



**MARQUETTE**  
UNIVERSITY

Anaerobic Treatment of High-Strength  
Industrial Wastes

**INDUSTRIAL WASTE TREATMENT  
TECHNOLOGIES AND DESIGN**

Dennis E. Totzke, P.E.  
Applied Technologies, Inc.  
Brookfield, WI

September 13 - 14, 2016  
Milwaukee, WI

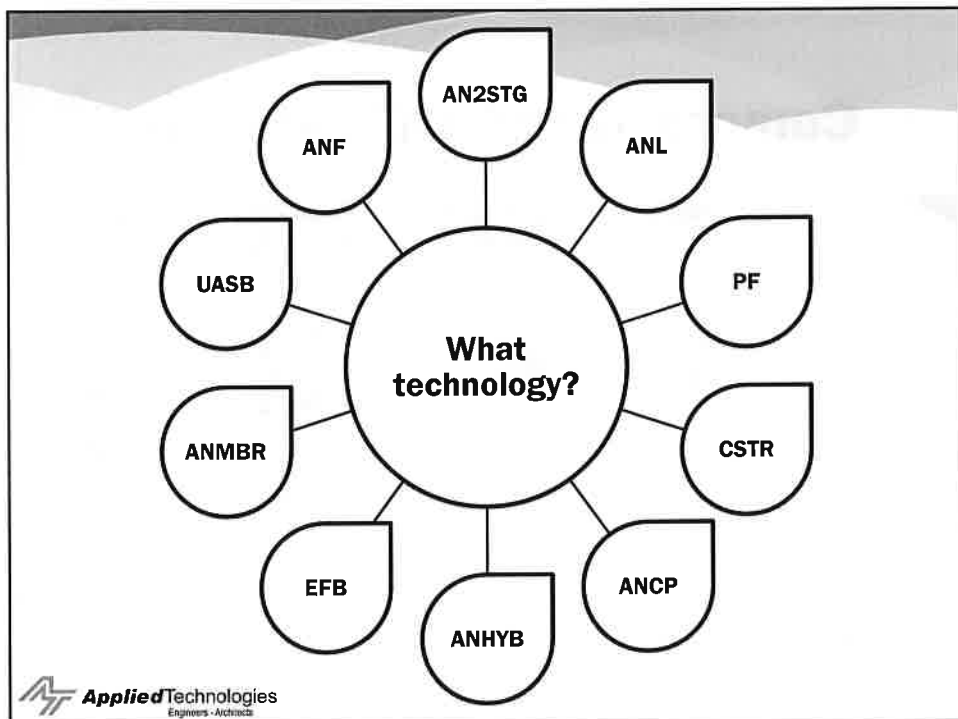


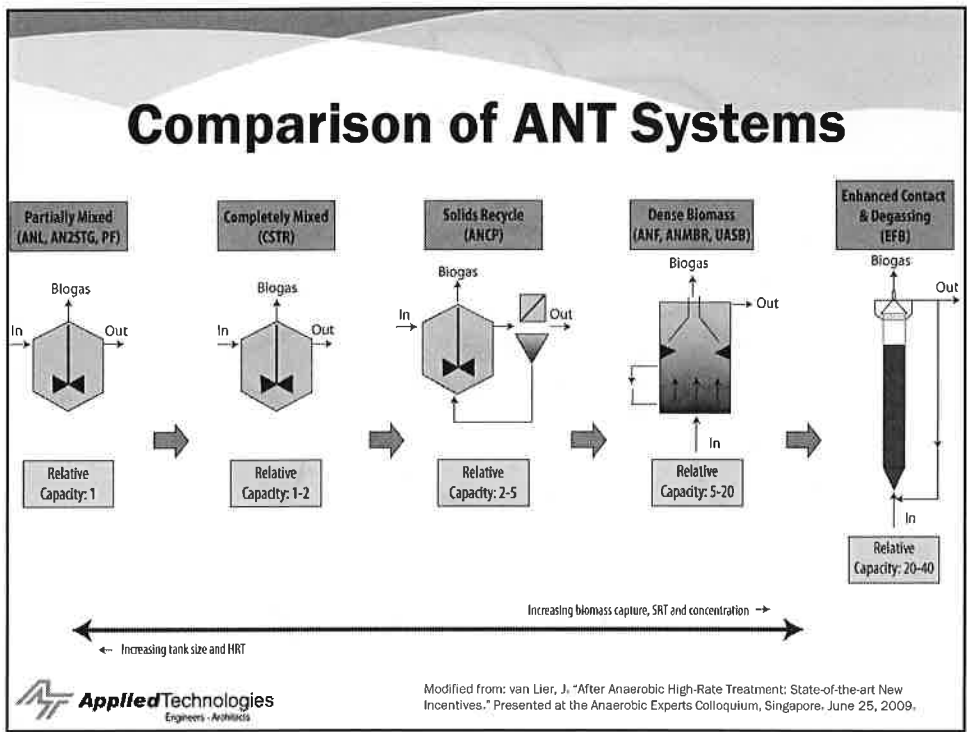
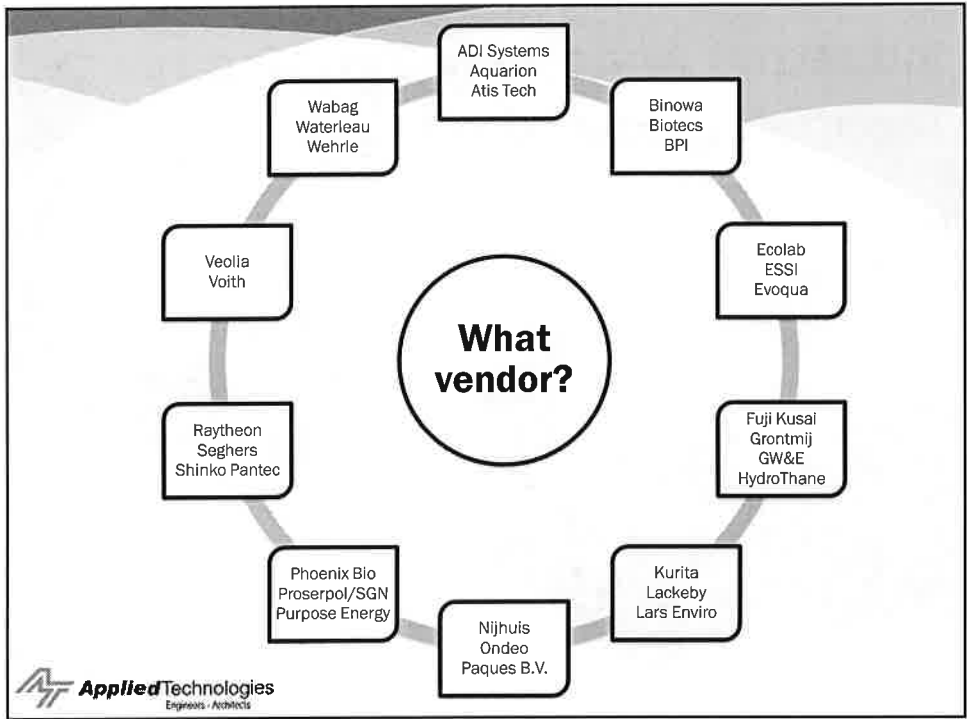
# Industrial Anaerobic Treatment Technologies and Design

September 13, 2018

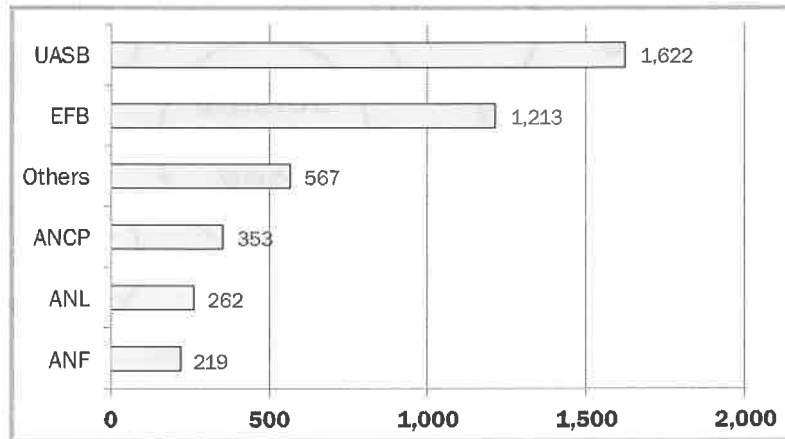
Dennis E. Totzke, P.E.  
Applied Technologies, Inc.

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Engineers - Architects



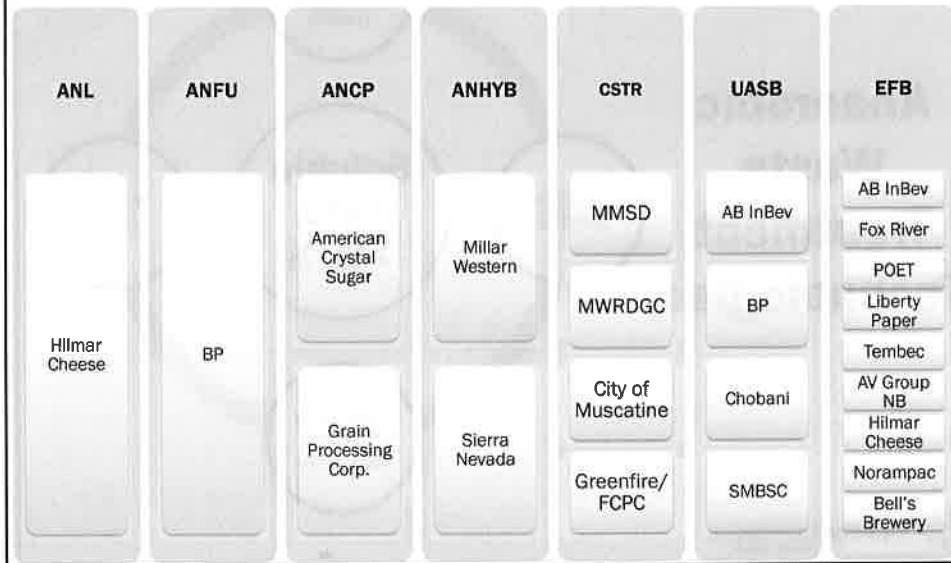


## Industrial ANT Installations Worldwide (as of 9/16)

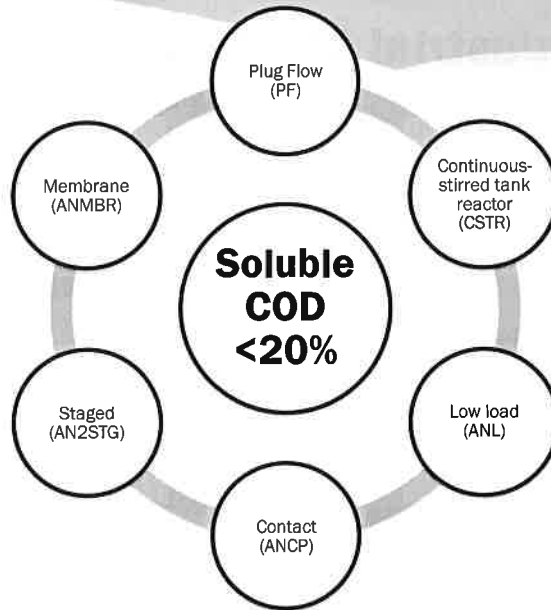


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## Attendee ANT Plants

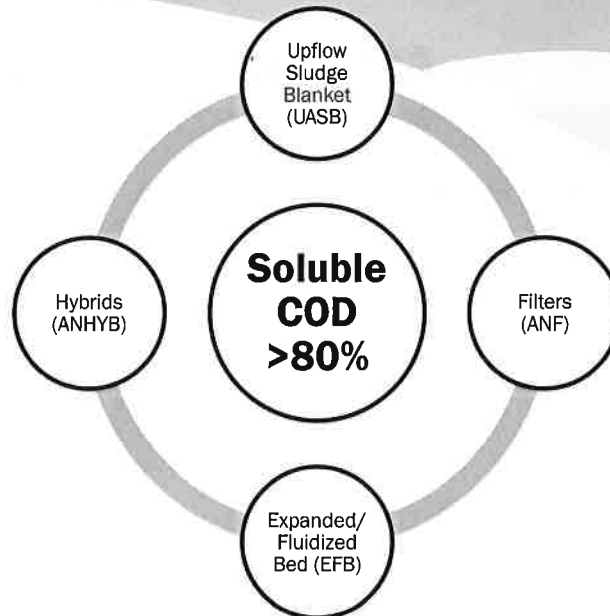


# Anaerobic Waste Treatment Technologies



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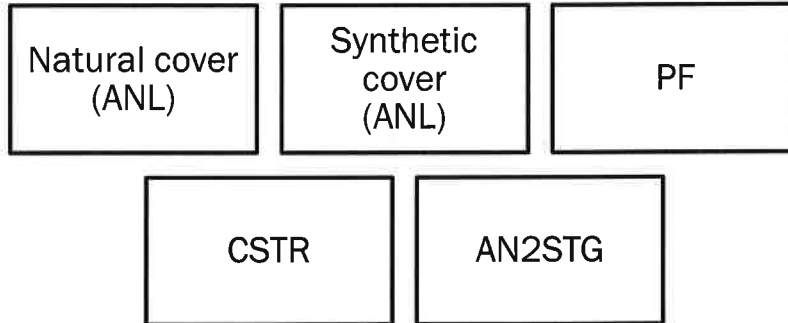
# Anaerobic Waste Treatment Technologies



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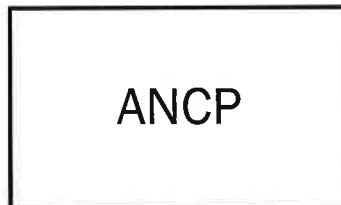
## Low-Load Technologies

< 2 kg TCOD/m<sup>3</sup>d



## Medium-Load Technologies

2 to 5 kg TCOD/m<sup>3</sup>d



## High-Load Technologies

5 to 20 kg TCOD/m<sup>3</sup>d

ANF

UASB

ANHYB

ANMBR

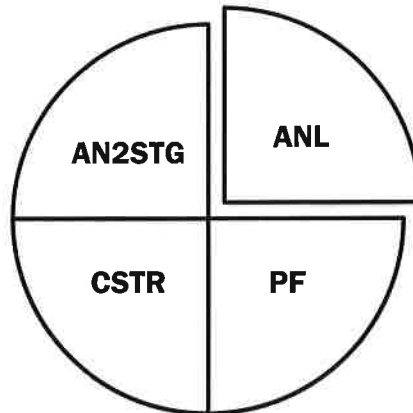
## Very High-Load Technologies

> 20 kg TCOD/m<sup>3</sup>d

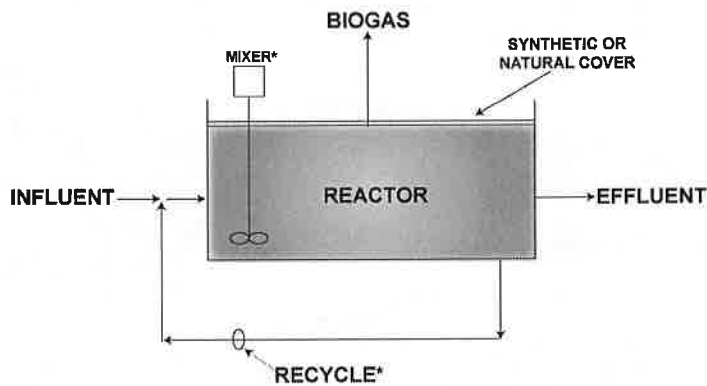
EFB

# Anaerobic Treatment Technologies

## Low Load

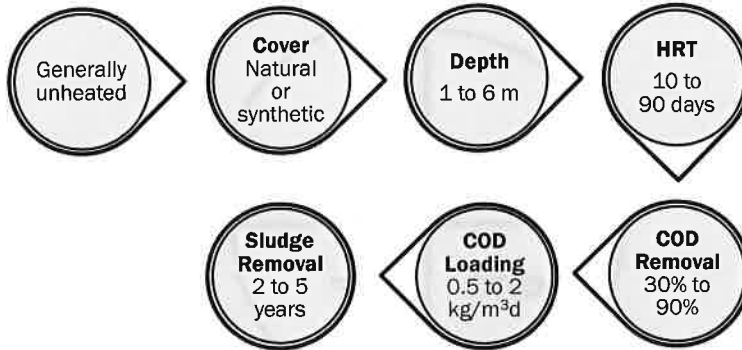


# Lagoon System Diagram



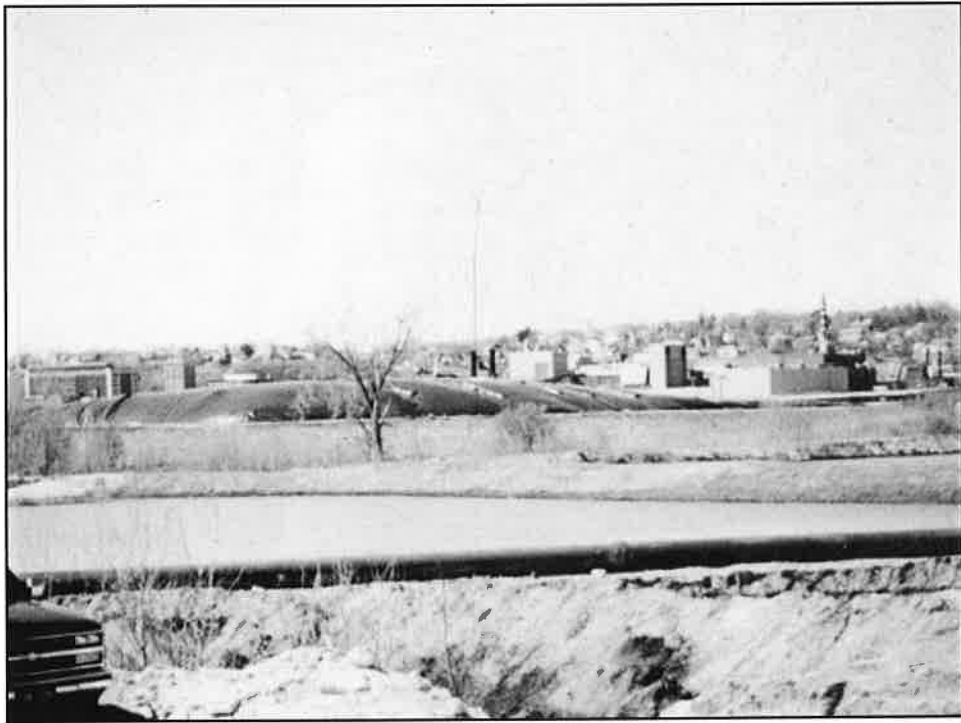
\*OPTIONAL FEATURE

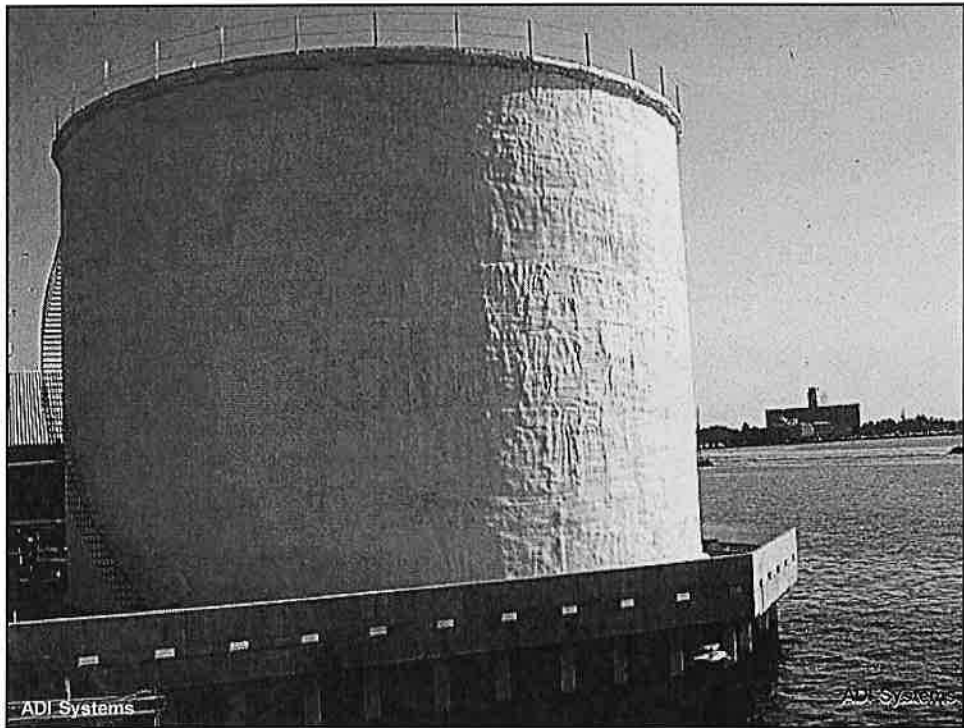
# Anaerobic Lagoon

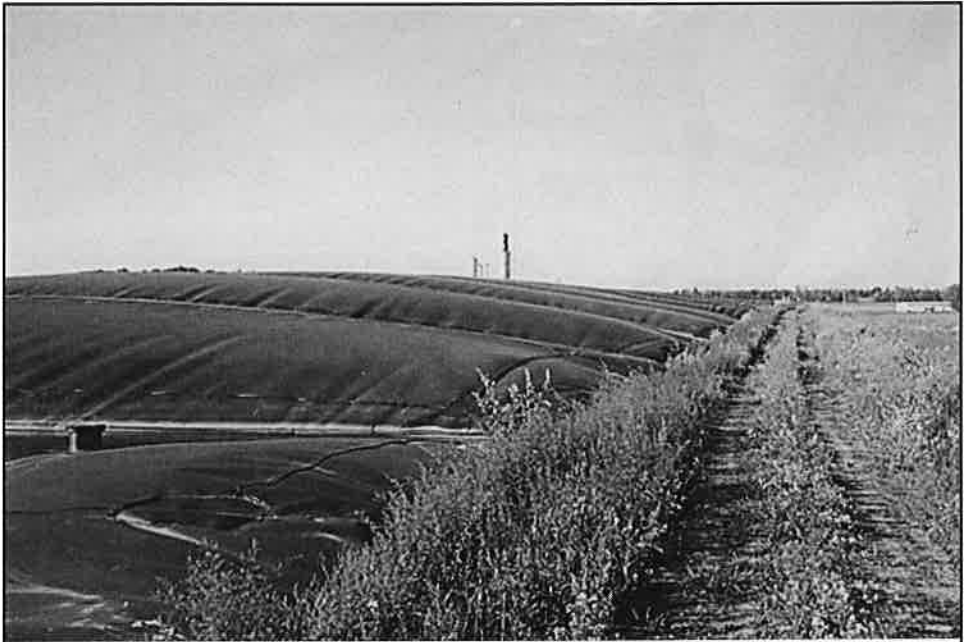


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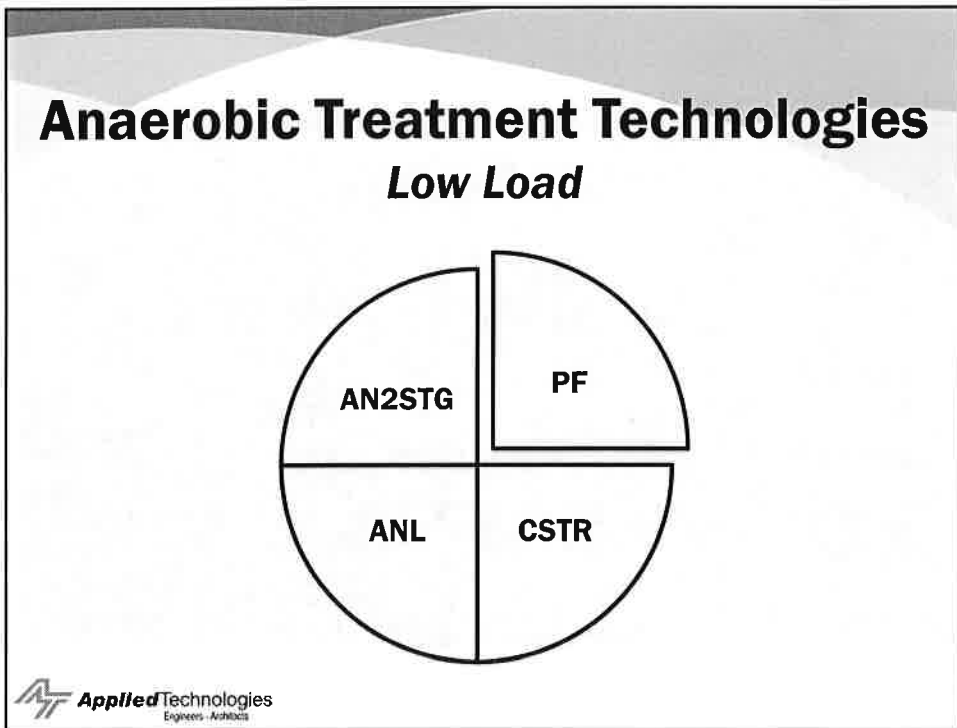




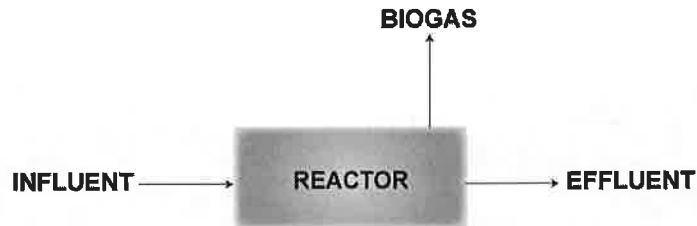
 **Applied Technologies**  
Engineers - Architects



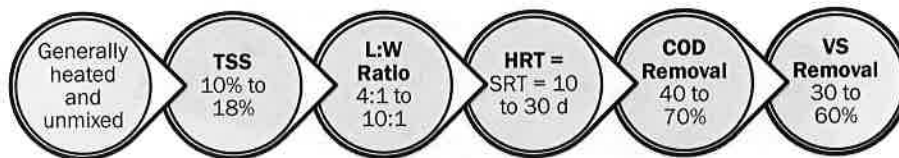
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# Plug Flow System Diagram

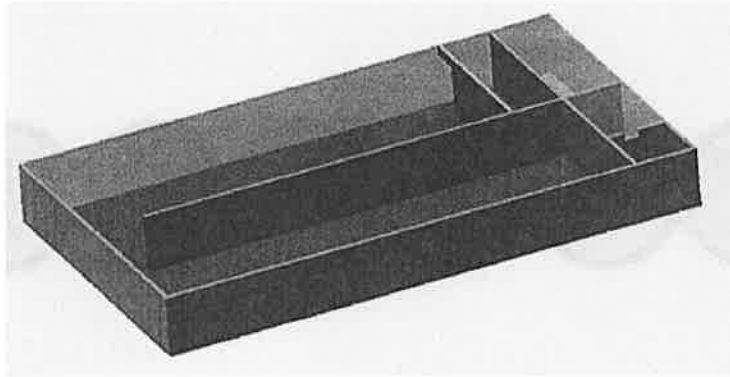


# Plug Flow System

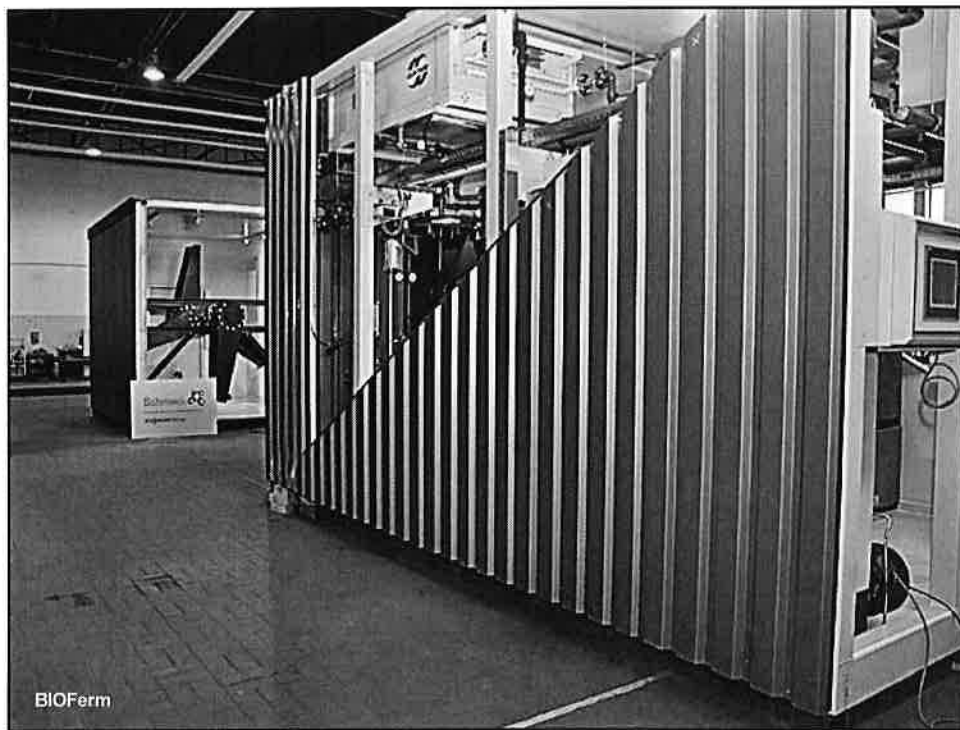
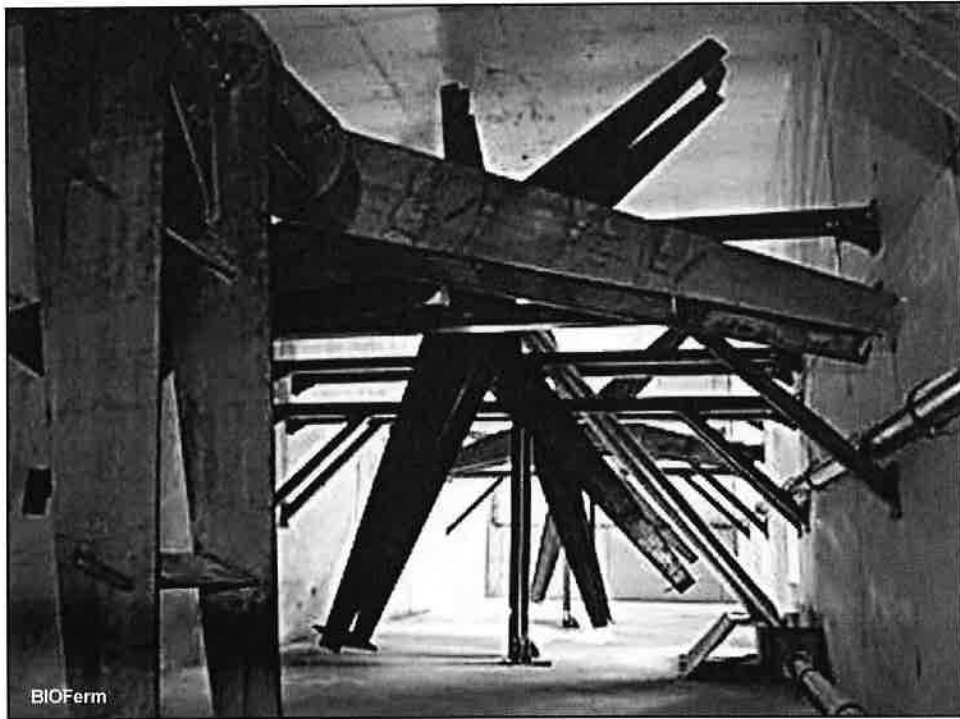




## 3-D View of Plug Flow

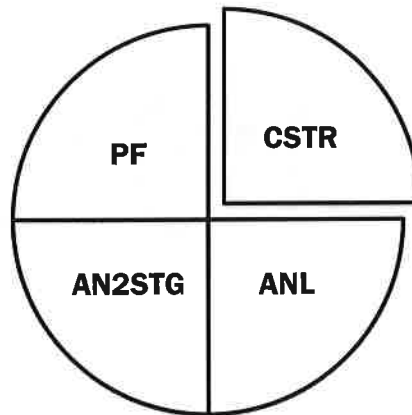




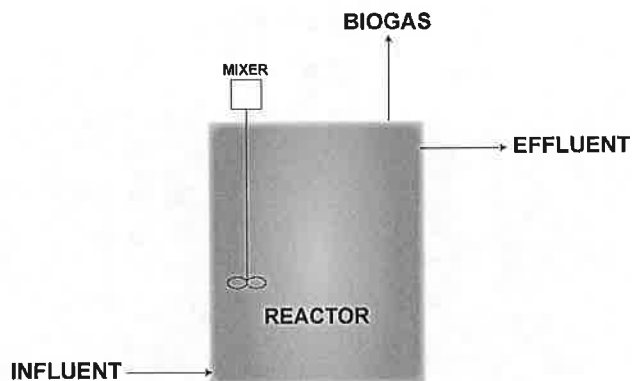


# Anaerobic Treatment Technologies

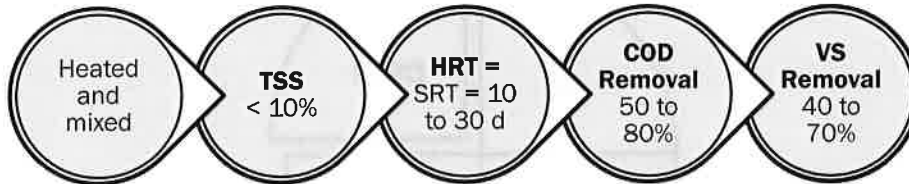
## Low Load



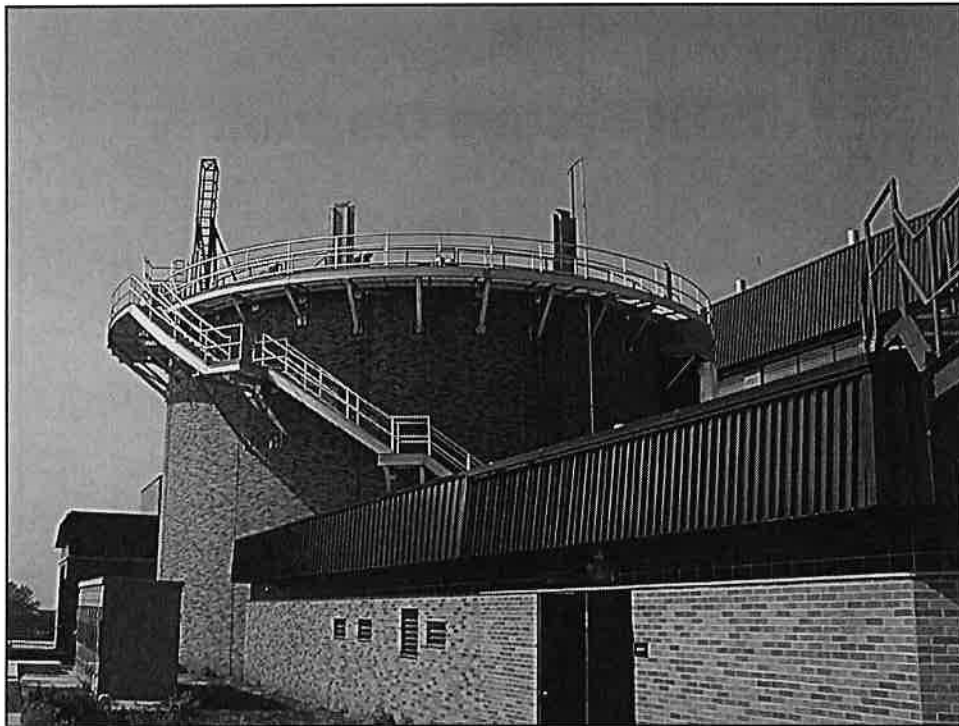
## CSTR System Diagram

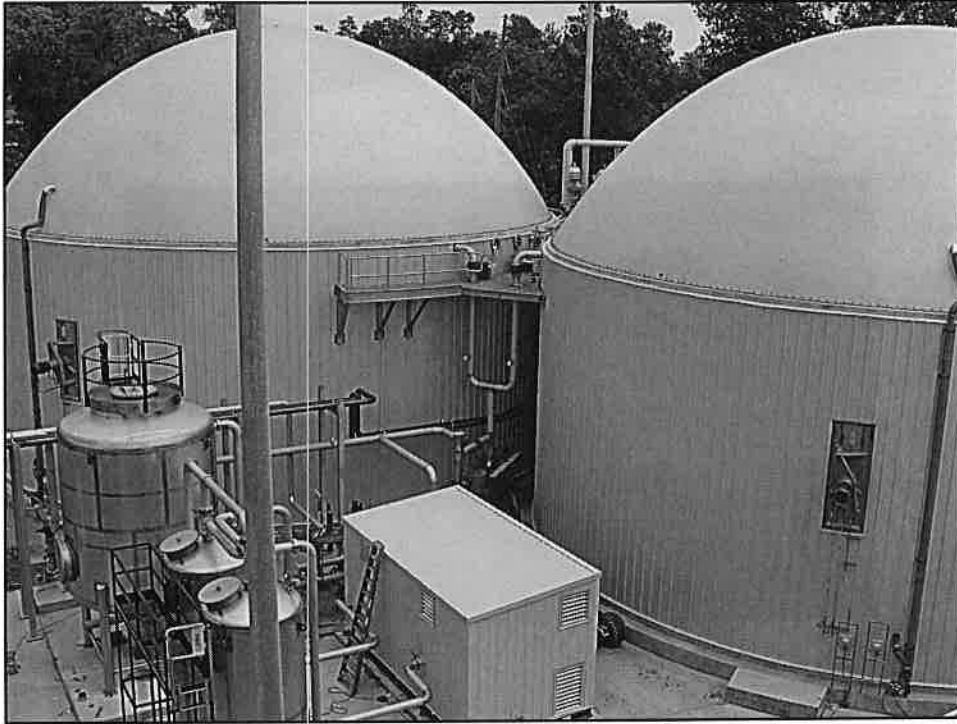


# CSTR System

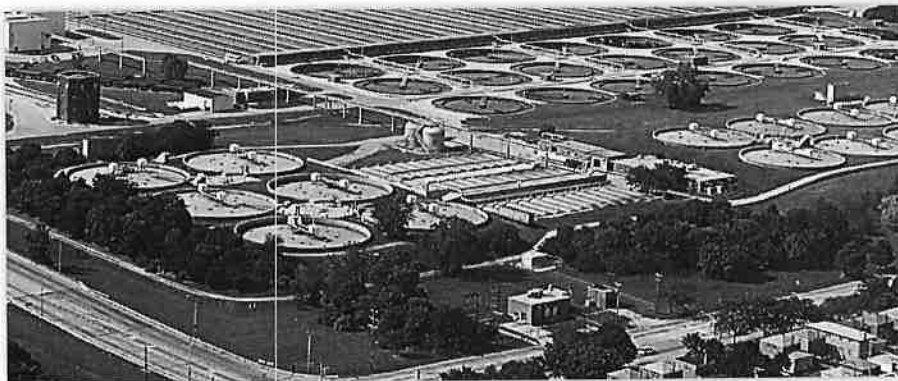


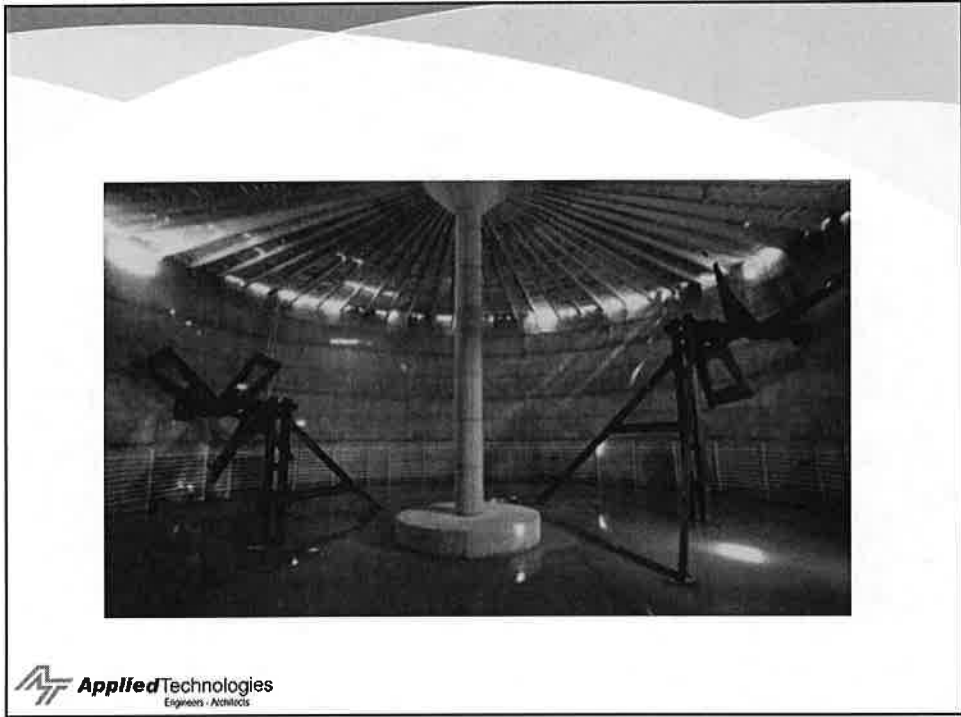
 **Applied Technologies**  
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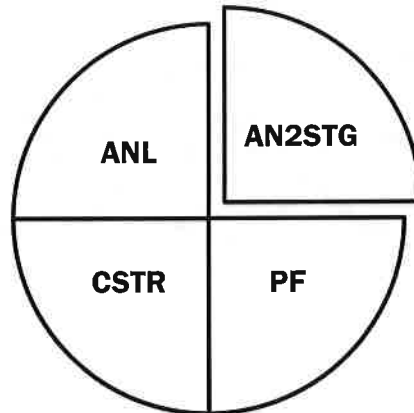
## **Stickney WRP Codigestion and Biogas Utilization Plan**



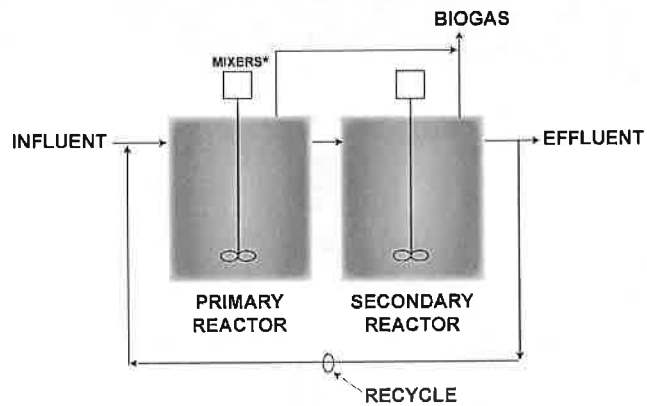


# Anaerobic Treatment Technologies

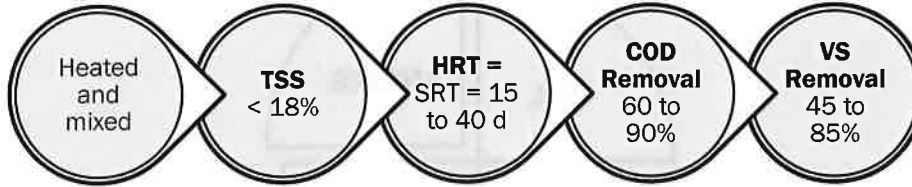
## Low Load



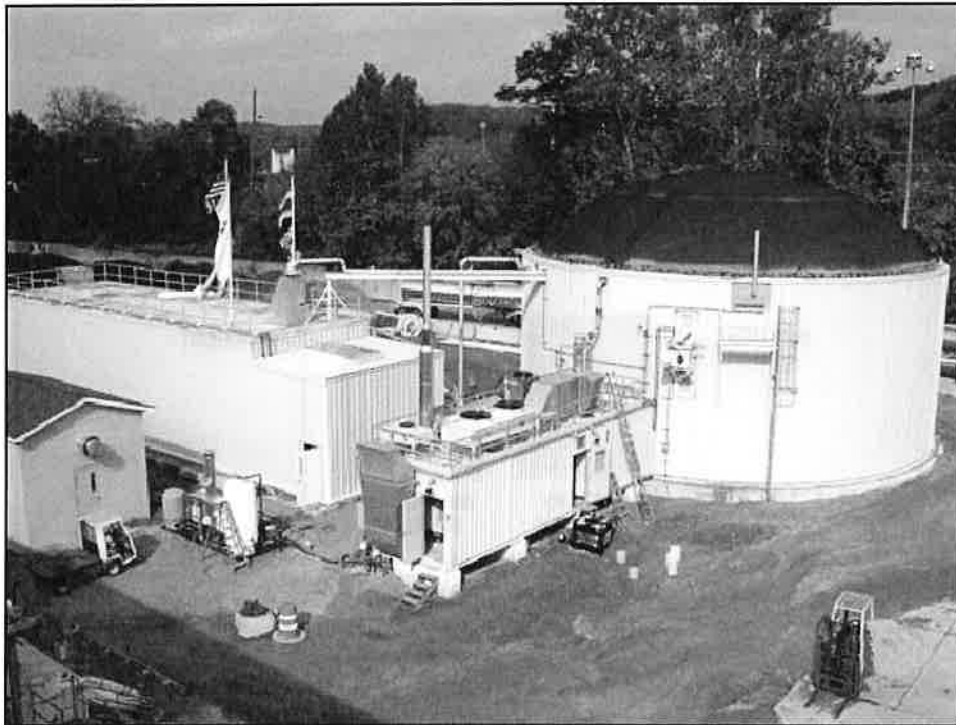
## Staged System Diagram

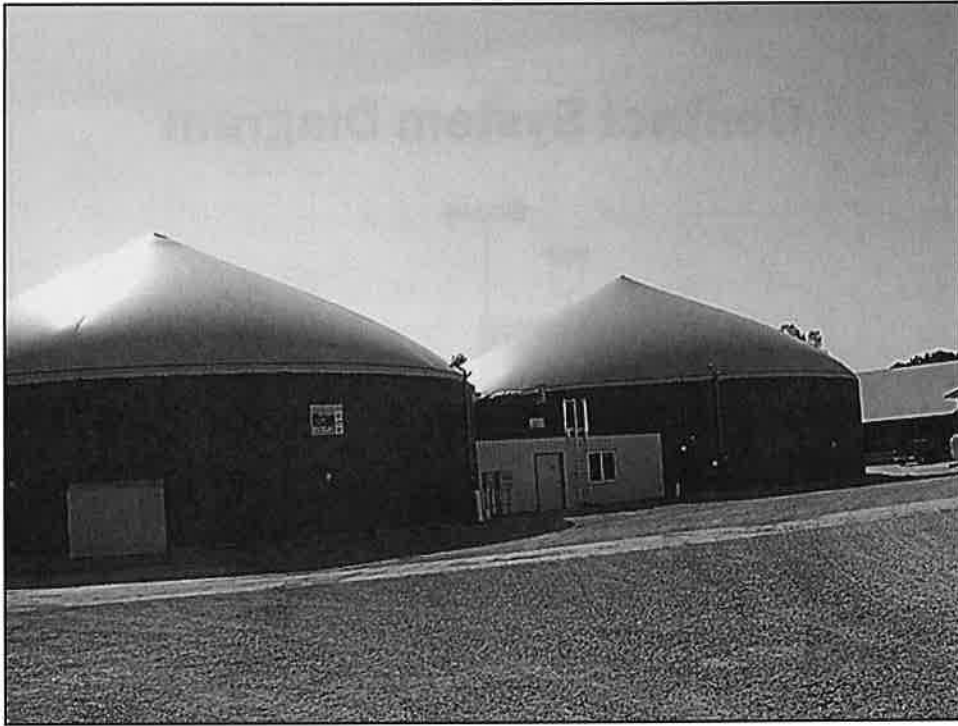


# Staged System

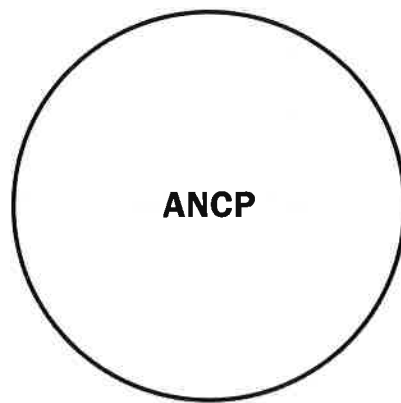


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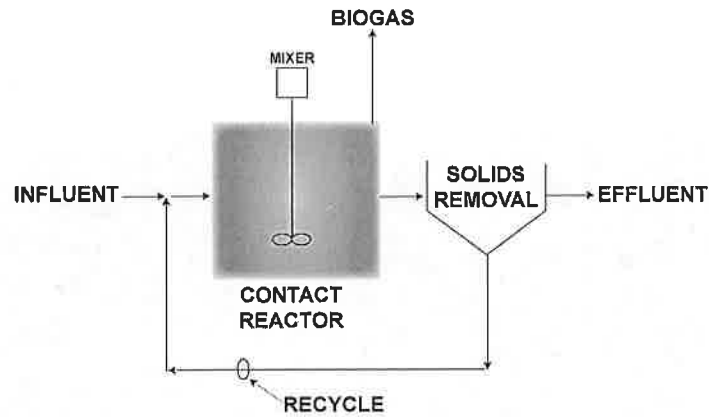




## **Anaerobic Treatment Technologies** *Medium Load*

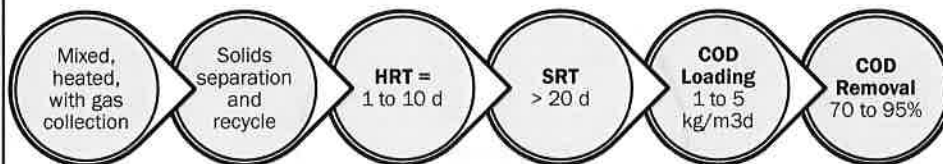


# Contact System Diagram

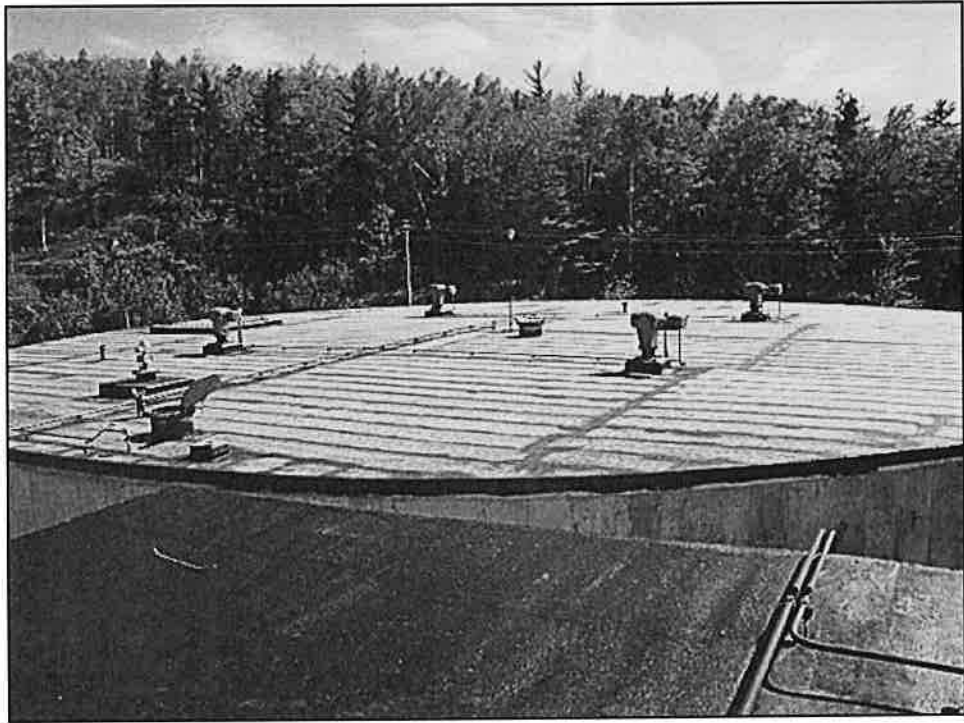
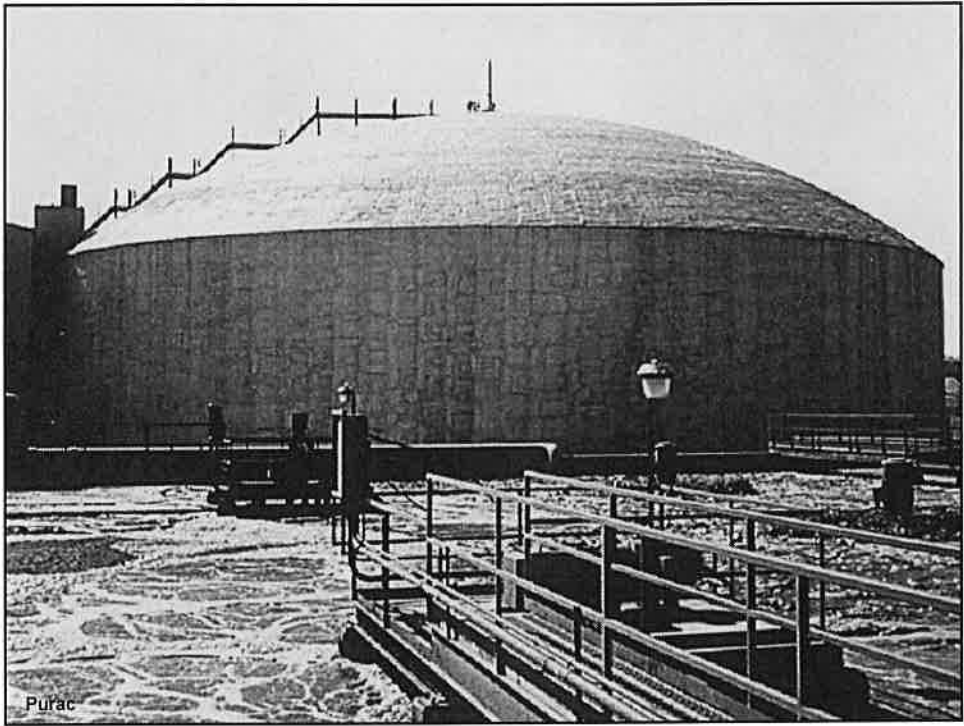


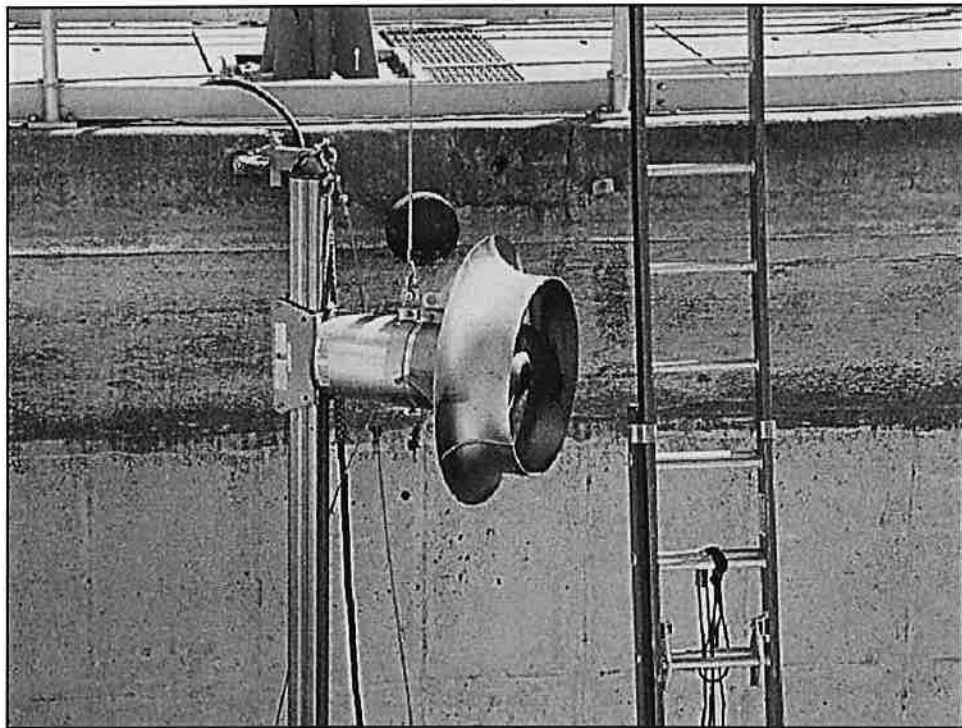
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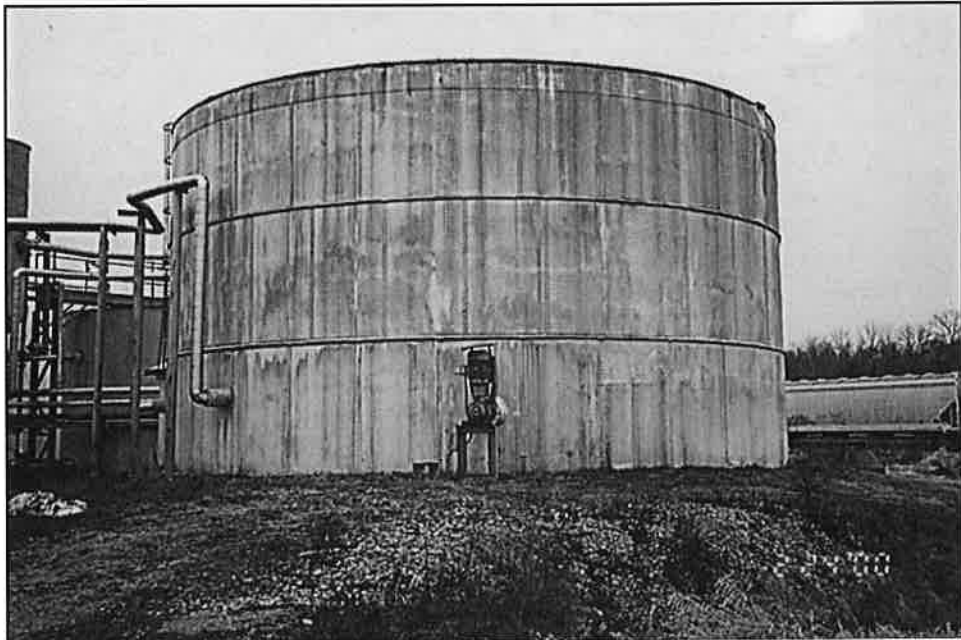
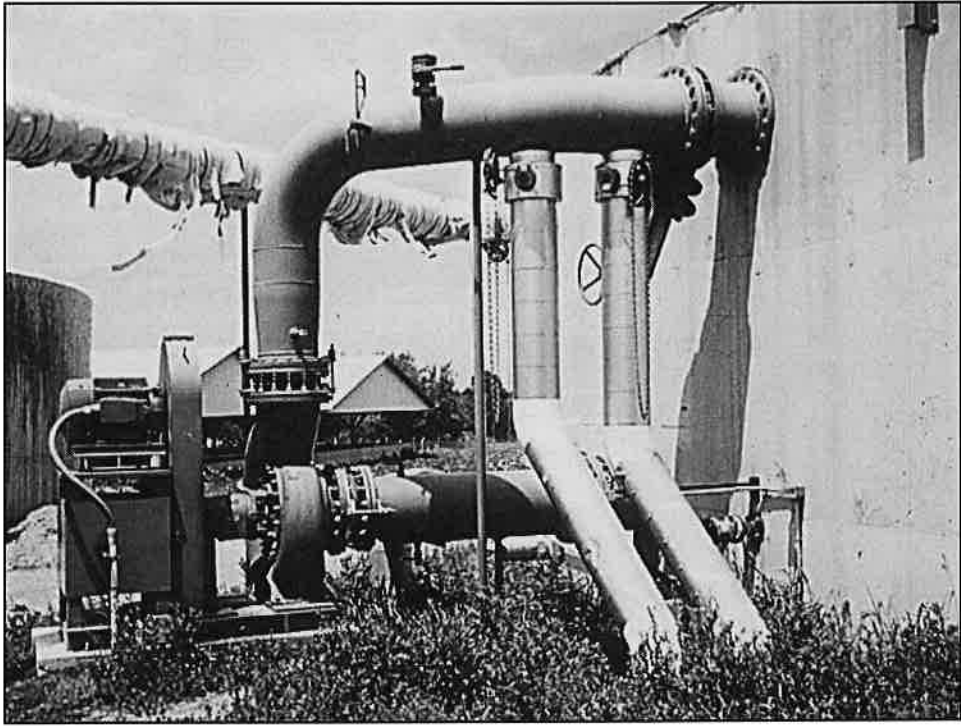
# Contact Process



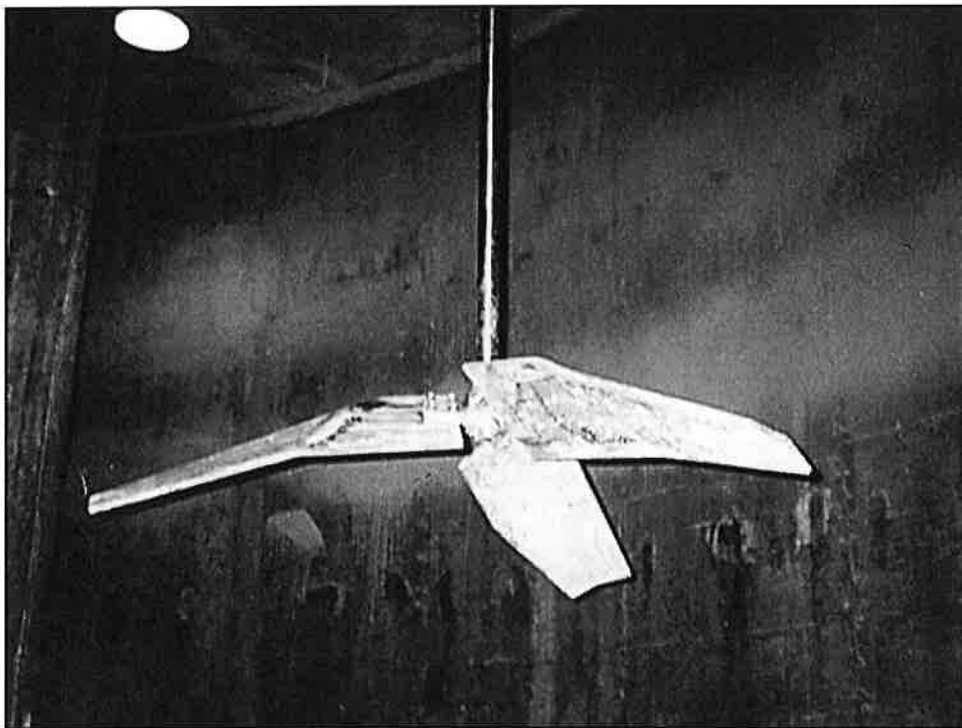
 **Applied Technologies**  
Engineers - Architects

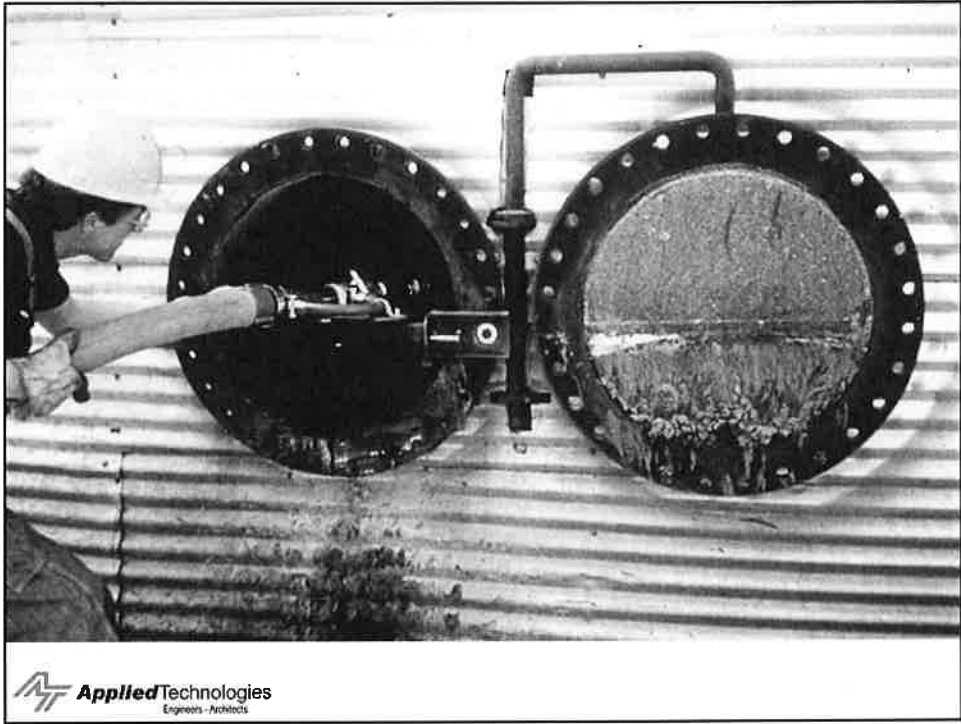


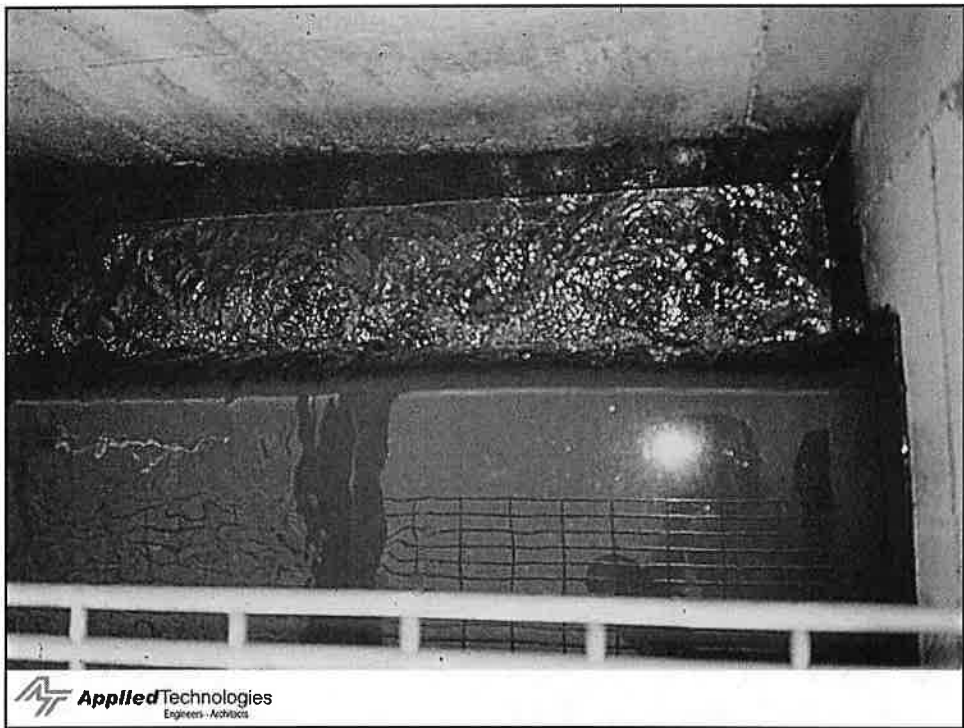
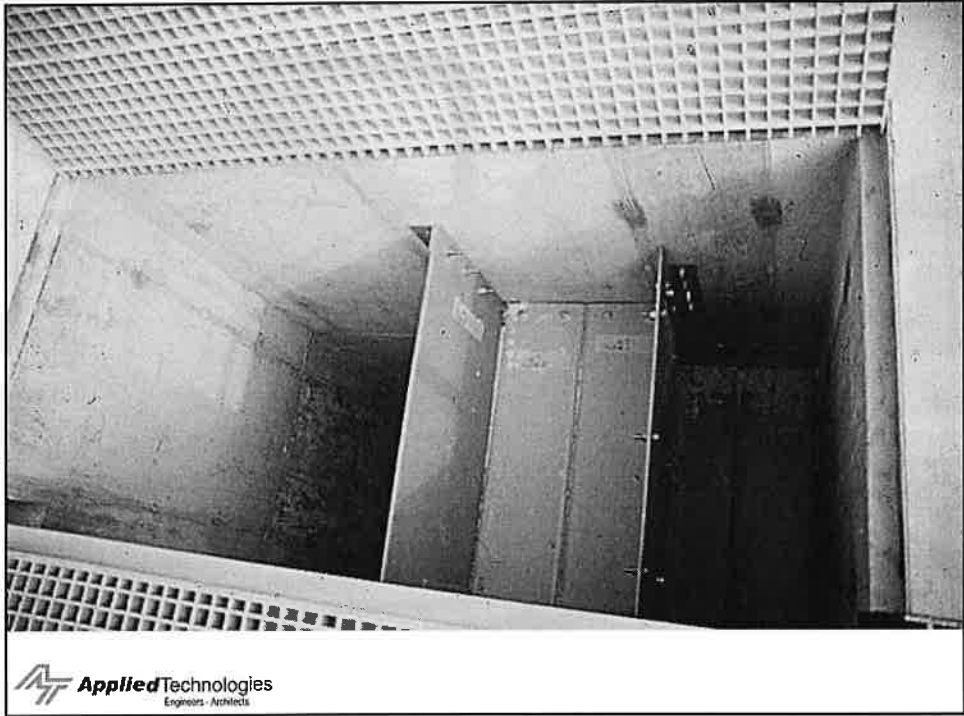


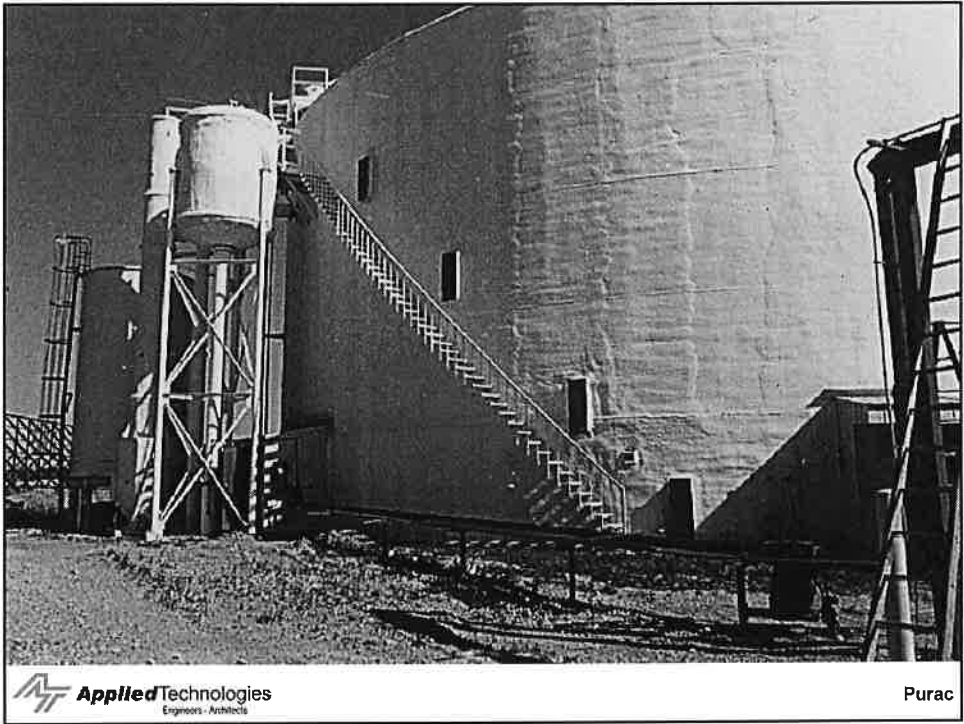


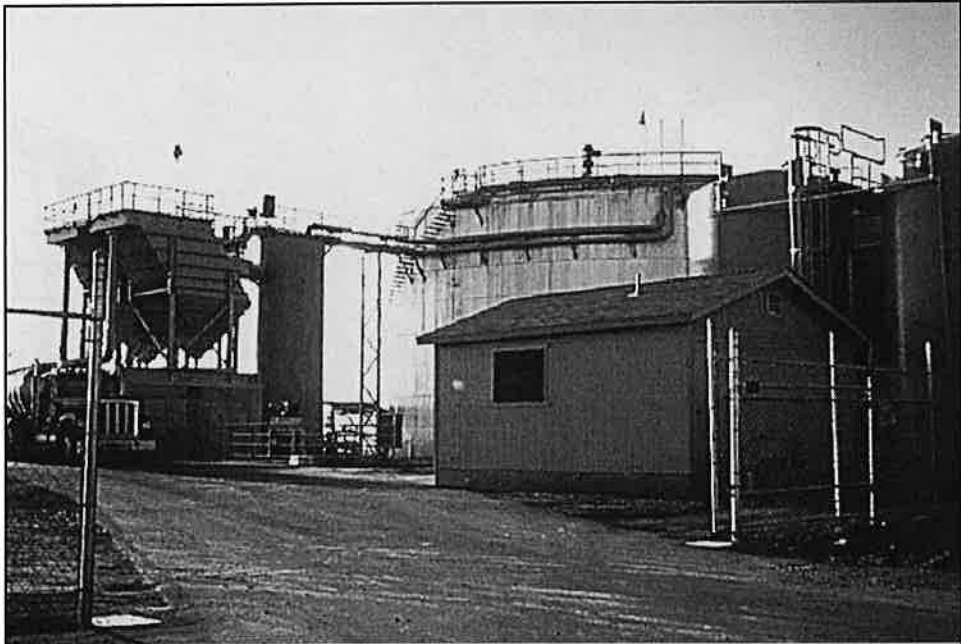
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Engineers - Architects











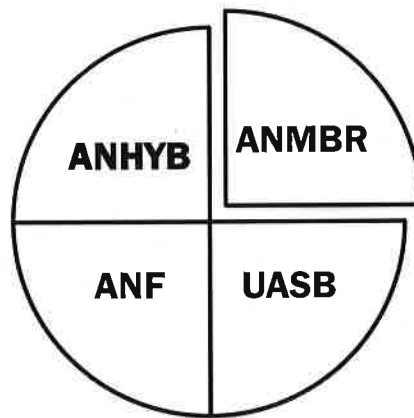
 **Applied Technologies**  
Engineers - Architects

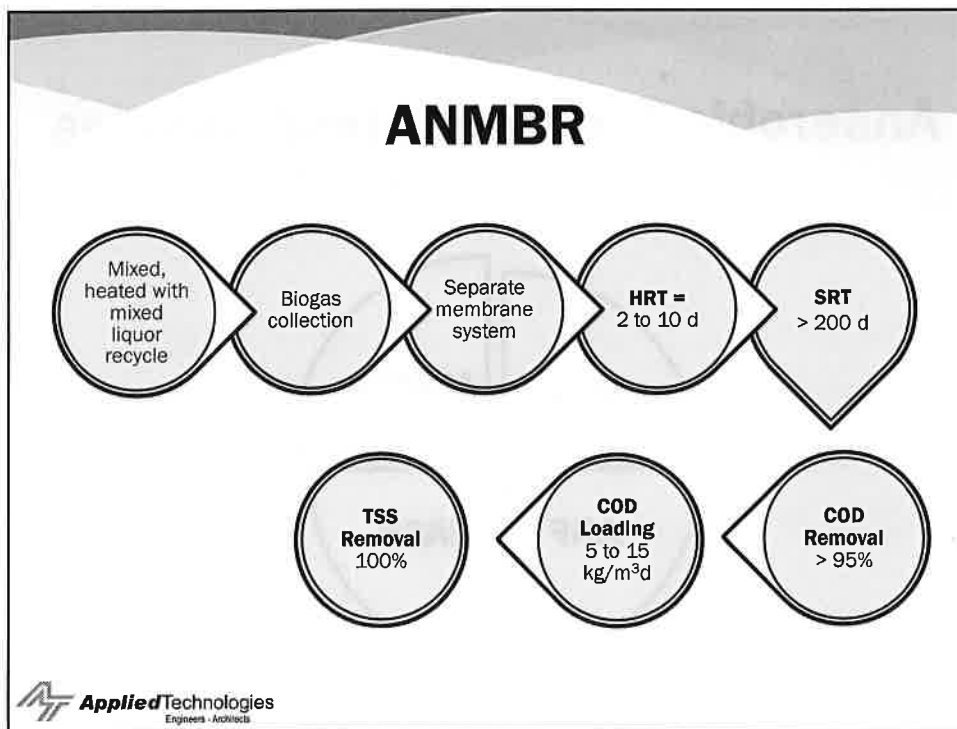
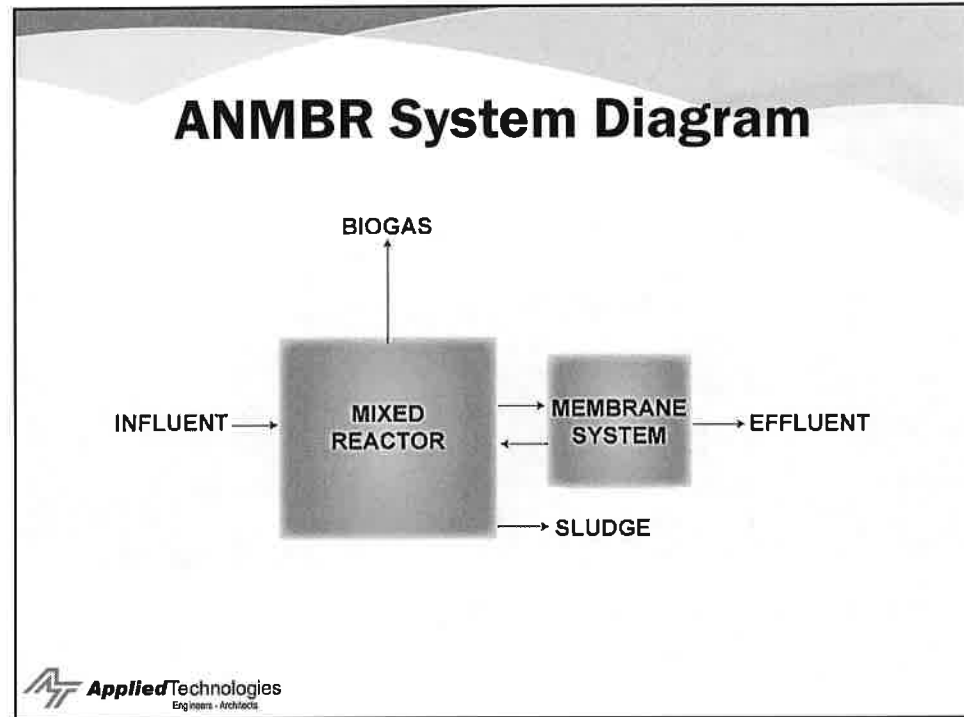


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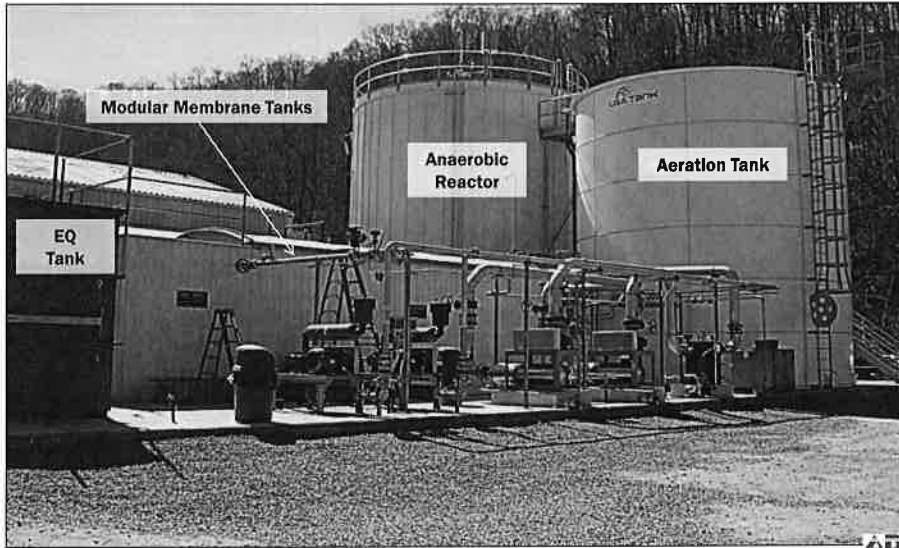


## Anaerobic Treatment Technologies *High Load*

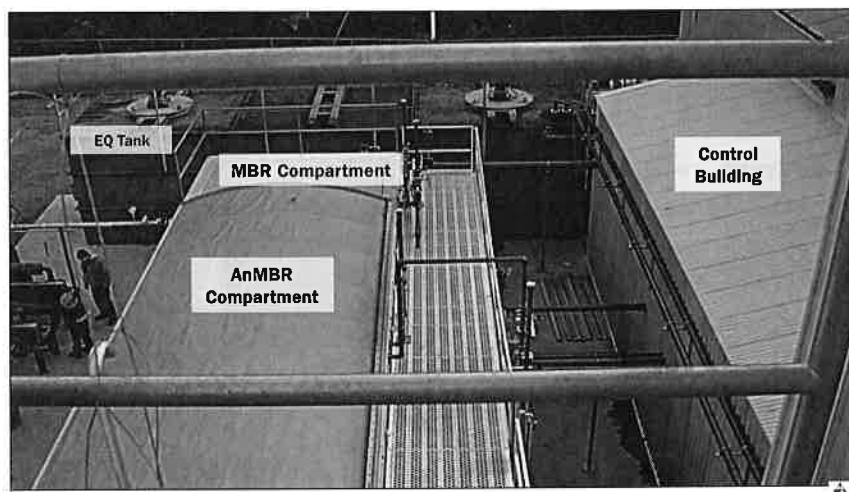




## AnMBR + MBR System

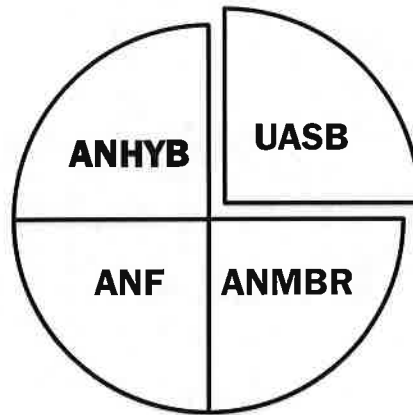


## Modular Combined AnMBR + MBR Tank

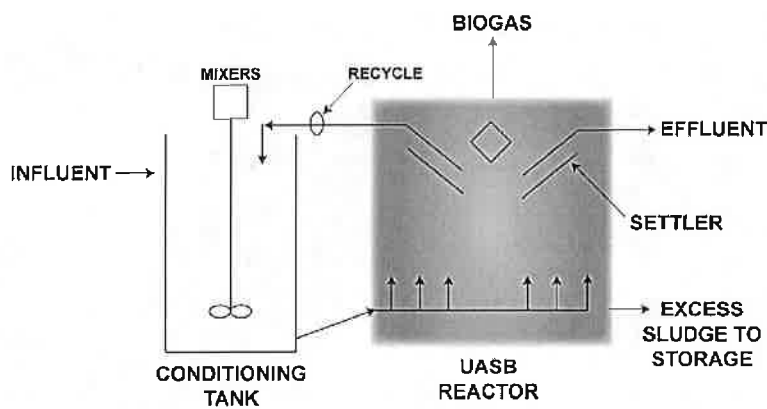


# Anaerobic Treatment Technologies

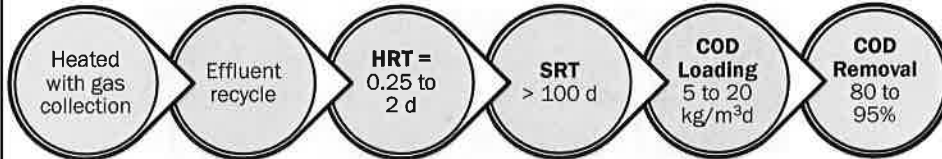
## High Load



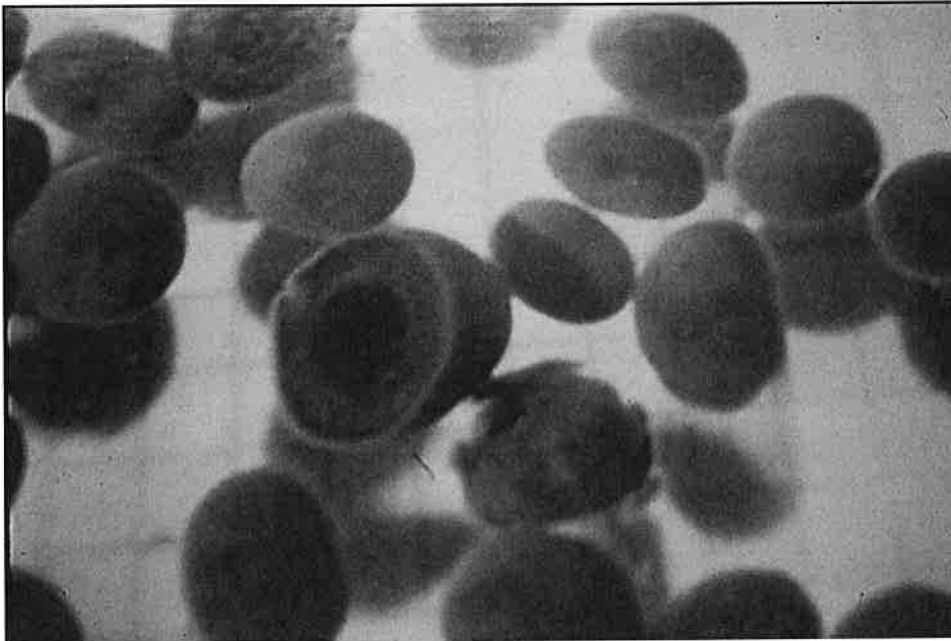
## UASB System Diagram

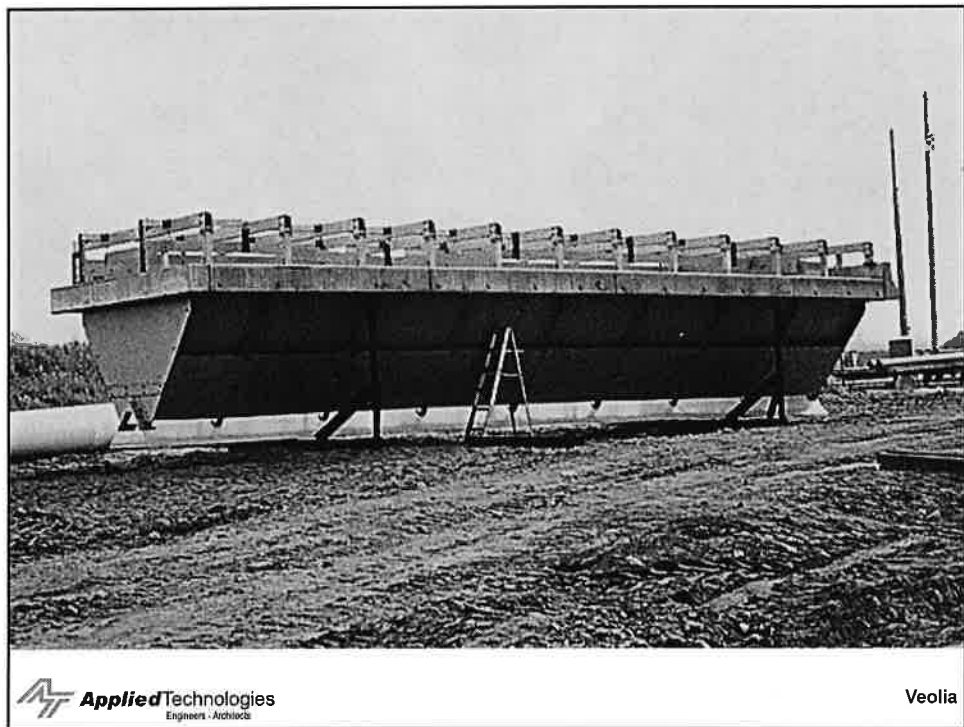
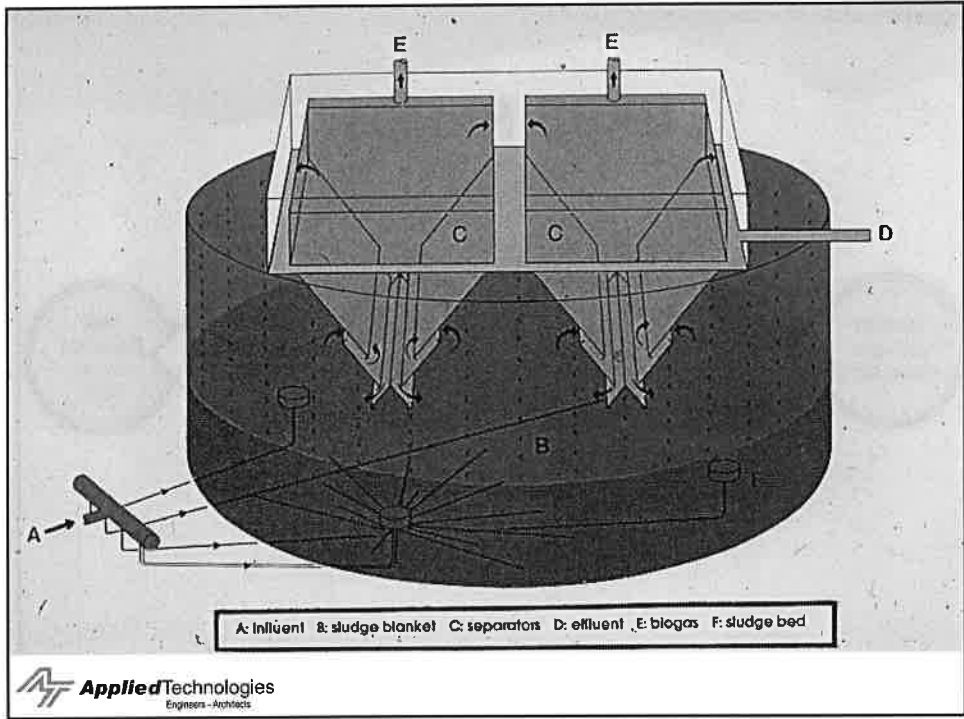


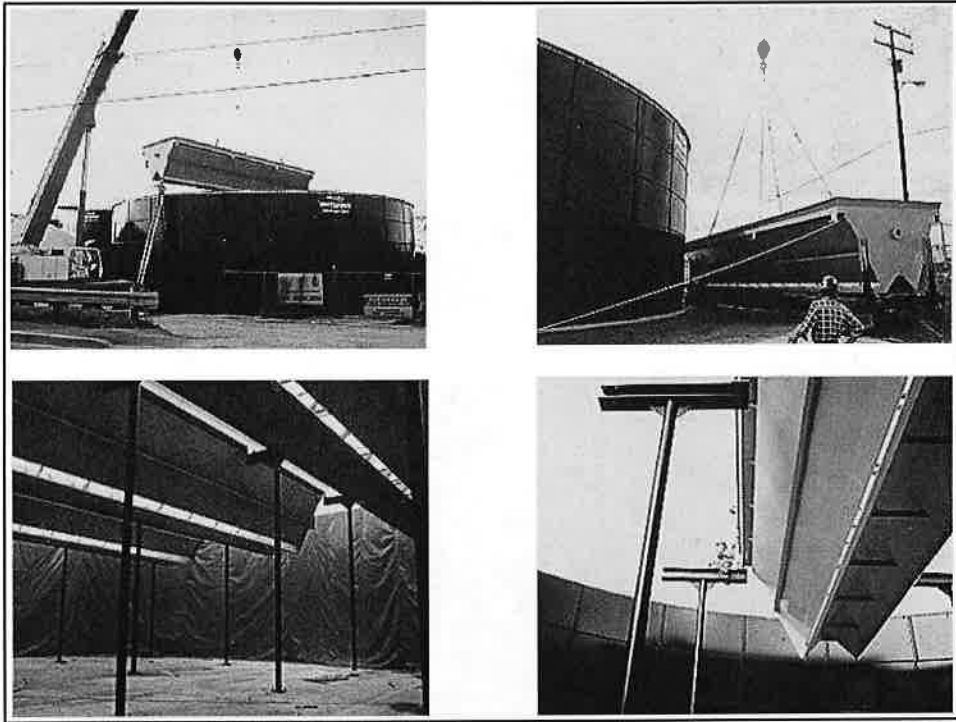
# UASB Process



*May include preconditioning and sludge storage systems*

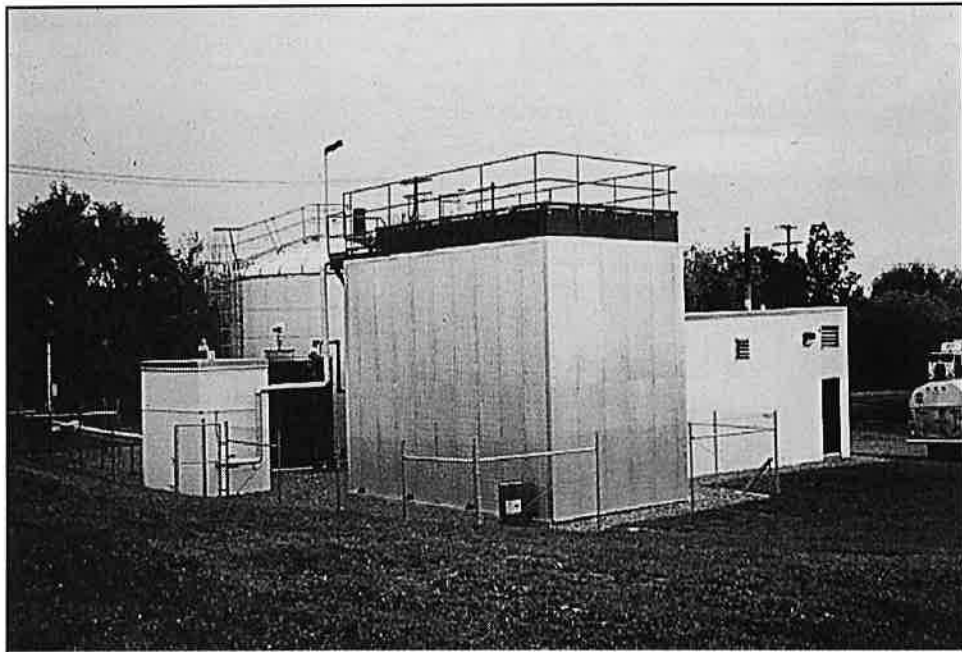


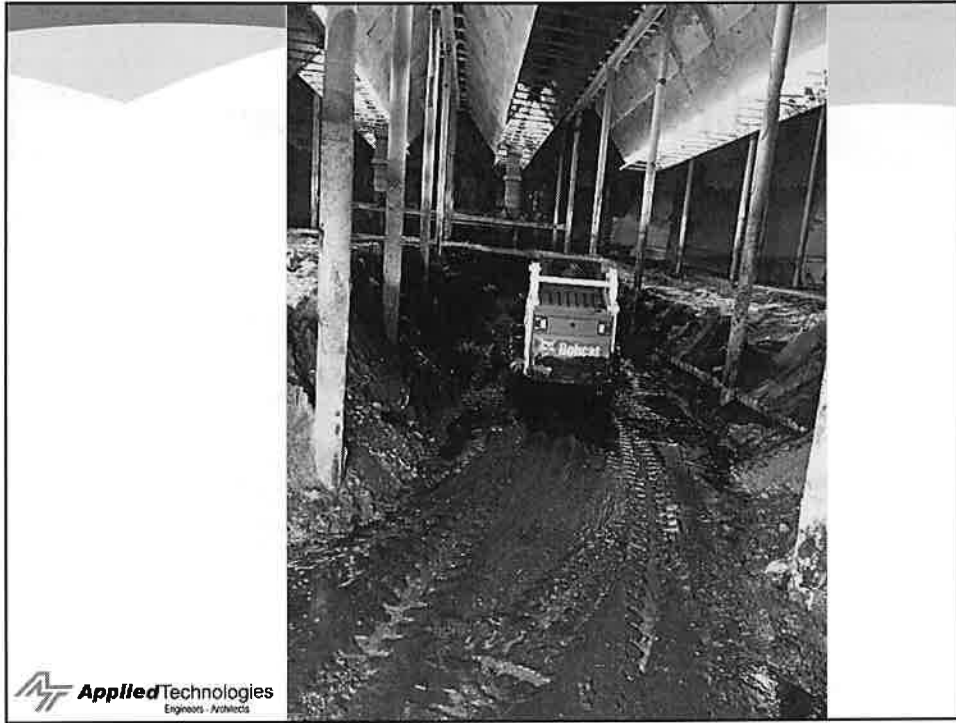




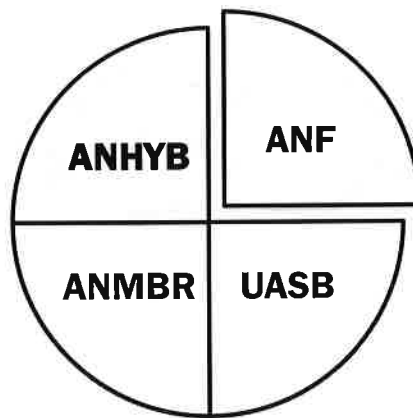
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Veolia

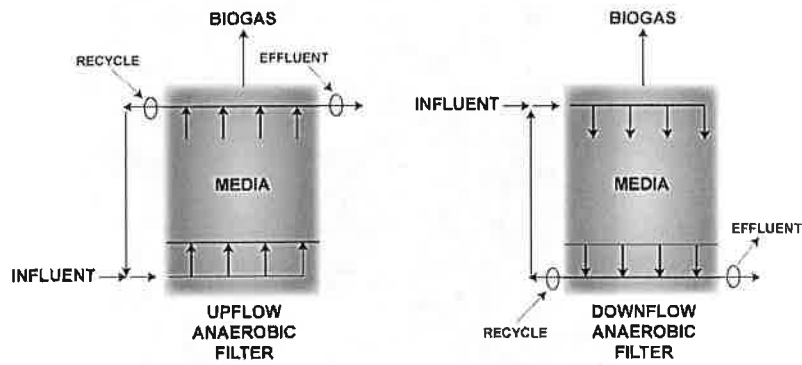




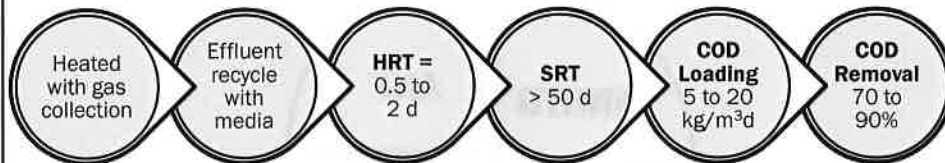
## Anaerobic Treatment Technologies *High Load*

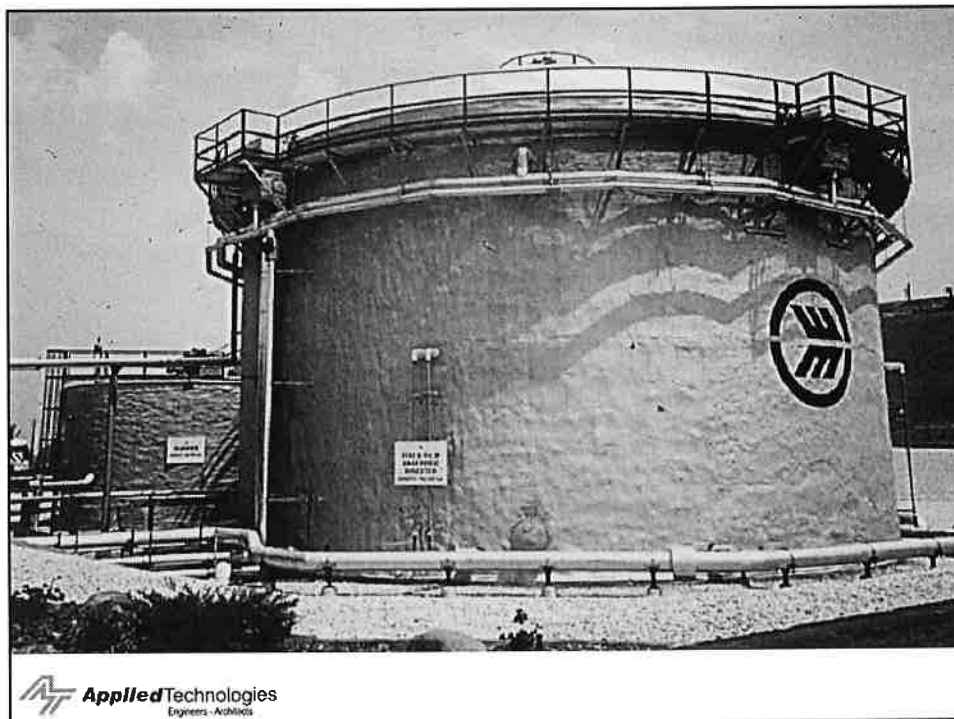
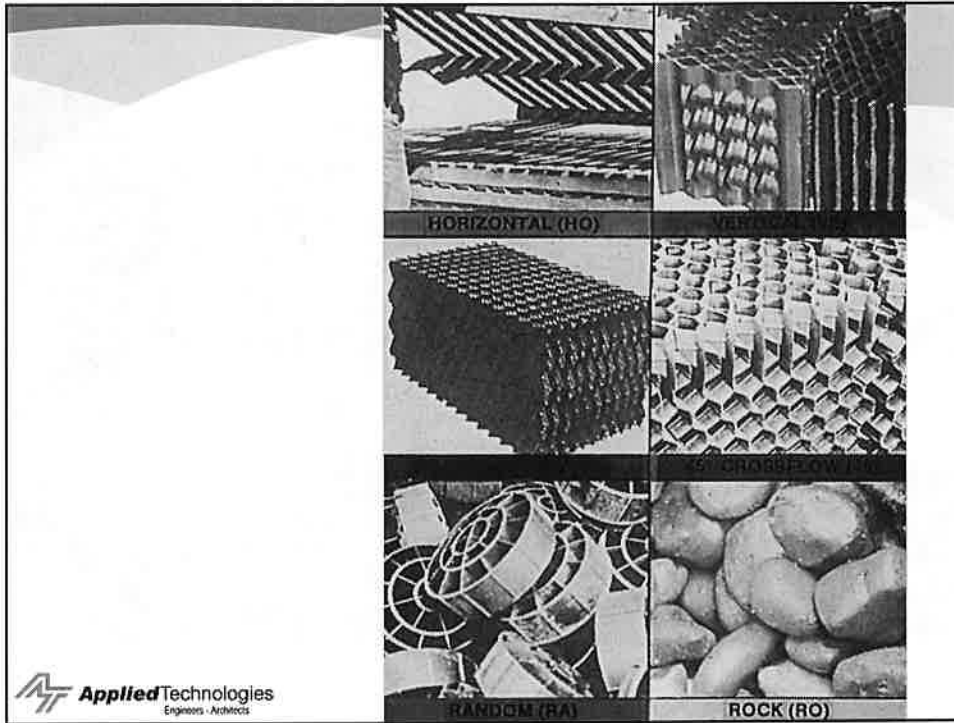


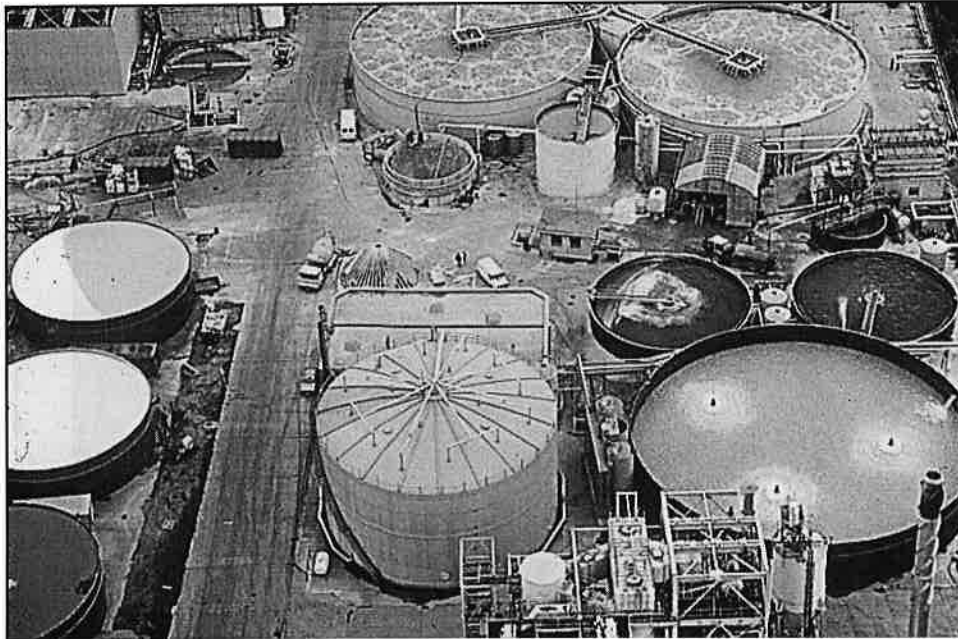
# Filter System Diagram



# Filters

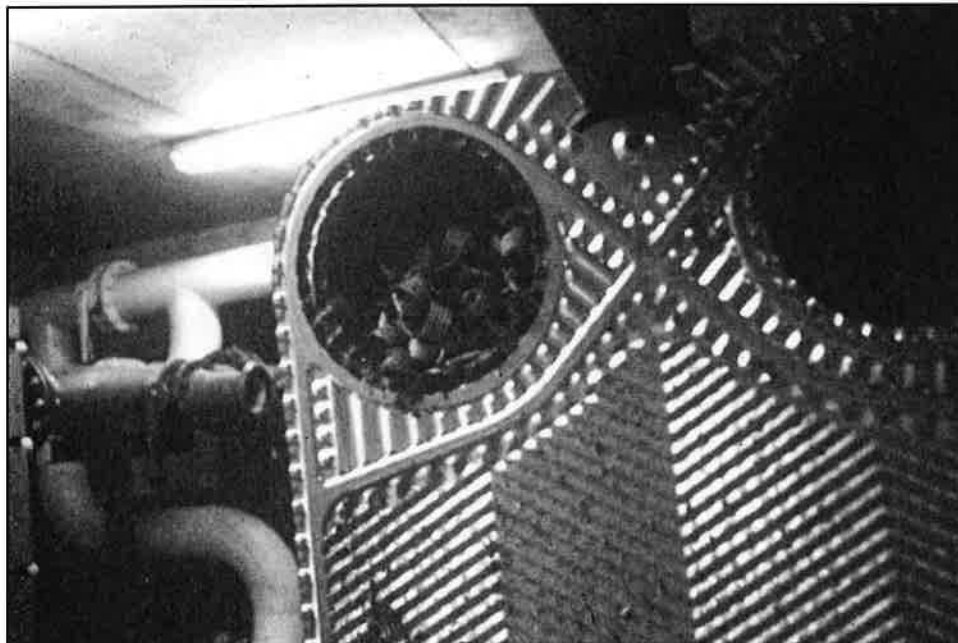




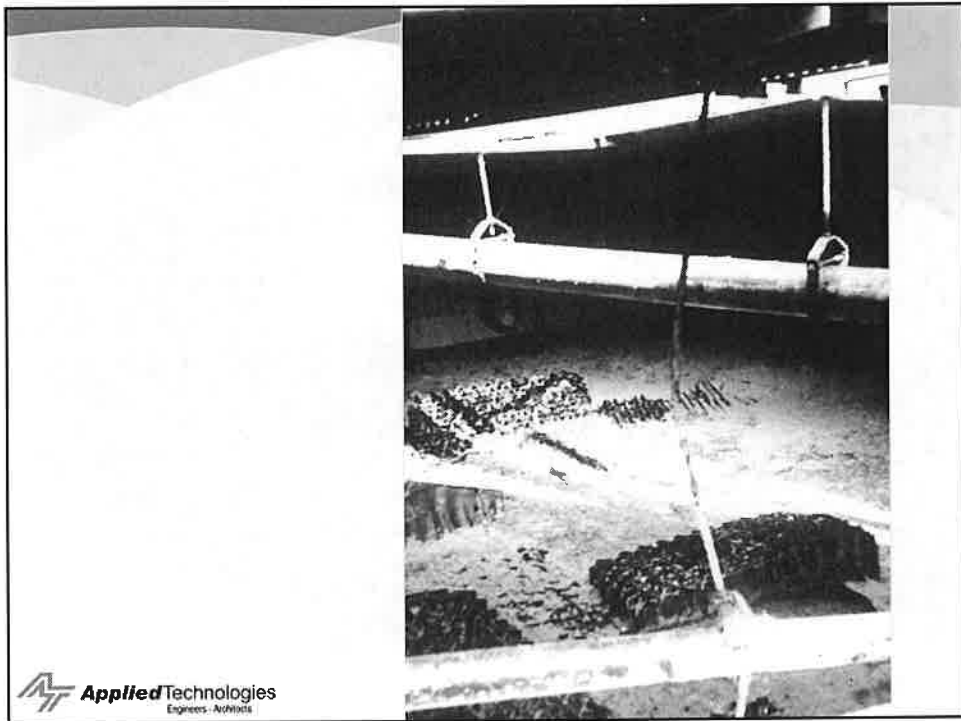
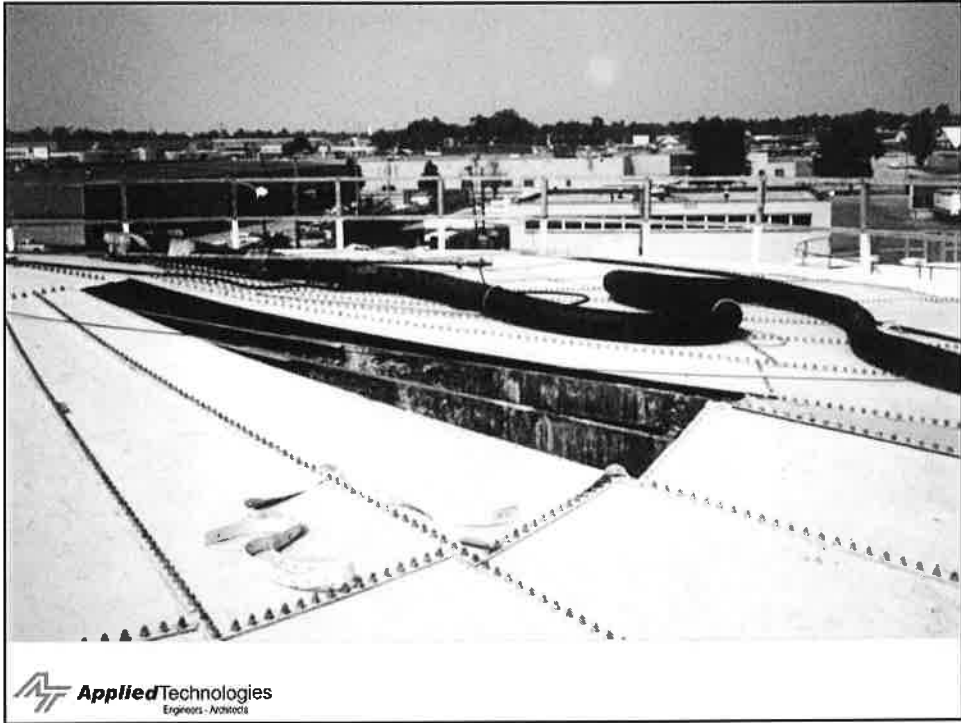


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SGN

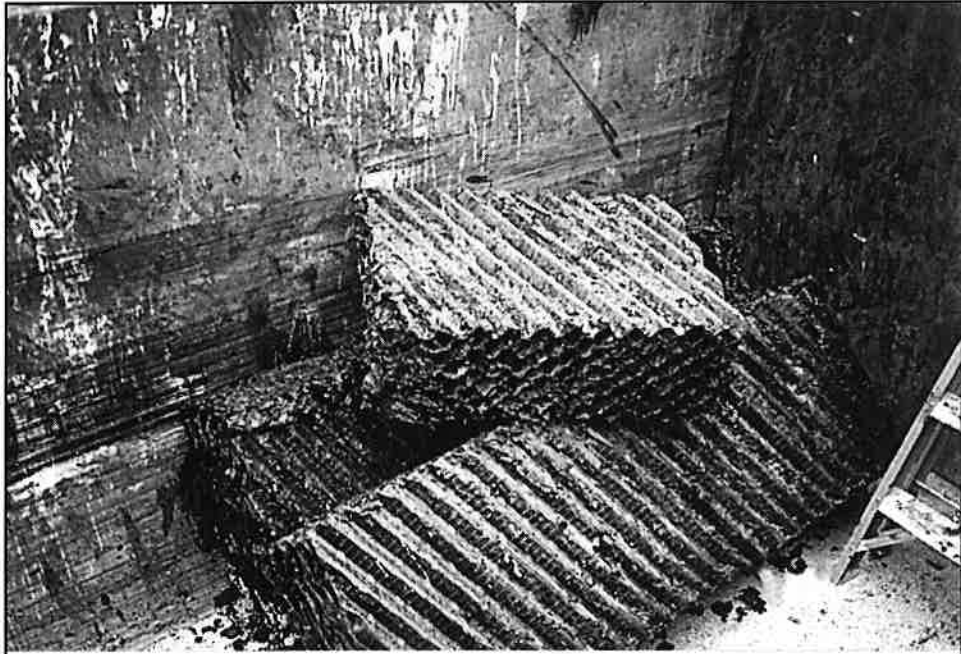


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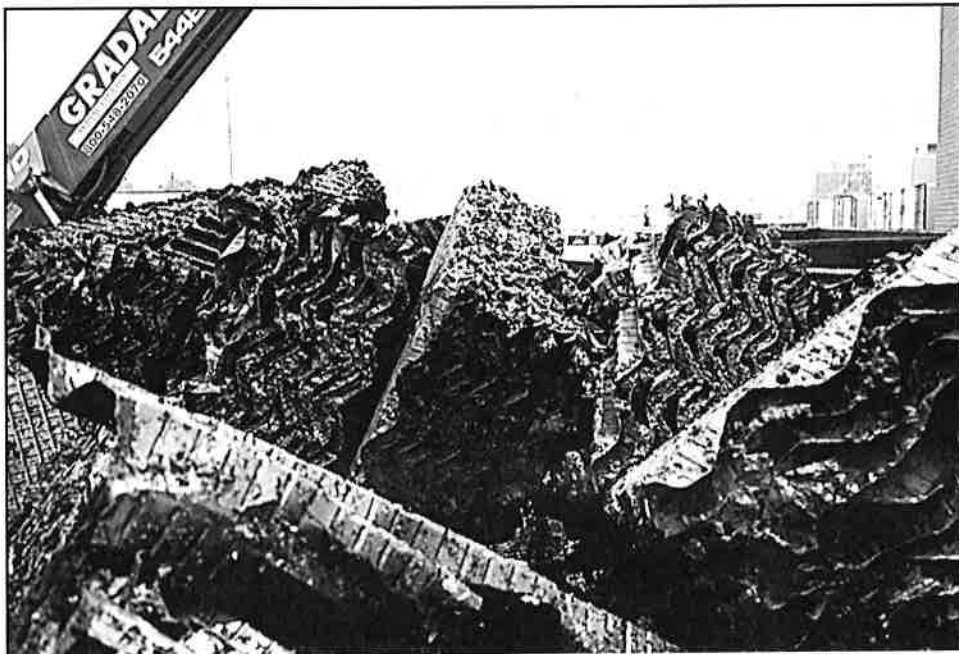
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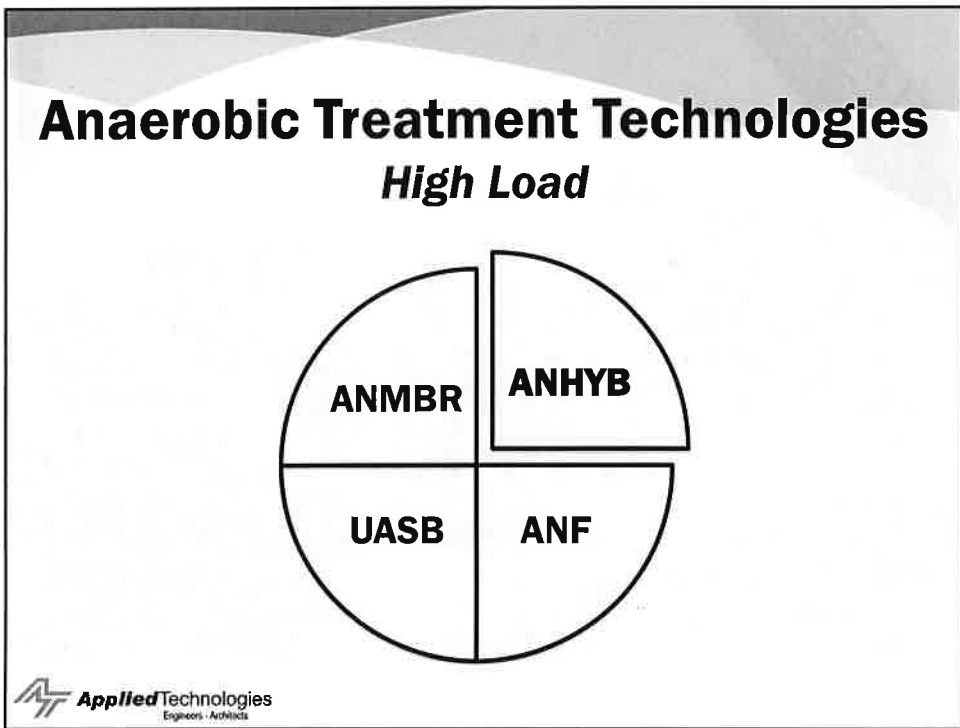
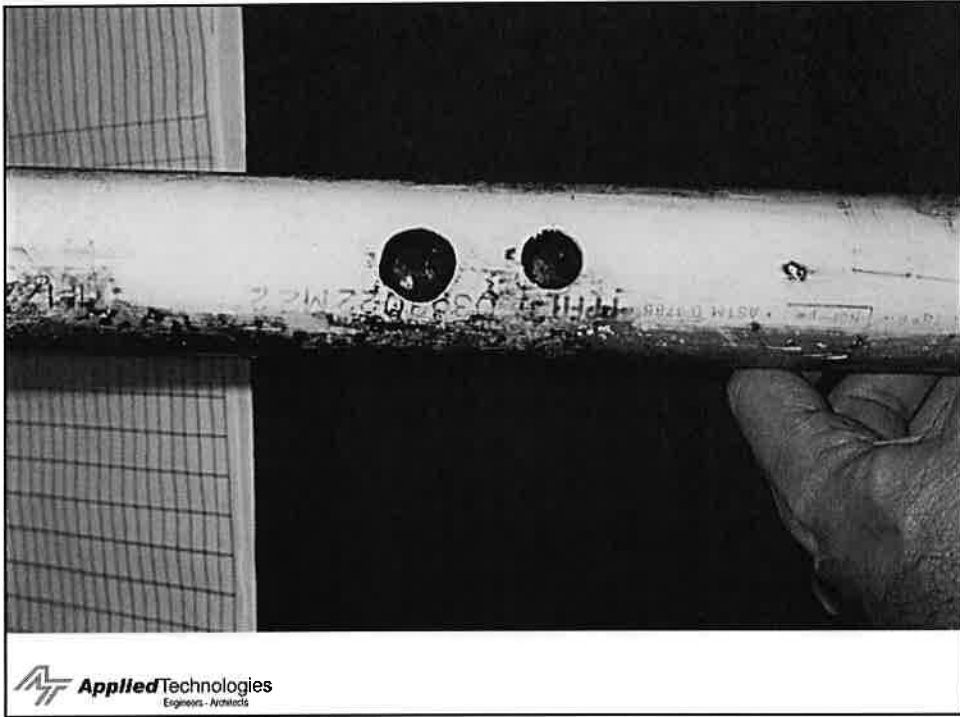
 **Applied Technologies**  
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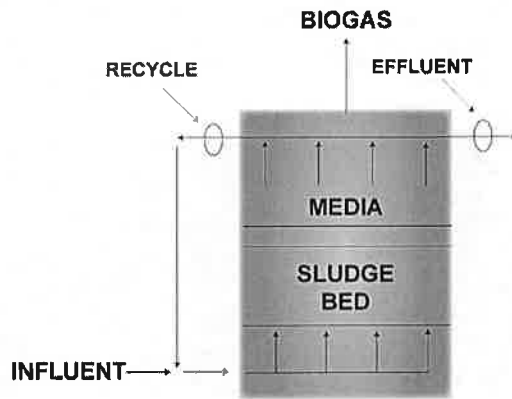
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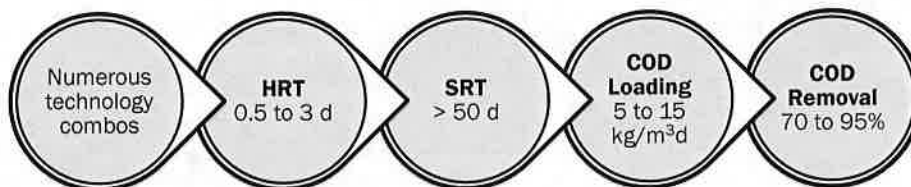


# Hybrid System Diagram

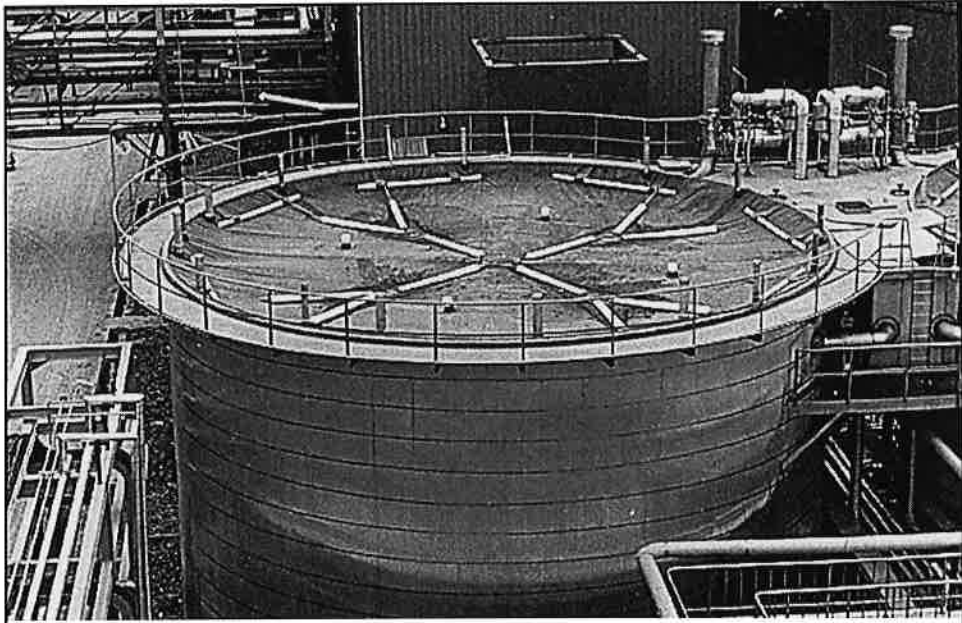


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# Hybrids

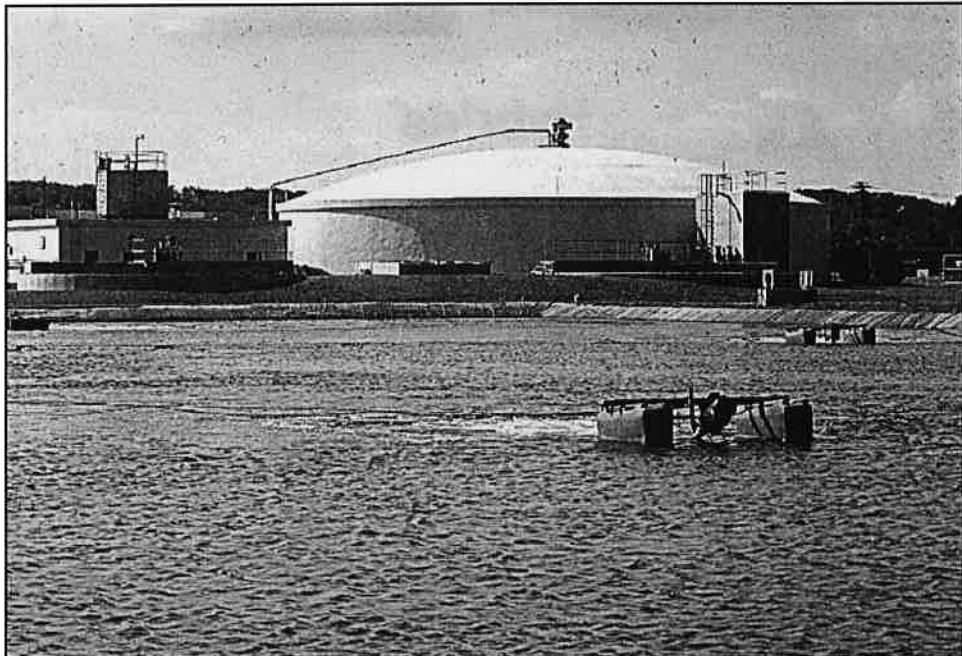


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ADI Systems

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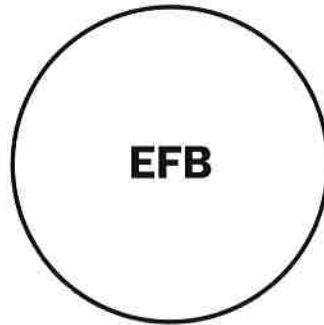


CET

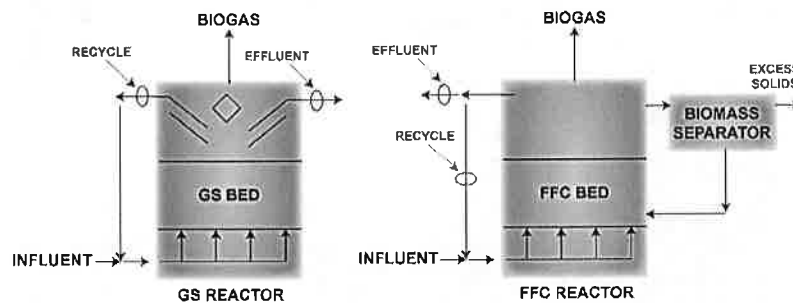
 **Applied Technologies**  
Engineers - Architects

# Anaerobic Treatment Technologies

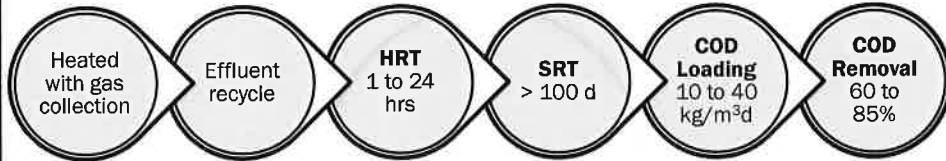
## Very High Load



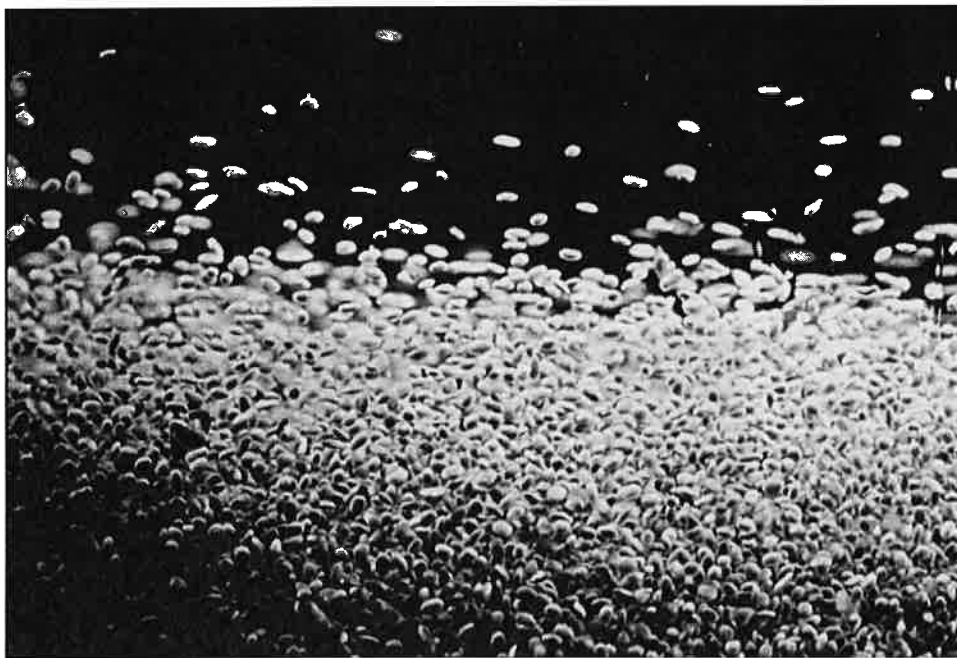
# Expanded/Fluidized Bed System Diagram



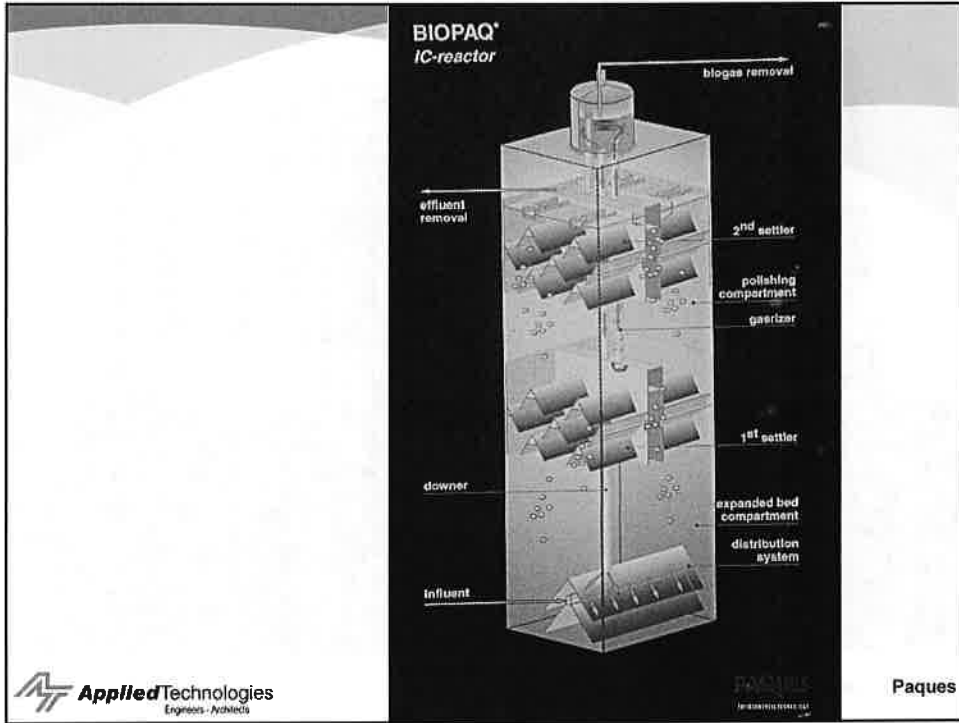
# Expanded/Fluidized Bed

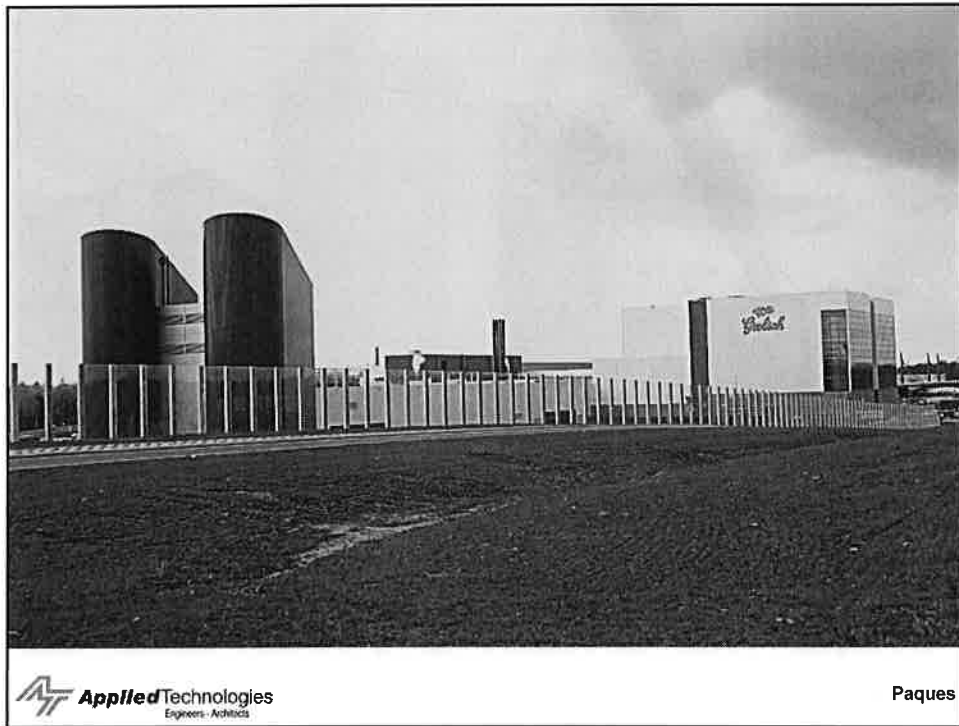


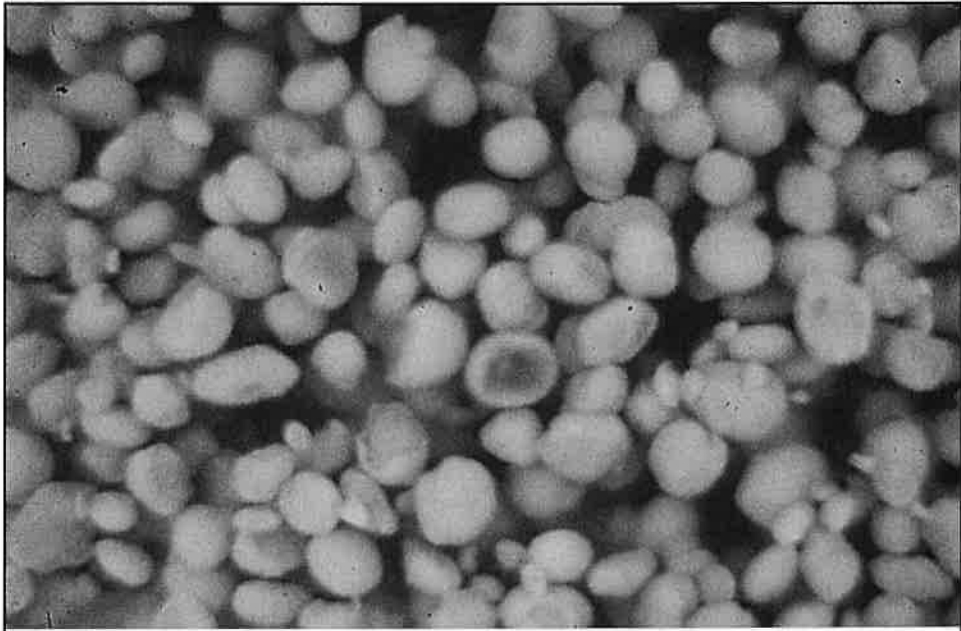
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Engineers - Architects



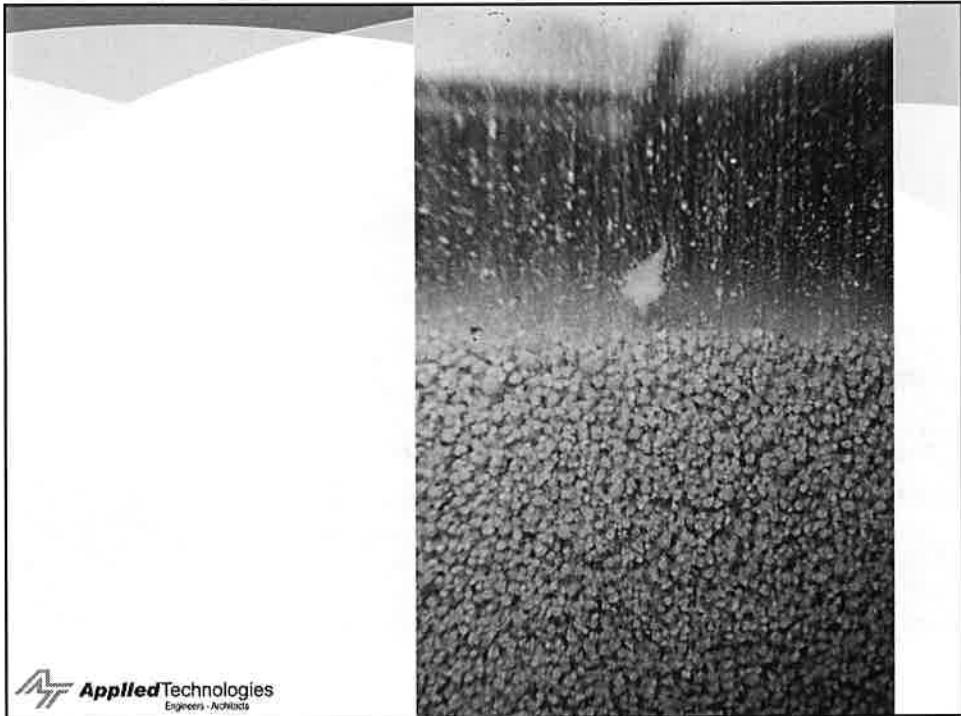
 **Applied Technologies**  
Engineers - Architects



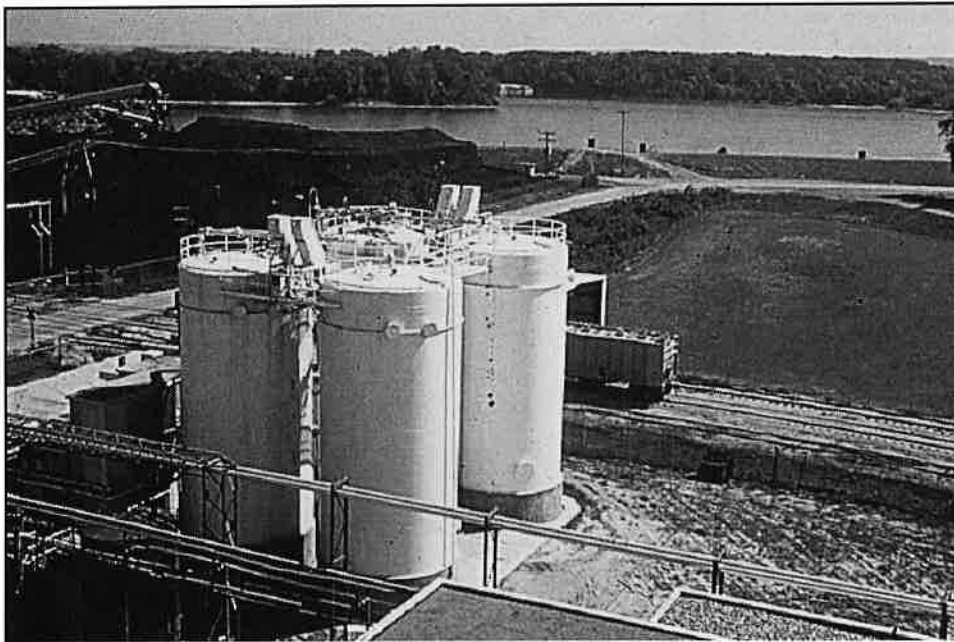




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 **Applied Technologies**  
Engineers - Architects

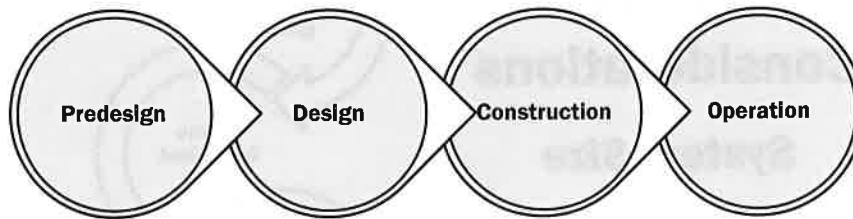
Ondeo



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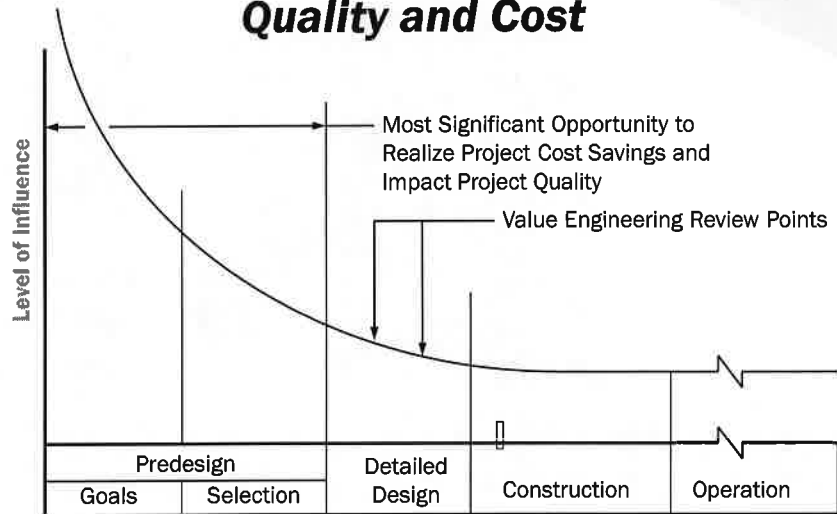
Ecovation

## Project Phases



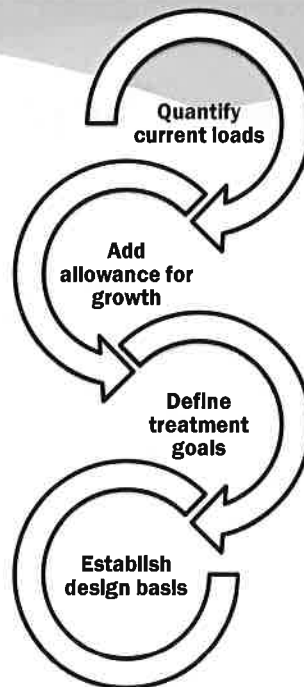
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# Project Impact Quality and Cost



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# Predesign Considerations System Size



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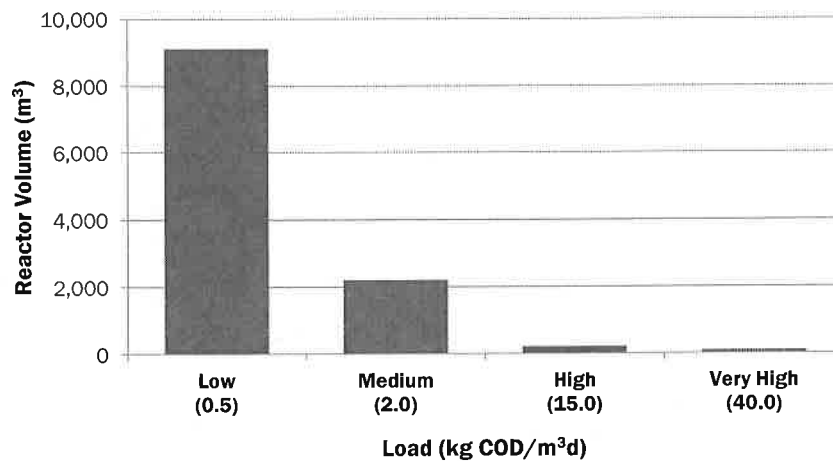
## Basis of Design

Parameter	Existing Conditions	5-year Production Projection 100% increase	Discharge Goal
Average Flow (gpd)	45,000	90,000	-
BOD (mg/L)	4,600	5,500	< 1,000
BOD (lbs/d)	1,730	4,130	-
COD (mg/L)	11,000	12,000	-
COD (lbs/d)	4,130	9,010	-
TSS (mg/L)	2,500	2,500	< 500
TSS (lbs/d)	940	1,880	-
VSS (%)	95	95	-
FOG (mg/L)	200	500	< 50
Total P (mg/L)	20	20	-
Ortho P (mg/L)	5	5	-
Ammonia-N (mg/L)	<1	<1	< 10
TKN (mg/L)	80	80	-
Alkalinity (mg/L)	1,500	1,500	-
pH (s.u.)	4 to 11	4 to 11	5 to 9
Calcium (mg/L)	500	500	-

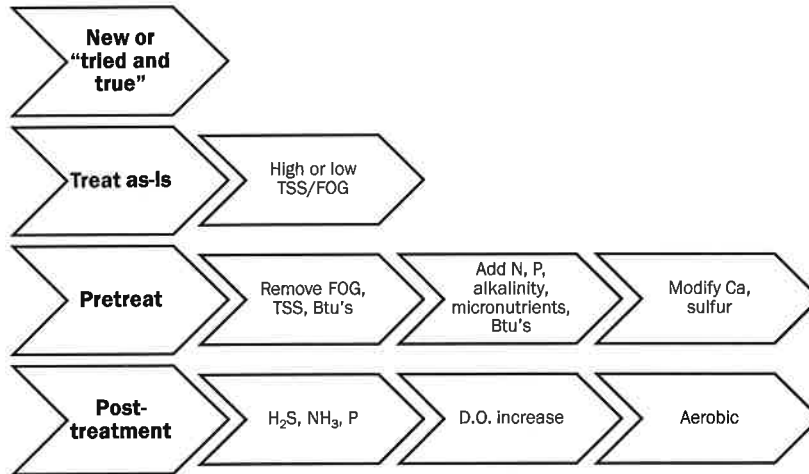
Notes:

1. Flow includes all high strength wastewater that is currently land applied.
2. Production increase estimate from plant manager.

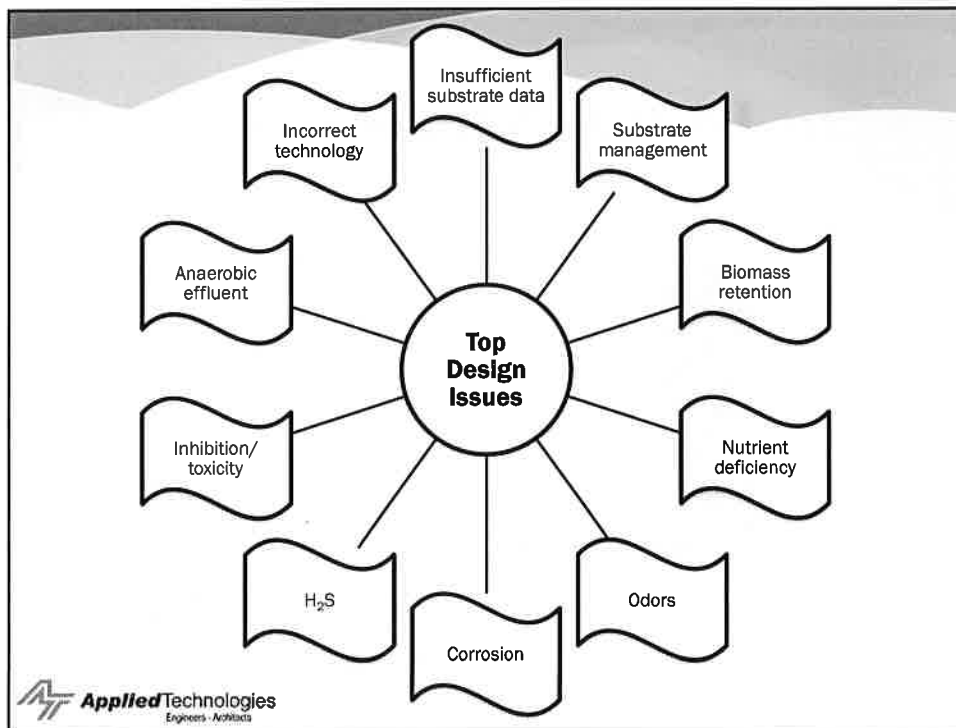
## Loading Versus Size



# Process Selection



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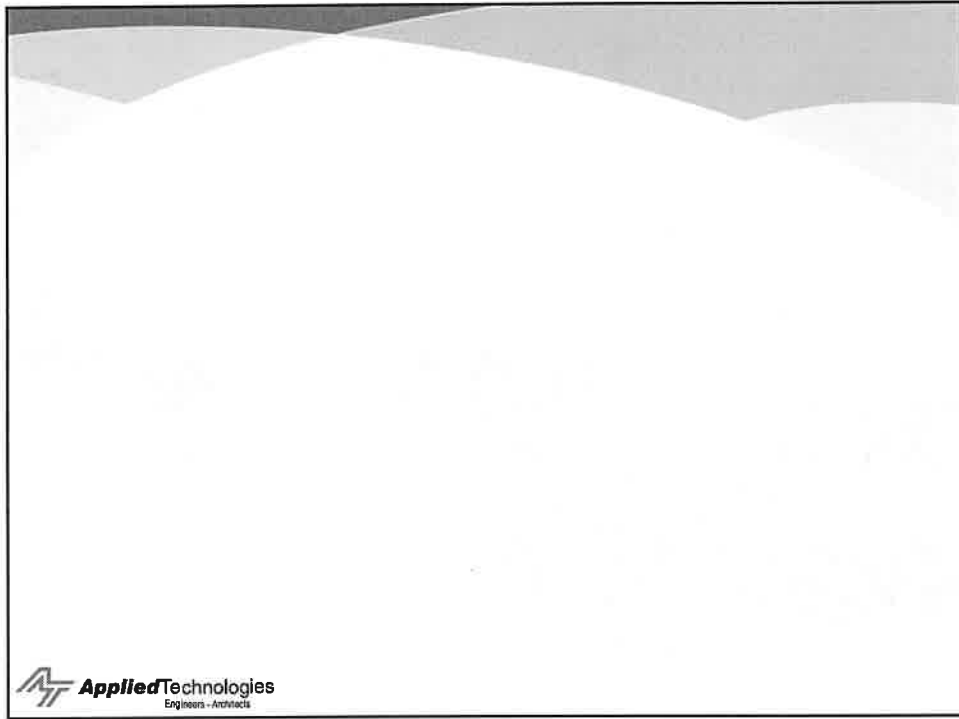
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2016

# Anaerobic Treatment Technology Overview

Written by  
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## INTRODUCTION

Anaerobic treatment technology has gained acceptance as the standard approach to treating a variety of unique, high-strength organic substrates produced by a wide range of industries and agricultural operations. Much of the early impetus for such applications was related to complying with waste discharge regulations and minimizing odor complaints.

Today, the major impetus for treating such streams anaerobically is financial, based on the need for a cost-effective, high-performance treatment technology with relatively low operating costs and the potential economic value of biogas, a byproduct of anaerobic treatment. Additionally, a secondary motivation is the financial impact of various funding opportunities that provide incentives to generate “green,” or renewable, energy from waste.

The number and types of anaerobic treatment systems being applied to industrial and agricultural waste streams have grown tremendously since the first technologies were introduced and commercially promoted in the late 1970s and early 1980s. Prior to this, only natural cover anaerobic lagoons and a few anaerobic contact process systems had been used for anaerobic wastewater treatment.

## TECHNOLOGY OVERVIEW

Compiling a list of commercially available anaerobic technologies is a daunting task, complicated by the wide range of technical descriptions, trade names, and research descriptions one can find. All of them take a different approach to retaining anaerobic biomass, the key factor in a successfully operating anaerobic treatment system. Fortunately, commercially available systems can be organized into the broad groups listed below.

- Low-Loaded Systems (ANL)
- Plug Flow Systems (PF)
- Continuously Stirred Tank Reactor (CSTR)
- Anaerobic Contact Process (ANCP)
- Anaerobic Filter (ANF)
- Upflow Anaerobic Sludge Blanket (UASB)
- Expanded/Fluidized Bed (EFB)
- Anaerobic Membrane Process (ANMBR)
- Anaerobic Hybrid Process (ANHYB)

### Low-Loaded System (ANL)

Generally an unmixed reactor system employing suspended/flocculating anaerobic biomass designed for a total chemical oxygen demand (COD) loading of less than 2 kg/m<sup>3</sup>d. This group includes anaerobic lagoons, ADI's modified low-loaded BVF technology, Lemna's modular system, GWE's COHRAL process, Waste Solutions' CIGAR process and a number of other systems. Another key characteristic of the ANL group is the very long design hydraulic retention time (HRT), which is typically much longer than the solids retention time (SRT), giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before settling or being washed out of the system.

### Plug Flow System (PF)

Generally an unmixed rectangular reactor system combining suspended/flocculating anaerobic biomass with high total suspended solids (TSS) substrates, designed for a COD loading of less than 2 kg/m<sup>3</sup>d (> 8% TSS). This group includes proprietary systems from BIOFerm, DVO, Eisenmann, RCM, Viessmann, and a number of other systems. Another key characteristic of the PF group is the very long design HRT, which gives the anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being discharged from the system.

### Continuously Stirred Tank Reactor (CSTR)

A completely mixed reactor system employing suspended/flocculating anaerobic biomass, designed for a COD loading of less than 3 kg/m<sup>3</sup>d. This group includes generic-design systems as well as proprietary systems from GWE, Viessmann, WelTec, and a number of others. Another key characteristic of the CSTR group is the very long design HRT, which gives the anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being washed or wasted out of the system.

### Anaerobic Contact Process (ANCP)

A completely mixed reactor system employing suspended/flocculating anaerobic biomass with a downstream anaerobic biomass capture and recycle system, designed for a COD loading of less than 5 kg/m<sup>3</sup>d. This group includes generic-design systems as well as proprietary systems from Evoqua, GWE, Ondeo, Purac, Waterleau, and a number of others. Another key characteristic of the ANCP group is that the design

HRT is less than the SRT, with the anaerobic biomass capture and recycle system giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being wasted from the system.

### Anaerobic Filter (ANF)

An unmixed reactor system employing primarily fixed film anaerobic biomass attached to supporting media, designed for a COD loading of 5 to 20 kg/m<sup>3</sup>d. Available in upflow (ANFU) and downflow (ANFD) configurations. This group includes generic-design systems as well as proprietary systems from BPI (Bacardi), GWE, Ondeo, Proserpol (SGN), and a number of others. Another key characteristic of the ANF group is that the design HRT is less than the SRT, with the anaerobic fixed film biomass system giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being washed out of the system.

### Upflow Anaerobic Sludge Blanket (UASB)

A high liquid/solids contact system employing dense, heavy, granular anaerobic biomass, designed for a COD loading of 5 to 20 kg/m<sup>3</sup>d. This group includes proprietary systems from Biotecs, GWE, Paques, Veolia, Waterleau, and a number of others. Another key characteristic of the UASB group is that the design HRT is much less than the SRT, with the dense anaerobic granular biomass giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being wasted from the system.

### Expanded/Fluidized Bed (EFB)

A very high liquid/solids contact system employing either dense, heavy, granular anaerobic biomass or fixed film anaerobic biomass attached to supporting media (sand, pumice, etc.), designed for a COD loading of 10 to 40 kg/m<sup>3</sup>d. This group includes proprietary systems from Aquarion, Ecolab, Hydrothane, Paques, Veolia, Voith, and a number of others. Another key characteristic of the EFB group is that the design HRT is much less than the SRT, with the anaerobic granular biomass or the attached biomass giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being wasted or washed from the system.

### Anaerobic Membrane Process (ANMBR)

A completely mixed reactor system employing suspended/flocculating anaerobic biomass and a synthetic membrane biomass capture and recycle

system, designed for a COD loading of 5 to 15 kg/m<sup>3</sup>d. This group includes proprietary systems from ADI, GE, GWE, HydroThane, Veolia, Wehrle, and a number of others. Another key characteristic of the ANMBR group is that the design HRT is much less than the SRT, with the membrane retention system giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being wasted from the system.

### Anaerobic Hybrid Process (ANHYB)

A combination of standalone anaerobic technologies employing suspended/flocculating, fixed-film, and/or granular anaerobic biomass, designed for a COD loading of 5 to 15 kg/m<sup>3</sup>d. This group includes proprietary systems from ADI, Ondeo, Waterleau, and a number of others. Another key characteristic of the ANHYB group is that the design HRT is much less than the SRT, with the combination of technologies giving anaerobic organisms sufficient time to reproduce sustainably and degrade substrate before being wasted from the system.

## TECHNOLOGY SUPPLIERS

Table 1 outlines the major suppliers of industrial anaerobic treatment technology, the technologies they currently market, and the approximate number of total installations they have as of September 2016. Over the last 25-30 years, the number of industrial non-lagoon anaerobic installations worldwide has increased by nearly an order-of-magnitude and now exceeds 4,800.

In addition to the large increase in industrial installations, there has been a steady but reduced rate of increase in the number of agricultural plants, primarily in Europe, with between 14,000 and 15,000 plants installed, most operating as codigestion systems. Table 2 lists some of the major suppliers of agricultural/codigestion anaerobic technology active in the United States. As of May 2015, there were an estimated 8,928 agricultural/codigestion anaerobic digestion facilities in Germany alone.<sup>1</sup>

New suppliers such as RWL have recently entered the anaerobic wastewater treatment market in North America. A number of well-established European suppliers of high solids codigestion technologies, such as Eisenmann, Entec, OWS, Viessmann, and Weltech, continue to be active in the North American market, while Anaergea, Ecovation and MT Energies have dropped out.

**Table 1**  
**Installed Anaerobic Treatment Systems - Industrial Facilities**

Company	System Type									Total No. of Systems
	ANCP	ANFD	ANFU	ANHYB	ANL	ANMBR	CSTR	EFB	UASB	
ADI Systems <sup>1</sup>				✓	✓	✓	✓		✓	200
Aquarion (SH&E Group) <sup>2</sup>								✓	✓	46
Atis Tech									✓	8
Binowa	✓						✓			26
Biotecs									✓	125
BPI (Bacardi)		✓								10
Custom (non-vendor) Design	✓	✓	✓	✓	✓		✓			655
Ecovation <sup>3</sup> (see Waterleau)								✓		23
ESSI (See ADI Systems) <sup>4</sup>				✓						11
Evoqua <sup>4</sup>	✓	✓	✓	✓						18
Fuji Kusai			✓						✓	20
Grontmij			✓						✓	65
GWE <sup>5</sup>	✓		✓		✓	✓	✓	✓	✓	301
HydroThane <sup>1</sup>						✓	✓	✓	✓	61
Kurita									✓	41
Lackeby (Purac)	✓									86
Lars Enviro		✓					✓		✓	156
Nijhuis	✓								✓	39
Ondeo (Phillip Muller) <sup>6</sup>	✓		✓					✓	✓	111
Paques B.V.				✓				✓	✓	1,073
Phoenix Biosystems (ICM)								✓	✓	127
Proserpol/SGN	✓	✓	✓							50
Raytheon (Badger-Celrobics)			✓							24
Seghers Engineering									✓	43
Shinko Pantec			✓						✓	32
Veolia (Biothane) <sup>7</sup>	✓				✓	✓	✓	✓	✓	670
Voith <sup>4</sup>								✓	✓	32
Wabag	✓		✓						✓	91
Waterleau (Biotim) <sup>8</sup>	✓		✓						✓	196
Wehrle						✓		✓	✓	15

1. ADI markets its technologies as well as the proprietary technologies of HydroThane and E.S.S.I. in North America.
2. Aquarion acquired the assets of SH&E in June 2014.
3. Waterleau purchased Ecovation from Ecolab in 2016 and markets its MFT technology in North America.
4. Evoqua, formerly Siemens, markets its technologies and the proprietary technologies of Voith.

5. GWE markets its anaerobic processes in North America through GWE, its 100% owned North America division.
6. Suez markets Ondeo's proprietary anaerobic technology in North America.
7. Veolia purchased Biothane in 2008.
8. Waterleau purchased Biotim in 2009 and still markets as Biotim.

**Table 2**  
**Suppliers of Anaerobic Treatment Systems - Agricultural Facilities**

Company	System Type								
	AN2STG	ANCP	ANDRY	ANFU	ANHYB	ANL	CSTR	PF	UASB
Agraferm Technologies							✓		
Agri-Waste Technologies						✓			
Biogas Nord	✓						✓		
BTA International							✓		
CTU - Kompogas							✓	✓	
DVO						✓	✓	✓	
Eisenmann	✓		✓				✓	✓	
ENTEC		✓		✓	✓				✓
Keter Organica							✓		
Lipp							✓		
OTV Krüger		✓		✓					
PlanET							✓		
RCM						✓	✓	✓	
Schwarting							✓		
UTS							✓		
Weltec							✓		
Viessmann	✓		✓				✓	✓	

## DESIGN CONSIDERATIONS

Regardless of the specific anaerobic technology employed to degrade an organic waste stream, certain technical issues must be evaluated and resolved prior to choosing one. General design considerations common to all anaerobic treatment applications include:

- Equalization requirements: volume, retention time, type of mixing, pH and odor control
- Pretreatment requirements: TSS/FOG removal, sanitizer handling, size reduction
- Need for substrate heating/cooling and type of heat exchanger
- Nutrient (micro and/or macro) requirements: N, P, S, Fe, Cu, etc.
- Need for pH and/or alkalinity adjustment of the waste stream
- System odor and corrosion control concerns

- Handling of biogas, excess sludge, and anaerobic effluent
- Process control requirements: degree of monitoring and control
- Staffing and training requirements

## Anaerobic Lagoon

The anaerobic lagoon, perhaps the simplest and lowest capital cost anaerobic technology, is usually found in rural areas. It is generally of earthen construction and built as a single-cell process, although multiple cells can be arranged in series or parallel configurations. Influent TSS are allowed to settle and decompose in the lagoon. The large volume provides both solids storage capacity and limited wastewater equalization. As the organic material in the wastewater is degraded, biomass develops in the lagoon. Some of the biomass is partially suspended by hydraulic turbulence and the agitation caused by biogas rising through the

liquid. Mechanical mixing and/or sludge recycle are occasionally added to enhance biomass/substrate contact. The anaerobic lagoon or pond is characterized as a low-loaded system with typical COD loadings in the range of 0.5 to 2 kg/m<sup>3</sup>d (about 30 to 125 lb/1,000 ft<sup>3</sup>d).

The natural cover anaerobic lagoon is the oldest and most frequently applied anaerobic technology. It is used primarily in the agricultural, meat, and poultry industries. In these systems, solids and/or fat, oil, and grease (FOG) separate from the wastewater under quiescent conditions. As the material accumulates at the water surface, a thick floating layer develops, effectively forming a lagoon cover. One of the earliest literature descriptions of a natural cover industrial anaerobic lagoon was for a food processing plant wastewater treatment application in Australia.<sup>2</sup> There are thousands of such installations throughout the world, primarily in the rural areas of Southeast Asia and Latin America. This low-loaded technology is relatively inexpensive to build and operate. There are no major commercial suppliers of this form of anaerobic lagoon technology since such systems are generally custom-designed by a consulting engineer, industrial plant staff, or agricultural personnel.

Synthetic cover anaerobic lagoons are a more recent development, arising out of a desire to increase the performance (COD/BOD removal) of the low-loaded lagoon system and to capture and control odors and biogas. There are a number of membrane cover material manufacturers in the United States including GSE Lining Technology and J.P. Stevens. EFI, GTI, IEC, Lemna, Leyfield, Seaman, Watersaver and others fabricate and supply synthetic lagoon covers with material from the various suppliers, either of their own design or according to specifications prepared by a consulting engineer or owner. GSE and Seaman alone have provided material for synthetic covers for over 130 anaerobic lagoons.

Specific design considerations for anaerobic lagoons include the following:

- Availability of space
- Proximity to subdivisions, commercial areas, and individual residences
- Hydrogeological and geotechnical constraints (e.g., groundwater level, soil permeability)
- Frequency and magnitude of high winds
- Duration and intensity of freezing weather
- Natural cover or synthetic cover

- Membrane or panel synthetic cover
- UV degradation resistance
- Sludge recycle, gas collection and reuse, mechanical mixing and other special features
- Eventual need to remove settled solids
- Rainwater/snowmelt removal from cover

ADI Systems is the leading commercial marketer of low-loaded system technology. Its turnkey low-loaded system, referred to as the ADI-BVF, incorporates intermittent mechanical mixing, sludge recirculation, and influent wastewater heating to increase anaerobic activity and performance. Thus, its system is more aptly termed a modified, low-loaded technology. It has been employed in earthen lagoons as well as concrete and steel tanks. ADI has over 140 such installations operating or under construction worldwide. Environmental Treatment Systems, GWE, Lemna Corporation, Veolia, and several engineering consultants offer low-loaded systems as well.

### Anaerobic Contact Process

Analogous to the aerobic activated sludge process, the anaerobic contact process employs a completely mixed reactor and solids recycle to maximize biomass/substrate contact. Consequently, efficient mixing and biomass separation/return are essential to successful system performance. Key components for the contact process are the completely mixed reactor, the optional mixed liquor degassing unit, and the biomass solids separation device. COD loadings for the anaerobic contact process typically range from 1 to 5 kg/m<sup>3</sup>d (about 60 to 310 lb/1,000 ft<sup>3</sup>d).

The anaerobic contact process, termed a medium-loaded technology, has been applied to meat processing wastewaters as far back as the late 1950s<sup>3</sup>. It is one of few anaerobic technologies that can actively and consistently degrade high TSS/FOG waste streams without a buildup of solids in the reactor. Due to its similarity to conventional anaerobic solids digestion, numerous contact systems have been designed by consulting engineers on a non-proprietary (custom) basis. In addition, GWE, Ondeo, OTV Krüger, Purac, Wabag (formerly VA Tech and CT Environment) Waterleau, and several other companies provide commercial systems. As of September 2016, there were more than 350 contact process systems operating at industrial facilities worldwide. Table 3 lists anaerobic contact system installations for some of the major suppliers.

**Table 3**  
**Anaerobic Contact Process Installations by Vendor**

Industry	Custom	Entec	Ondeo	Purac	Wabag	Waterleau
Agricultural	8	5				1
Beverage		2	3	5	27	12
Brewery					1	
Candy						
Chemicals	1		2	3	1	2
Dairy	6				2	6
Food	3	1		1	1	2
Fruit		1		1	1	
Meat/Poultry/Fish	6			3		2
Paper	1		1	16	18	1
Starch	1		1	6	3	2
Sugar		2	21	41	12	2
Vegetable	4	2	3	2		1
Yeast		2		6	1	
Miscellaneous	4	3			2	6
<b>TOTAL</b>	<b>34</b>	<b>18</b>	<b>31</b>	<b>84</b>	<b>69</b>	<b>37</b>

Purac, the leading supplier of this anaerobic process, shifted its marketing attention away from the anaerobic wastewater treatment field some years ago, reducing the number of active commercial suppliers of this anaerobic technology in North America. They still market the technology outside North America.

Within this category of anaerobic technology, some full-scale thermophilic plant operating data is available. Three plants in North America were used to treat wheat starch processing wastes at temperatures ranging from 50°C (120°F) to 60°C (140°F). These plants had been in operation for more than seven years, all achieving greater than 80% COD removal on an annual average basis. They are now all shut down.

From a design perspective, some of the major application issues to be addressed specifically for a contact process system are:

- Mesophilic or thermophilic process operation
- Steel, reinforced concrete, or prestressed concrete reactor construction
- Side-entering or top-entering mixing
- Atmospheric versus vacuum degasification
- Solids removal via sedimentation or gas flotation

- Lamella or conventional clarifier sedimentation
- Plow-type versus suction-type conventional clarifier solids removal
- Special features such as membrane separation and degasifier odor control

### ANMBR – Anaerobic Membrane Bioreactor Process

The anaerobic membrane process (ANMBR) is the newest of the many anaerobic wastewater treatment technologies available in the marketplace today. The use of membranes as part of an anaerobic process has long been considered and even tested on a research basis. The first full-scale installation of the process was reportedly at a treatment facility in Japan designed to handle septage and garbage.<sup>4</sup>

The general process arrangement consists of an ANCP or ANHYB reactor that holds the anaerobic biomass. Substrate is introduced to the reactor and mixed with the anaerobic biomass. The combined liquid is then directed to a bank of membranes that retains the biomass and other solids in the reactor system and allows treated wastewater to pass through and out of the system. The membrane subsystem can be located within the anaerobic digester or outside and downstream of the anaerobic reactor. ANMBR systems

can be run at mesophilic or thermophilic temperatures and are advertised as high-loaded processes with COD loadings between 5 to 15 kg/m<sup>3</sup>d (approximately 310 to 940 lb/1,000 ft<sup>3</sup>d). However, to date nearly all have been medium-loaded.

A number of membrane equipment suppliers have also tried to commercialize the ANMBR. Kubota Company of Japan was the first manufacturer to develop a full-scale ANMBR and use it on industrial wastewater treatment applications. ANMBR systems are marketed in North America by ADI, GE, GWE, and Veolia. Worldwide, Kubota has 20 ANMBR installations and Veolia has 14. Specific design conditions for an anaerobic membrane system are as follows:

- Steel or concrete reactor construction
- Type of mixing in the reactor
- Membrane reactor construction
- Type of membrane
- Membrane cleaning process and frequency
- Membrane replacement frequency
- Presence of chemicals incompatible with membrane material
- Excessive levels of FOG

## UASB – Upflow Anaerobic Sludge Blanket

The upflow anaerobic sludge blanket (UASB) process is a high-loaded process that generally employs a single reactor containing a bed of dense active granular anaerobic sludge with a blanket of flocculant, less dense sludge above. Influent wastewater is evenly distributed beneath the bed and flows upward through the biomass bed, usually about three to five meters in depth. The intimate biomass/substrate contact is developed through a combination of the hydraulic flow distribution and biogas generation. A three-phase separator is employed at the top of the reactor to separate biogas and TSS from the liquid. Typical COD loadings for UASB systems range from 5 to 20 kg/m<sup>3</sup>d (about 310 to 1,250 lb/1,000 ft<sup>3</sup>d).

Originally developed in Europe<sup>5</sup>, the UASB process is truly unique because of its dependence on the development of granular sludge for proper operation. Due to the difficulties involved with the development of such granular sludge and retaining it in the reactor at high hydraulic throughputs, UASB systems are generally provided commercially on a proprietary process basis. That is, a limited number of companies market such systems, selling the technology in a package that includes a specially designed influent distribution

**Table 4**  
**UASB Installations By Vendor**

Industry	Biotecs	Grontmij	GWE	Ondeo	Paques	Veolia	Waterleau
Agricultural							
Beverage	74		50	19	64	52	13
Brewery	13	8	104	14	79	75	58
Candy	1	2	4		9	6	1
Chemicals		3	1		22	22	1
Dairy	7	2	3	5	6	11	2
Food	3	5	13		21	24	3
Fruit	1		10		4	4	1
Meat/Poultry/Fish			2		2	2	2
Paper		1	3	5	67	22	5
Starch	2	3	35		5	16	2
Sugar	6	3	6	5	1	21	16
Vegetable		3	11	2	29	54	16
Yeast					10	17	
Miscellaneous	12	34	13	2	26	7	1
<b>TOTAL</b>	<b>119</b>	<b>64</b>	<b>255</b>	<b>52</b>	<b>345</b>	<b>333</b>	<b>123</b>

system, prefabricated settlers (to retain the sludge in the reactor), and an initial seed volume of the special granular sludge.

As of September 2016, there were over 1,600 UASB installations worldwide. The major suppliers of UASB technology are listed in Table 4 on the previous page, along with their industrial and agricultural installations. In North America, GWE, Paques, Veolia and Waterleau are most active in the UASB technology marketplace today. For a UASB system, some of the more specific design considerations include:

- Flow/load equalization
- Preconditioning (partial acidification) of the wastewater
- Limitation of influent TSS to 10% to 20% of influent COD
- Limitation of influent FOG levels to < 100 mg/L
- Steel or concrete reactor construction
- Corrosion resistant material selection for cover and proprietary settler
- Uniform, steady distribution of influent within sludge bed
- Adequate storage volume for backup sludge supply
- Specific need for minimum levels of calcium and micronutrients

### Anaerobic Filter

Anaerobic filters employ media within a reactor to support the development of high concentrations of active, fixed-film biomass. The choice of media varies considerably and has ranged from rocks to pall rings to reticulated polystyrene. These systems can be operated in either the upflow or downflow mode, depending on the selected design approach, with specific advantages and disadvantages to each. Anaerobic filters are considered high-loaded processes and COD loadings can typically range from 5 to 20 kg/m<sup>3</sup>d (about 310 to 1,250 lb/1,000 ft<sup>3</sup>d).

Following its original development in the 1960s, upflow anaerobic filter technology advanced rather slowly. The first full-scale food processing plant installation operated in the early-to-mid 1970s<sup>6</sup>. Since it was only intended to operate as a temporary system, it was eventually shutdown. The first attempt at large-scale commercial development of upflow filter technology was by Celanese Chemical Corporation, who ultimately installed three plants of its own design. The technology was later licensed to Badger Engineering for commercial development. Raytheon later acquired Badger Engineering and the rights to the Celrobics process. There are now nearly 30 installations, most of which are located in Japan.

Tri-Bio and Raytheon had been the most active marketers of upflow filter technology in the United States for some time but no longer are. Two other companies, Arcadis/Heidemij of the Netherlands and AgipGiza of Italy, have installations on-line in Europe but have not actively marketed their systems in North America. Table 5 lists upflow filter installations.

**Table 5**  
**Upflow Anaerobic Filter Installations by Vendor**

Industry	Ondeo	Raytheon	Shinko	Tri-Bio	Waterleau
Agricultural					
Beverage	4				
Brewery		1	1		1
Candy					1
Chemicals		12	7		1
Dairy	3				2
Food		6	9		
Fruit	1				
Meat/Poultry		1	2		1
Paper	1	1			
Starch		1	3		1
Sugar					
Vegetable	1	3	2		1
Yeast					
Miscellaneous		2	1	10	3
<b>TOTAL</b>	<b>10</b>	<b>27</b>	<b>25</b>	<b>10</b>	<b>11</b>

The application of downflow anaerobic filters has been popularized primarily by Biotechnical Processes, Inc. (Bacardi) in North America<sup>6</sup> and by Proserpol/SGN in Europe. These two companies are responsible for nearly all of the commercial applications of this technology (see Table 6). Amoco Chemicals has developed a proprietary downflow anaerobic filter design and has applied it in five of its production facilities. It is not marketed commercially. As of September 2016, there were nearly 220 anaerobic filter (upflow and downflow combined) systems worldwide.

**Table 6**  
**Downflow Anaerobic Filter Installations by Vendor**

Industry	BPI	Larsen	Proserpol/ SGN
Agricultural			
Beverage	6	12	24
Brewery	1		1
Candy			
Chemicals	1	3	7
Dairy		1	2
Food	1		
Fruit			4
Meat/Poultry			1
Paper			
Starch			1
Sugar	1	1	3
Vegetable			
Yeast			
Miscellaneous		1	3
<b>TOTAL</b>	<b>10</b>	<b>18</b>	<b>46</b>

Major design considerations for both upflow and downflow filter systems include the following:

- Flow/load equalization
- Provisions for wastewater pretreatment to limit TSS and FOG to the system
- Preconditioning of the wastewater
- Steel, reinforced concrete, or prestressed concrete reactor construction
- Internal media material, type, and configuration
- Uniform, steady distribution of influent flow
- Provision for removal of solids from media
- Identification of method for measuring biomass levels in reactor

## Anaerobic Expanded/Fluidized Bed

The anaerobic expanded, or fluidized bed technology, has become the most frequently applied technology available today. Reasons for this range from their very small space requirements, their capacity to handle high volumes of water quickly, to their “high tech” image. Performance is critically dependent on the efficient distribution of the influent/recycle stream to ensure a rapid, uniform flow through the reactor bed and adequate biomass growth.

The distinction between an expanded bed and a fluidized bed is not clearly defined. In general, literature references describe expanded beds as those undergoing an increase in bed volume of 5 to 25% over the initial (rested state) bed volume. In contrast, fluidized bed systems have been tested or operated with bed volumes 25 to 50% higher than initial bed volumes.

The conventional anaerobic expanded or fluidized bed, as originally developed, is a fixed film process that allows the growth of biomass on sand, anthracite, granular activated carbon, PVC or diatomaceous earth particles or another inert media. Upward hydraulic flow expands the bed and hydraulically holds the biomass-coated media in suspension. Very high fixed film biomass concentrations can be maintained within the reactor, allowing very high loading rates.

Expanded bed anaerobic technology is available with granular sludge biomass rather than inert media. Veolia<sup>8</sup> and Paques<sup>9</sup> have developed and marketed very high-loaded granular sludge systems that are able to handle 10 to 40 kg COD/m<sup>3</sup>d (about 1,250 to 2,500 lb COD/1,000 ft<sup>3</sup>d). As of September 2016, there were over 1,200 expanded/fluidized bed installations worldwide. Table 7 on the following page lists the current major commercial vendors of anaerobic expanded and fluidized bed technology. Aquarion, Ecolab, GWE, Paques, Veolia and Voith systems are actively marketed in North America.

**Table 7**  
**Anaerobic Expanded/Fluidized Bed**  
**Installations by Vendor**

Industry	Aquarion	Ondeo	Paques	Veolia	Voith
Agricultural					
Beverage	1	2	65	46	
Brewery	4	4	181	57	
Candy			13	5	
Chemicals	2	1	48	50	1
Dairy	2	1	11	6	
Food			27	10	
Fruit	11	1	12	7	
Meat/Poultry			2		
Paper	2	3	205	41	18
Starch		3	29	4	
Sugar	1	1	11	7	
Vegetable	2	1	30	37	
Yeast	1		23	19	
Miscellaneous	2	1	27	5	
<b>TOTAL</b>	<b>28</b>	<b>18</b>	<b>684</b>	<b>294</b>	<b>19</b>

Specific design considerations for expanded/fluidized bed systems are:

- Flow/load equalization
- Preconditioning (acidification) of the wastewater
- Limitation of influent TSS to 10 to 20% of influent COD
- Limitation of influent FOG levels to <100 mg/L
- Steel or fiberglass reactor construction
- Corrosion resistant material selection for cover and internals
- Carrier material selection for systems with a carrier media
- Carrier cleaning and solids removal system

### ANHYB and Two-Stage Systems

The combination of two or more anaerobic process configurations has led to the development of a number of hybrid reactor systems. For example, UASB technology has been coupled with both the contact process and the anaerobic filter technology in a single reactor,

while anaerobic filter technology has been employed in anaerobic lagoons. In the codigestion field, two-stage systems commonly couple a plug flow unit with a downstream CSTR unit. Such ANHYB configurations are designed to take advantage of the beneficial features of several anaerobic processes without realizing the high cost of employing multiple, separate processes. Organic loadings for these systems are similar to those of the anaerobic filter processes.

As Table 8 indicates, the number of commercially available ANHYB and two-stage systems is growing slowly. As of September 2016, there were nearly 150 ANHYB installations worldwide. Both ADI and Waterleau are marketing ANHYB systems. ADI has 22 installed systems and Waterleau has 15. The two-stage anaerobic process separates the acid-forming and methane-forming phases into individual stages. Conceptually, each stage is designed independently, resulting in two reactors, each of which is operated to optimize a particular phase of the anaerobic process. Eisenmann and Viessmann appear to be the most successful marketers of this system, having many operational codigestion installations in Europe.

**Table 8**  
**ANHYB/AN2STG Process Installations by Vendor**

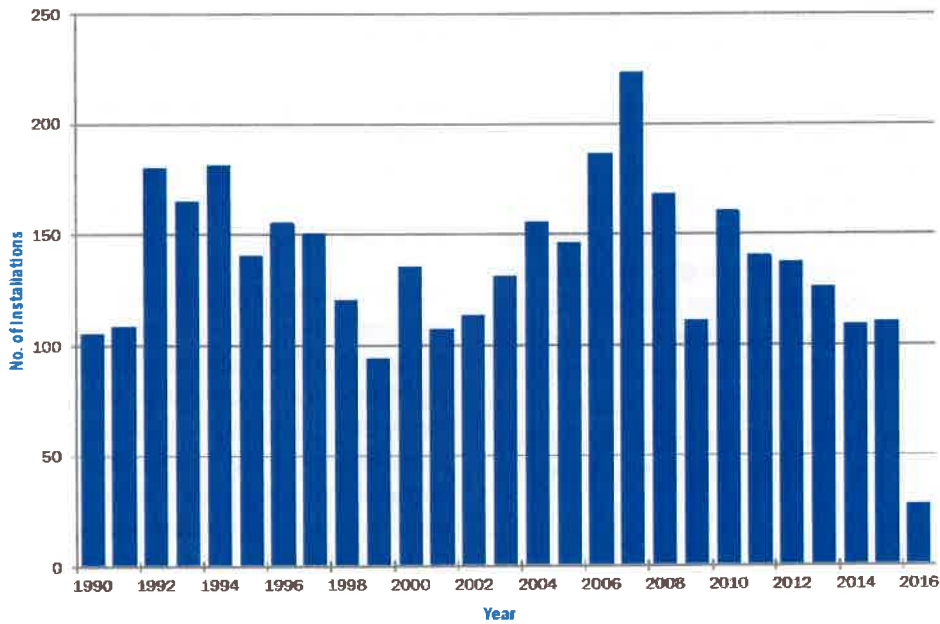
Industry	ADI	Eisenmann	Nijuis	Waterleau
Agricultural				
Beverage				5
Brewery	2			
Candy				
Chemicals	17			1
Dairy				1
Food	1			
Fruit				
Meat/Poultry				
Paper	1			1
Starch				
Sugar				
Vegetable				1
Yeast				4
Miscellaneous	1	77	19	1
<b>TOTAL</b>	<b>22</b>	<b>77</b>	<b>19</b>	<b>15</b>

## TECHNOLOGY SUMMARY

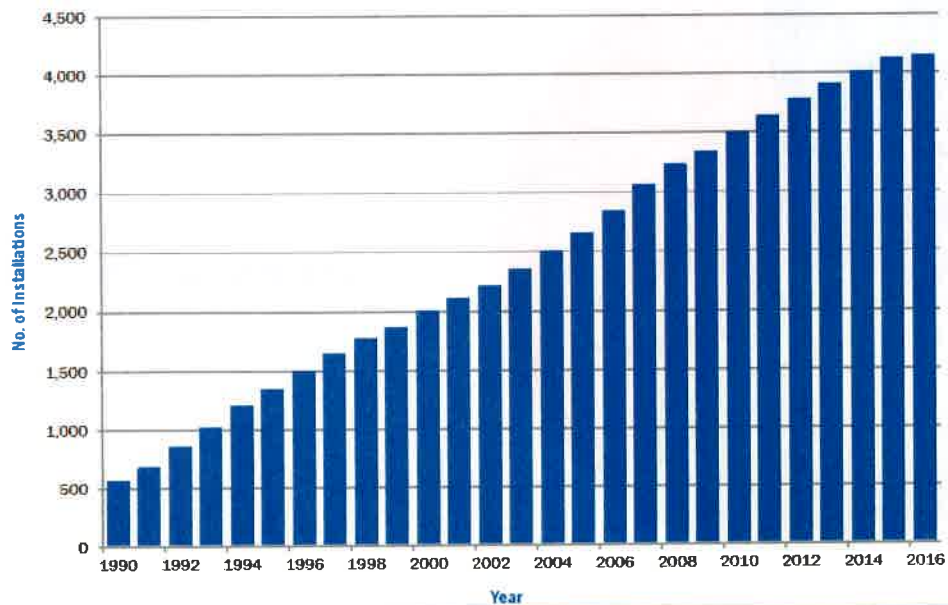
In addition to the companies listed in Tables 1 and 2, a number of unlisted companies market anaerobic treatment technology, but only a few currently have installations. Among these firms are Atis Tech (UASB) and Wehrle (UASB). Consulting engineering firms that have custom-designed at least five anaerobic systems include Applied Technologies, CET, CH2M Hill, and HDR Engineers.

The number of installed anaerobic systems has increased steadily since the late 1970s. Figure 1 illustrates the number of systems constructed since 1980. Figure 2 illustrates the cumulative number of anaerobic installations since 1980. The market for industrial anaerobic technology continues to be healthy, with approximately 100-125 new non-lagoon installations being built each year.

**Figure 1**  
**Industrial Anaerobic System Installations - Worldwide**



**Figure 2**  
**Cumulative Anaerobic System Installations - Worldwide**



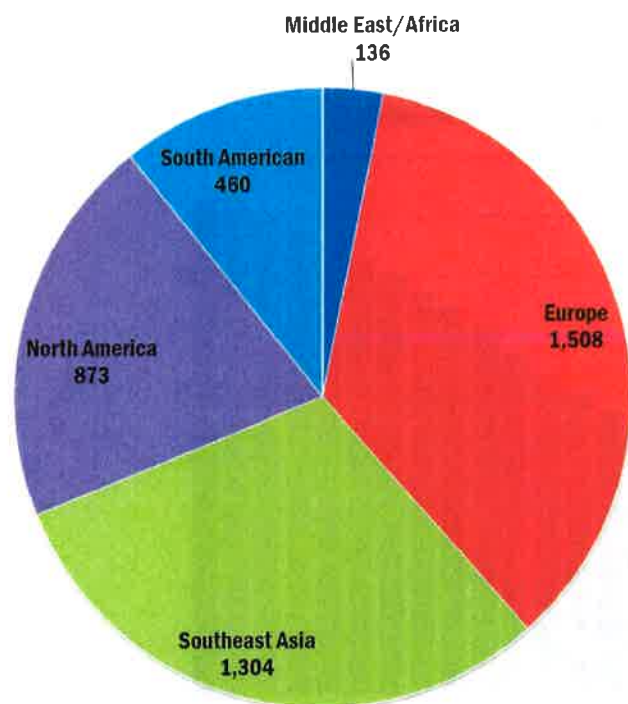
In the industrial market, the anaerobic lagoon is the most commonly applied anaerobic technology; there are an estimated 4,000 in Latin America and 9,000 in China<sup>10</sup>. The next most frequently applied technology is the UASB, with over 1,600 installations. The fluidized/expanded bed process follows with over 1,200 installations worldwide. The number of contact process installations remains just over 350. The total number of filter installations is just over 200. The ANHYB technology is the least used anaerobic technology, with about 150 installations. The anaerobic membrane process is growing with just over 40 installations worldwide. For the agricultural market, CSTR technology is the most frequently applied anaerobic technology, with over 10,000 installations located mainly in Europe.

Anaerobic lagoons are used primarily in the agricultural field, and to a lesser degree, in the meat and poultry industries. The anaerobic contact process is applied most commonly in the sugar, beverage (distillery), ice cream, and agriculture wastes industries. ANMBR systems appear to be best suited to high TSS, moderate FOG waste streams. UASB systems are used extensively in the beverage, brewery, pulp and paper, and vegetable processing industries. Anaerobic filters are employed commonly in the landfill leachate, chemical, and beverage production fields. Fluidized bed technology is used primarily by the brewery, paper, and chemical industries.

Figure 3 shows the global geographic distribution of industrial anaerobic installations by region for all installations listed in my database. It is not surprising that Europe has the highest number of anaerobic installations, having been the leading proponent of anaerobic wastewater treatment since the late 1970s. The increasingly large number of installations in Southeast Asia and North America testifies to the cost-effectiveness of this technology. Figure 4 on the following page depicts the geographic distribution of industrial anaerobic installations (non-agricultural) by country (top 16 only). The three countries with the greatest growth in anaerobic systems are China, India, and the United States.

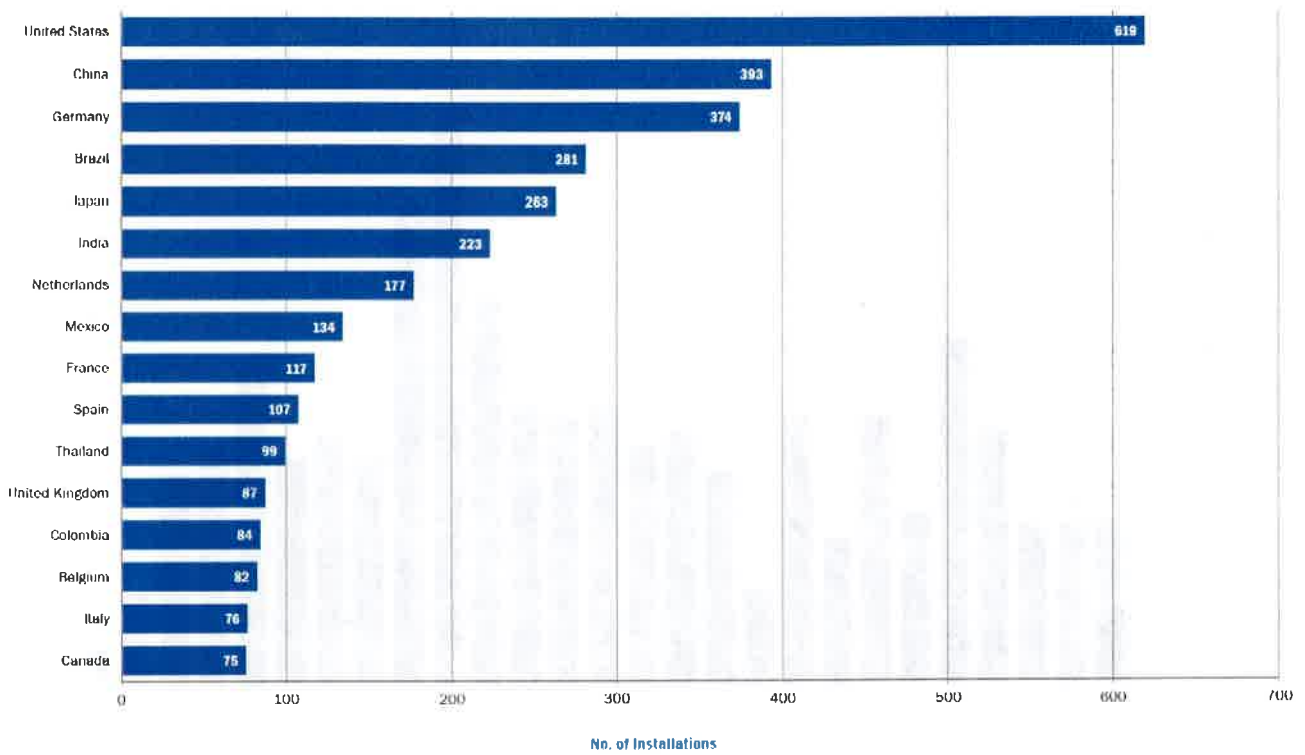
Since this paper is updated annually for presentation at the “Anaerobic Treatment of High-Strength Industrial Wastes” seminar, in September it is fitting that the geographic distribution of industrial anaerobic installations within the United States be reviewed. Figure 5 shows the distribution of industrial anaerobic installations by state (top 10 only).

The remaining 290 installations in the United States are distributed over another 38 states. As expected, many anaerobic installations are located in states with significant food, beverage, and agricultural product production capacity. Over 50% of the anaerobic installations in the United States are located in the Midwest. Figures 6 and 7 show the growth in anaerobic installations in the United States. It appears that the American market is still growing at a rate of 20 to 25 new non-lagoon installations per year.

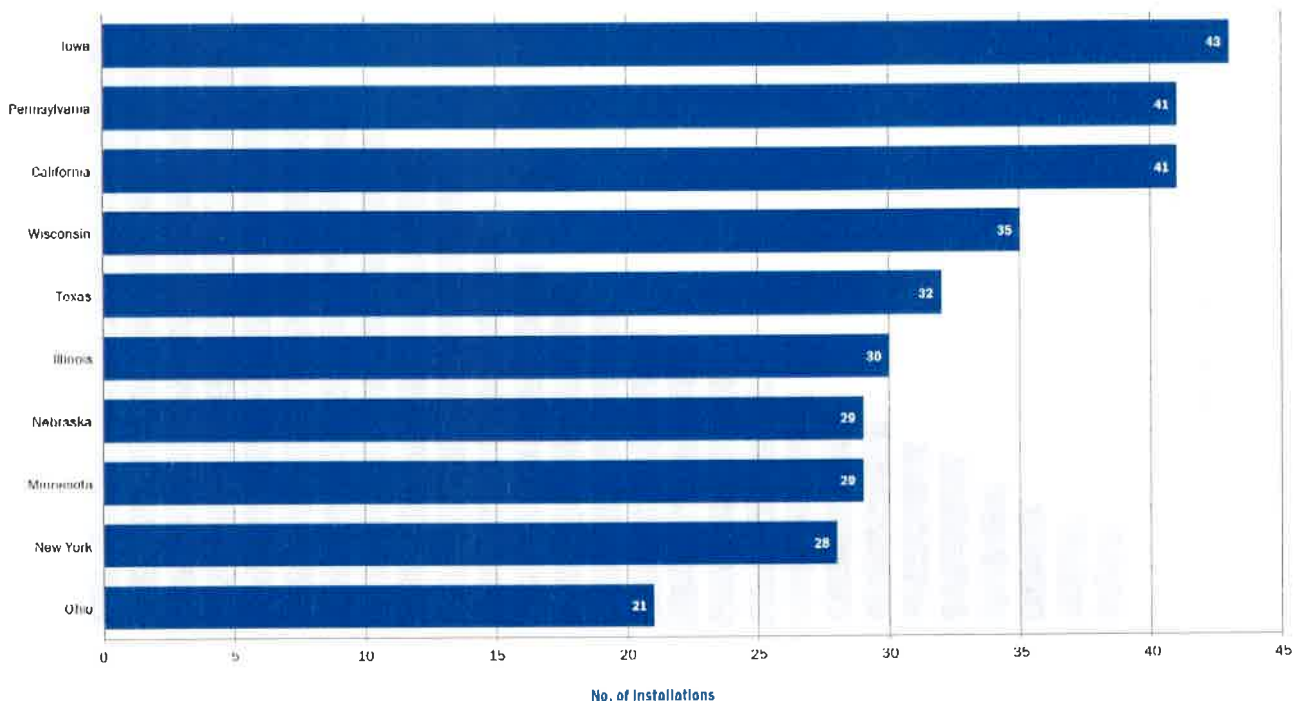


**Figure 3**  
**Anaerobic Installations by Region**

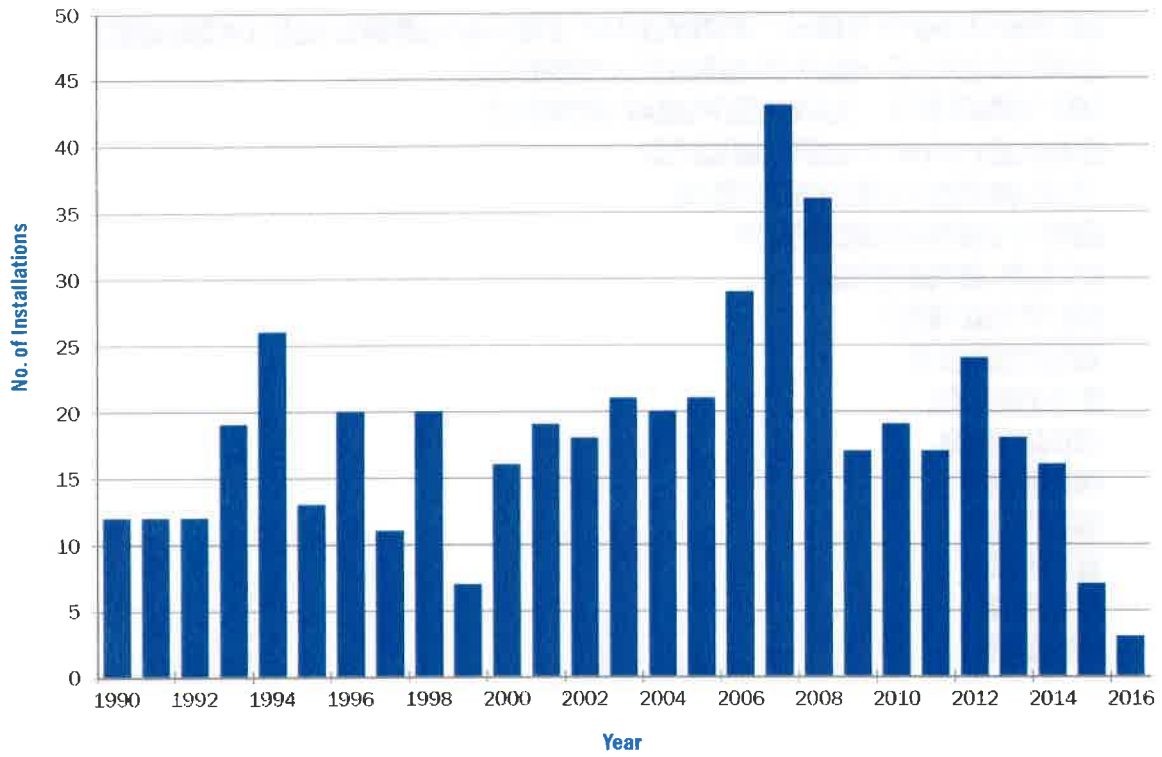
**Figure 4**  
**Top 16 Anaerobic Installations by Country**



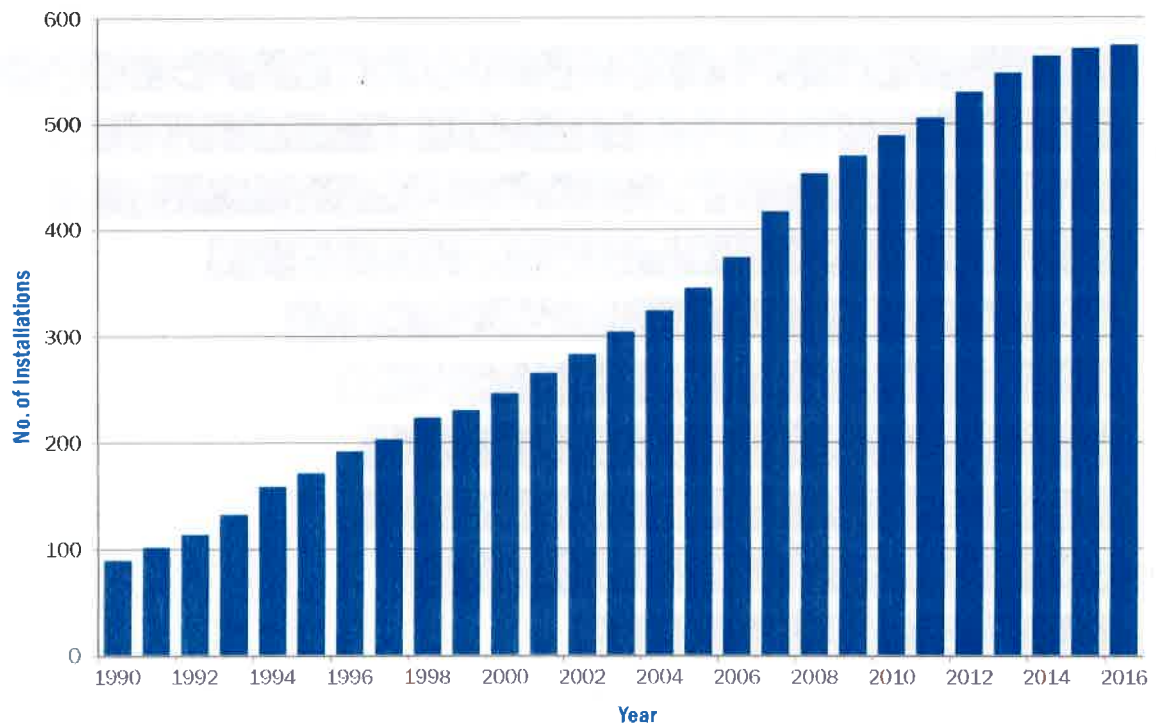
**Figure 5**  
**Top 10 Anaerobic Installations by State**



**Figure 6**  
**Anaerobic System Installations - USA**



**Figure 7**  
**Cumulative Anaerobic System Installations - USA**



## CLOSING

On an applications level, the number of consulting engineers and design-build companies with anaerobic wastewater treatment experience continues to increase. Both Macarie<sup>11</sup> and Monroy, et al.<sup>12</sup> have documented the increases in the number of anaerobic applications in the chemical industry and the country of Mexico, respectively. Although larger companies with significant financial resources dominate the worldwide anaerobic technology marketplace, new companies such as Aquarion, Cambrian Innovation, and RWL continue to emerge. In addition, suppliers of anaerobic technology are now focusing efforts in the field of codigestion using municipal biosolids or agricultural manures as base substrates. A recent article written by Dennis Totzke<sup>13</sup> discussed the reasons for the significant future growth in anaerobic codigestion systems.

Although the number of industrial anaerobic installations has grown significantly over the last 40 years, the feedback of useful operating information remains relatively slow. Much of the limited data that is made available to potential users comes from the anaerobic technology suppliers. Industrial operators of most anaerobic systems are hesitant to discuss performance data and problems or disclose operating costs. More seminars and workshops are needed to assemble and present data on existing installations so that current and potential users of anaerobic technology can benefit from the dissemination of full-scale operating results.

With respect to future developments in the field of anaerobic treatment, a paper written by Van Lier, J.B., et al.<sup>14</sup> provided a succinct summation of potential changes:

- Optimization of anaerobic systems through reactor staging, hybridization, thermophilic treatment, accelerated hydrolysis, improved solids retention and better process control
- Fine-tuning of anaerobic conversions to produce readily disposable effluents
- Utilization of anaerobic treatment processes as a core technology in systems designed to reclaim products and energy from waste streams

More recently, the application of anaerobic technology to manure, thin stillage, and regionally mixed substrates continues to gain increased attention. A recent paper by Zitomer, et al<sup>14</sup> reviewed a large number of potential co-digestates and estimated their economic benefits.

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