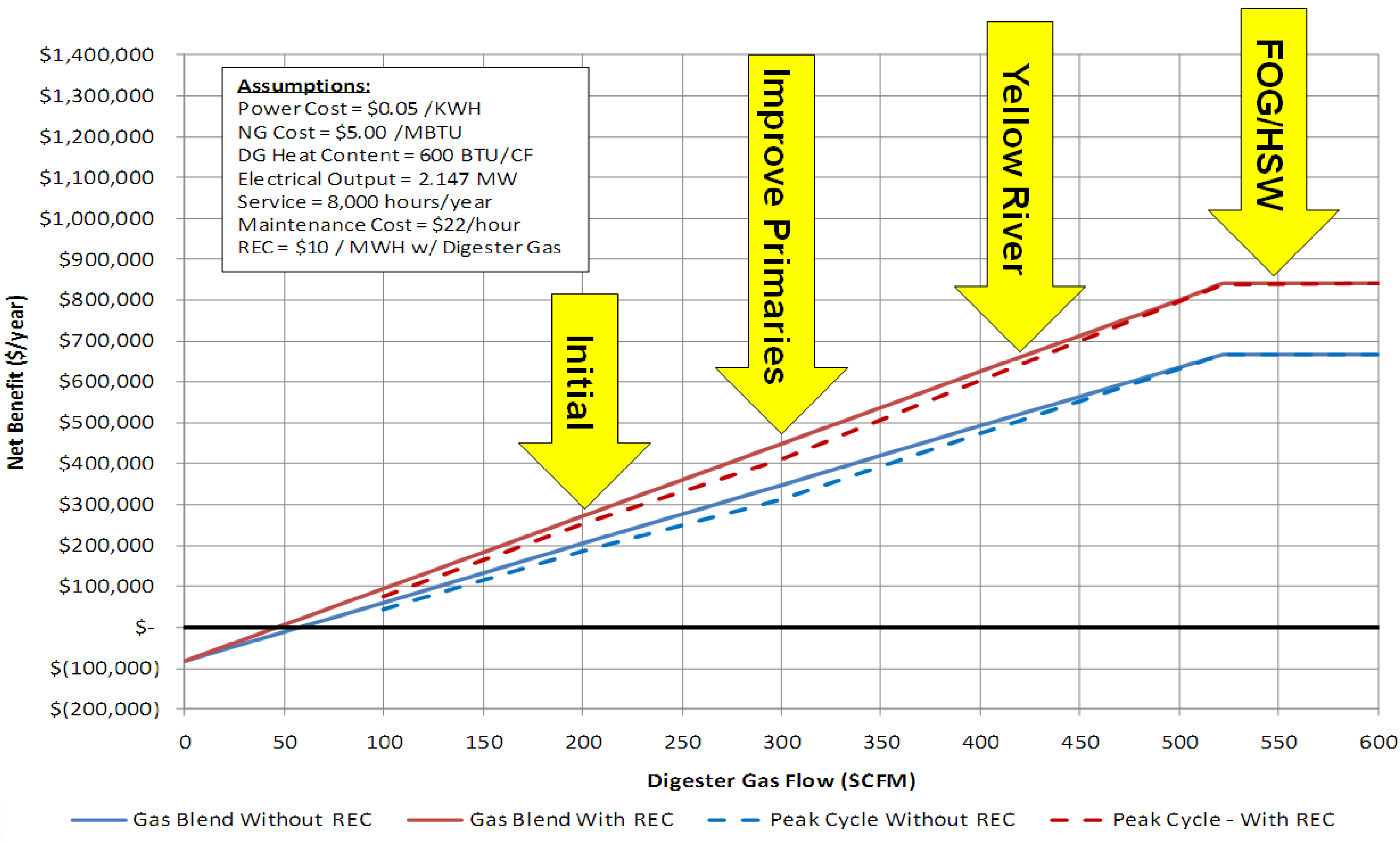
Primary clarifier operating performance for settling and capture was less than expected.

- **Primary clarifiers that "don't work"**
  - **Poor capture efficiency**
  - **Poor in-tank thickening**
- **In Plant Sampling and Testing**
  - **Confirmed perceptions**
  - **BioWin also confirmed some findings**



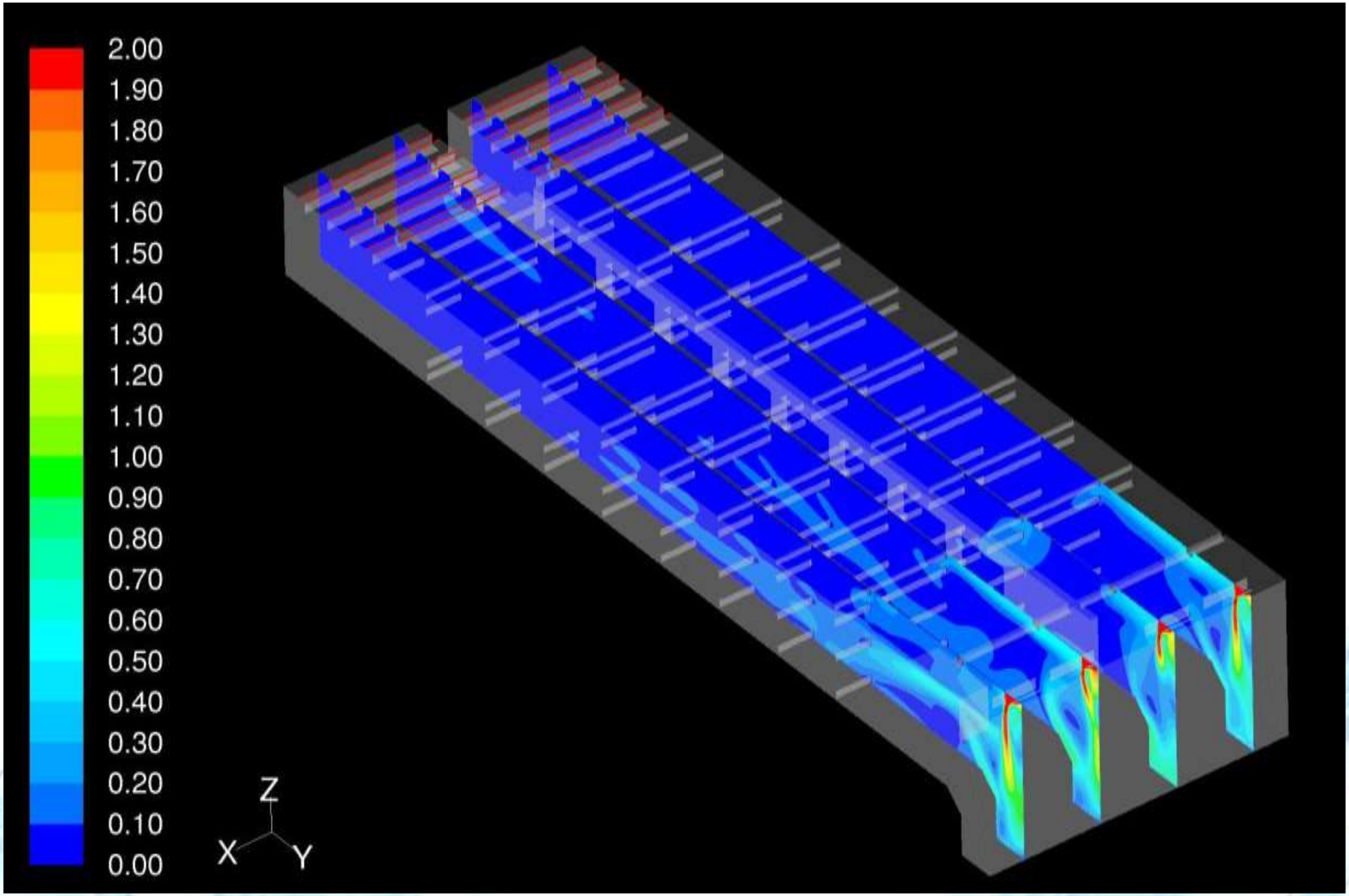
Pending new CHP system was to be added for beneficial use of digester gas.

… but the plant was "short" on digester gas production to meet maximum value solution.

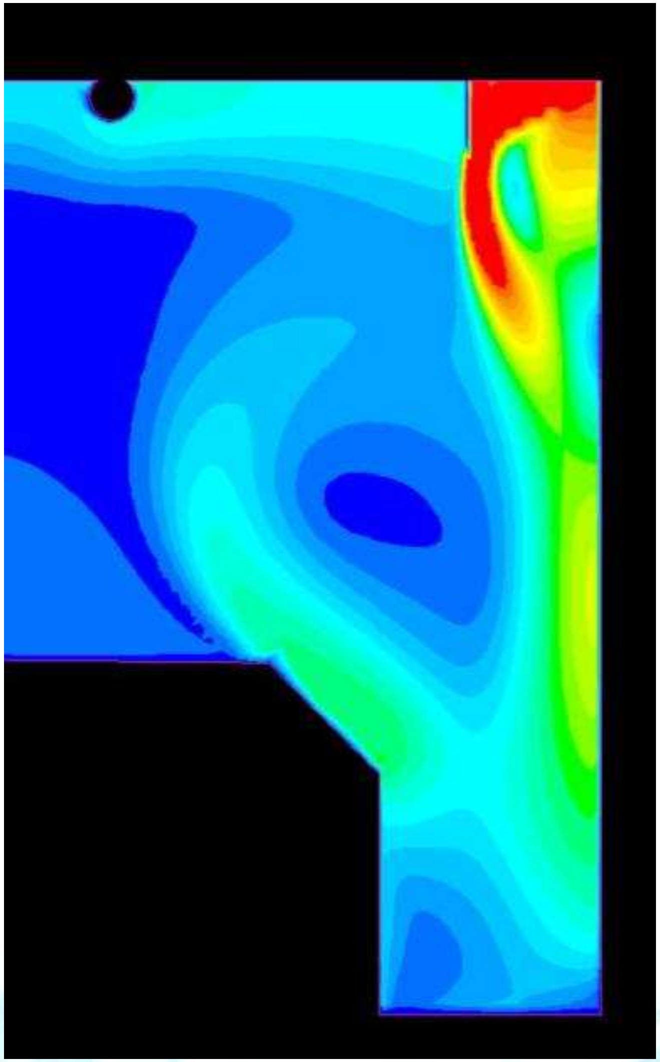


On-site settling column tests were conducted to get site-specific settling characteristics.

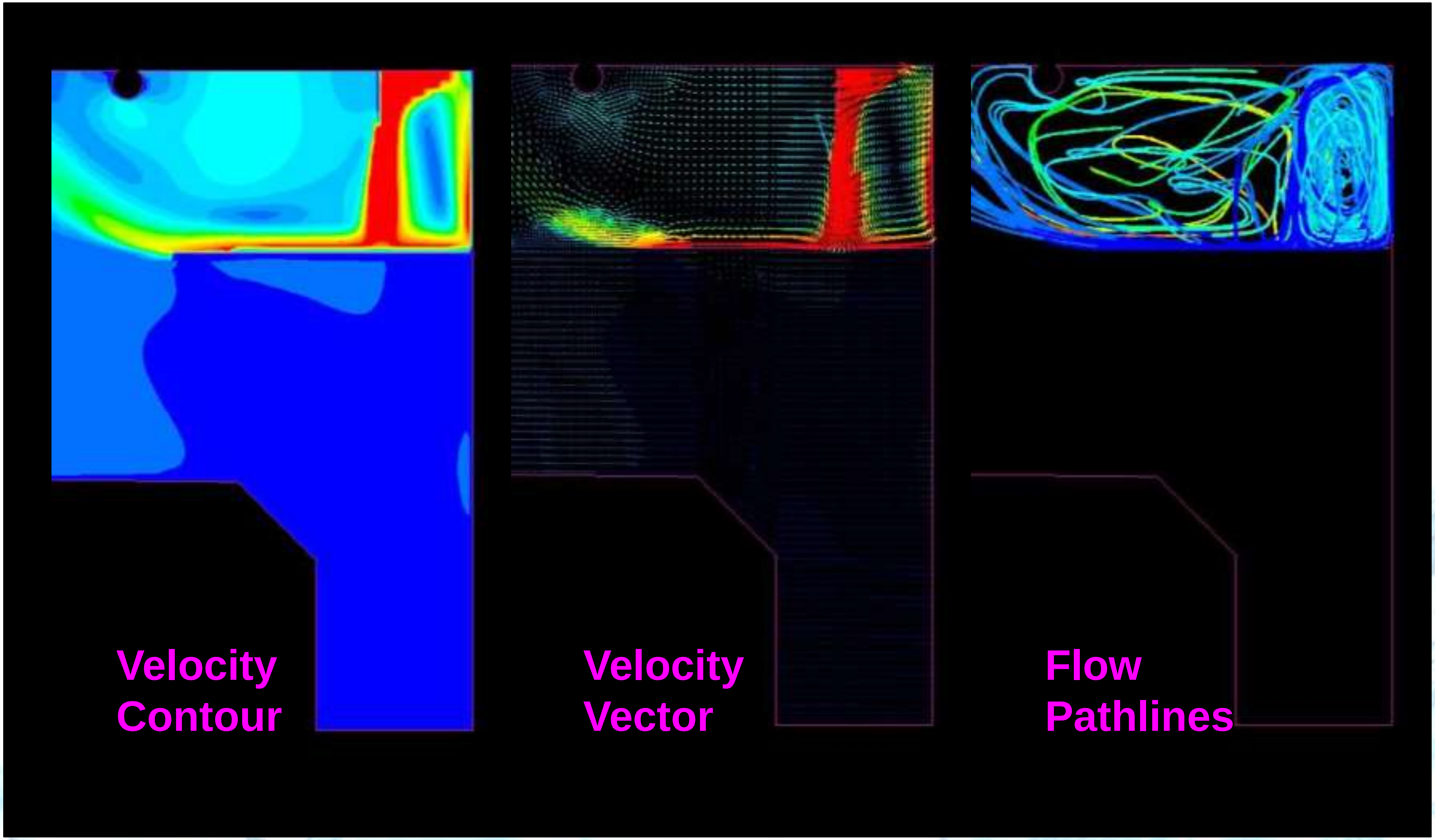
A 3-D CFD model was developed and calibrated to field performance data for the primary clarifiers



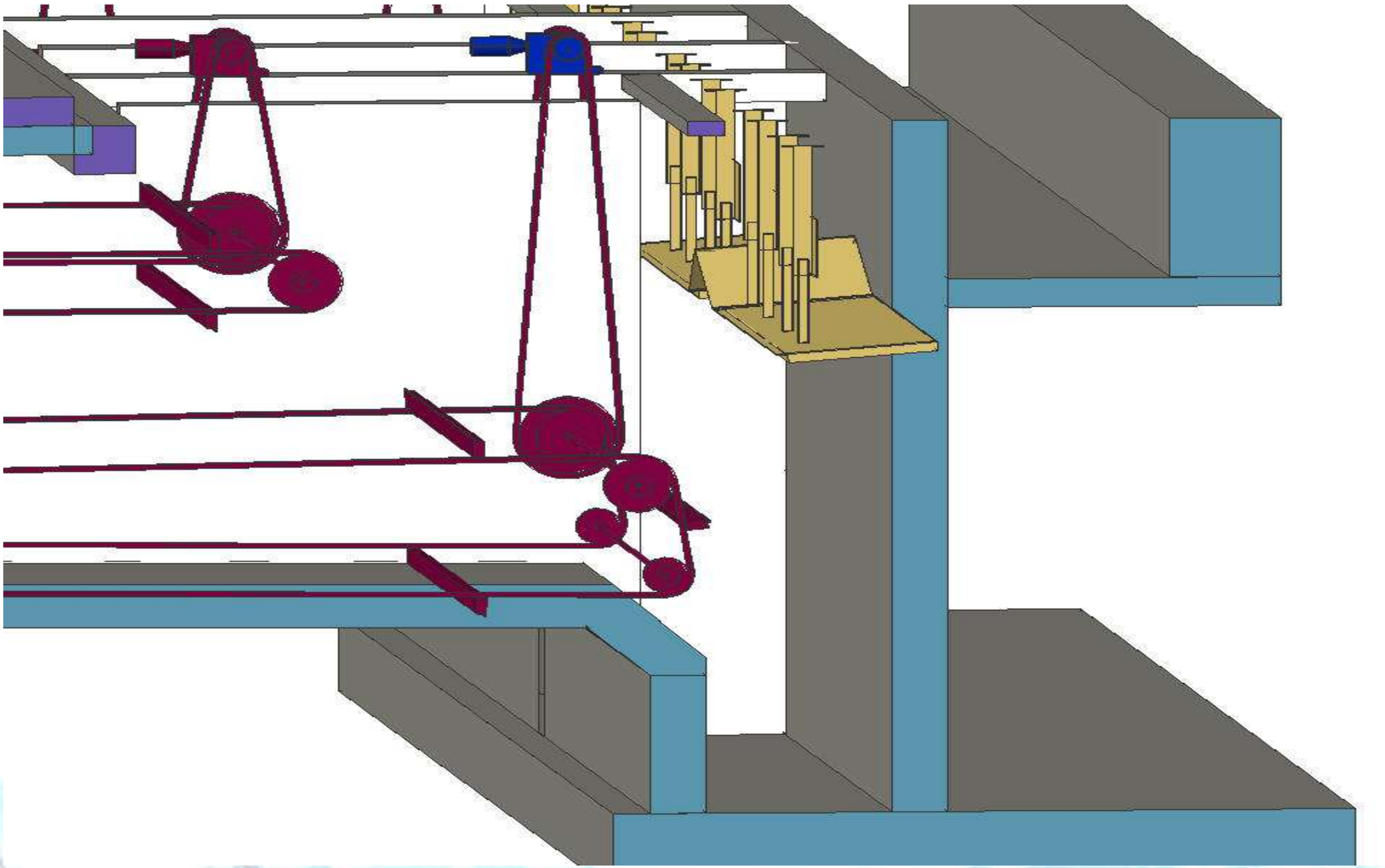
Scour from the vertical inlet baffle was causing poor thickening system performance



CFD modeling also used to develop a modified inlet baffle configuration to improve settling

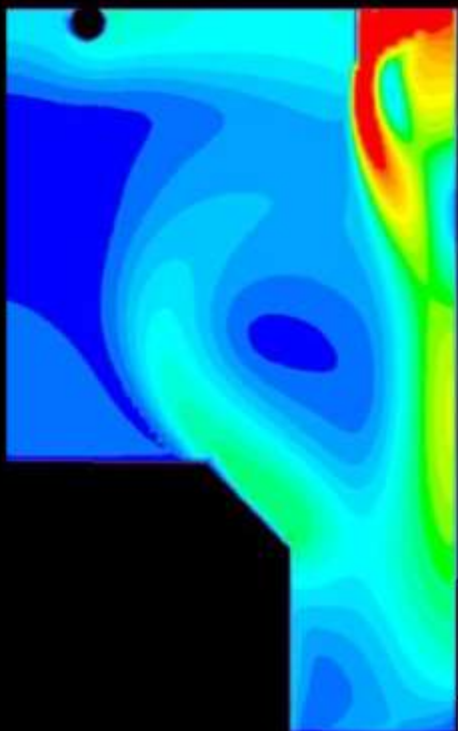


A new inlet baffle system was designed to eliminate scouring in the clarifier sludge well.



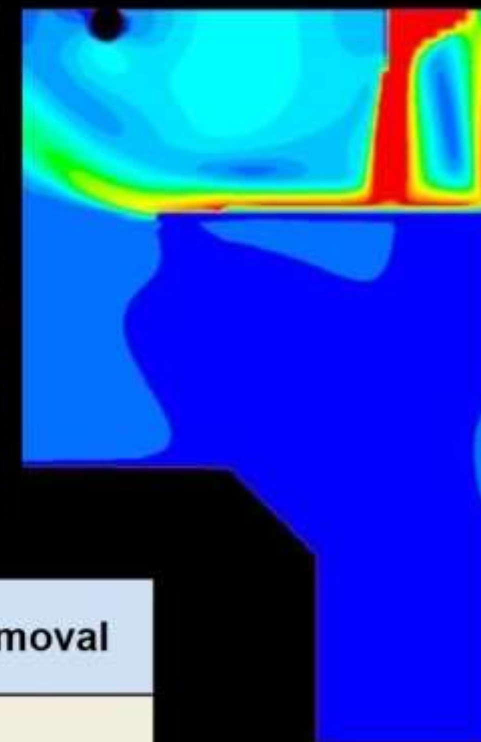
The modified baffle configuration was installed in one primary clarifier to test performance.

Field testing confirmed a 50% increase in clarifier TSS removal from 31% to 48% after baffle installed



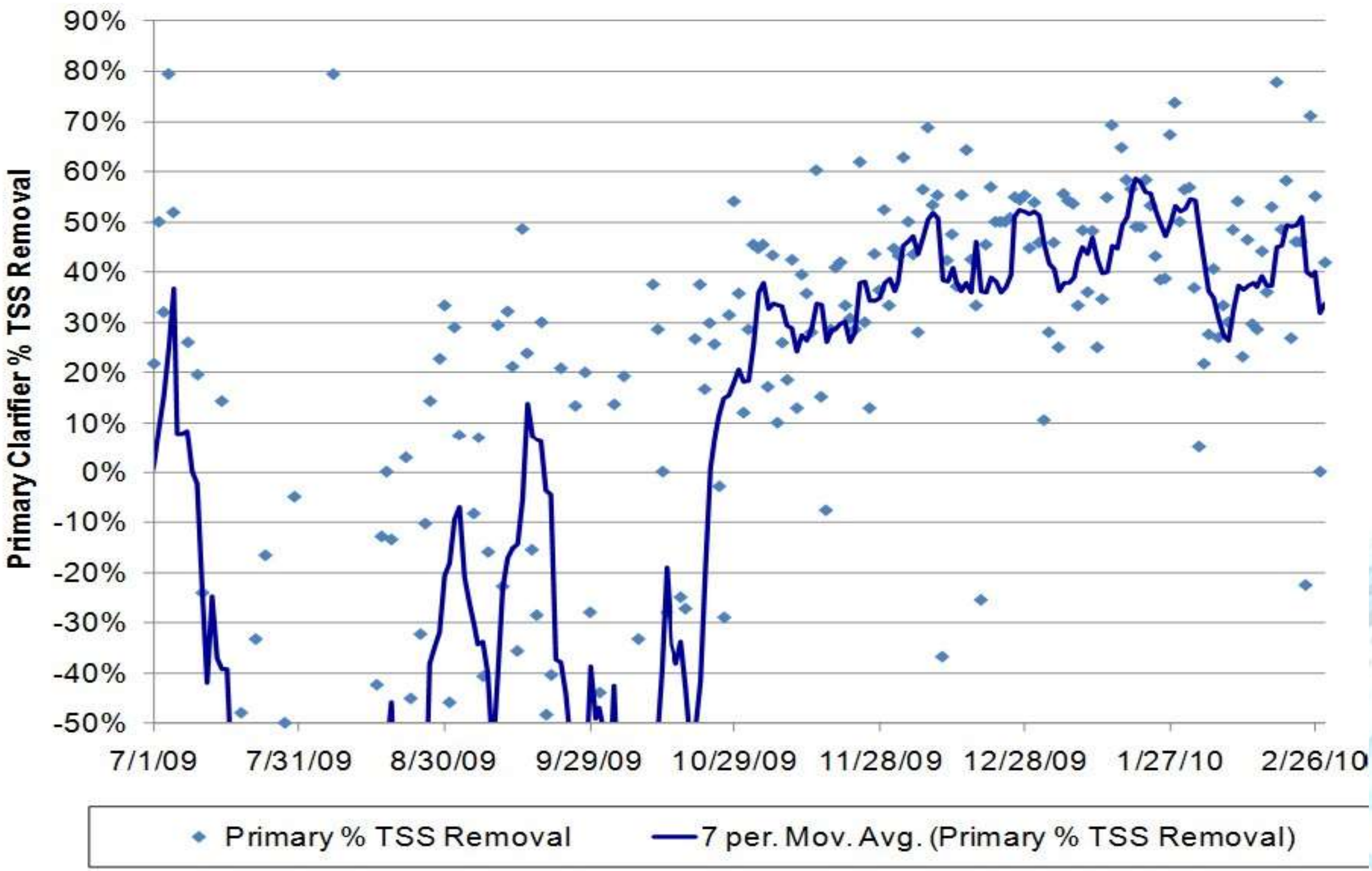
Before

Primary Clarifier	% TSS Removal
Primary 9 – Baffle Installed	48%
Primary 10 – As Is	31%

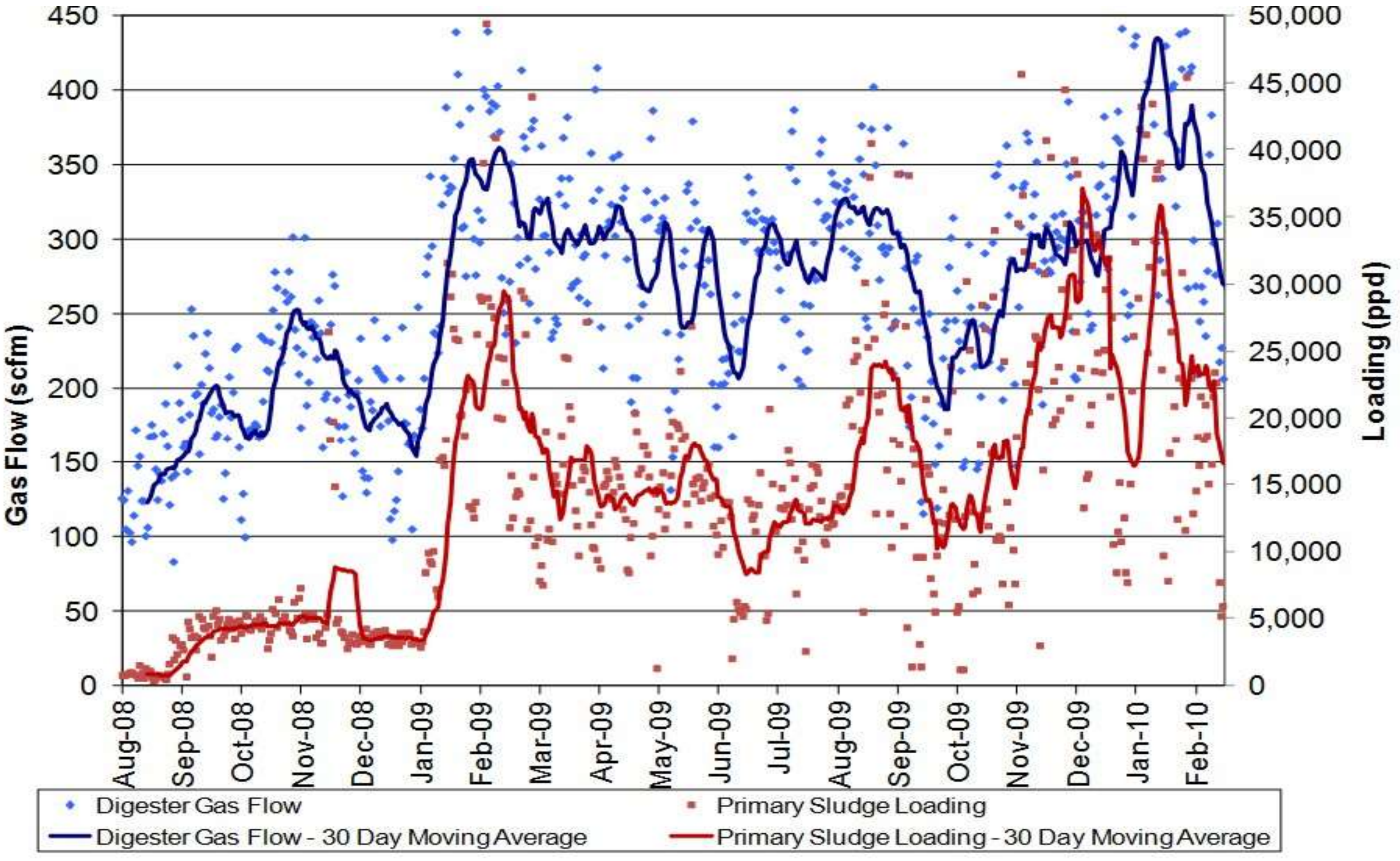


After

Primary clarifier effectiveness TSS removal increased dramatically following improvements.



Digester gas production rates also increased with increased primary sludge to digestion.



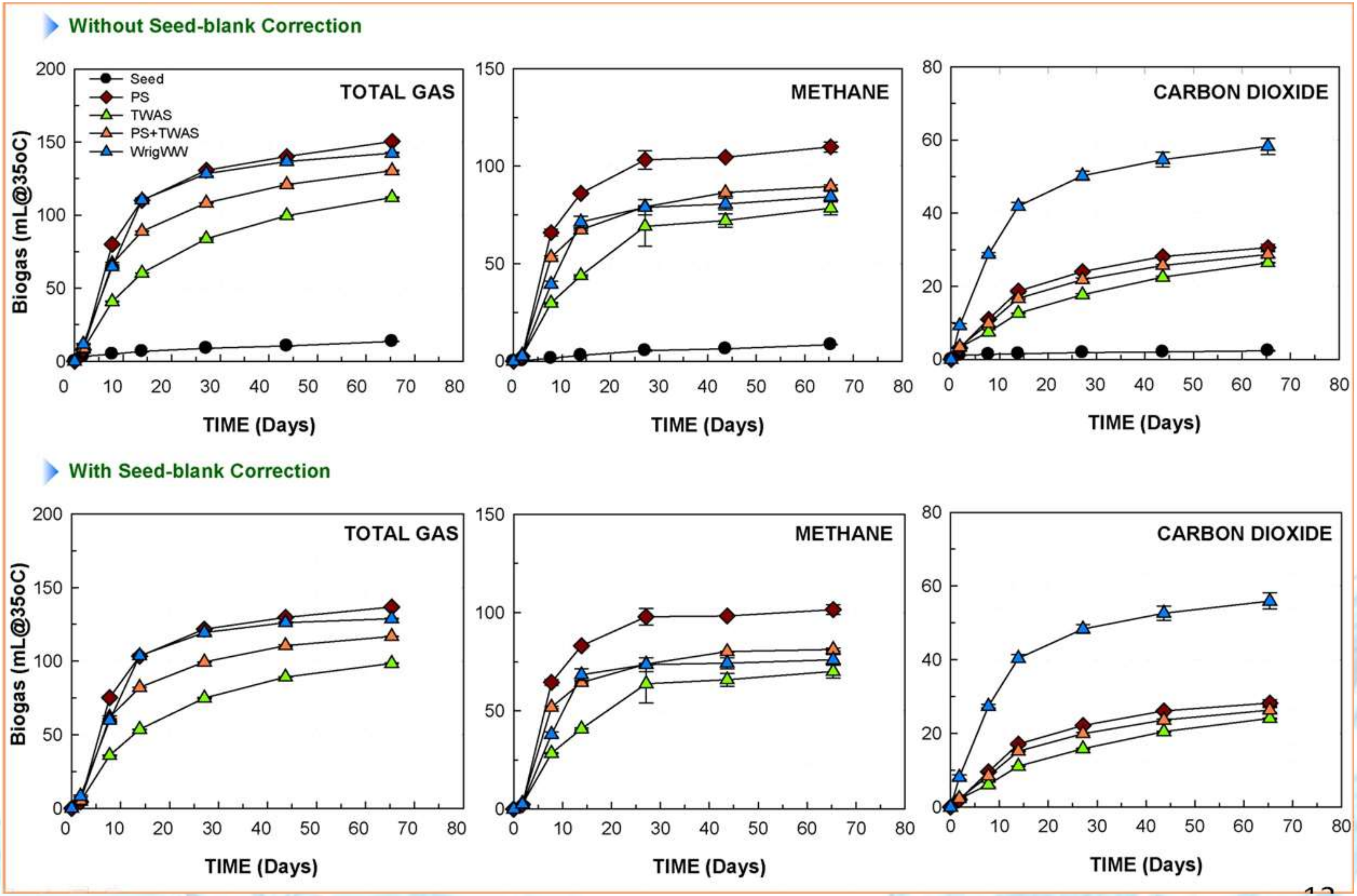
Other opportunities were also identified during the primary clarifier optimization study.

- **BioWin calibration and special sampling verified “true” loadings much lower helping “capacity crisis”**
- **Improved primary clarifier performance reduced loads to secondary process**
- **Digesters were still short on capacity**
- **Recommended co-thickening to 5.5% on RDTs replacing high energy WAS thickening centrifuges**

DG2E facility generates 2.1MW output power and saves over $1MM per year in purchased power.

FOG/HSW receiving added for co-digestion of select streams to boost gas production.

Ultimate degradability and treatability testing was conducted on prospective HSW streams.



GTW Characterization

Percentile	Solids (%TS)	Volatile Solids (%VS)	Total COD (mg/L)	Soluble COD (mg/L)
10%	3.2%	94%	77,000	7,000
50%	7.4%	97%	142,000	12,000
90%	11.7%	98%	207,000	16,000

Percentile	TKN (mg/L)	tCOD:TKN	TP (mg/L)	tCOD:TP
10%	326	120	36	1,500
50%	545	230	55	2,500
90%	1,160	420	80	3,500

GTW Characterization

Percentile	Solids (%TS)	Volatile Solids (%VS)	Total COD (mg/L)	Soluble COD (mg/L)
10%	3.2%	94%	77,000	7,000
50%	7.4%	97%	142,000	12,000
90%	11.7%	98%	207,000	16,000

Percentile	TKN (mg/L)	tCOD:TKN	TP (mg/L)	tCOD:TP
10%	326	120	36	1,500
50%	545	230	55	2,500
90%	1,160	420	80	3,500

GTW Characterization

Percentile	Solids (%TS)	Volatile Solids (%VS)	Total COD (mg/L)	Soluble COD (mg/L)
10%	3.2%	94%	77,000	7,000
50%	7.4%	97%	142,000	12,000
90%	11.7%	98%	207,000	16,000

Primary Sludge
tCOD:TKN = 44

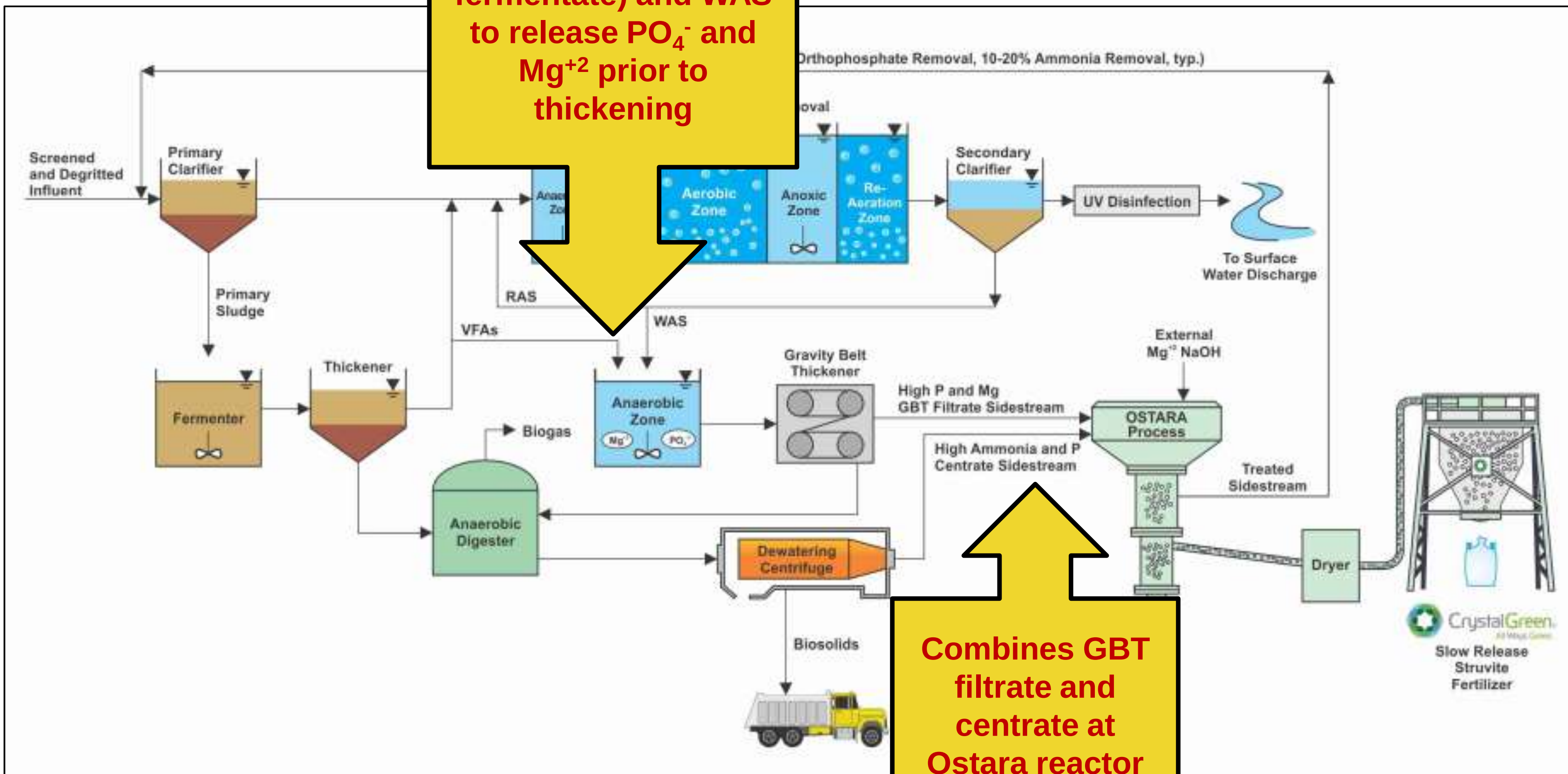
Primary Sludge
tCOD:TP = 200

Percentile	TKN (mg/L)	tCOD:TKN	TP (mg/L)	tCOD:TP
10%	326	120	36	1,500
50%	545	230	55	2,500
90%	1,160	420	80	3,500

Construction underway for installation of on-site struvite recovery system using WASSTRIP

WASSTRIP

Wasstrip combines VFAs (PS or fermentate) and WAS to release PO_4^- and Mg^{+2} prior to thickening



Combines GBT filtrate and centrate at Ostara reactor

Questions

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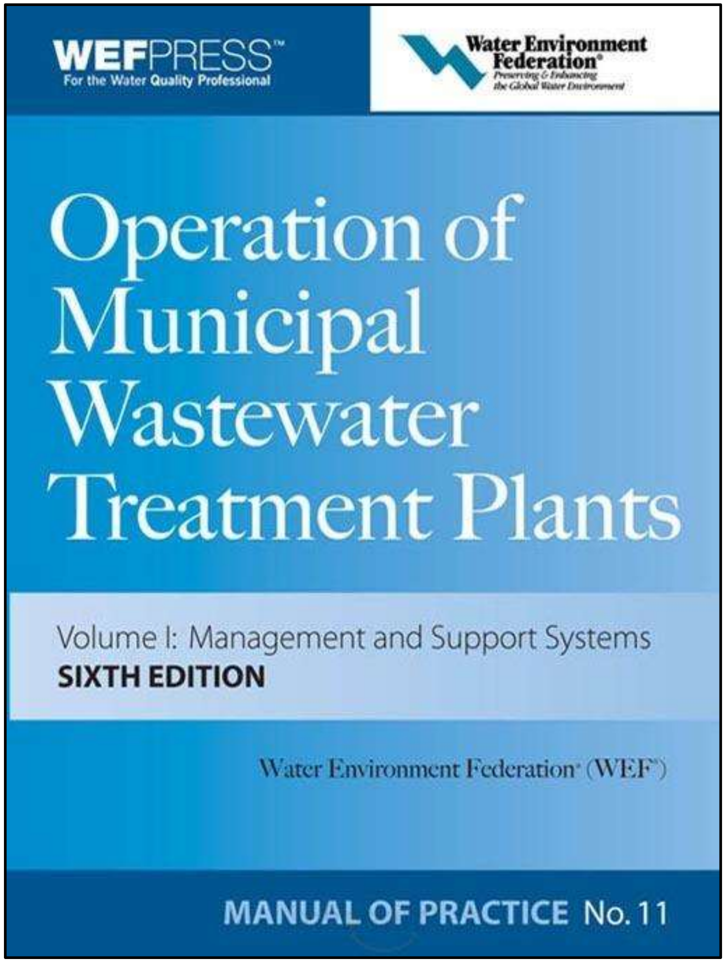
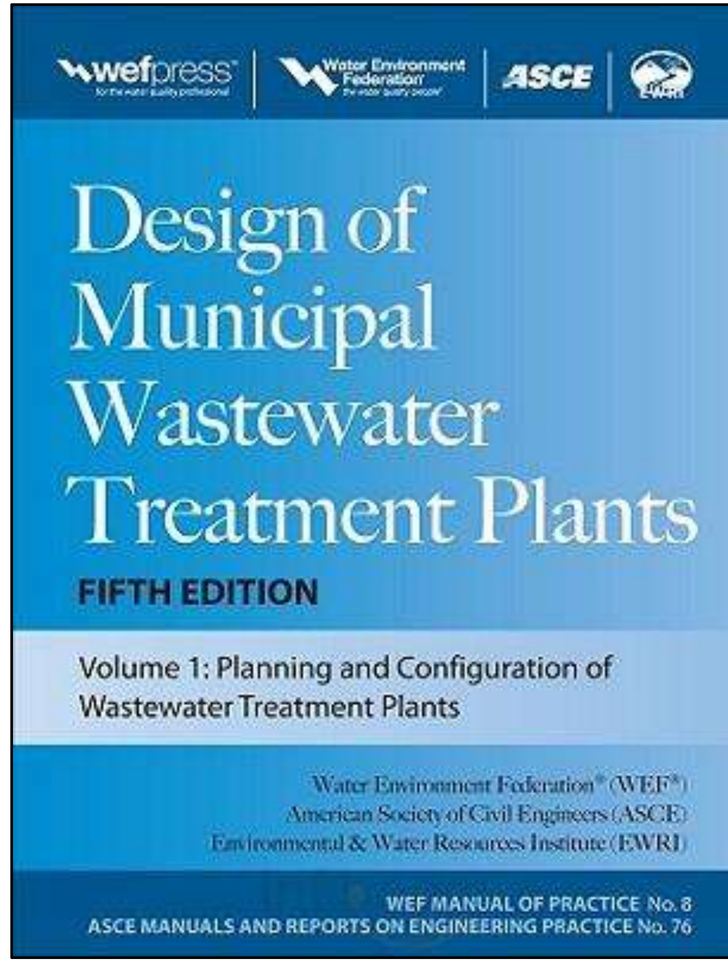
Hazen and Sawyer, PC

hlong@hazenandsawyer.com
919-833-7152

Some recommended reference sources could include:





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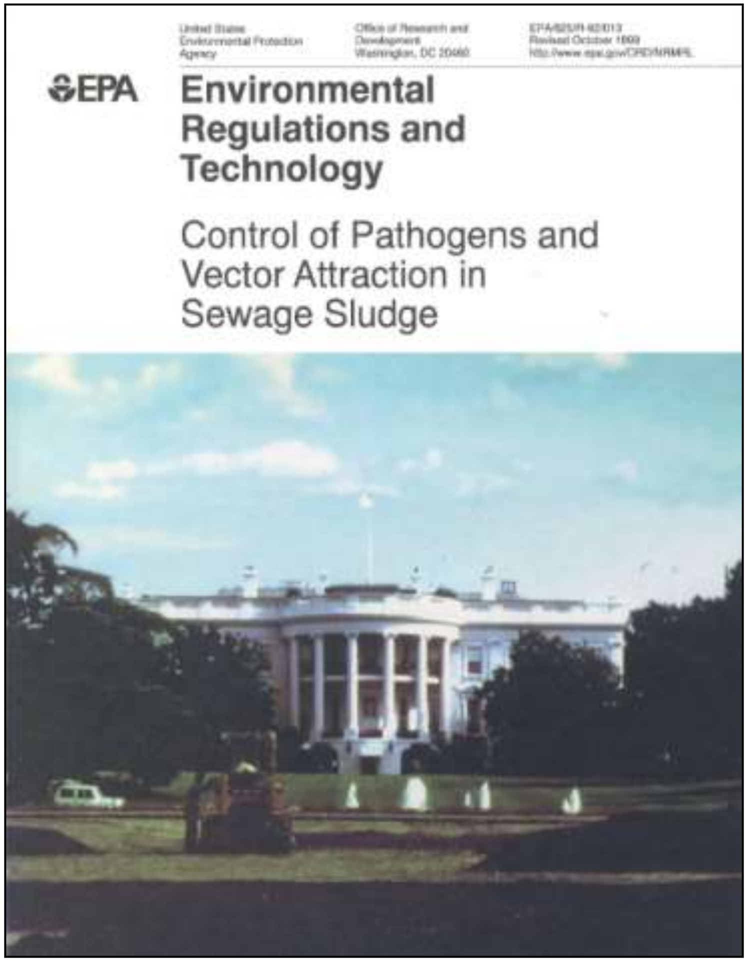
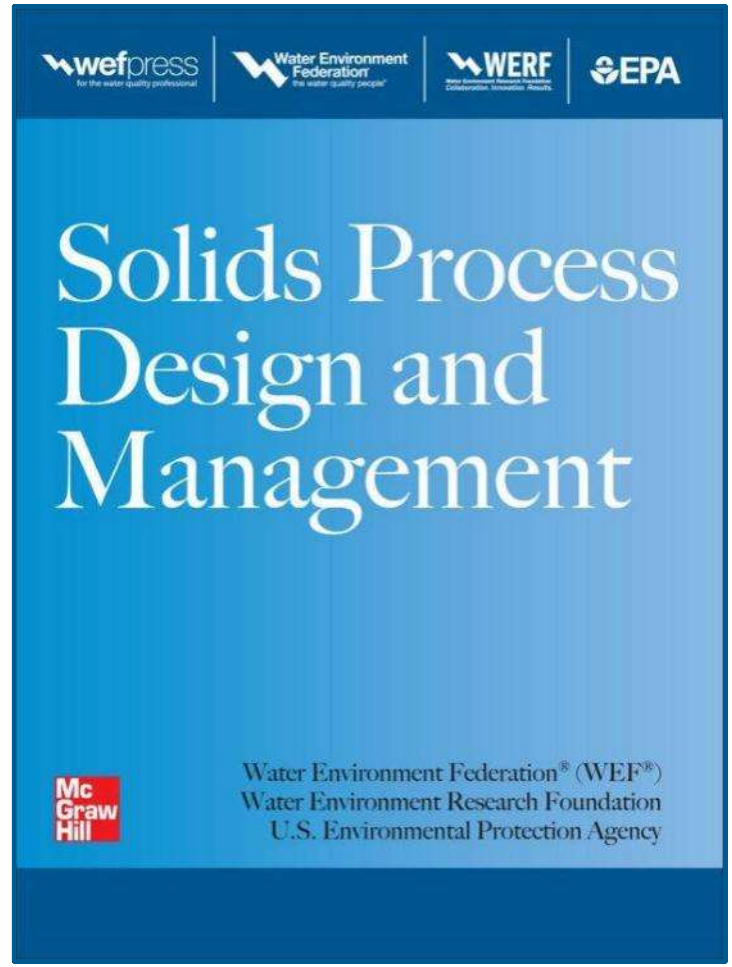
Some recommended reference sources could include:





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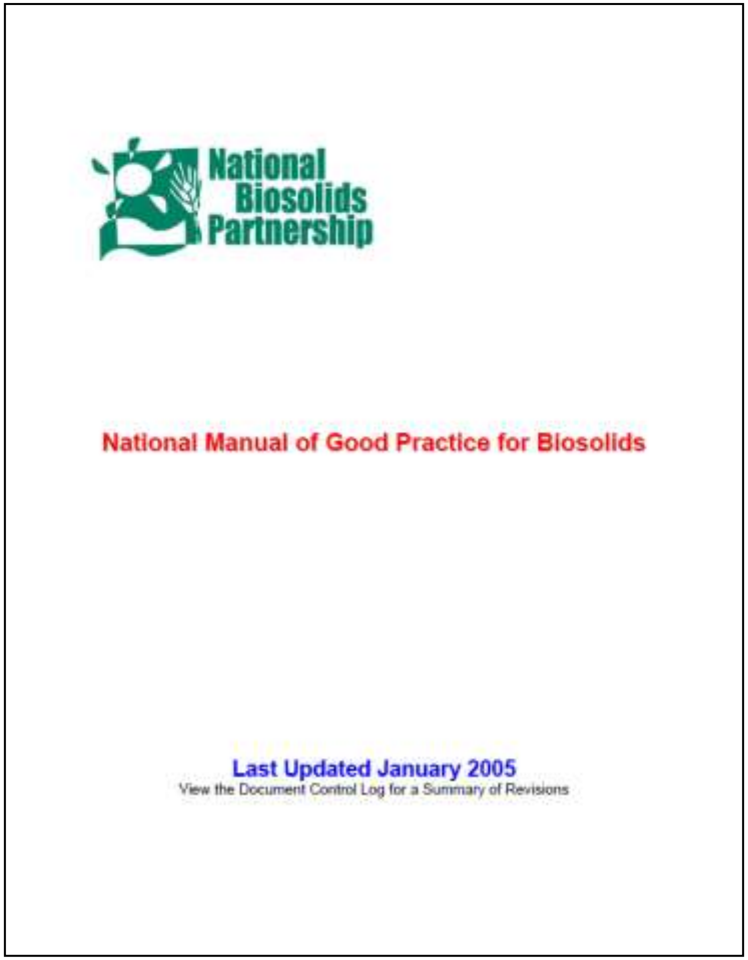

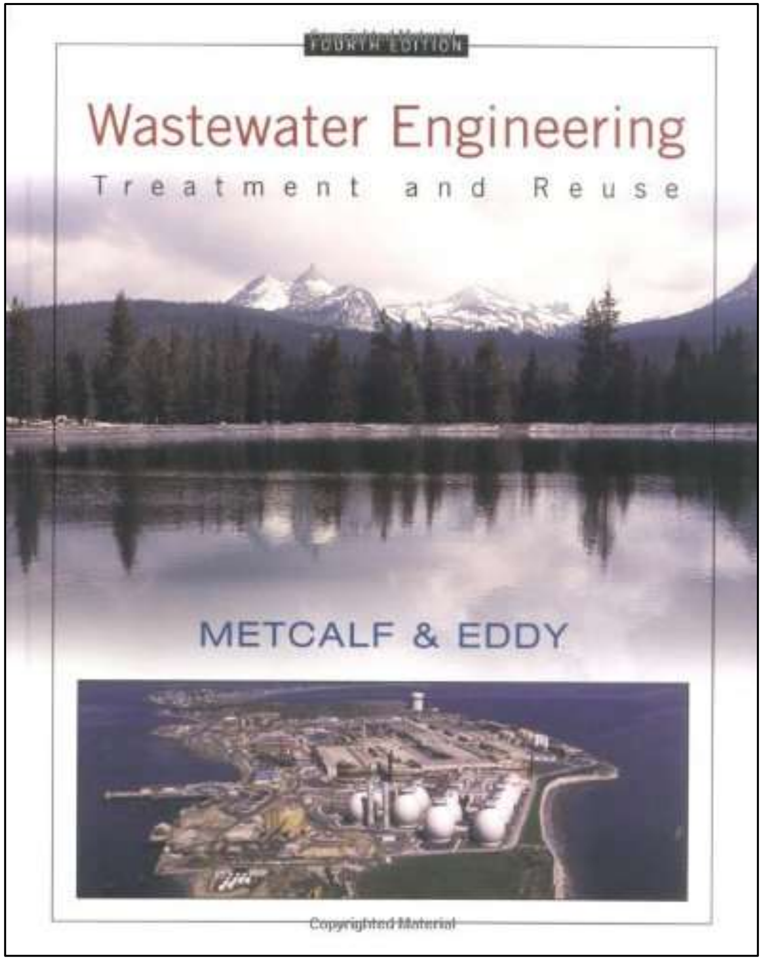

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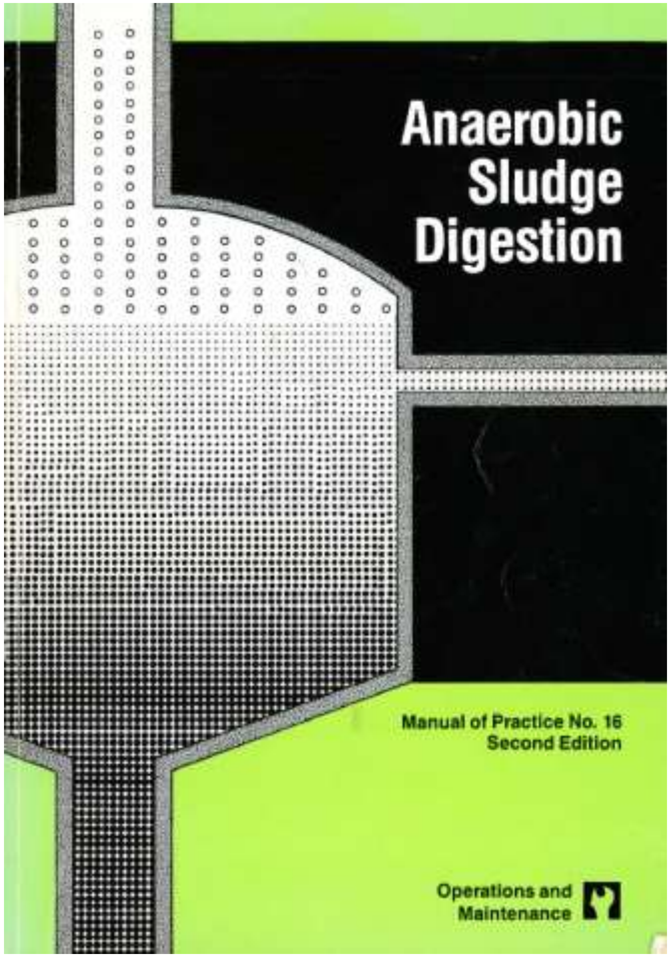

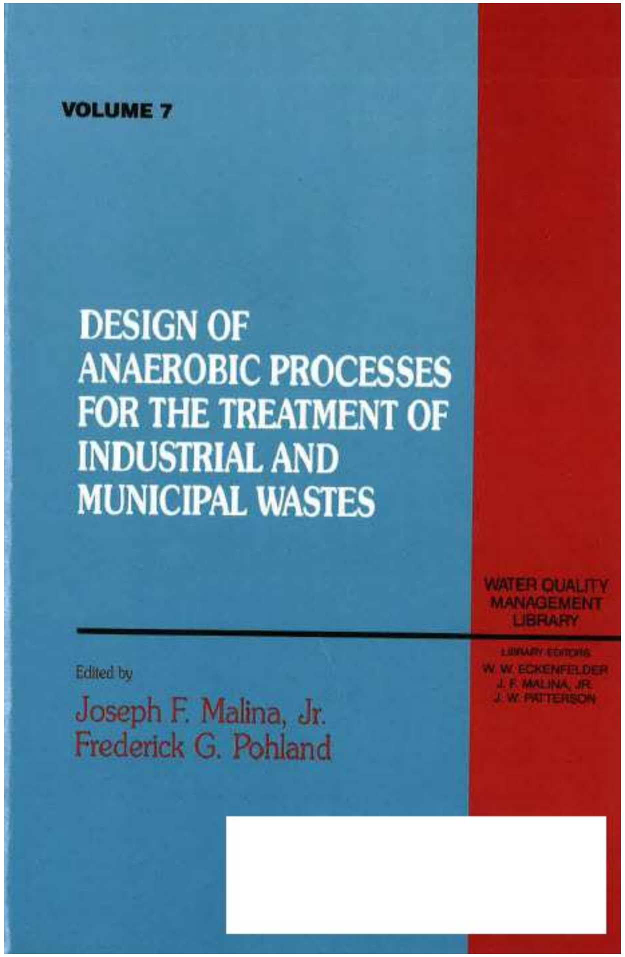

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