Estimation Methods of GHG Emissions from Waste Sectors

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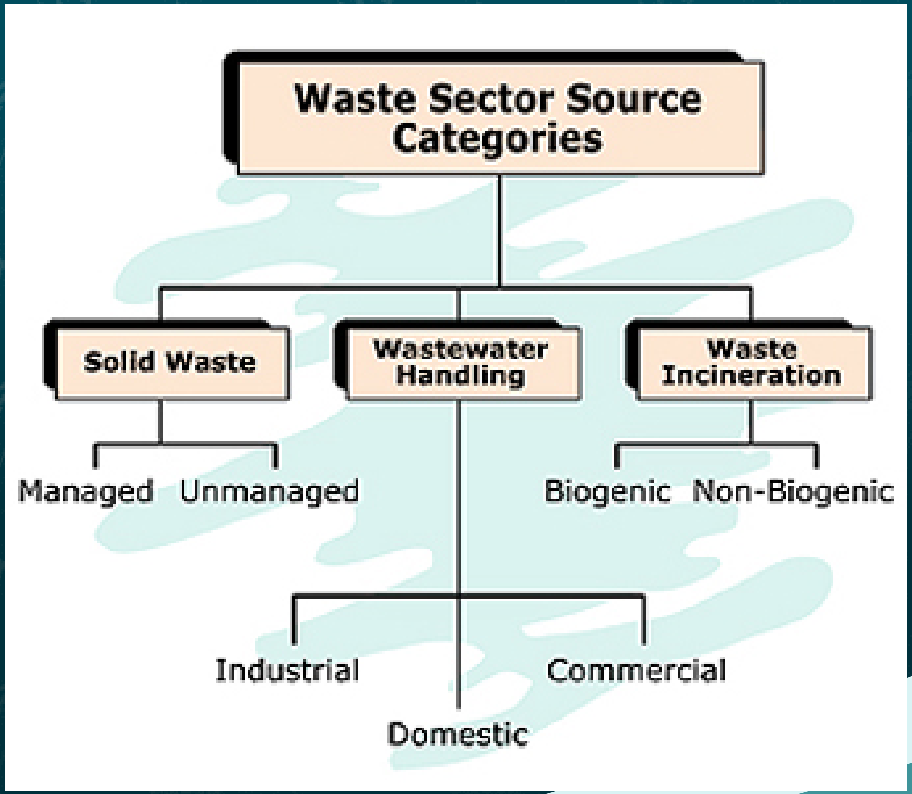
BACKGROUND

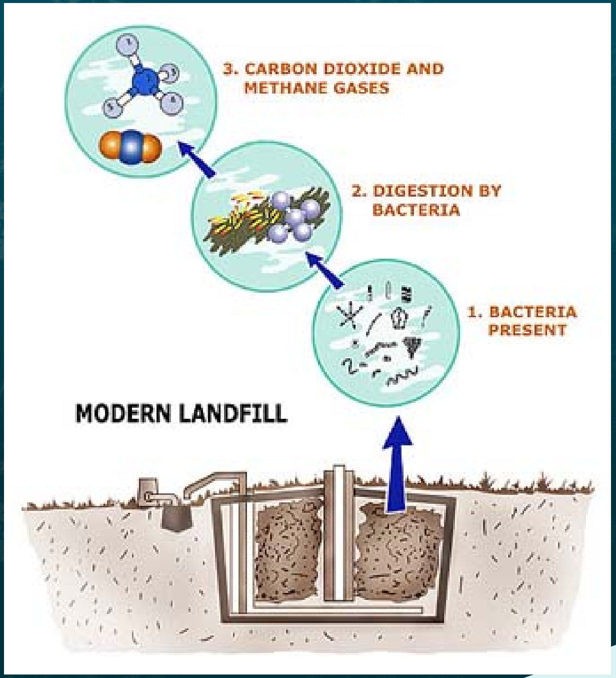
Waste Sector Categories

- **Waste Sector** is composed of Solid Waste Disposal on Land(SWDL), Wastewater Handling(WH), Waste Incineration(WI).
  - Recently, Biological Treatment of Solid Waste (ex, composting) is added.



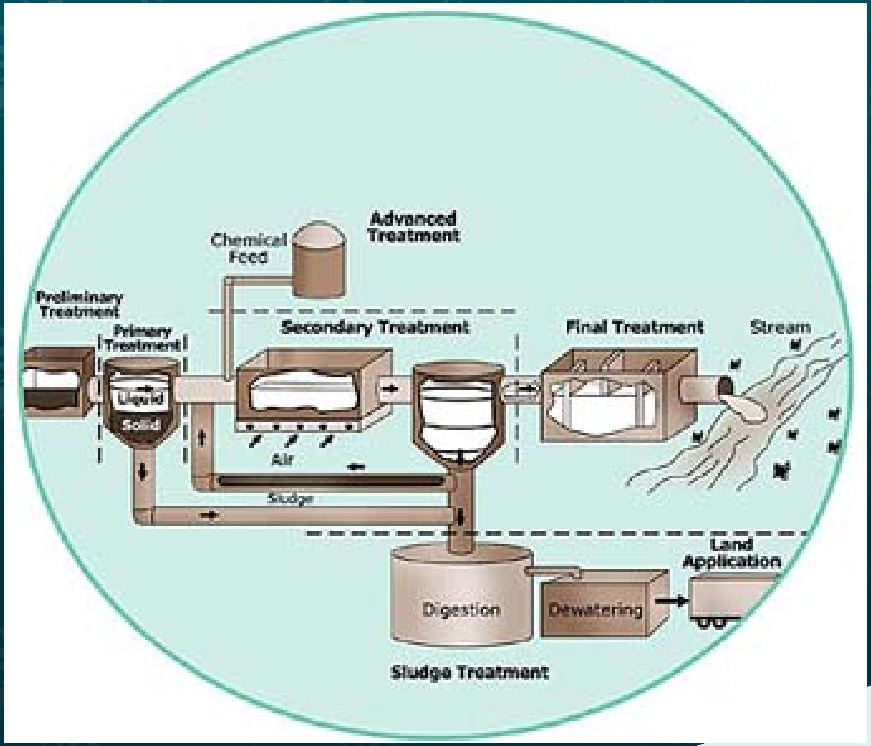
Background on Waste Sector

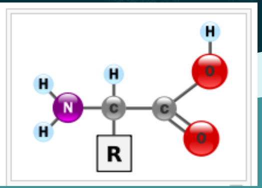
- **Solid waste disposal on land(SWDL)**
  - The final disposal of Solid Waste(SW) by placing it <u>in a controlled fashion</u> in a place intended to be permanent. This term is used for both controlled dumps and sanitary landfills.
    - Secure Landfill?
  - **SWDL** is divided into managed waste disposal on land, and unmanaged waste disposal sites.



Background on Waste Sector

- **Wastewater handling(WH)**
  - The process of wastewater treatment under controlled conditions to reduce its concentrations of contaminants (BOD, SS, etc.)
  - WH is divided into <u>industrial wastewater</u>, and <u>domestic and commercial wastewater</u>.
  - N_2O emissions are made from the human sewage component of domestic wastewater; Protein

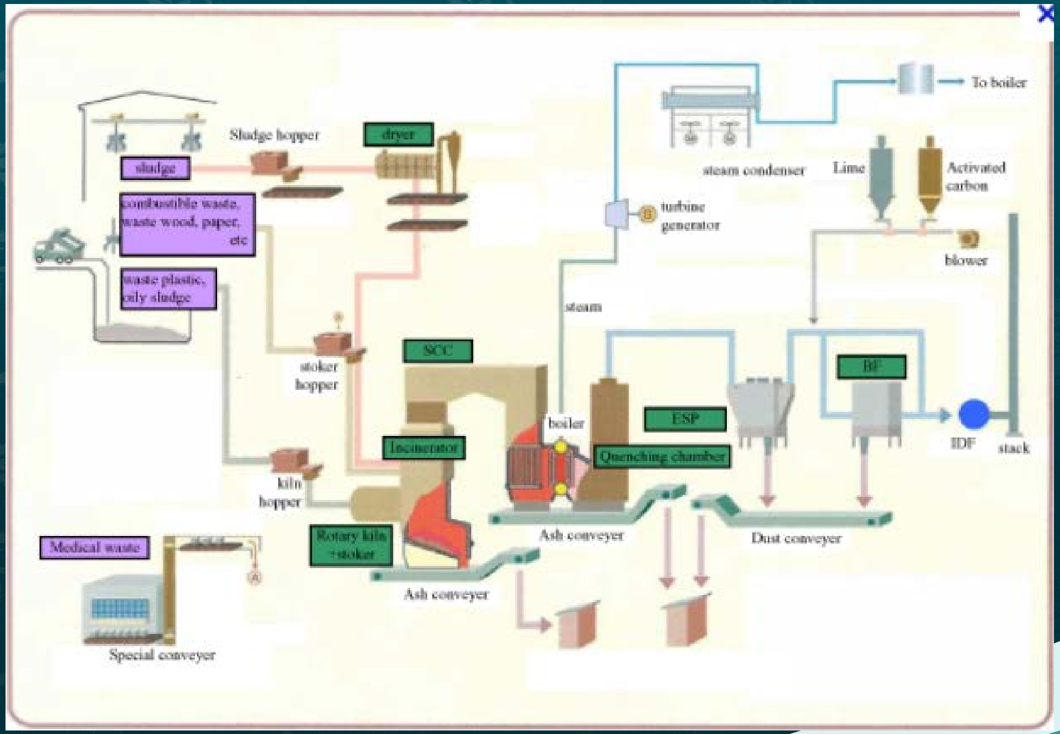




Amino Acid

Background on Waste Sector

- **Waste incineration(WI)**
  - The process of burning SW under controlled conditions to reduce its weight and volume, and often to produce energy
- **Incinerated wastes?**
  - Waste incinerated is divided into wastes of biogenic origin, and those of non-biogenic origin(e.g. plastics, rubber, certain textiles, waste oil, etc.).



Major Processes Related to GHG Emissions

Emission producing Processes	SWDL	WWH	WI
Methanogenesis	**CH_4**	**CH_4**	
Nitrification and Denitrification		**N_2O**	
Incineration			**CO_2, CH_4, N_2O**
General Decomposition	CO_2	CO_2	

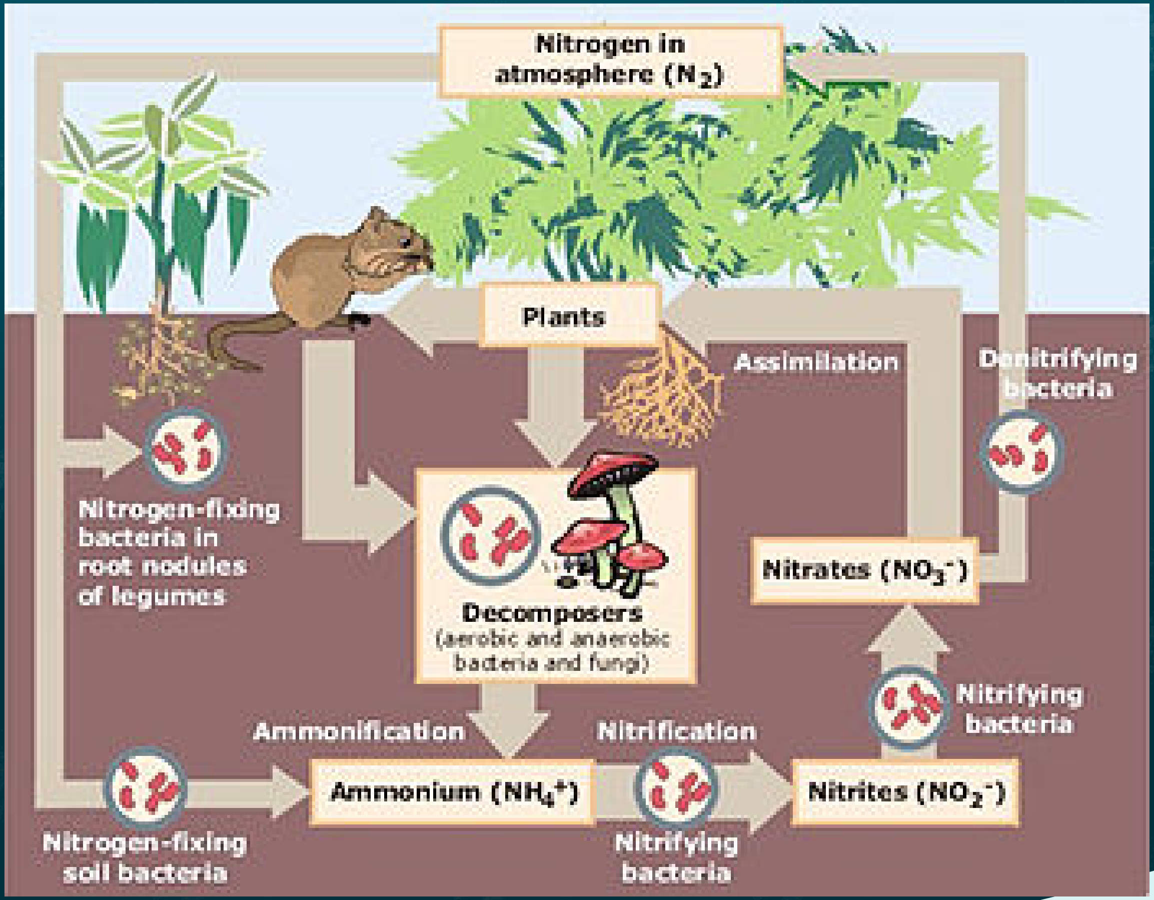
Major Processes

- **Methanogenesis**
  - The process by which methanogenic bacteria breakdown waste to produce methane. The process only occurs under **anaerobic conditions**
  - The amount of methane produced through methanogenesis is related to the balance between aerobic and anaerobic processes and is therefore influences by waste management practices, waste composition, and physical factors(e.g., moisture, temperature, and pH)
- **Waste subsector: SWDL and WH**
  - Methanogenesis occurs in land disposal sites for solid waste where near optimal anaerobic conditions are often created.
  - Methane is also produced in the process of wastewater handling when the wastewater undergoes anaerobic or partially anaerobic treatments.

Major Processes

- **Nitrification / Denitrification**
  - The biological process of nitrification and denitrification produces N_2O
    - Nitrification : Oxidation of ammonia to nitrite(NO_2^-) and then nitrate(NO_3^-) by microorganisms; $NH_3 \rightarrow N_2O \rightarrow NO^-_2 \rightarrow NO^-_3$
    - Denitrification : Reduction of nitrate to nitrogen(N_2) by microorganisms; $NO^-_3 \rightarrow NO^-_2 \rightarrow N_2O \rightarrow N_2$
  - The process can occur during WH and it especially important to consider when waste flows have relatively high nitrogen contents.

Major Processes



Major Processes

- **Incineration**
  - The characteristics of the incineration(combustion) process, the technologies used, and composition of the waste itself are important parameters determining emissions.

Contents

- (Session1) Solid Waste Disposal on Land
- (Session2) Wastewater Incineration

(Session 1)
Solid Waste Disposal on Land

(Session 1)
1.1. Landfill Processes

Landfill Process

Solid Wastes

Transfer Station

Landfills

Leachates

Leachate Treatment

LFG

Landfill Gas Collection and Transfer

Electricity Generation Facility

Landfill Process

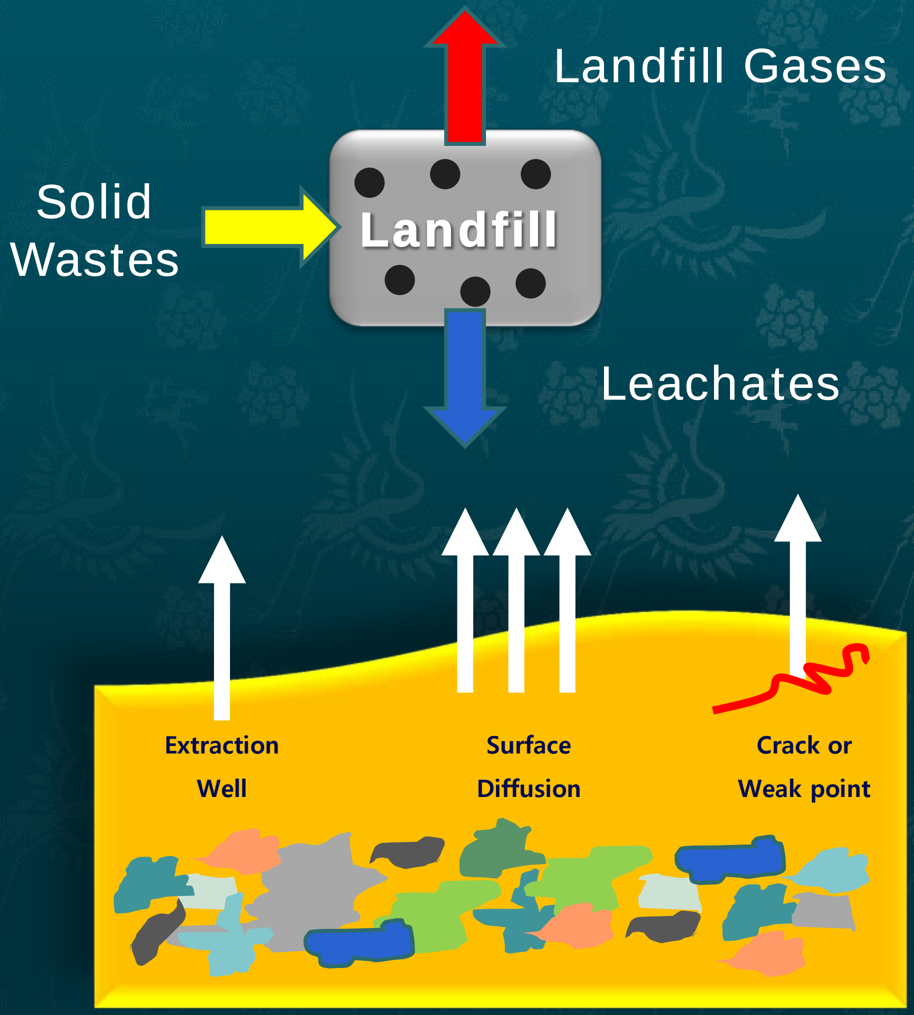
Process		Explanation
Inlet processes of SW	[1] Transfer Station	▪Pre-treatment processes performing separation of recyclables and compaction of SW before transferring to landfill
	[2] Weighing Station	▪Weighing station of SW for landfills
Landfilling	[3] Landfill Site	▪Landfilling of SW, non-combustibles that cannot be recycled, inorganic residues from incineration process
Leachate Treatment	[4] Leachate Treatment	▪Treatment process of leachates (*in situ* primary treatment) ▪Transferring to domestic and commercial wastewater treatment plant
LFG Treatment	[5] Collection and Transfer of LFG	▪Collection of landfill gas(LFG) and transfer to energy recovery system
	[6] Electricity Generation	▪Generation of electricity and heat energy from LFG

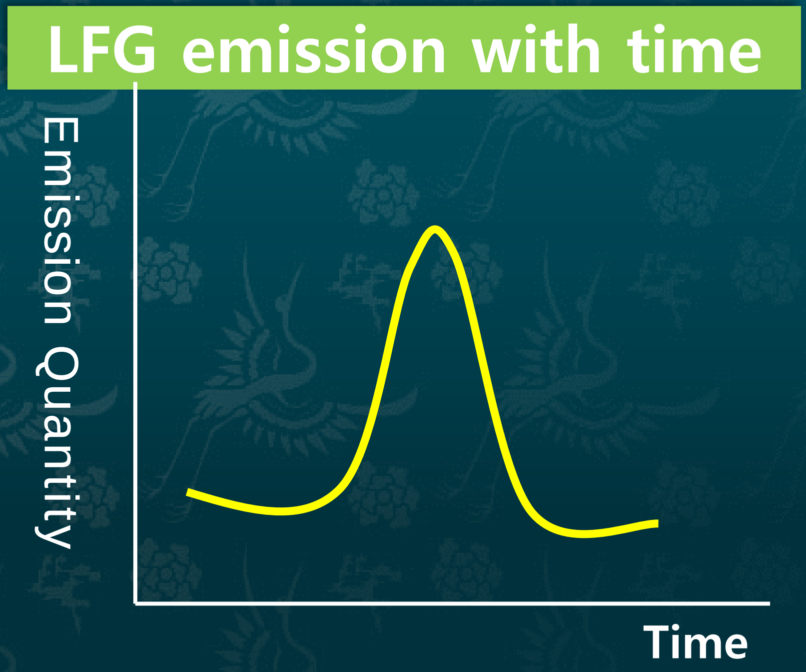
(Session 1)
1.2. Methane Emission from SWDL

Emissions from SWDL

- Landfills are large anthropogenic sources of methane(CH_4) emissions which result from the decomposition of organic landfill materials such as paper, food scraps, and yard trimmings.

Emissions from SWDL





Emissions from SWDL

- The decomposition process primarily results from biological activity through which microorganisms derive energy. After being placed in a landfill, organic waste is initially digested by aerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars.
- These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria.
- Methane-producing anaerobic bacteria convert these fermentation products into stabilized organic materials and biogas consisting of approximately 50% CO_2 and 50% CH_4 by volume(less than 1% of NMVOCs).
  - The percentage of CO_2 in biogas may be smaller because some CO_2 dissolves in leachates.
- Methane production typically begins one or two years after waste disposal in a modern landfills and may last from 10 to 60 years.

Degradation Processes of Organic Wastes in Landfill

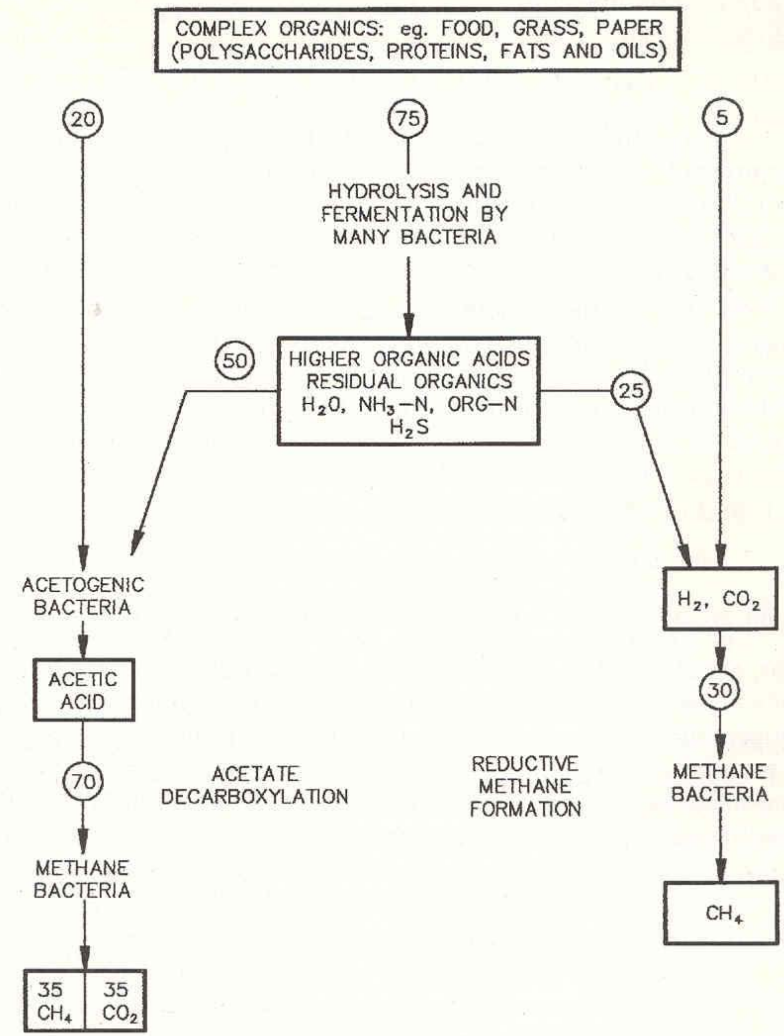


Fig. 4.3 Biodegradation pattern for organic matter. The numbers in circles give the percent of carbon.

Phases of LFG and Leachates Generation

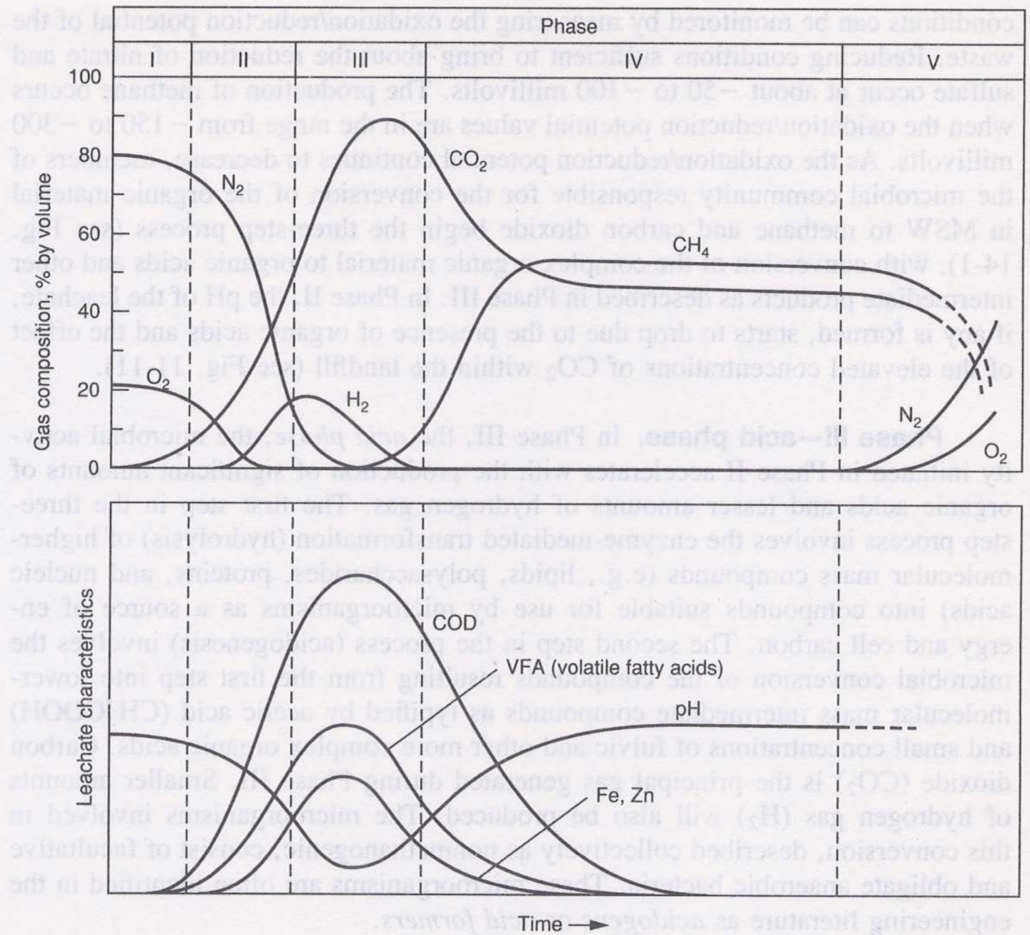


FIGURE 11-11
Generalized phases in the generation of landfill gases (I = initial adjustment, II = transition phase, III = acid phase, IV = methane fermentation, and V = maturation phase). (Adapted from Refs. 13, 34, 37, and 38.)

Phases of LFG Generation

- **Phase I : Initial Adjustment**
  - Organic biodegradable components in MSW(Municipal Solid Waste) undergo microbial decomposition under **aerobic conditions** because of air trapped within landfill.
- **Phase II : Transition Phase**
  - Oxygen is depleted and anaerobic conditions begin to develop.
  - Organic materials are converted into organic acids and other intermediate products.

Phases of LFG Generation

- **Phase III : Acid Phase**
  - Microbial activities accelerate the biological degradations with the production of significant amounts of organic acids and lesser amounts of hydrogen gas.
    - **1st step** : Breakdown of high molecular weight compounds into smaller ones suitable for a source of energy and cell carbon
    - **2nd step** : Further breakdown process to generate acetic acid and other smaller molecular weight compounds
    - **3rd step** : CO_2 and H_2 would be generated from acetic acid

Phases of LFG Generation

Phase IV : Methane Fermentation Phase

- Anaerobic microorganisms convert the acetic acid and hydrogen gas formed in acid phase to CH_4 and CO_2.
- Both methane and acid formation proceed simultaneously, although the rate of acid formation is considerably reduced.
- pH will rise to more neutral values in the range of 6.8 to 8.

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Phases of LFG Generation

- **Phase V : Maturation Phase**
  - Maturation phase occurs after the readily available biodegradable organic material had been converted to CH_4 and CO_2.
  - The rate of LFG generation diminishes significantly because most of the available nutrients have been removed with the leachate.
  - The principal LFG evolved in this phase are CH_4 and CO_2.
  - The leachate will often remain humic and fulvic acids, which are difficult to process further biologically.

Emissions from SWDL

- Methane emissions from landfills are a function of several factors, including:
  1) the total amount of MSW in landfills, which is related to total MSW landfilled annually for **the last 50 years**;
  2) the amount of methane that is recovered and either flared or used for energy purpose; and
  3) the amount of methane oxidized in landfills instead of being released into the atmosphere.

Emissions from SWDL

- Key parameters for estimating methane emissions from solid waste disposal on land are **1) the quantity of carbon** contained in the waste, **2) the availability of that carbon to the biodegradation process**, and **3) the moisture content**.
- Most solid waste contains a mixture of biogenic and non-biogenic components, and the carbon in the non-biogenic waste (ex; plastics) is generally not able to be decomposed by anaerobic bacteria.

Treatment and Utilization of LFG

◇Treatment : Flaring

Treatment and Utilization of LFG

- Measuring CH_4 flow rate and collection samples

Treatment and Utilization of LFG

- **Utilization**
  - Electricity Generation
    - Gas Engine, Gas Turbine, Steam Turbine
  - Medium Quality Gas: Direct use of LFG as a fuel after minimum pre-treatments (Removing dust and siloxane)
  - High Quality Gas : CLG, Fuel Cell
    - CH_4 concentration > 95%
      - CH_4 in LFG : 50%
      - LFG Heating value : 4,000~5,000 kcal/Nm^3 (Half of LNG)
    - Separation and Purification Process are necessary to obtain high-quality gas

(Session 1)

1.3. Estimation of Methane Emission from SWDL

Estimation Methodologies

- **GHG Emission Rate(tCO_2-eq/yr) =**

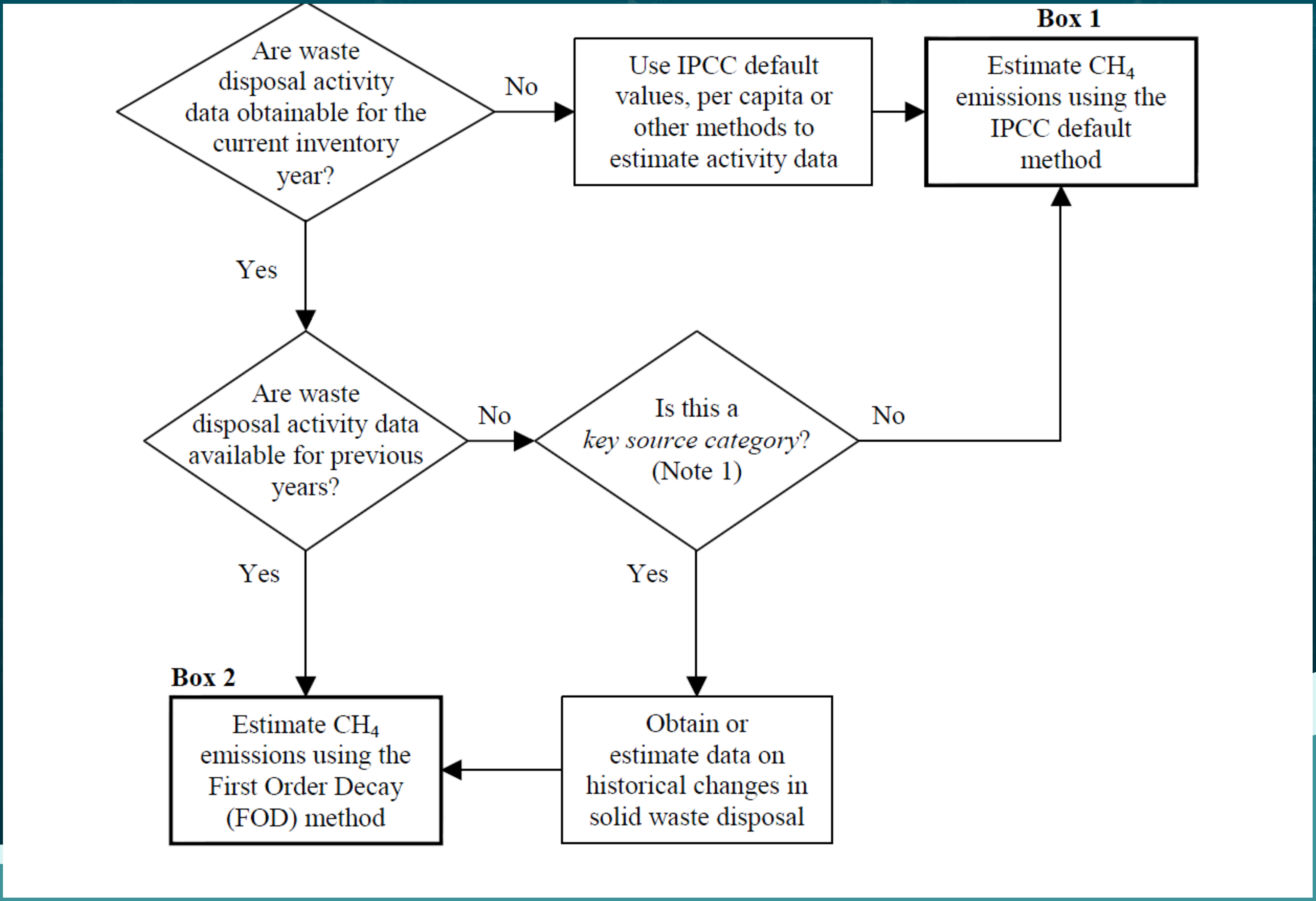
  Activity Data X Emission Factor

- **Activity Data**
  - Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time.
- **Emission Factor**
  - A coefficient that relates the activity data to the amount of chemical compound which is the source of later emissions
  - Emission quantity per unit activity data

Estimation Methodologies

- IPCC(1996) guideline showed two methodologies;
  - Tier 1 : Default Method
  - Tier 2 : First Order Decay Method
  - Tier :
    - Level of Complexity of Estimation Methods; higher tier method is likely to be more accurate but does not guarantee the accurate results.

Decision Tree for Choosing Methodology



Tier 1; Default Method

$$Q_{CH_4} = \left(\boxed{MSW_T \times MSW_F} \times \boxed{MCF \times DOC \times DOC_F \times F} \times 16/12 - R\right) \times (1 - OX)$$

where Q_{CH_4} = Methane Generation(Gg/yr),

MSW_T = Total MSW generated (Gg/yr),

MSW_F = Fraction of MSW disposed to landfills (Fraction)

MCF = Methane Correction Factor (Fraction)

DOC = Degradable Organic Carbon (Fraction)

DOC_F = Fraction DOC dissimilated

F = Fraction of methane in landfill gas

R = Recovered methane (Gg/yr)

OX = Oxidation Factor (Fraction)

MSW_T and MSW_F

- **MSW_T**
  - Total MSW(MSW_T) can be calculated from population and per capita annual generation rate of MSW.
- **MSW_F**
  - Fraction of landfill treatment can be calculated from population and per capita annual landfill rate of MSW

MSW Generation Data

TABLE 2.1
MSW GENERATION AND TREATMENT DATA - REGIONAL DEFAULTS

Region	MSW Generation Rate[1, 2, 3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified[4]
Asia					
Eastern Asia	0.37	0.55	0.26	0.01	0.18
South-Central Asia	0.21	0.74	-	0.05	0.21
South-East Asia	0.27	0.59	0.09	0.05	0.27
Africa[5]	0.29	0.69	-	-	0.31
Europe					
Eastern Europe	0.38	0.90	0.04	0.01	0.02
Northern Europe	0.64	0.47	0.24	0.08	0.20
Southern Europe	0.52	0.85	0.05	0.05	0.05
Western Europe	0.56	0.47	0.22	0.15	0.15
America					
Caribbean	0.49	0.83	0.02	-	0.15
Central America	0.21	0.50	-	-	0.50
South America	0.26	0.54	0.01	0.003	0.46
North America	0.65	0.58	0.06	0.06	0.29
Oceania[6]	0.69	0.85	-	-	0.15

[1] Data are based on weight of wet waste.

[2] To obtain the total waste generation in the country, the per-capita values should be multiplied with the population whose waste is collected. In many countries, especially developing countries, this encompasses only urban population.

[3] The data are default data for the year 2000, although for some countries the year for which the data are applicable was not given in the reference, or data for the year 2000 were not available. The year for which the data are collected, where available, is given in the Annex 2A.1.

[4] Other, unspecified, includes data on recycling for some countries.

[5] A regional average is given for the whole of Africa as data are not available for more detailed regions within Africa.

[6] Data for Oceania are based only on data from Australia and New Zealand.

MCF (Methane Correction Factor)

- MCF reflects the way in which MSW is managed and the effect of management practices on CH_4 generation.

TABLE 3.1
SWDS CLASSIFICATION AND METHANE CORRECTION FACTORS (MCF)

Type of Site	Methane Correction Factor (MCF) Default Values
Managed – anaerobic [1]	1.0
Managed – semi-aerobic [2]	0.5
Unmanaged [3] – deep (>5 m waste) and /or high water table	0.8
Unmanaged [4] – shallow (<5 m waste)	0.4
Uncategorised SWDS [5]	0.6

[1] **Anaerobic managed solid waste disposal sites**: These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste.

[2] **Semi-aerobic managed solid waste disposal sites**: These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system.

[3] **Unmanaged solid waste disposal sites – deep and/or with high water table**: All SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 metres and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.

[4] **Unmanaged shallow solid waste disposal sites**; All SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 metres.

[5] **Uncategorised solid waste disposal sites**: Only if countries cannot categorise their SWDS into above four categories of managed and unmanaged SWDS, the MCF for this category can be used.

Sources: IPCC (2000); Matsufuji *et al.* (1996)

Degradable Organic Carbon (DOC)

- DOC is the organic carbon in waste that is accessible to biochemical decomposition, and should be expressed as Gg C per Gg waste.
- The DOC in bulk waste is estimated based on the composition of waste and can be calculated from a weighted average of the degradable carbon content of various components of the waste stream.

DOC

TABLE 2.4
DEFAULT DRY MATTER CONTENT, DOC CONTENT, TOTAL CARBON CONTENT AND FOSSIL CARBON FRACTION OF DIFFERENT MSW COMPONENTS

MSW component	Dry matter content in % of wet weight [1]	DOC content in % of wet waste		DOC content in % of dry waste		Total carbon content in % of dry weight		Fossil carbon fraction in % of total carbon	
	Default	Default	Range	Default	Range [2]	Default	Range	Default	Range
Paper/cardboard	90	40	36 - 45	44	40 - 50	46	42 - 50	1	0 - 5
Textiles [3]	80	24	20 - 40	30	25 - 50	50	25 - 50	20	0 - 50
Food waste	40	15	8 - 20	38	20 - 50	38	20 - 50	-	-
Wood	85 [4]	43	39 - 46	50	46 - 54	50	46 - 54	-	-
Garden and Park waste	40	20	18 - 22	49	45 - 55	49	45 - 55	0	0
Nappies	40	24	18 - 32	60	44 - 80	70	54 - 90	10	10
Rubber and Leather	84	(39) [5]	(39) [5]	(47) [5]	(47) [5]	67	67	20	20
Plastics	100	-	-	-	-	75	67 - 85	100	95 - 100
Metal [6]	100	-	-	-	-	NA	NA	NA	NA
Glass [6]	100	-	-	-	-	NA	NA	NA	NA
Other, inert waste	90	-	-	-	-	3	0 - 5	100	50 - 100

[1] The moisture content given here applies to the specific waste types before they enter the collection and treatment. In samples taken from collected waste or from e.g., SWDS the moisture content of each waste type will vary by moisture of co-existing waste and weather during handling.

[2] The range refers to the minimum and maximum data reported by Dehoust *et al.*, 2002; Gangdonggu, 1997; Guendehou, 2004; JESC, 2001; Jager and Blok, 1993; Würdinger *et al.*, 1997; and Zeschmar-Lahl, 2002.

[3] 40 percent of textile are assumed to be synthetic (default). Expert judgement by the authors.

[4] This value is for wood products at the end of life. Typical dry matter content of wood at the time of harvest (that is for garden and park waste) is 40 percent. Expert judgement by the authors.

[5] Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii et al., 1985; Rose and Steinbüchel, 2005).

[6] Metal and glass contain some carbon of fossil origin. Combustion of significant amounts of glass or metal is not common.

DOC_F
(DOC Dissimilated)

- Fraction of degradable organic carbon which decomposes is an estimate of the fraction of carbon that is ultimately degraded and released from SWDS, and reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions.
- Default DOC_F is 0.5 which depends on many factors like temperature, moisture, pH, composition of waste, etc.

F(Fraction of CH_4 in LFG)

- Most waste in SWDS generated a gas with approximately 50 percent CH_4. Only material including substantial amounts of fat or oil can generate gas with substantially more than 50%. The IPCC default value is 0.5.

R(Recovered Amount of CH_4)

- LFG can be collected through LFG extraction well.



OX(Oxidation Factor)

- The OX reflects the amount of CH_4 from SWDS that is oxidized in the soil or other material covering the waste.
- CH_4 oxidation is achieved by methanotrophic micro-organisms in cover soils and can range from negligible to 100% of internally produced CH_4.
- Sanitary, well-managed SWDS tend to have higher oxidation rates than unmanaged dump sites.

TABLE 3.2
OXIDATION FACTOR (OX) FOR SWDS

Type of Site	Oxidation Factor (OX) Default Values
Managed [1], unmanaged and uncategorised SWDS	0
Managed covered with CH_4 oxidising material [2]	0.1

[1] Managed but not covered with aerated material

[2] Examples: soil, compost

Tier 2 : First Order Decay (FOD) Method

$$G_{CH_4}(t) = \sum_{x} \left\{ \left(A \times k \times MSW_T(x) \times MSW_F(x) \times L_0(x) \times e^{-k(t-x)} \right) \right\}$$

$$E_{CH_4}(t) = \sum_{x} \left(Q_{CH_4} - R(t) \right) \bullet \left(1 - OX \right)$$

where t = year of inventory

x = years for which input data should be added

A = $(1-e^{-k})/k$; normalization factor which corrects the summation

k = methane generation rate constant(yr^{-1})

MSW_T = Total municipal solid waste generated in year x (Gg/yr)

MSW_F = Fraction of MSW disposed at SWDS in year x

$L_0(x)$ = Methane generation potential ($MCF(x) \cdot DOC(x) \cdot DOC_F \cdot F \cdot 16/12$)

Tier 2 : FOD Method

$$Q_{CH_4}(t) = M_0 L_0 \left(e^{-k(t-1)} - e^{-kt} \right)$$

where

t	=	year of inventory
$M_0(x)$	=	Landfilled amount at a year x
$L_0(x)$	=	Methane generation potential ($MCF \cdot DOC \cdot DOC_F \cdot F \cdot 16/12$) landfilled at a year x

Tier 2 : FOD Method

- Decomposition kinetics of MSW: $$\frac{dM_w}{dt} = -kM_w$$
- Generation kinetics of CH_4: $$\frac{dM_{CH_4}}{dt} = -L_0 \frac{dM_w}{dt} = kL_0M_w = kL_0M_0 \exp(-k \cdot t)$$
- Total generation quantity until year *t*: $$M_{CH_4}(t) = M_0L_0(1 - e^{-k \cdot t})$$
- Generation quantity during one year from *t-1* to *t*:

$$Q_{CH_4}(t) = M_0L_0\left(e^{-k(t-1)} - e^{-kt}\right)$$

Tier 2 : FOD Method

TABLE 3.3
RECOMMENDED DEFAULT METHANE GENERATION RATE (k) VALUES UNDER TIER 1

(Derived from k values obtained in experimental measurements, calculated by models, or used in greenhouse gas inventories and other studies)

Type of Waste		Climate Zone*							
		Boreal and Temperate (MAT ≤ 20°C)				Tropical[1] (MAT > 20°C)			
		Dry (MAP/PET < 1)		Wet (MAP/PET > 1)		Dry (MAP < 1000 mm)		Moist and Wet (MAP ≥ 1000 mm)	
		Default	Range[2]	Default	Range[2]	Default	Range[2]	Default	Range[2]
Slowly degrading waste	Paper/textiles waste	0.04	0.03[3,5] – 0.05[3,4]	0.06	0.05 – 0.07[3,5]	0.045	0.04 – 0.06	0.07	0.06 – 0.085
	Wood/ straw waste	0.02	0.01[3,4] – 0.03[6,7]	0.03	0.02 – 0.04	0.025	0.02 – 0.04	0.035	0.03 – 0.05
Moderately degrading waste	Other (non – food) organic putrescible/ Garden and park waste	0.05	0.04 – 0.06	0.1	0.06 – 0.1[8]	0.065	0.05 – 0.08	0.17	0.15 – 0.2
Rapidly degrading waste	Food waste/Sewage sludge	0.06	0.05 – 0.08	0.185[4]	0.1[3,4] – 0.2[9]	0.085	0.07 – 0.1	0.4	0.17 – 0.7[10]
Bulk Waste		0.05	0.04 – 0.06	0.09	0.08[8] – 0.1	0.065	0.05 – 0.08	0.17	0.15[11] – 0.2

Uncertainties of the default parameters in the IPCC Methods

Parameter	Uncertainty Range [b]
Total Municipal Solid Waste (MSW_T) and Fraction of MSW sent to SWDS (MSW_F)	Country-specific: >±10% (<–10%, >+10%. The absolute value of the uncertainty range is greater than 10%.) for countries with high quality data (e.g. weighing at all SWDS) For countries with poor quality data: more than a factor of two.
Degradable Organic Carbon (DOC) = 0.21 (maximal default value in the *IPCC Guidelines*)	–50%, +20%
Fraction of Degradable Organic Carbon Dissimilated (DOC_F) = 0.77	–30%, +0%
Methane Correction Factor (MCF) = 1 = 0.4 = 0.6	 –10%, +0% –30%, +30% –50%, +60%
Fraction of CH_4 in Landfill Gas (F) = 0.5	–0%, +20%
Methane Recovery (R)	The uncertainty range will depend on how the amounts of CH_4 recovered and flared or utilised are estimated, but the uncertainty is likely to be relatively small compared to other uncertainties if metering is in place.
Oxidation Factor (OX)	Include OX in the uncertainty analysis if a value other than zero has been used for OX itself. In this case the justification for a non-zero value should include consideration of uncertainties, as specified in Section 5.1.1.2, Choice of Emission Factors and Activity Data.
Methane Generation Rate Constant (k) = 0.05	–40%, +300%

[a] The estimates are valid only for the default values given in the *IPCC Guidelines* or in the table, and are based on expert judgement.
[b] If the evaluation of additional data on the parameters provides data for the revision of the default values, the uncertainty range should also be changed. When country-specific values are used, they should be accompanied with appropriate uncertainty values.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; CH_4 Emissions from Solid Waste Disposal).

(Session 1)
1.4. Quality Assurance, Quality Control

Quality Assurance/Quality Control

- **Estimate of the emissions using different approaches**
  - If the emissions are estimated with the FOD method, inventory agencies should also estimate them with the IPCC default method.
  - The results can be useful for cross-comparison with other countries.
  - Inventory agencies should record the results of such comparisons for internal documentation, and investigate any discrepancies

Quality Assurance/Quality Control

- **Review of emission factors**
  - Inventory agencies should cross-check country-specific values for estimation with the available IPCC values.
  - The intent of this comparison is to see whether the national parameters used are considered reasonable relative to the IPCC default values, given similarities or differences between the national source category and the emission sources represented by the default.

Quality Assurance/Quality Control

- **Review of activity data**
  - Inventory agencies should compare country-specific data to IPCC default values for the following activity level parameters: MSW_T, MSW_F, and DOC.
  - They should determine whether the national parameters are reasonable and ensure that errors in calculations have not occurred.
  - If the values are very different, inventory agencies should characterize municipal solid waste separately from industrial solid waste.

Quality Assurance/Quality Control

- **Where survey and sampling data are used to compile national values for solid waste AD, QC procedures should include:**
  - Reviewing survey data collection methods, and checking the data to ensure they were collected and aggregated correctly. Inventory agencies should cross-check the data with previous years to ensure the data are reasonable.
  - Evaluating secondary data sources and referring QA/QC activities associated with the secondary data preparation. This is particularly important for solid waste data, since most of these data are originally prepared for purposes other than GHG inventories

Quality Assurance/Quality Control

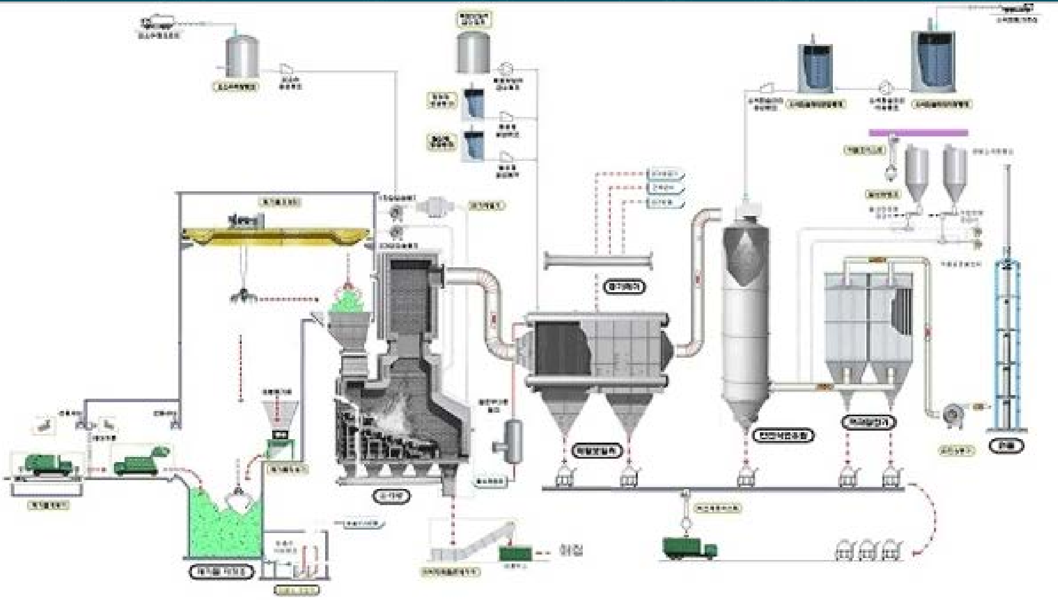
- **Involvement of industry and government experts in review**
  - Inventory agencies should provide the opportunity for experts to review input parameters. For example, individuals with expertise in the country’s solid waste management practices should review the characteristics of the solid waste stream and its disposal. Other experts should review the methane correction factors.

Quality Assurance/Quality Control

- **Verification of emissions**
  - Inventory agencies should compare national emission rates with those of similar countries that have comparable demographic and economic attributes.
  - This comparison should be made with countries whose inventory agencies use the same landfill CH_4 emissions method.
  - Inventory agencies should study significant discrepancies to determine if they represent errors in the calculation or actual differences.

(Session 2)
Waste Incineration

Stoker Incinerator



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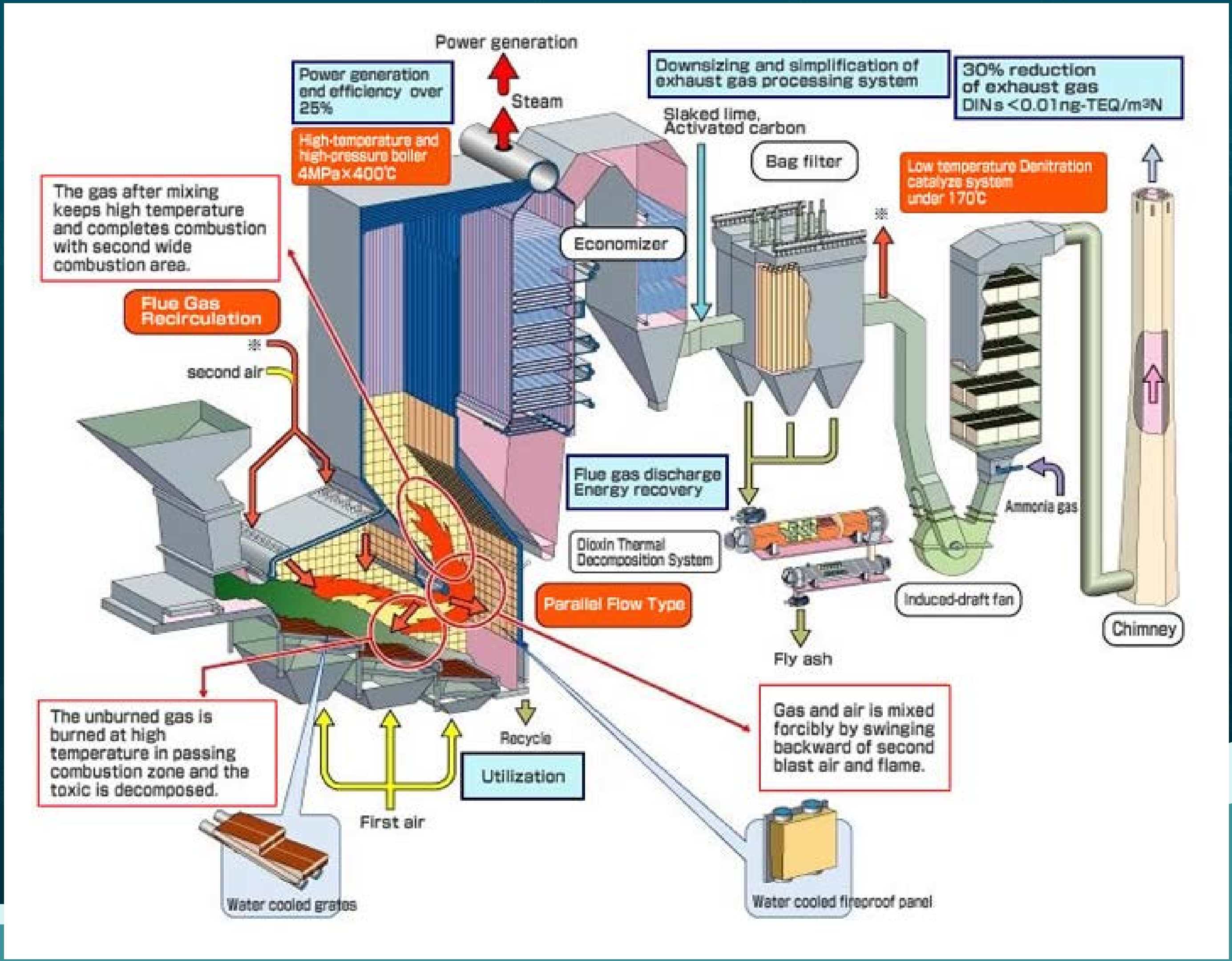
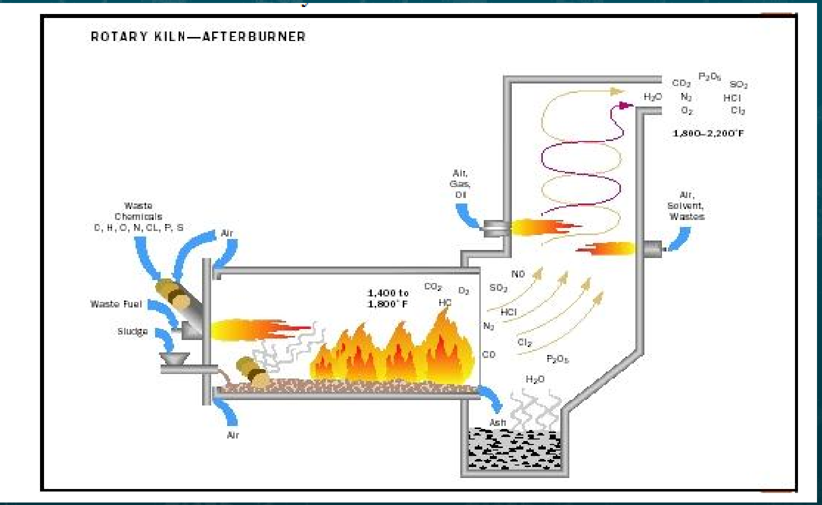
Stoker Incinerator

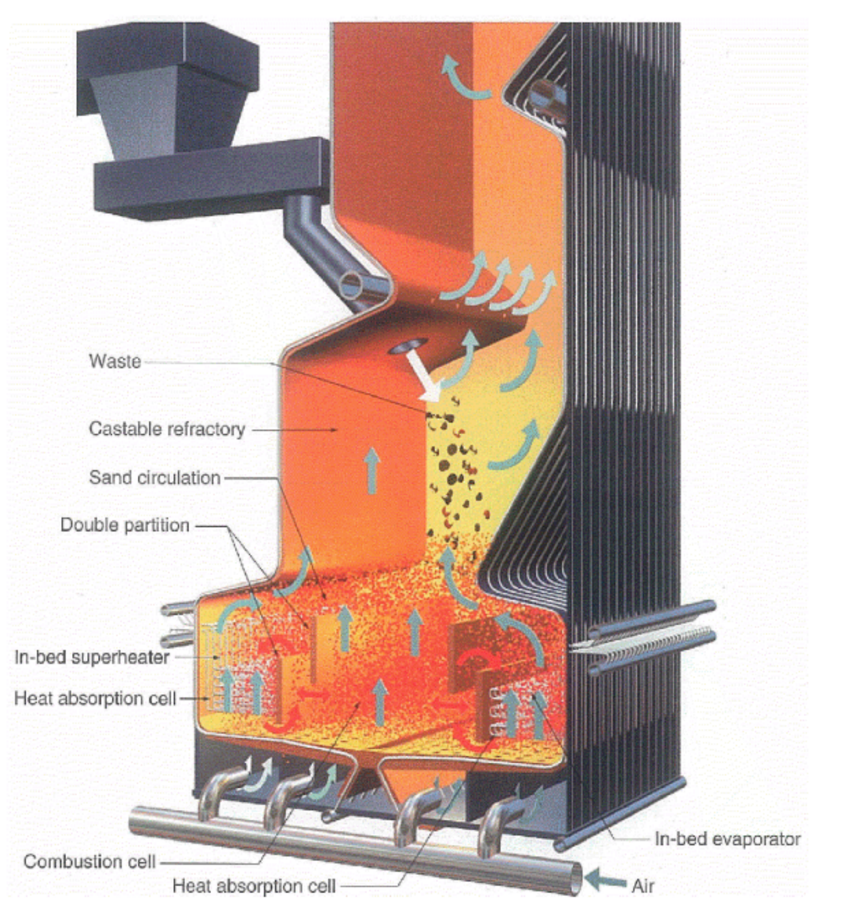


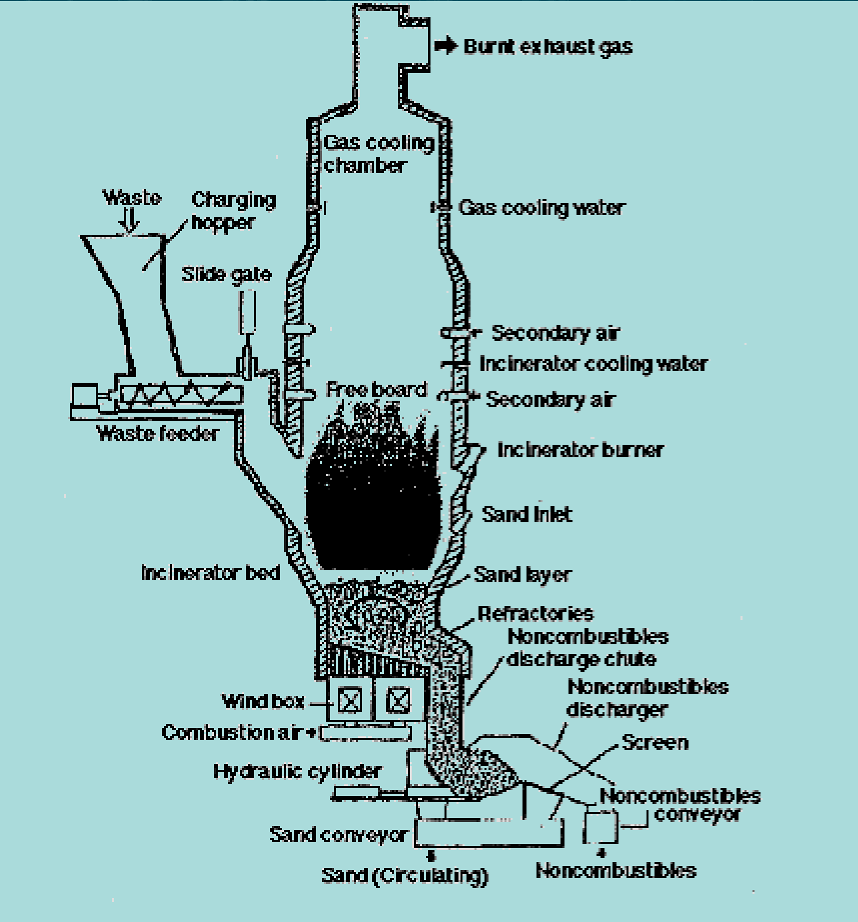
Rotary Kiln Incinerator

Rotary Kiln Waste Incinerator Plant with Vertical Thermo-Reactor



Fluidized Bed Incinerator






Thank You !

Application of biogas plant to recycle organic wastes

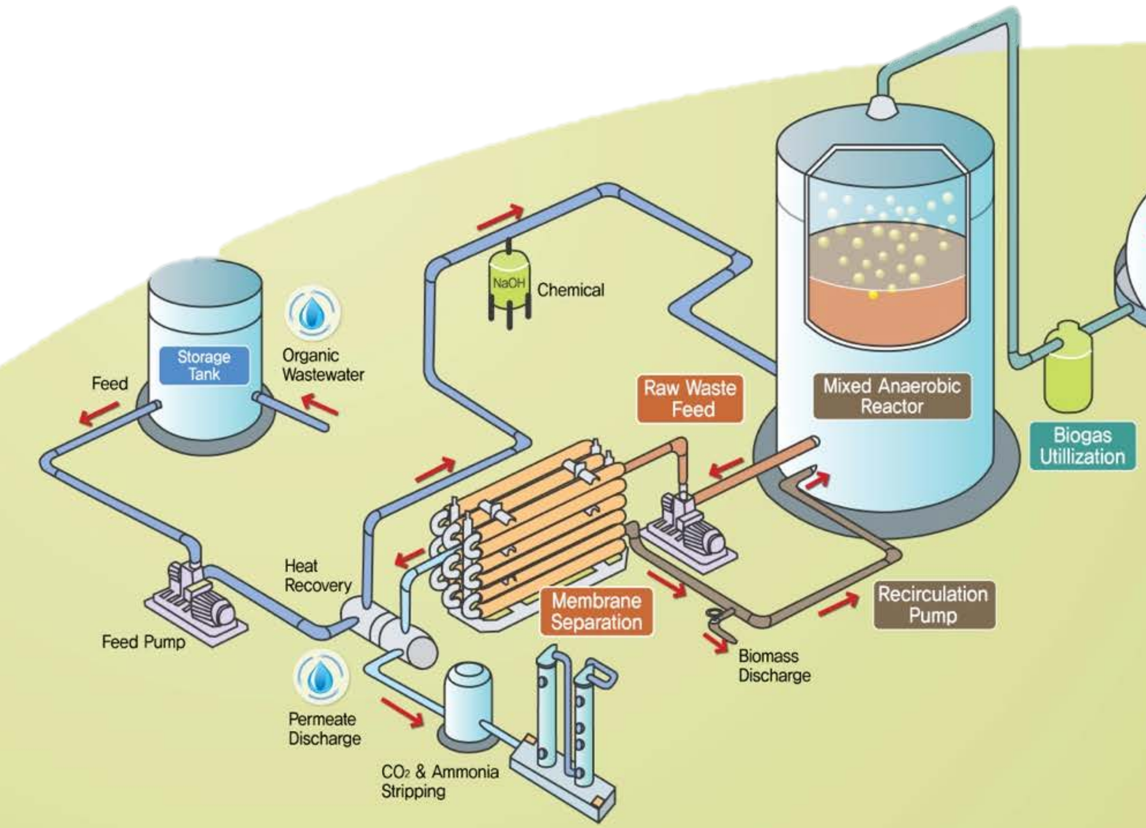
2013. 09. 16

YOUNG-O KIM

HYUNDAI ENGINEERING & CONSTRUCTION

INOVATION
for Eco-SUSTAINABILITY

"Harvesting
Clean Energy & Clean Water from Wastewater"



Talk outline

1. Value of Organic Wastes
2. Anaerobic Digestion description.
3. Stage of Biogradation
4. Anaerobic Membrane Bioreactor (AnMBR)
5. See Hyundai Biogas Plant (HAnDs) Results
6. Opportunity for Application

Where do organic wastes come from?

Industrialization

Urbanization

Population

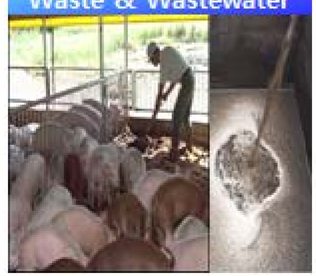
Industrial Wastewater

OFMSW

Sewage

Food Waste

Livestock Waste & Wastewater



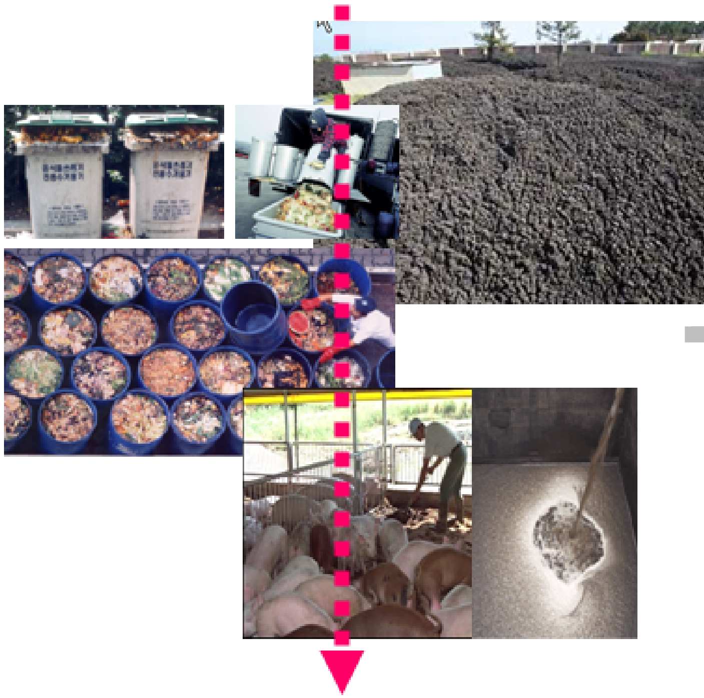
Sewage Sludge

Ecosystem Destruction

Threatening survival of human beings

Paradigm of organic wastes treatment

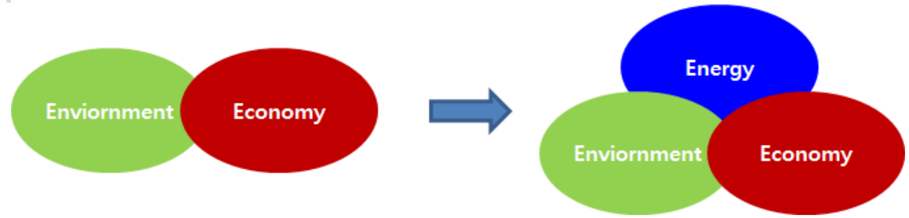
Treatment
&
Disposal

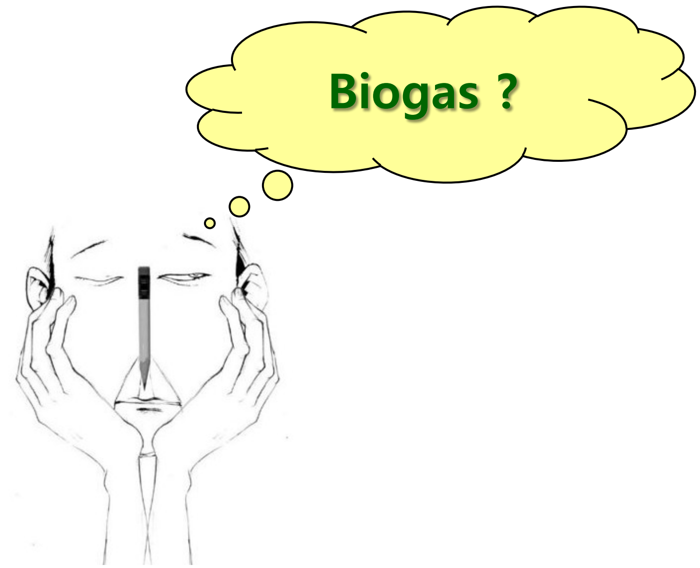


Recycling
&
Regeneration

2Es

3Es

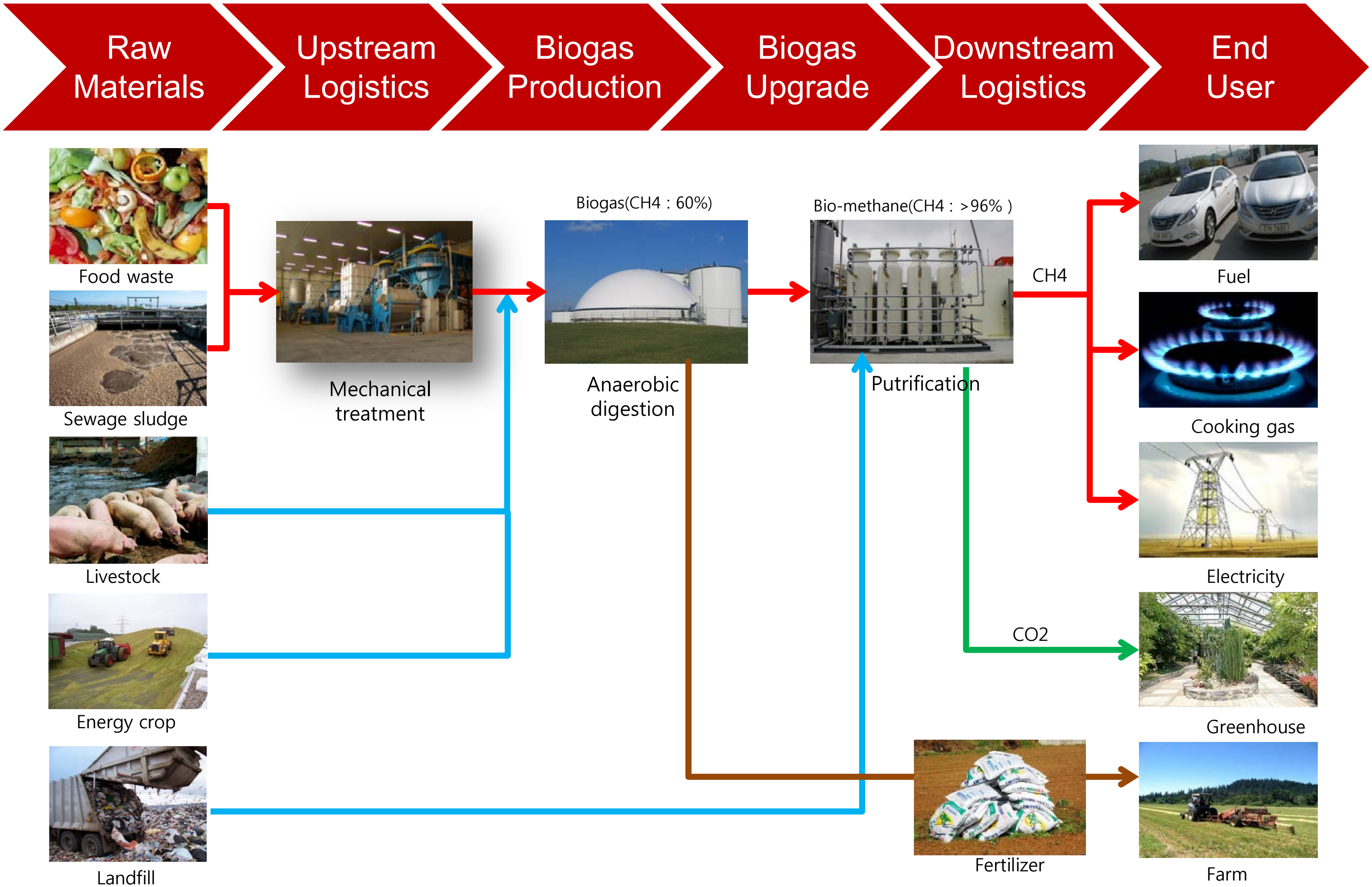




Anaerobic Digestion

- Biogas production (Bioenergy)
- Greenhouse gas reduction
- Efficient organic removal

Value Chain



Raw Materials
Upstream Logistics
Biogas Production
Biogas Upgrade
Downstream Logistics
End User
Food waste
Sewage sludge
Livestock
Energy crop
Landfill
Mechanical treatment
Biogas(CH4 : 60%)
Anaerobic digestion
Bio-methane(CH4 : >96%)
Putrification
CH4
CO2
Fertilizer
Fuel
Cooking gas
Electricity
Greenhouse
Farm

Characteristics of Organic Wastes in Korea

High Volatile Solid Content

- Readily biodegradable
  → Easy corruption
- Renewable energy source

High Moisture Contents

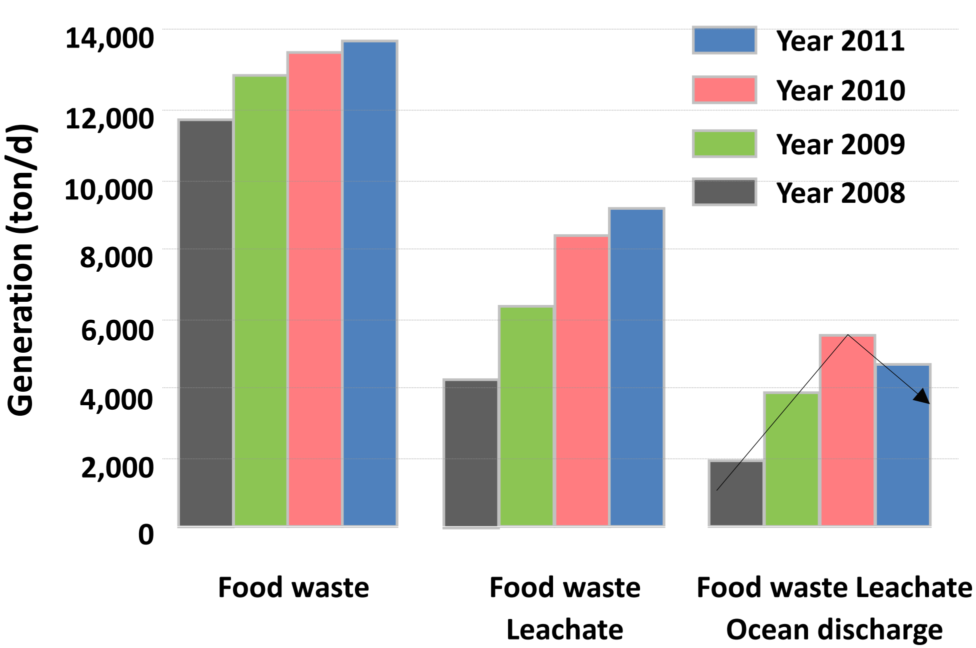
- Hard to apply physical and chemical treatment such as incineration etc.
- High cost for management

Heterogeneous Bacteria/ Pathogens

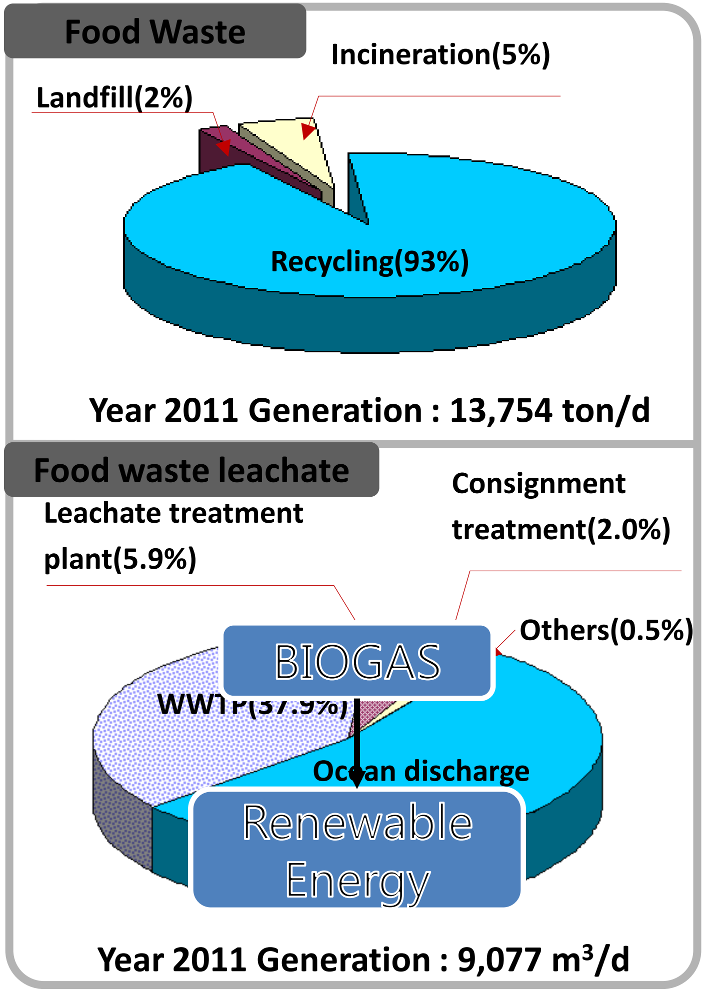
- Necessity of pretreatment
- Hard to apply microbial /enzyme treatment techniques
  → due to contamination or competition between microorganisms

Generation and Treatment of Food Waste

Year's Generation and Discharge



Source : Korea Ministry of Environment (2011)



Anaerobic Digestion : Biogas History

19th century

- 1800's France
  - Sludge tank
- England and Germany
  - Septic & Imhoff tank

~ 1930's

- Biological Anaerobic digester
  - Mixer
  - temperature
  - HRT(over 30 days)

~ 1970's

- Many type of Anaerobic digester
  - Basic Research
  - Application
  - Single stage

1980's ~ Present

- High rate of Anaerobic digester
  - Multi stage
  - Feedstock
    : Wastewater, Manure
    Foodwaste

→ Membrane + AD

What is Biogas Digestion

- Reduce
  - Smell
  - Greenhouse gas
  - Pathogen level
- Produce biogas
- Improve fertilizer value of manure
- Protect water resources

- Biogas Digestion is the process of taking biogas to produce electricity, heat, or hot water
- Biogas means a gas formed by carbon dioxide and methane from breakdown of organic materials such as manure.

- **Basic of digestion**

Substrates must be degradable

Substrates must/should be available at a constant mass/volume flow

Substrates should have a nearly constant composition

Concentration of organic dry matter should be higher than 2 %

Substrates should be a liquid slurry

Digester volume should be more than about $100m^3$

What is a Digester?

- Digester is a vessel or container where the biogas process takes place. Bacteria breaks down waste products to create biogas. Products may be fed into the chamber such as manure and food waste or the container could be used to cover a place that is already giving off biogas such as a swamp or a landfill.
- Biodigester is a system that promotes decomposition of organic matter.
- It produces biogas, generated through the process of anaerobic digestion.
- Biogas generated can be used for cooking, heating, electricity generation, and running a vehicle.

Basic Designs of Digester

- Continuous-fed
- Batch-fed

The Process of Biodigestion

Organic wastes (100%)

Disintegration

for sludge digestion

iomass lysis

- Complex organic matter is degraded to basic structure by hydraulic bacteria.
  - Protein -> Polypeptide and Amino Acid
  - Fat -> Glycerin and Fatty Acid
  - Amylose -> Monosaccharide and Polysaccharide

lysis

enzymatic

ess

- Also called the acidogenesis
- Simple organic matters are converted into H^2 and CO_2
- Acting bacteria in this process are called hydrogen-producing bacteria and acid-producing bacteria.

Acidogenesis

- Acetogenesis.
- The short-chain fatty acids are metabolized by synthrophic acetogenic and homoacetogenic bacteria into acetate, carbon dioxide, and hydrogen.

genesis

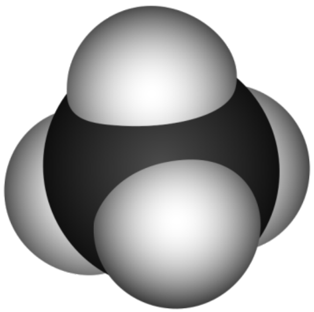
- Methanogenesis
- In this process, acetic acid, H_2, CO_2, are converted into CH_4.
- Methane-producing bacteria have strict PH requirement and low adaptability to temperature.

ogenesis

CH_4 (90%)

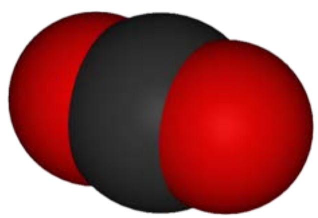
What is Biogas ?

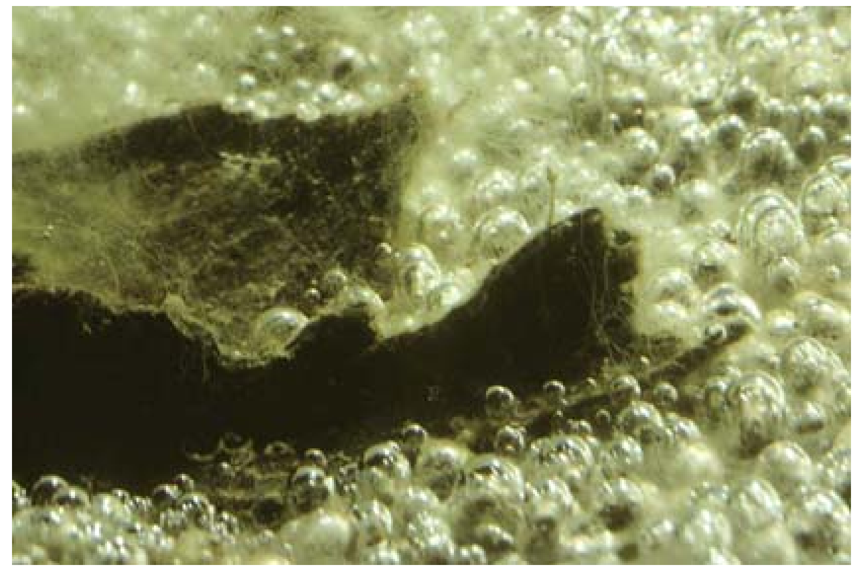
- A mixture of methane and carbon dioxide



CH_4

CO_2





- Methane or 'swamp gas', produced naturally in swampy ponds

What is this?

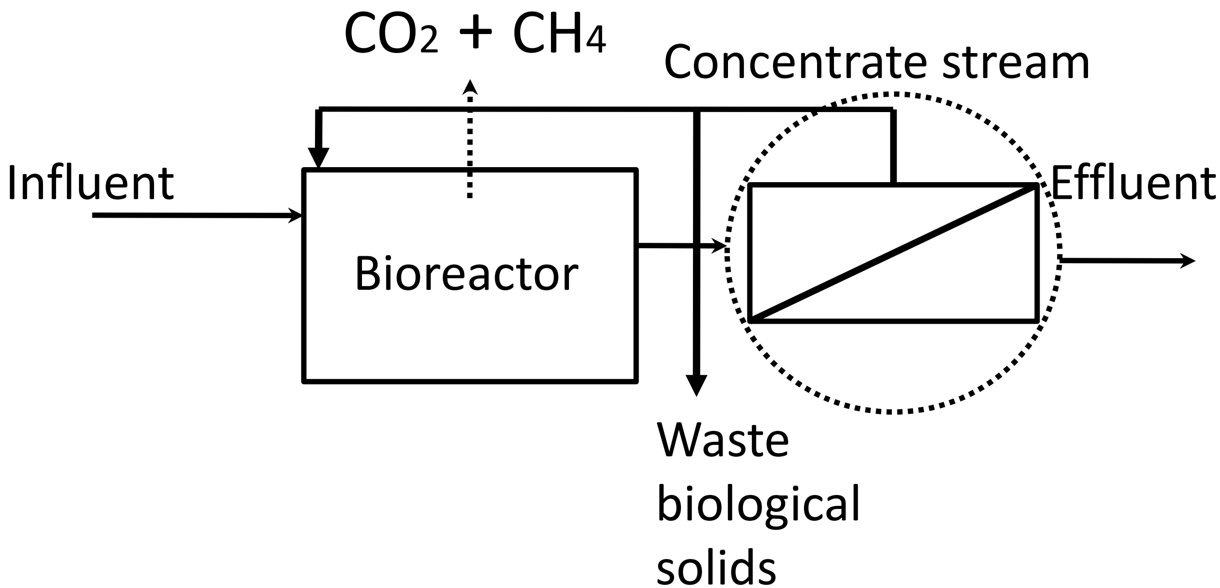
What is it used for ?

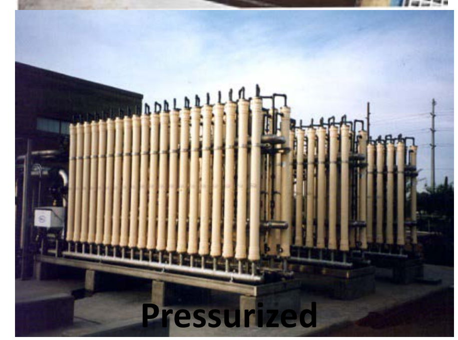
- Biogas is a fuel used as an energy source for light, heat or movement

Potential of Biogas

Biogas potential:	total organic solids (%)	m^3 CH_4/m^3 substrate
Waste water, municipal	0.05	0.15
Waste water, food industry	0.15	0.5
Sewage sludge	2	5 to 10
Cow manure	8	20 to 30
Pig manure	6 to 8	30 to 50
Food waste	15 to 20	100 to 120
Food waste leachate	6 to 14	30 to 60

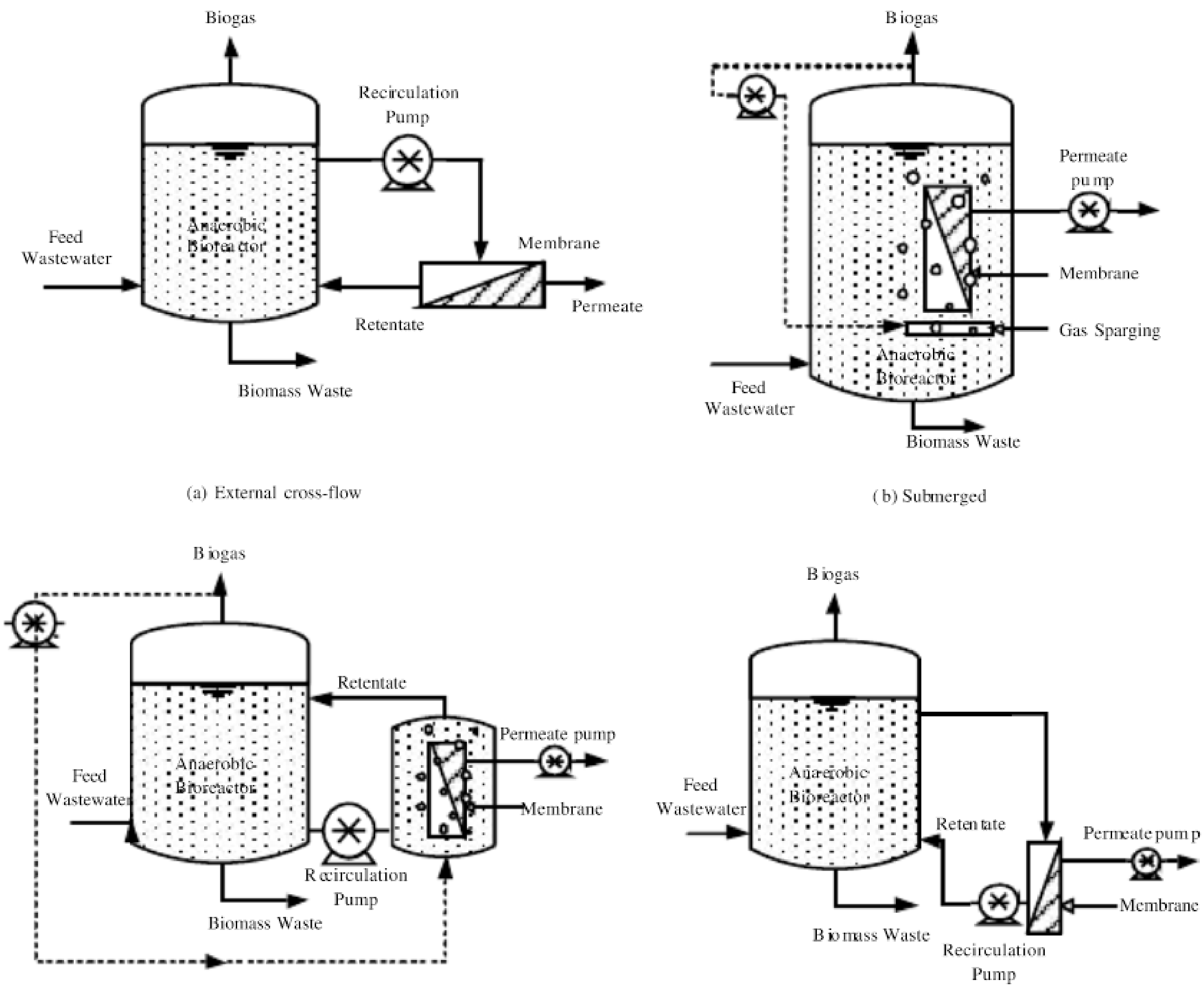
Anaerobic Membrane Bioreactor(AnMBR)





- Providing long SRT needed while operating at short HRT as required to reduce reactor size
- Pressurized type use more since membrane cleaning is easier to perform

Types of AnMBR



(a) External cross-flow

(b) Submerged

(c) External gas-lift

(d) External semi dead-end

Research of AnMBR

Wastewater	Volume (m^3)	Temp. (℃)	MLSS (g/L)	OLR ($g/m^3/d$)	Removal (%)	Reference
Sweet factory	0.09	35~37	-	8~9	97~99	Defour et al., 1994
Feed industry	0.4	37	6~8	4.5	81~94	He et al., 2005
Soybean processing	2	30	-	2.5	71	Yushina and Hasegawa, 1994
Brewery	0.12	36	> 50	>28.5	97~99	Ince et al., 2000, 2001
Potato starch bleaching	4	-	15~100	1.5~5	65~85	Brockmann and seyfried, 1996, 1997
Palm oil mill	0.05	35	50~57	14.2~21.7	91.7~94.2	Fakhru'l-Razi and Noor, 1999
Kraft pulp mill	5	53	8	9~28	86~89	Imasaka et al., 1993
Sewage	0.018	24~25	16~22	0.4~11	60~95	Wen et al., 1999
Primary sludge	0.12	35	-	0.4~0.68	25~57	Ghyoot and Verstraete, 1997
Heat treated sewage	0.2	35~38	10~20	4~16	79~83	Kayawake et al., 1991
Swine manure	0.006	37	20~40	1~3	-	Padmasiri et al., 2007

Operating Conditions of Membrane system

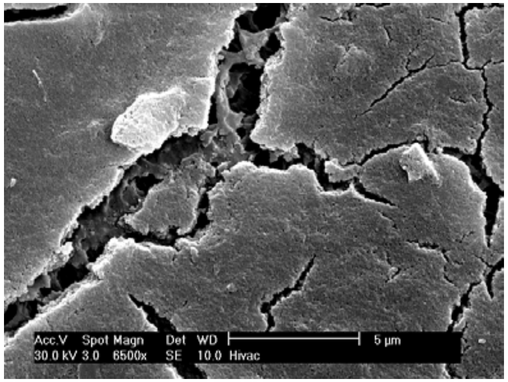
Type of wastewater	Scale[a]	Temp. (℃)	Membrane Material	Pore size[c]	Membrane area (m^2)	TMP (kPa)	linear velocity ($m. s^{-1}$)	Initial flux ($L. m^{-2}. h^{-1}$)	Final flux ($L. m^{-2}. h^{-1}$)	Reference
Wheat starch	P	40	-	18,000 D	144	690	-[d]	-	14~25	Butcher et al, 1989 Choate et al, 1983
Brewery effluent	P	35	Poly-ethersulfone	40,000 D	0.44	140~340	1.5~2.6	-	7~50	Strohwald et al, 1992
Maize processing	P	-	Poly-ethersulfone	20,000~80,000 D	668	450	1.6	-	8~37	Ross et al, 1992
Wool scouring	P	40~47	Poly-acrylonitrile	13,000 D	3.1	2~2.2[e]	-	30~45	17~25	Hogetsu et al, 1992
Glucose, peptone	L	35~38	Ceramic	0.2	0.4	30~200	0.5~4	-	12.5~125	Shimizu et al, 1992
Kraft mill effluent	P	48.4	Ceramic, aluminum oxide	0.16	1×24	60	1.75	50	27	Imasaka et al, 1993
Acetate	L	35	Ceramic	0.2	0.20	25~150	0~3.5	-	18~127	Beaubien et al. 1996
Sewage sludge	L	30~35	Poly-ether sulfone	60,000 D	0.3	375	0.75	31	19	Ghyoot et al, 1997
Molasses[f]	L	20	Polypropylene	10	0.051	-	-	100~160	10~80	Hernandez et al, 2002
Sewage	P	10~28	Ceramic	13,000 D	13.6	1~2[e]	2	-	15~20	Tanaka et al, 1987
Heat-treated liquor from sewage sludge[f]	P	35~38	Ceramic	0.1	1.06	200[g]	0.2~0.3	8~13	3~8	Kayawake et al, 1991
Food waste leachate	P	55	Polyvinylidene fluoride	0.04	13.1	100~300	1~3	-	15	Kim et al, 2011

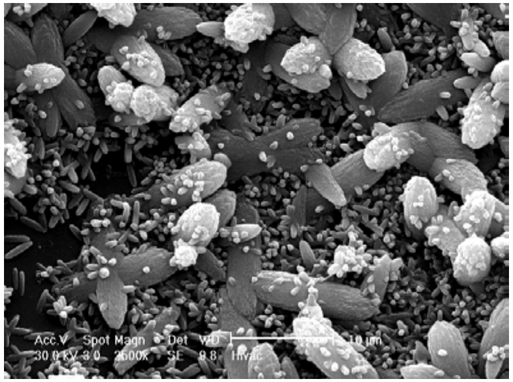
[a]All membranes were external cross−flow unless otherwise noted. [b]L = laboratory/bench scale, P = pilot scale.
[c]D = Daltons (molecular weight cutoff). [d]−Indicates value not reported.
[e]Pressure reported as kg/cm^2. [f]Submerged membrane.
[g]−Indicates value not reported

Membrane fouling and control

- Membrane fouling is an inevitable and complex phenomena
- Biogas sparging, fluidized media for submerged system
- TMP, cross-flow velocity for pressurized system

  Effectiveness varies depending upon foulant materials (e.g., particle size distribution) and module design (e.g., channel height etc)





Application of AnMBR

New: Memthane®, for industrial high-strength wastewater

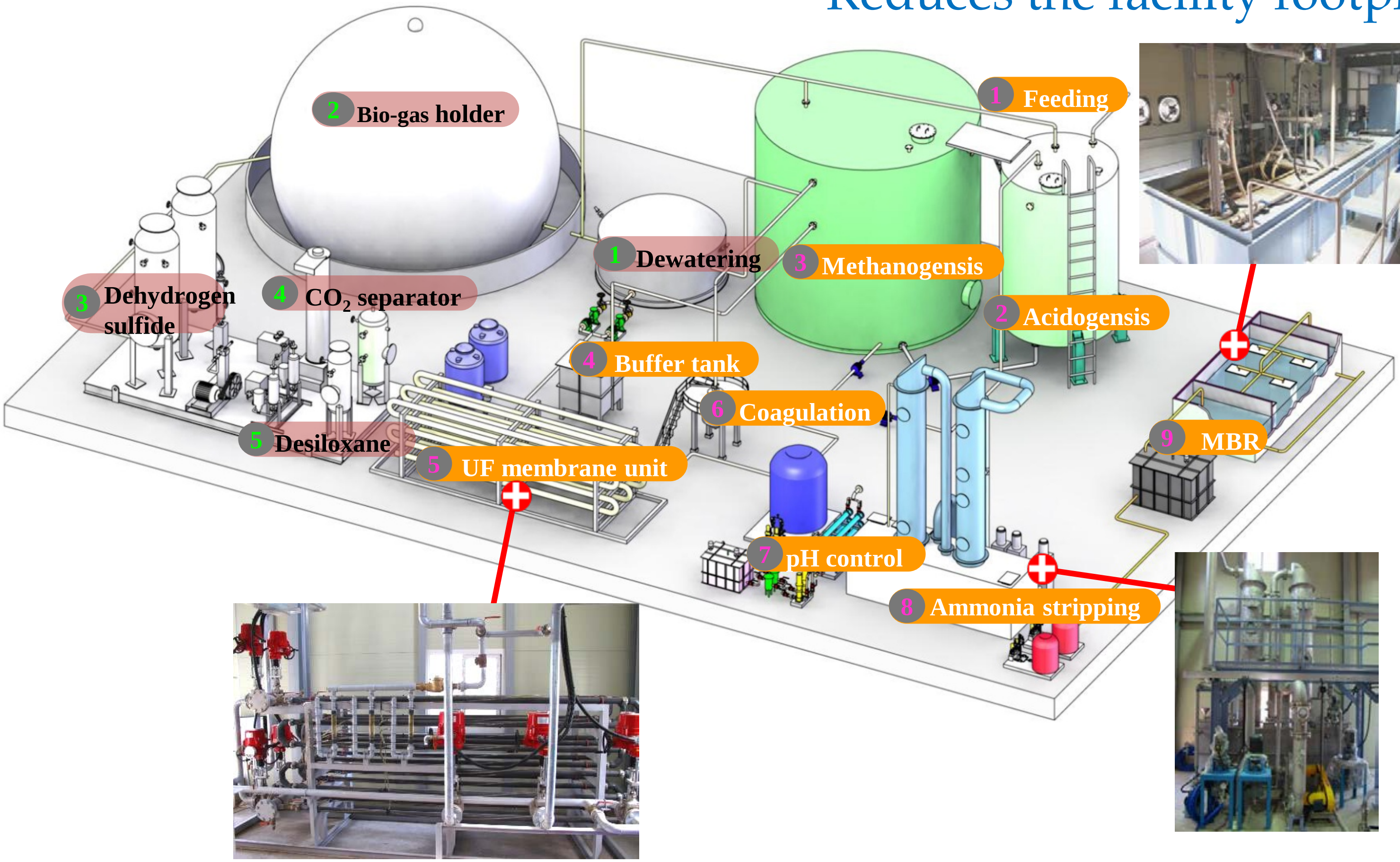
Biothane's anaerobic biological wastewater treatment and a Pentair's X-Flow Ultra Filtration membrane separation process. Influent is fed to the anaerobic bioreactor where the organic components are converted into energy-rich biogas. Next, the anaerobic effluent is processed through the UF membrane unit, separating the 'clean' permeate from the biomass. The biomass is returned to the bioreactor, while the ultra-clean filtrate is discharged as particle-free, low BOD/COD effluent, often at levels low

"The valuable methane-rich biogas produced can cover

Memthane®, Veolia's Anaerobic Membrane Bio-Reactor (AnMBR), delivers high-energy efficiency and

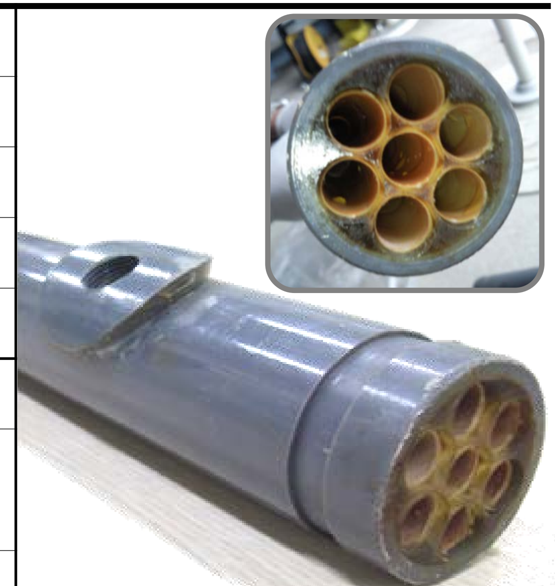
Pilot-plant of AnMBR : HAnDs

- Maximizes biogas energy
- Excellent effluent quality
- Easy nutrient recovery as fertilizer
- Odor-free
- Vastly reduces biosolid disposal costs
- Reduces the facility footprint



Specifications of Membrane Unit

Spec.	Shape	Tubular
	Material	PVDF
	Diameter	11 mm
	MWCO	100 k Dalton
	Max. working Temp.	90 ℃
Operating condition	Total membrane area	13.1 m^2
	Operating pressure	1~3 kgf/cm^2 (In-Out)
	Cross-flow velocity	1~2 m/sec



Why Crossflow Membrane ?

5

- Flat-sheet membranes can only be installed in a submerged tank, which client pays to build
- For membrane cleaning, the entire membrane tank must be drained, halting treatment of wastewater
- Crossflow membranes are installed on skids with minimal footprints, and require no storage tank of any kind
- Much easier cake-fouling control just by adjusting the crossflow velocity
- Possible clean-in-place, meaning any individual membrane can be bypassed and removed from the system for cleaning without even pausing treatment

Picture of Plant

Characteristics of Food Waste Leachate

Properties of food waste leachate

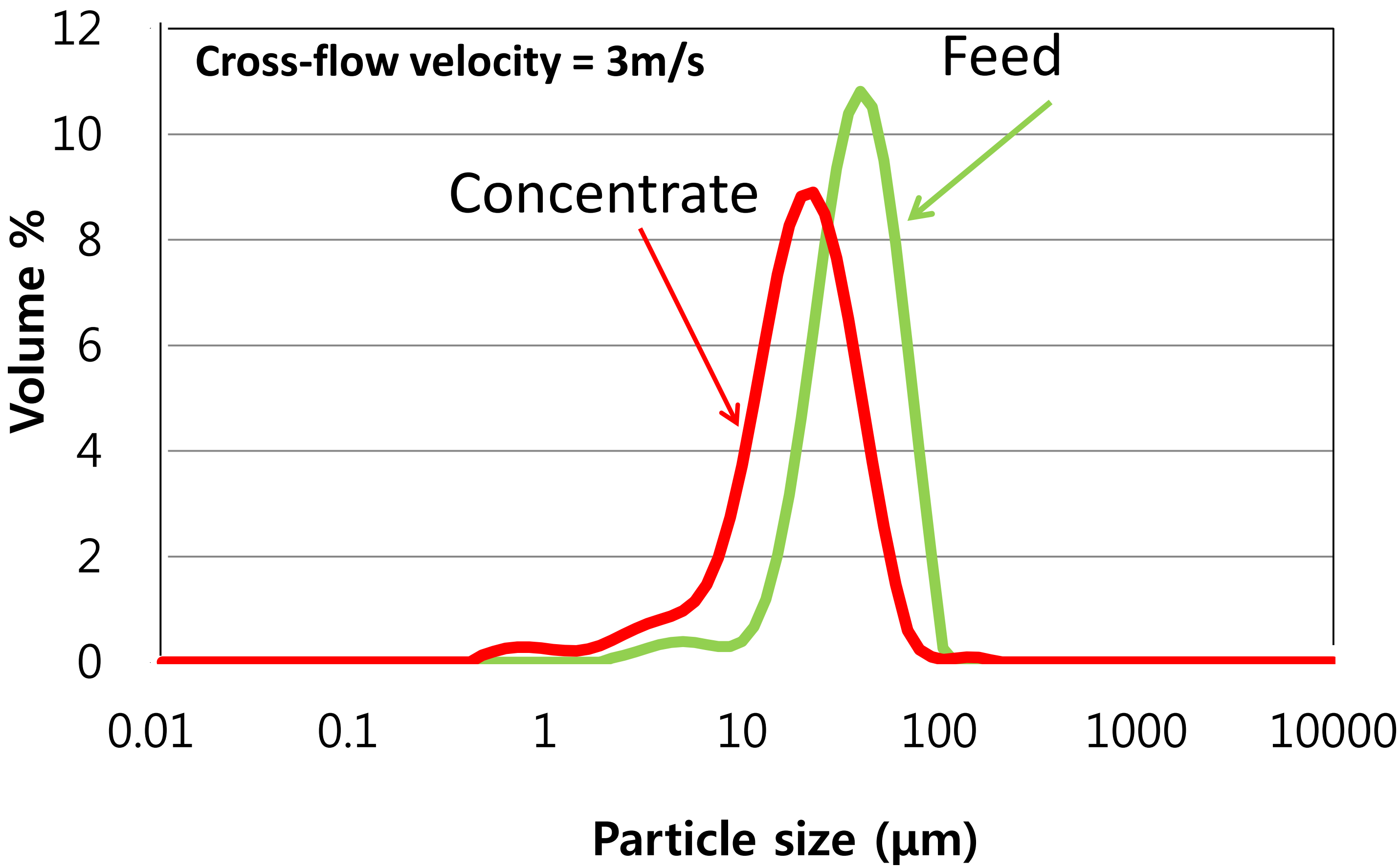
- High solid content
- High Biodegradability
- High Nitrogen ·Phosphorus
- High variation of leachate quality

Qualities of food waste leachate

pH	COD_{Cr}	T-N	SS
3.9 (3.1~4.3)	141,393 mg/L (100,358~183,753)	3,246 mg/L (1,239~4,404)	42,653 mg/L (5,614~80,540)

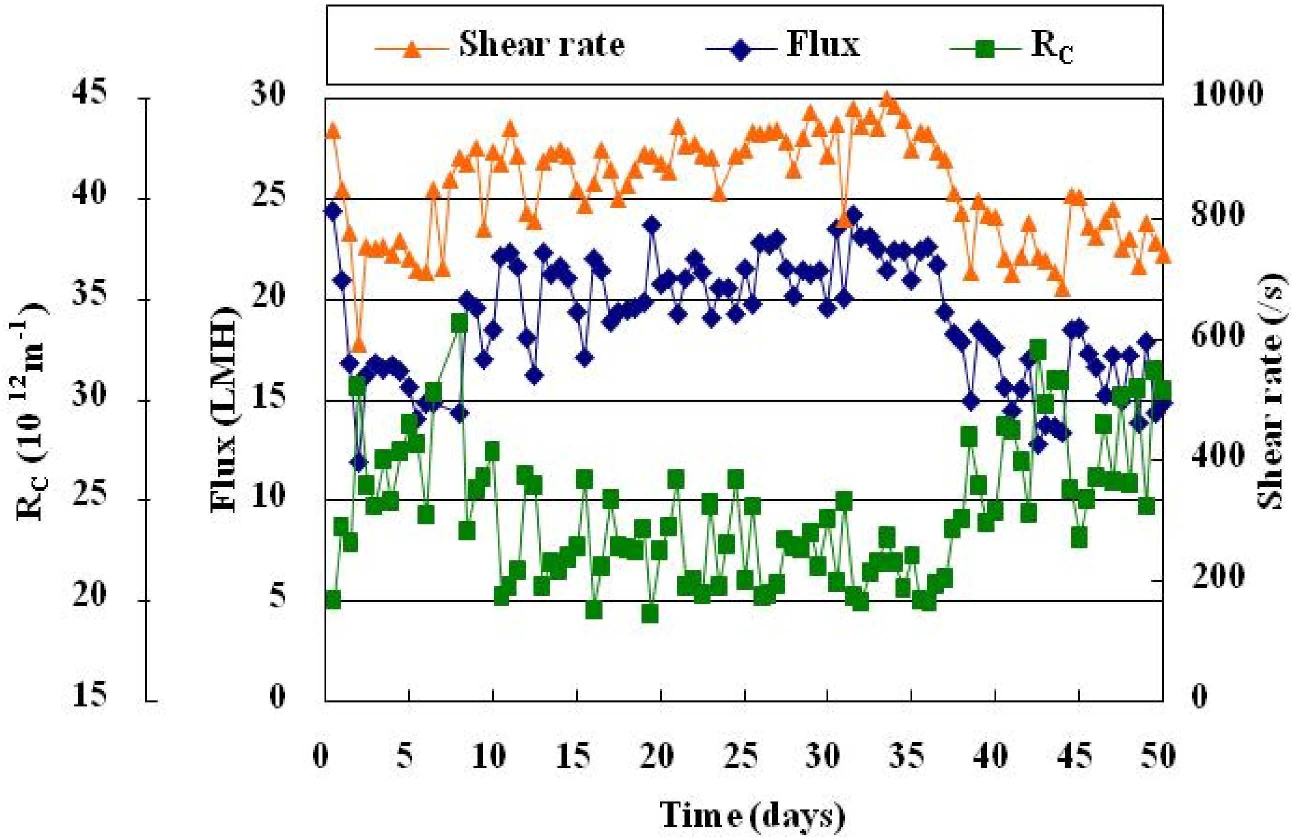
※ Source:
SUDOKWON Landfill Site Management Corp.(2008), "The feasibility study of biogas production with organic waste"

Change of Floc Size Distribution in Membrane Concentrate Stream



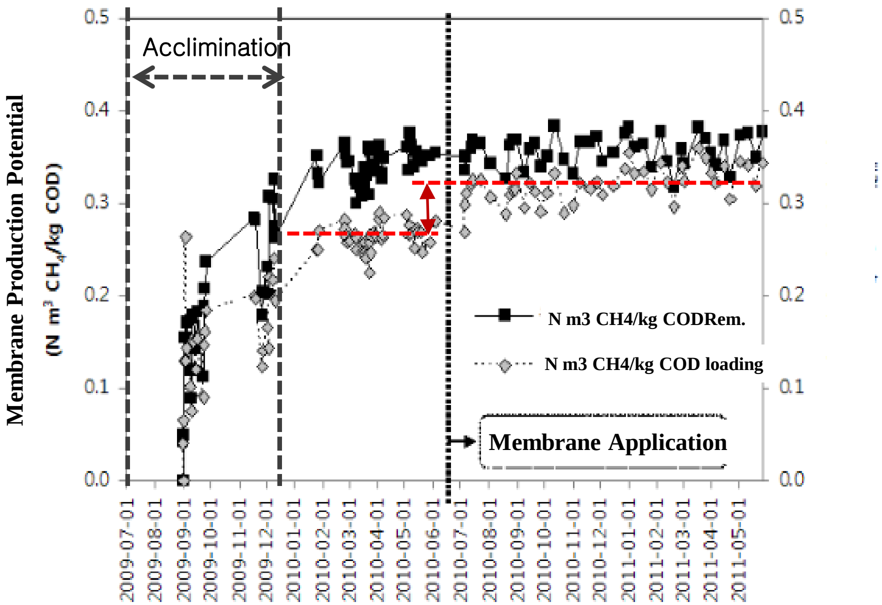
Long term Operation of AnMBR

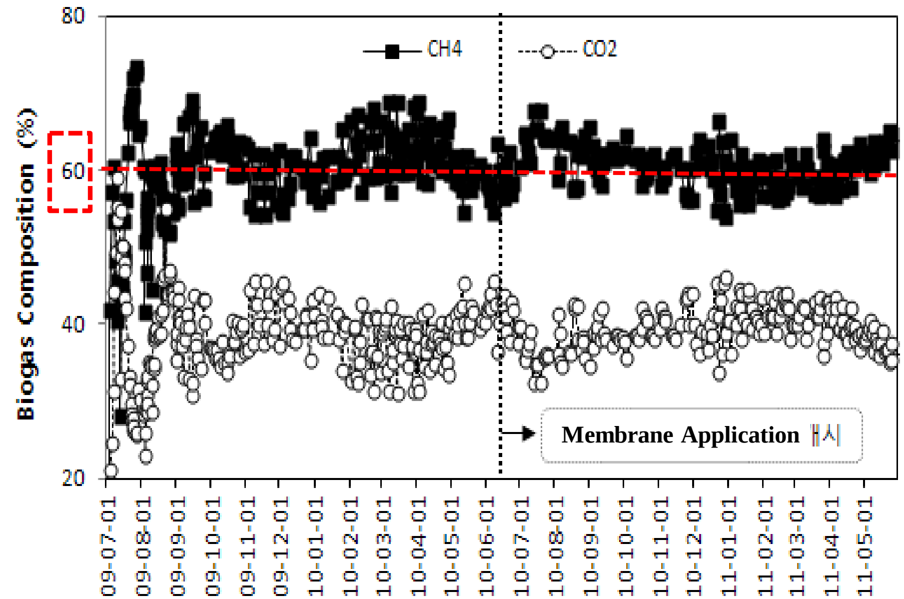
TMP
=0.8 kgf/cm²



- Shear rate played critical role in controlling membrane fouling

Biogas Production Potential and Compostion





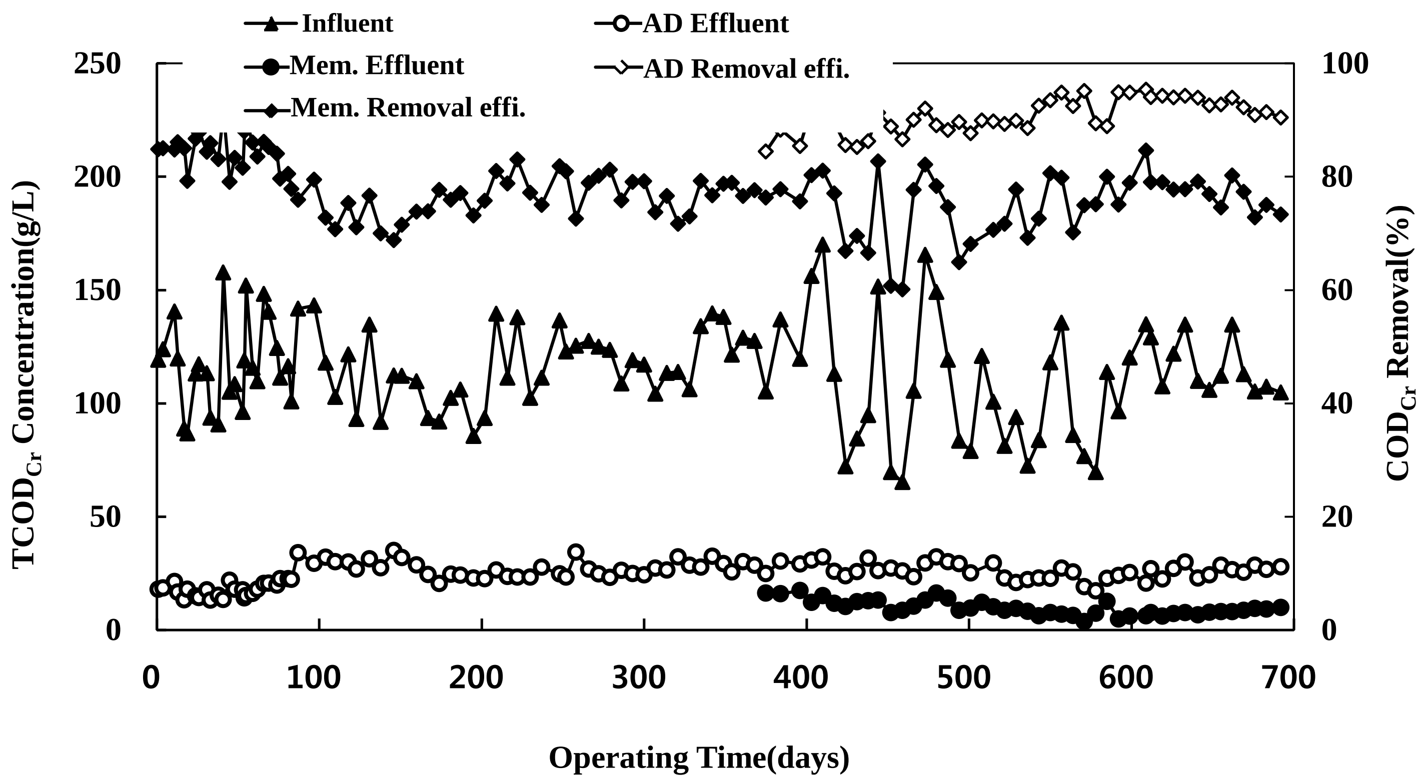
(단위 : Nm³ CH_4/kg COD)

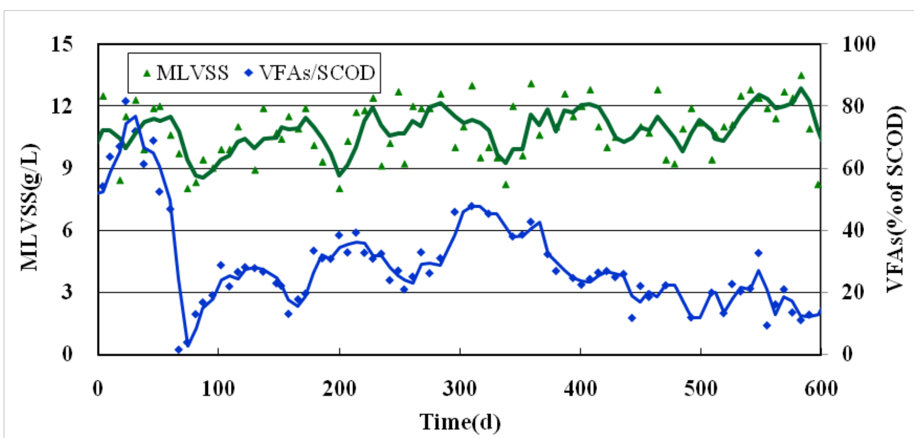
	Before	After	Variation
CH_4 production/ CODloading	0.28 (0.25~0.29)	0.32 (0.29~0.36)	△22.1%
CH_4 production/ CODRem.	0.34 (0.30~0.38)	0.36 (0.32~0.38)	△6.0%

Composition	CH_4 (%)	CO_2 (%)	H_2S (ppm)
Content	63 (56~68)	37 (32~44)	1,582 (1,100~2,360)

1. Biogas Production : 567 N㎥/ton_COD_{Rem}
2. Methane Yield : 359 N㎥/ton_COD_{Rem}

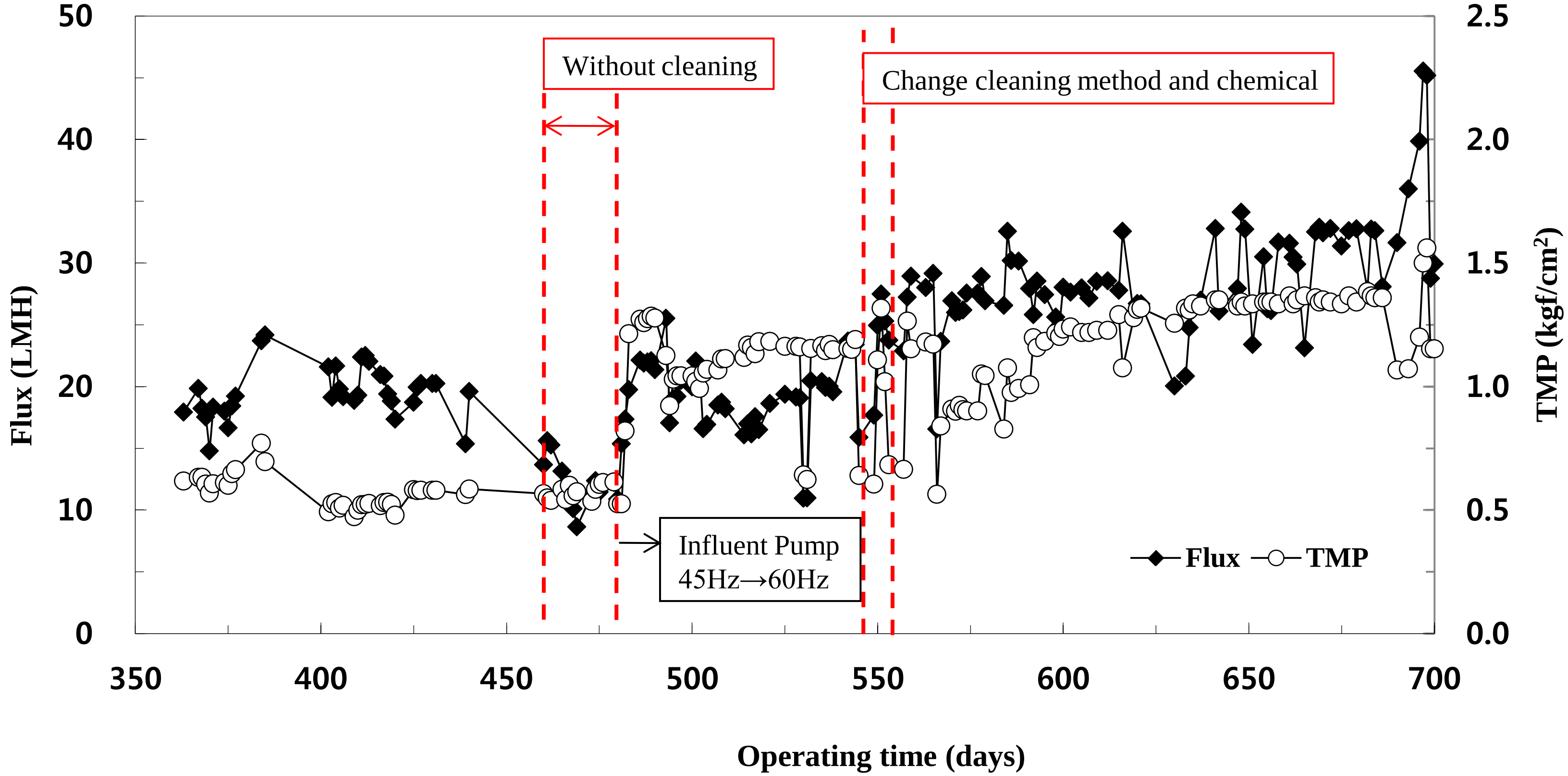
COD Removal Efficiency



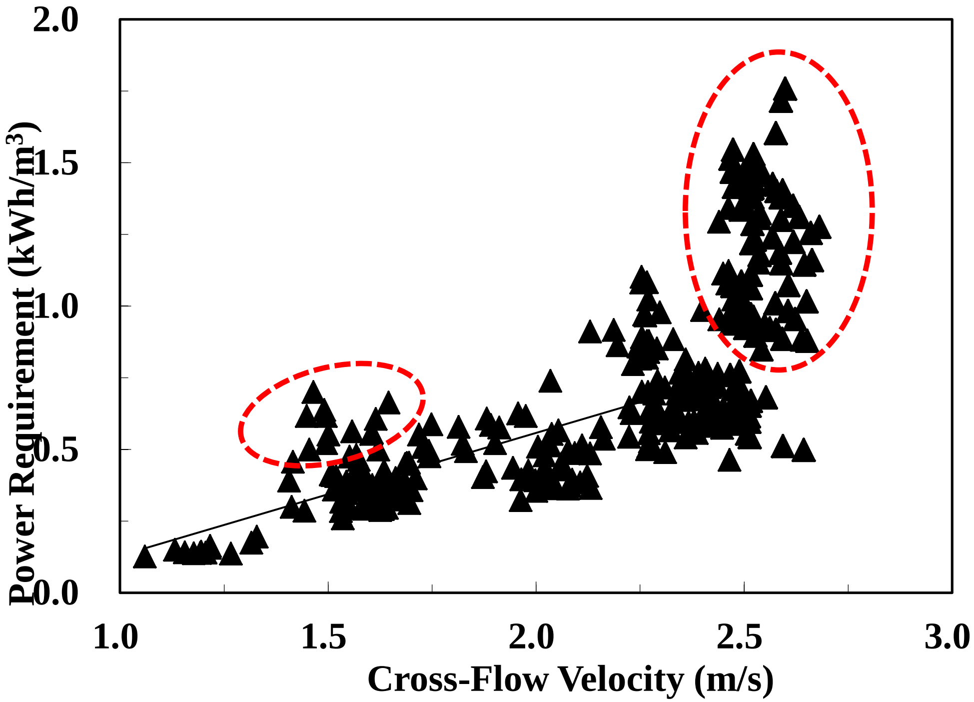


MLVSS has been increasing continuously since the digester was integrated with UF membrane

Variation of Flux and TMP in AnMBR



Relationship between Cross-flow velocity and Power Requirement in AnMBR



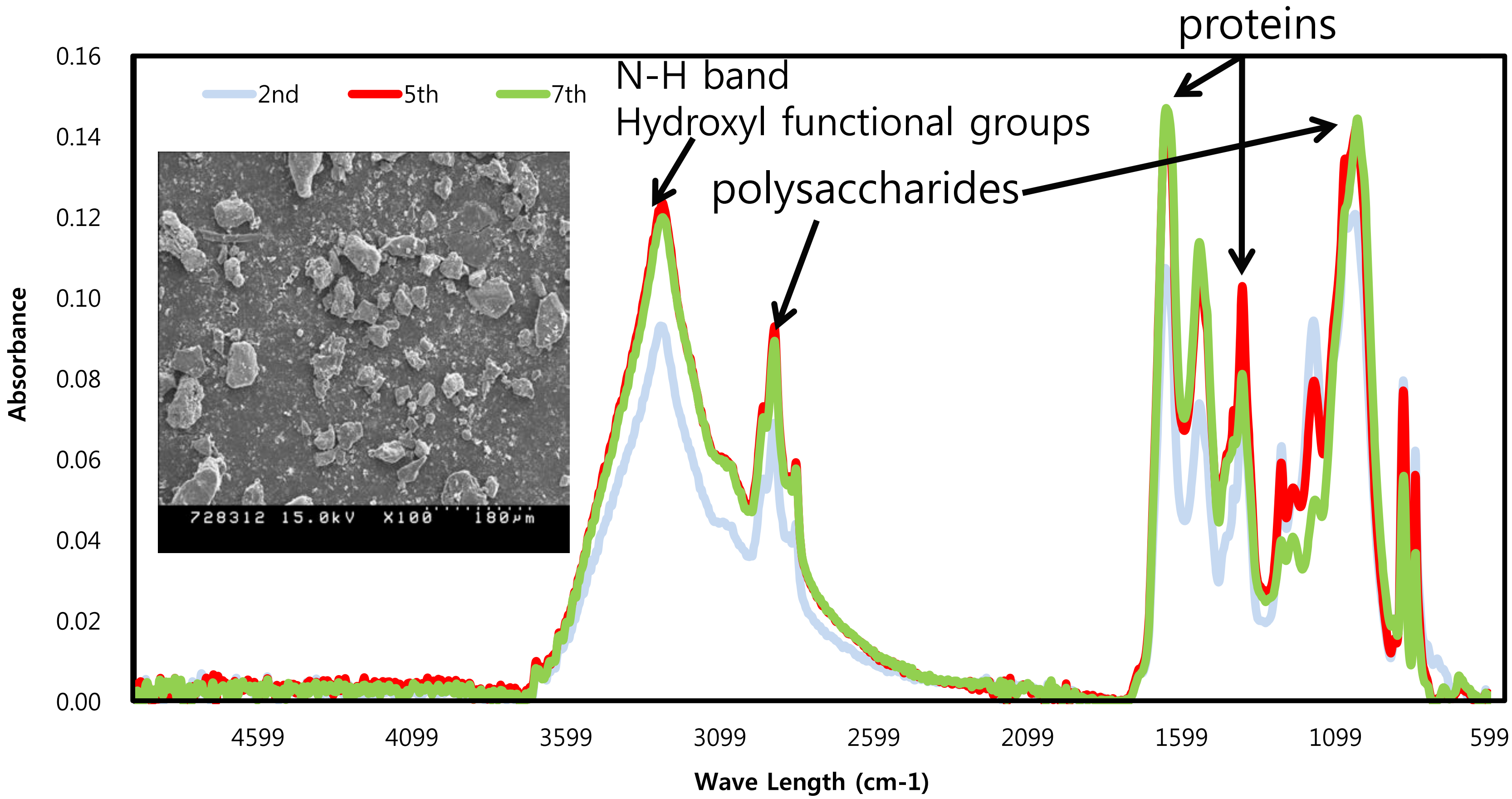
$$P = \frac{QE}{1000}$$

P : Power Requirement (kW)
Q : Recycle rate (m^3/s)
E : Pressure loss (N/m^3)

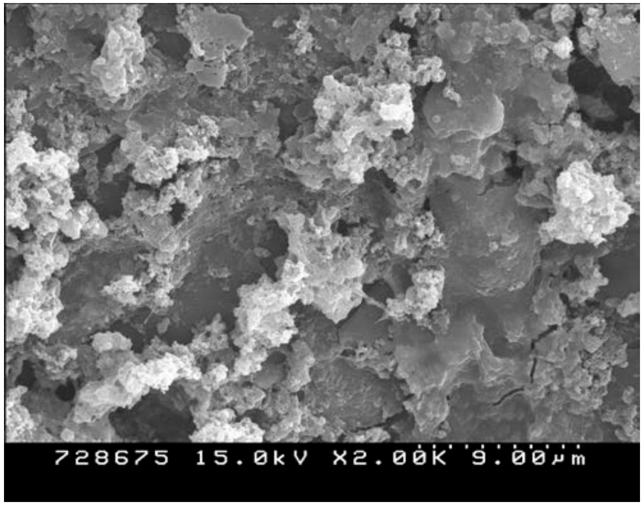
Source by Kim, J.H., MaCarty, P.L.(2011)

- The more fouling progressed, the more required electrical power to get the constant flux

Membrane Autopsy Works-FTIR Observation on Membrane Surface



Cake Layer after chemical cleaning

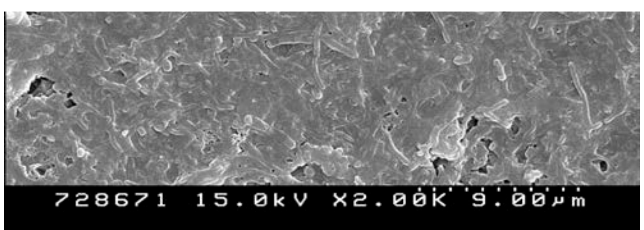


after NaOCl chemical cleaning

	Foodwaste Leachate	Methanogenic Sludge
Ca^{2+} (mg/L)	> 1,000	> 800
pH	< 4.0	> 7.5
Alkalinity (mg $CaCO_3$/L)	-	> 10,000
LSI	< - 4.0	> +4.0

after NaOH chemical cleaning

- At an LSI value greater than zero, the concentrate stream is supersaturated with calcium carbonate and would likely scale membrane surface as cake layer formation
- Strong binding and solidification can lead to pronounced cake resistance

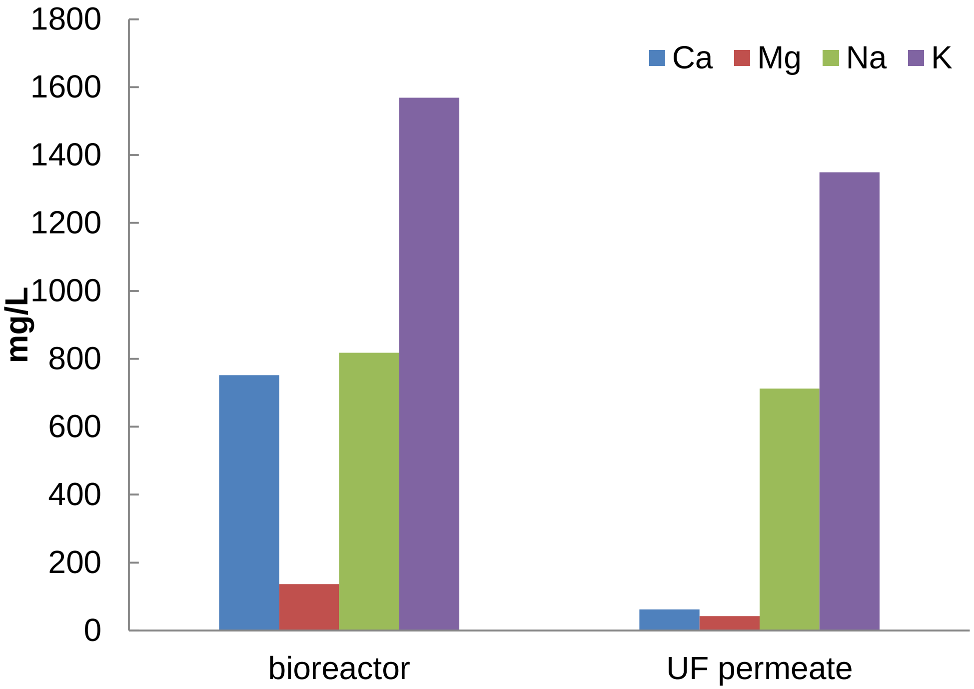


after citric acid chemical cleaning

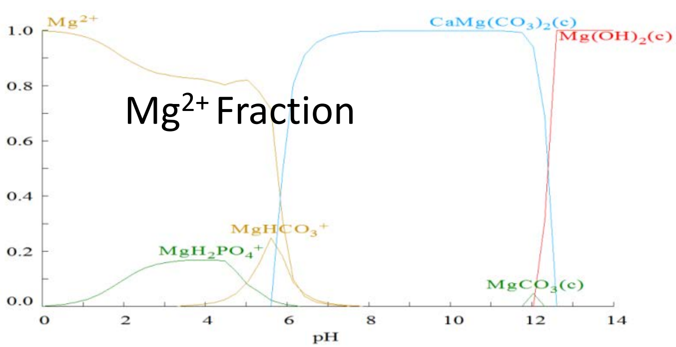
rate?

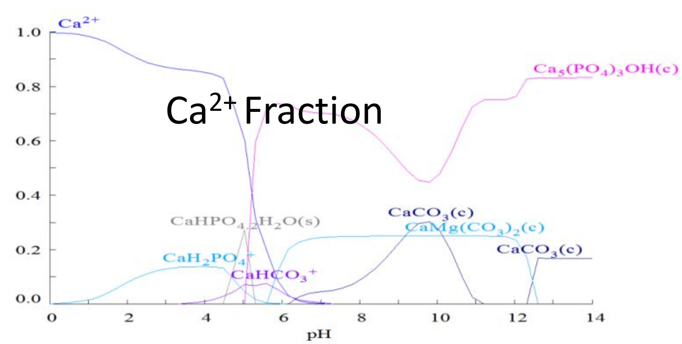
Cross-flow velocity = 3 m/s
TMP= 0.8 bar

Membrane Scale and Rejection



- High rejection of calcium (>95 %) is caused by membrane scale
- About 40 % rejection of Mg : struvite, $NH_4MgPO_4 \cdot 6H_2O$?
- High calcium content may inhibit formation of struvite





$[Ca^{2+}]_{tot}$=20 mM,
$[NH_3]_{tot}$=200 mM
$[CO_3^{2-}]_{tot}$=200 mM
$[PO_4^{3-}]$=10mM
$[Mg^{2-}]_{tot}$=5 mM,
$[K^+]_{tot}$=40 mM

Water Quality of HAnDS®

	$TCOD_{Cr}$	$SCOD_{Cr}$	BOD_5	SS
Sludge	25,000 mg/L (15,000~32,000)	12,050 mg/L (7,600~13,300)	11,900 mg/L	14,990 mg/L (8,200~21,400)
Permeate	13,700 mg/L (8,700~16,300)	11,700 mg/L (7,600~15,200)	8,100 mg/L	<3 mg/L

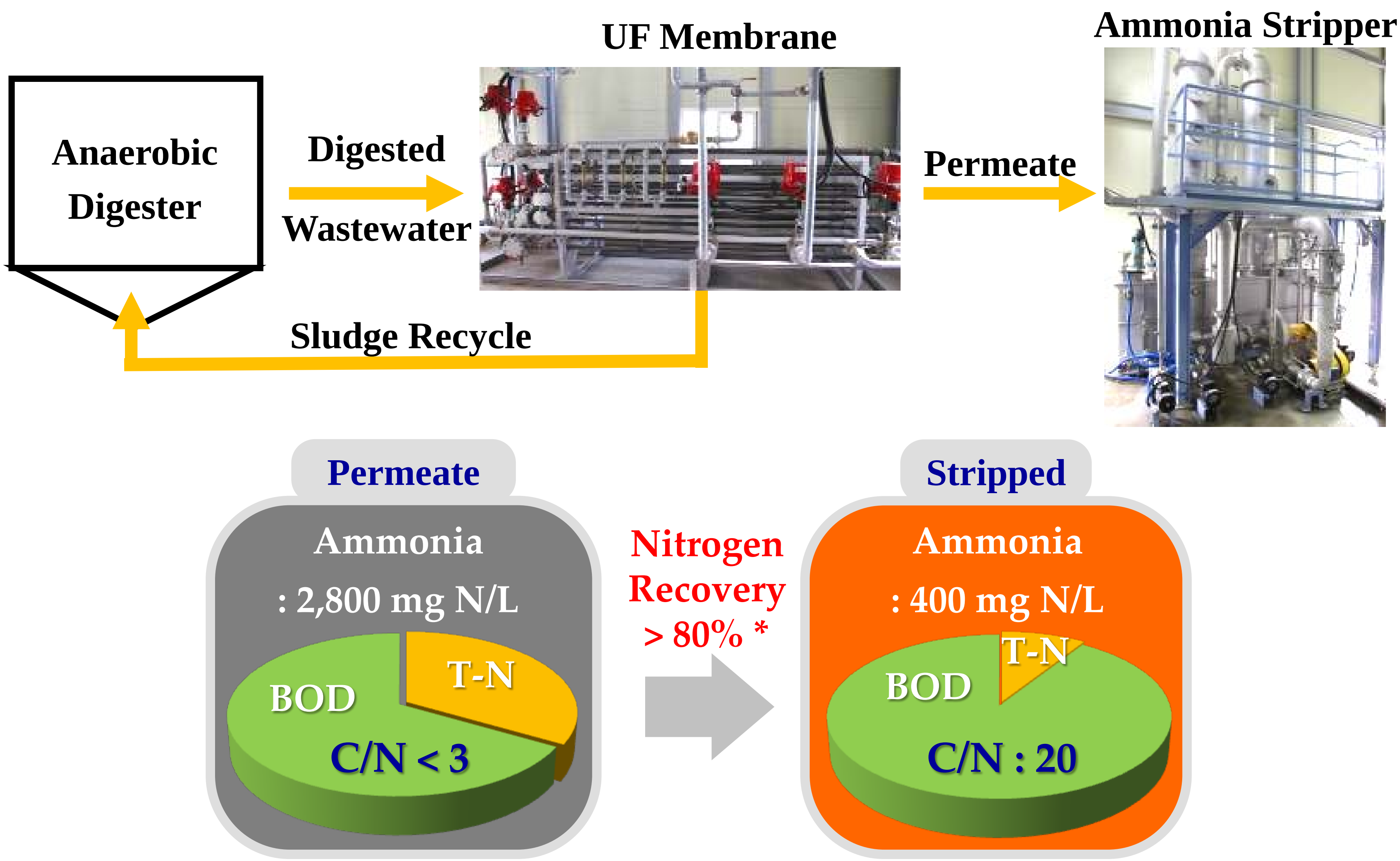
Water Quality of HAnDS®

5

(Unit : mg/L)	Food Waste Leachate	Anaerobic Digestion	Ultrafiltration	Aerobic MBR*
BOD_5	51,000	9,000	6,000	<3.0
COD_{Cr}	120,000	25,000	10,000	300
TN	3,000	4,000	2,000	<60
TS (g/L)	65	25	<10	-
n-Hexane	11,000	380	350	-

(*After ammonia stripping process)

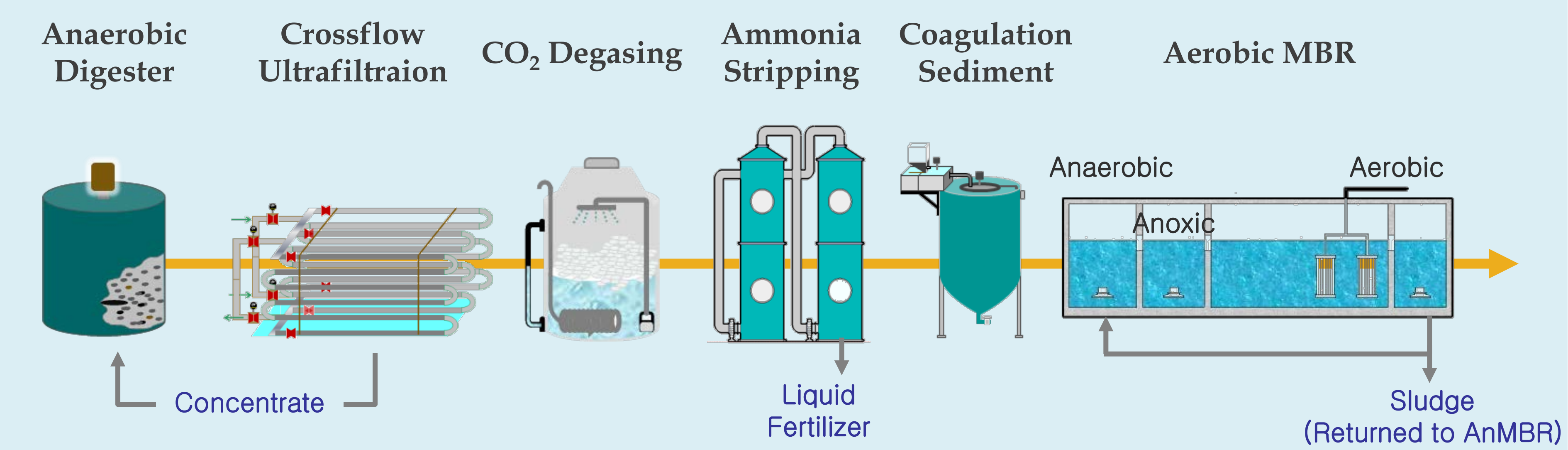
Addendum : Ammonia Stripping



*Recovery can be controlled by the operating conditions: temperature, pH and air volume

How to apply ?

Anaerobic Membrane Bioreactor (AnMBR, Korean NET No.352)




Biogas–ren drivkraft
LPG
GPL
NATURGAS
kompogas erdgas
SULZER
NGV
GG OZ 212
Wastes
Energy
Biogas

Seoul National University Seminar

Anaerobic Digestion & Biogas Plants

- From Organic wastes to Energy -

KOLON GLOBAL CORPORATION

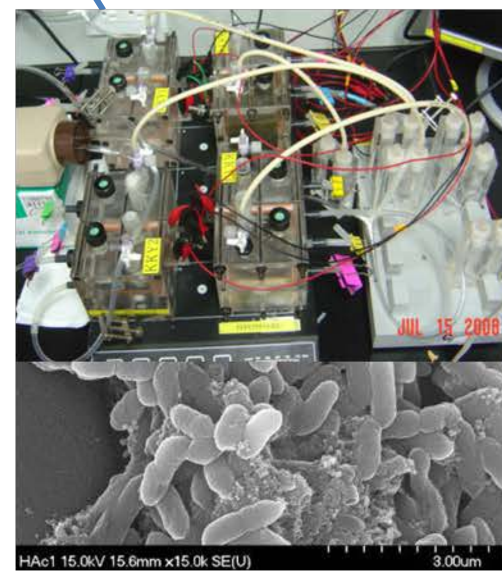
R&BD Center

Oct. 14. 2013

Kyu-Jung Chae (채규정)

Work Experiences

2000~ BNR | Biogas plant | **2004~** MBR | **2006~** MFC&MEC | **2011~** Energy



Chae et al., Water Sci. Technol., 49(5-6), 2004
Chae et al., Water Sci. Technol., 50(6), 2004
Chae et al., J. Environmental Management, 88(4), 2008
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Chae et al., J. of KOWREC, 9(4), 2001
Chae et al., J. of KOWREC, 9(3), 2001

Chae et al., Biores. Technol., 101, 2010
Chae et al., Environ. Sci. Technol., 43(24), 2009
Chae et al., Biores. Technol., 100 (14), 2009
Chae et al., Int. J. of Hydrogen Energy, 2009
Chae et al., Int. J. of Hydrogen Energy, 33, 2008
Chae et al., Energy & Fuels, 22(1), 2008
Kim et al., Environ. Eng. Res., 13(2), 2008
Ajayi et al., Int. J. of Hydrogen Energy, 2008 etc.
Choi et al., Biores. Technol., 102, 2011
Kim et al., Biores. Technol., 102, 2011 ……

1

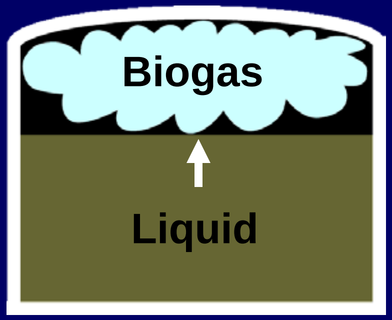
Anaerobic Digestion

Fundamentals

How Are Biofuels Produced?

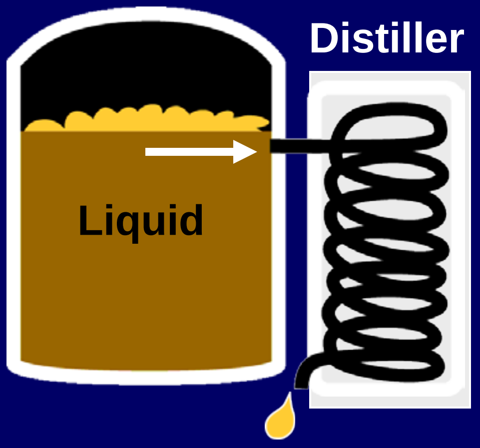
Anaerobic Digestion

Biogas:
- Manure
- Microbes



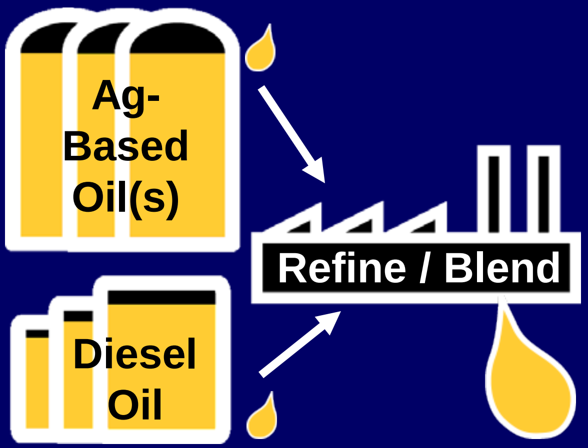
Fermentation and Distillation

Bioethanol:
- Yeast / Sugar
- Alcohol

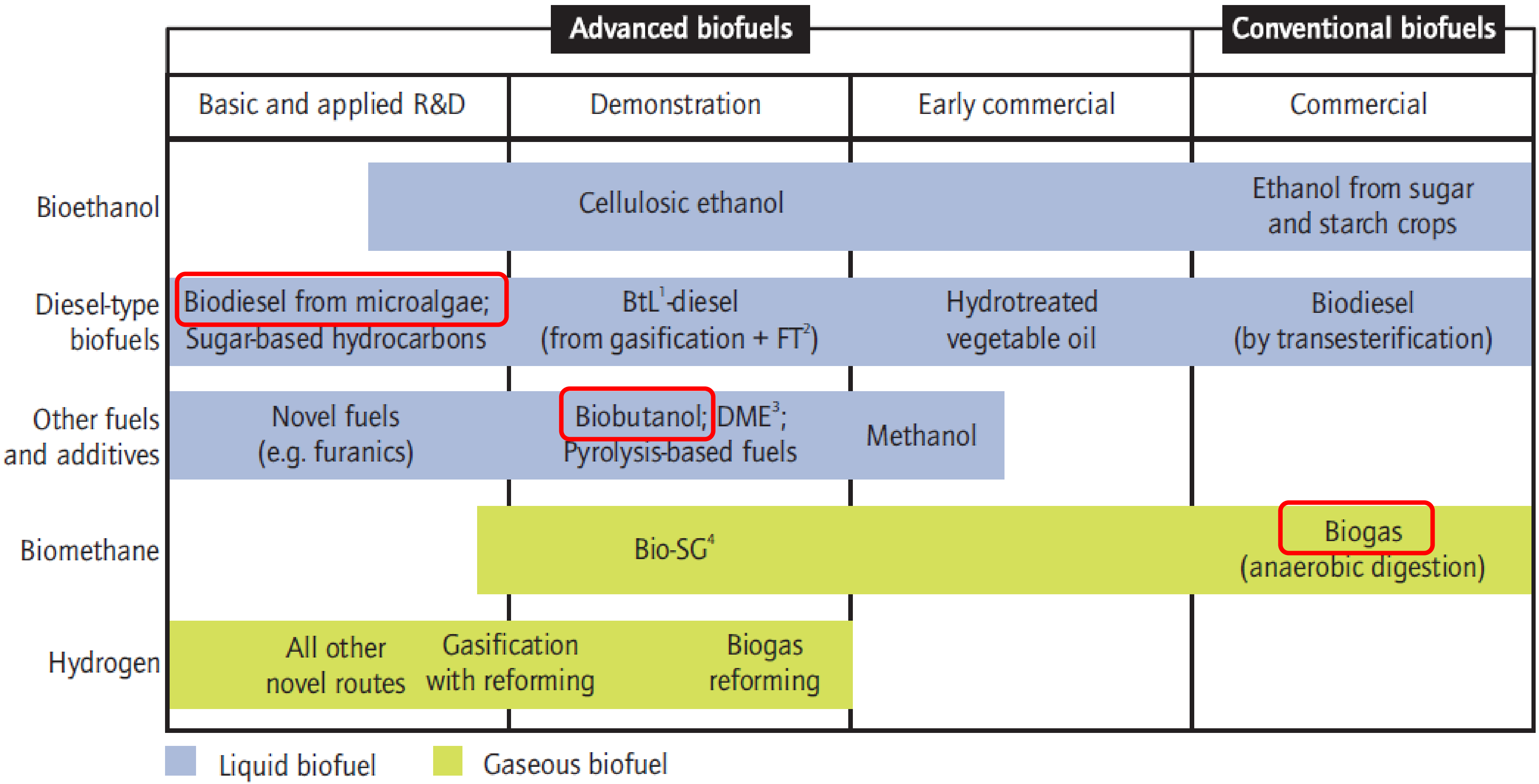


Extraction, Blending, and Refining

Biodiesel:
- Refined Diesel Fuel
- Refined Ag-Based Oils



Commercialization status
of main biofuel technologies



1. Biomass-to-liquids; 2. Fischer-Tropsch; 3. Dimethylether; 4. Bio-synthetic gas.

<Ref.: Technology Roadmap, Biofuels for Transport, IEA 2011>

What's Biogas?

Biogas is <u>NOT</u> pure methane (natural gas).

Methane (60%) CO2 (40%)

– with trace amounts of H2S and water vapor

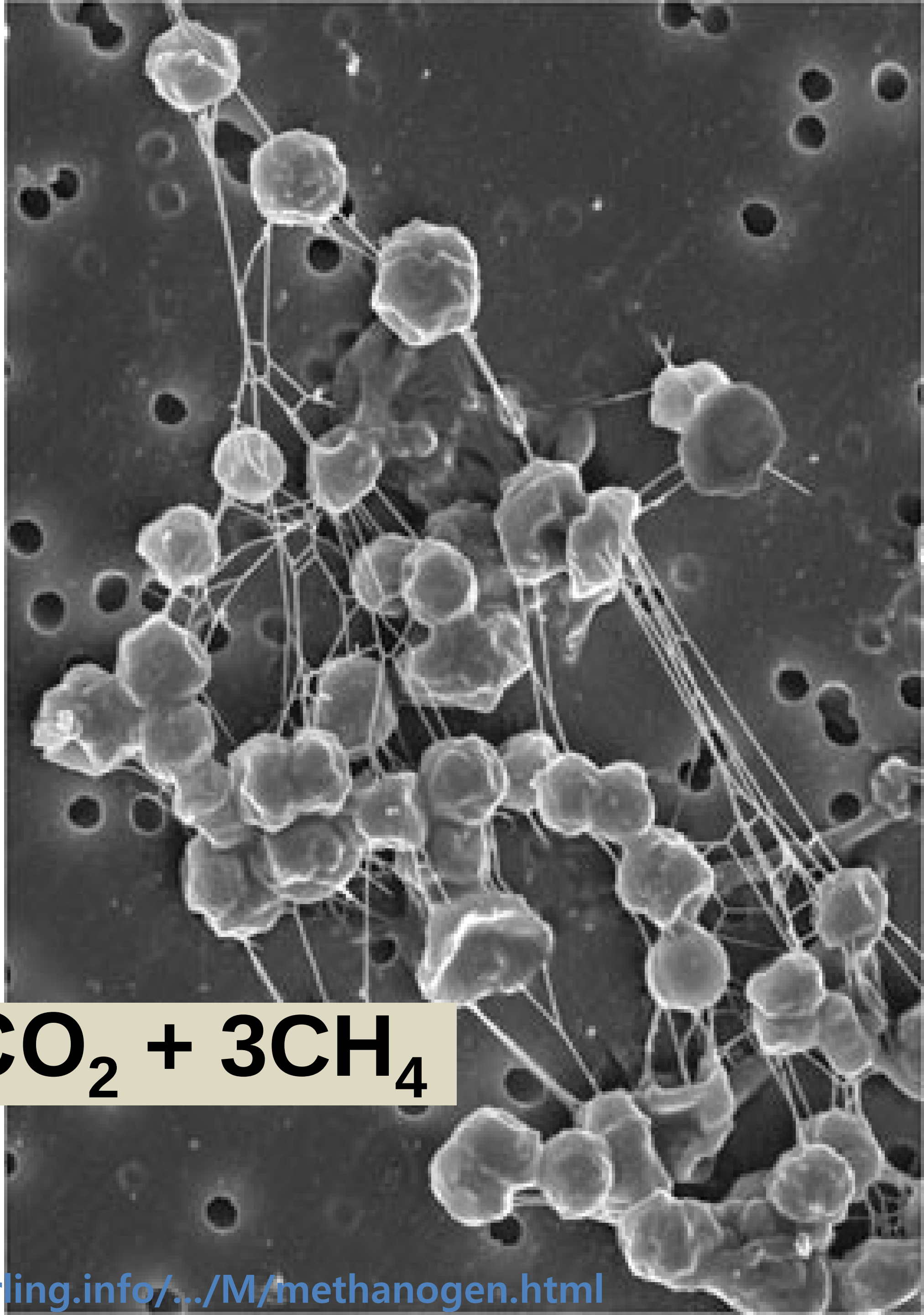
Typical Composition of Biogas

CH_4	50–75%
CO_2	25–50%
N_2	0–10%
H_2	0–1%
H_2S	0–3%
O_2	0–2%

What’s AD?

Anaerobic digestion (AD) is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy.

$$\text{e.g., } C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$



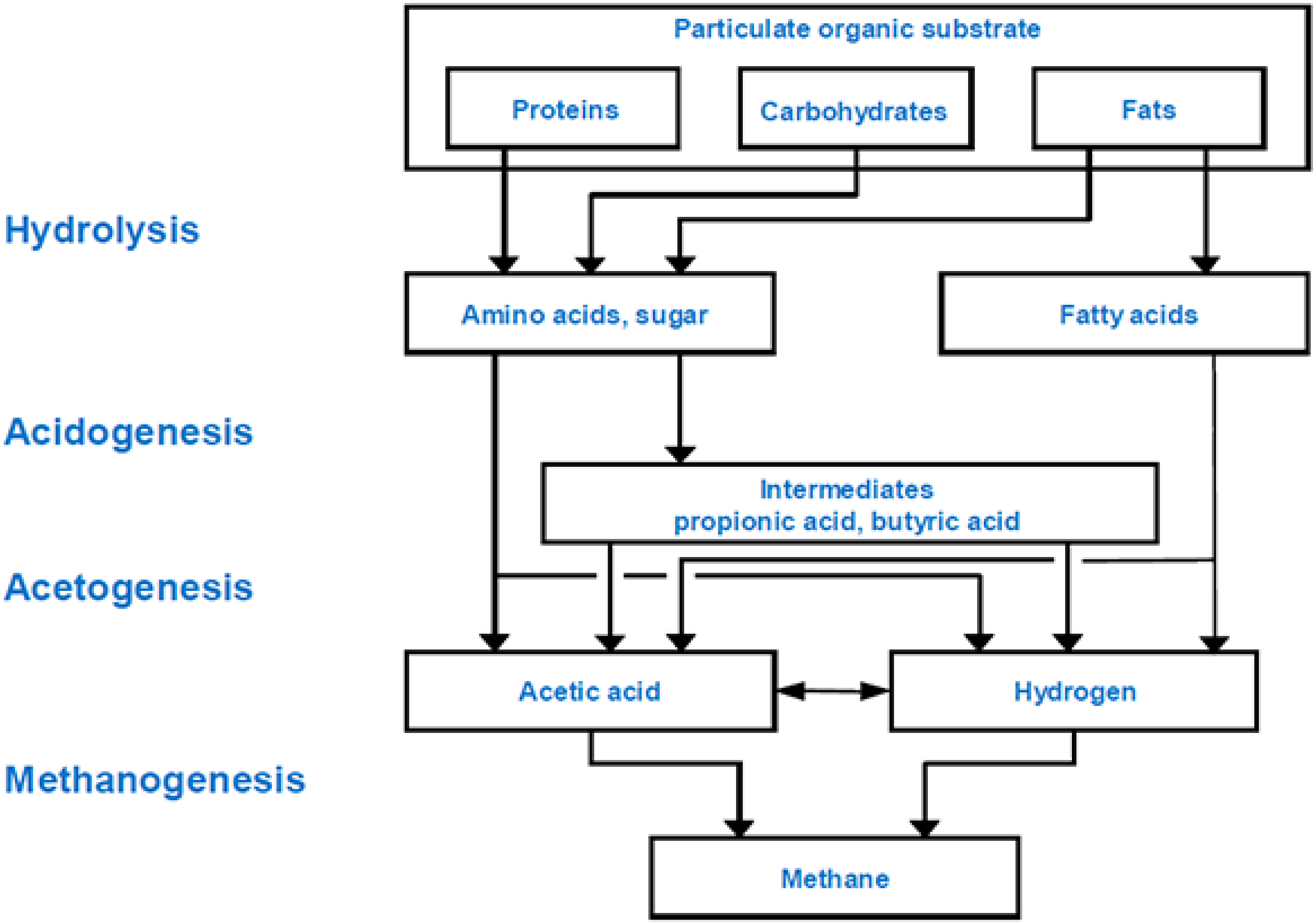
www.daviddarling.info/.../M/methanogen.html

Why anaerobic?

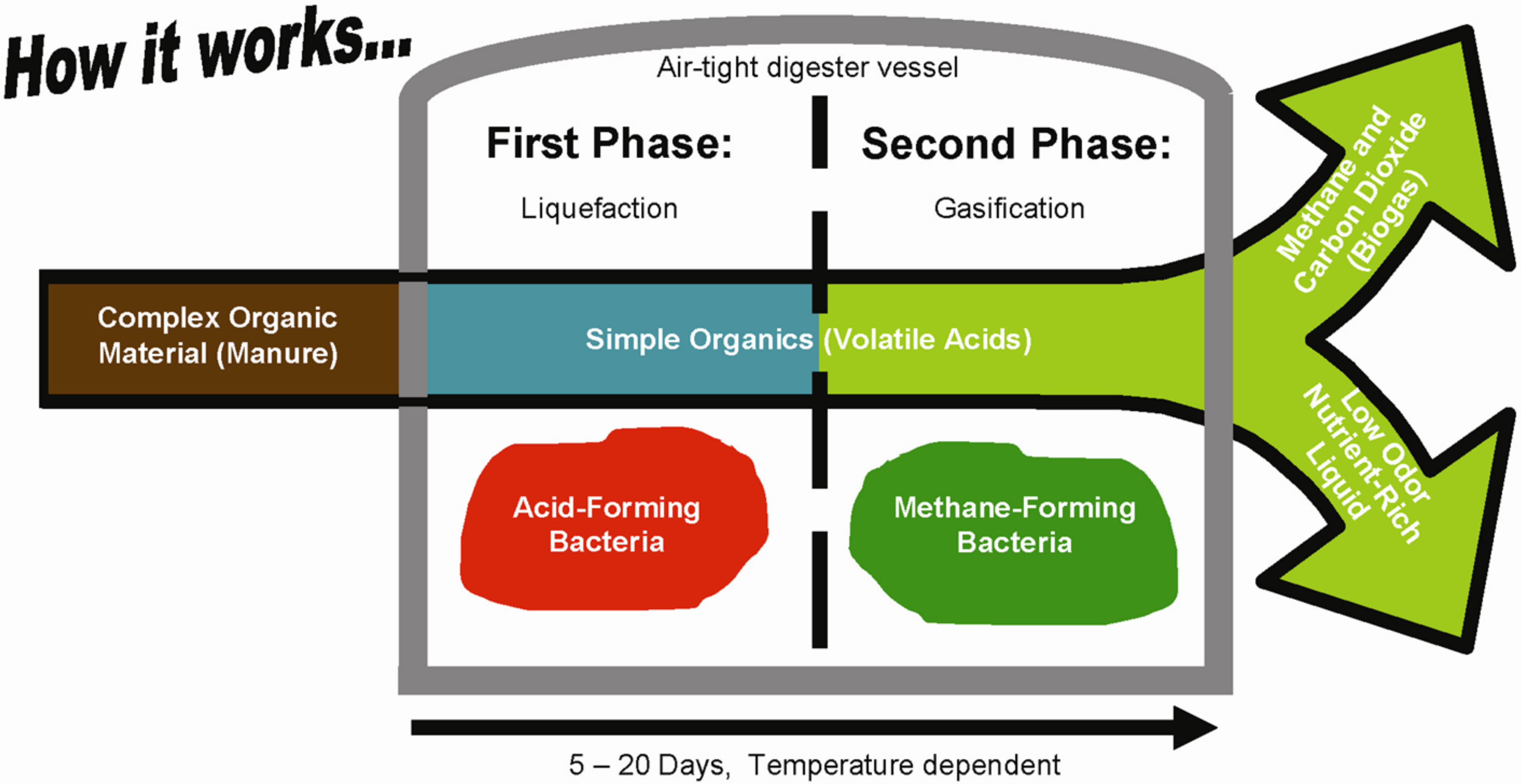
- **Advantages:**
  - Low energy input
  - Biogas production: net energy production
  - Minimal sludge production
  - Fertilizer quality sludge
  - Pathogen destruction
  - Odour reduction

- **Disadvantages:**
  - High investment
  - Ammonia & Phosphate production

Anaerobic biodegradation



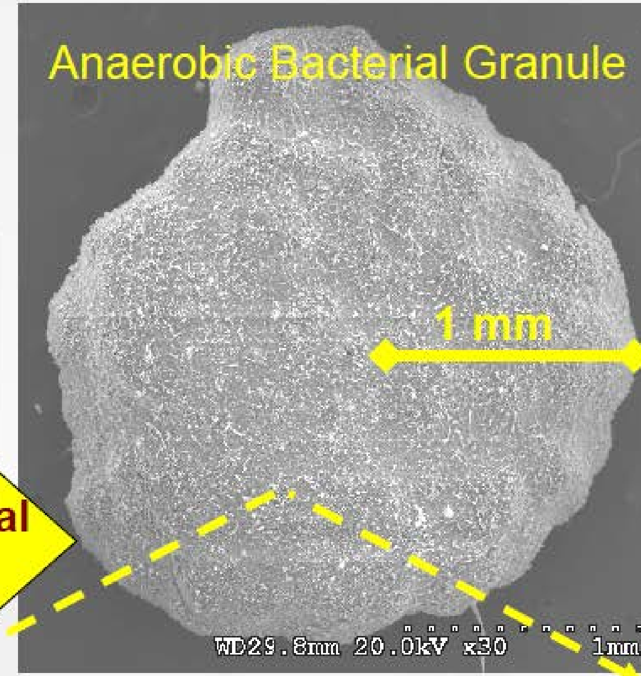
Anaerobic digestion uses microbes in an oxygen-free tank to break down manure into Biogas and a nutrient-rich liquid.

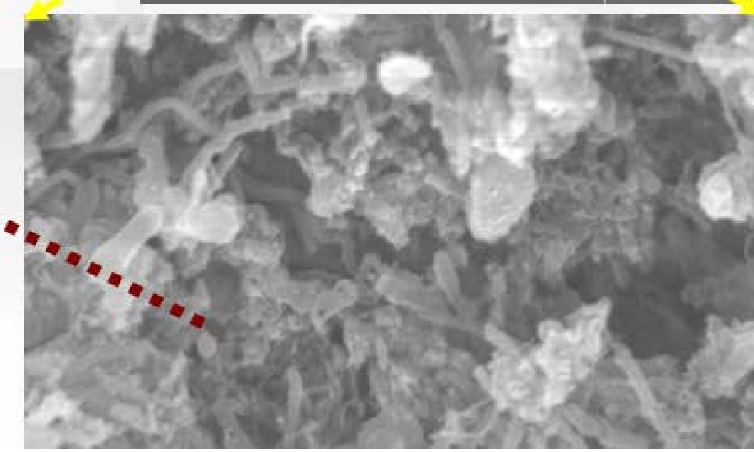


Anaerobic Bacterial Granule: A Community of Bacterial Species for Anaerobic Digestion of Biomass

Anaerobic Digestion depends on consortia of Hydrolytic & Acidogenic Bacteria working with Methane-producing bacteria (methanogens) growing in STRUCTURED COLONIES or FILMS for structural support and metabolic interchange.

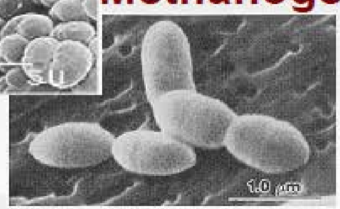
Structured Microbial Colonies





Methanogens

Methanosarcina mazei

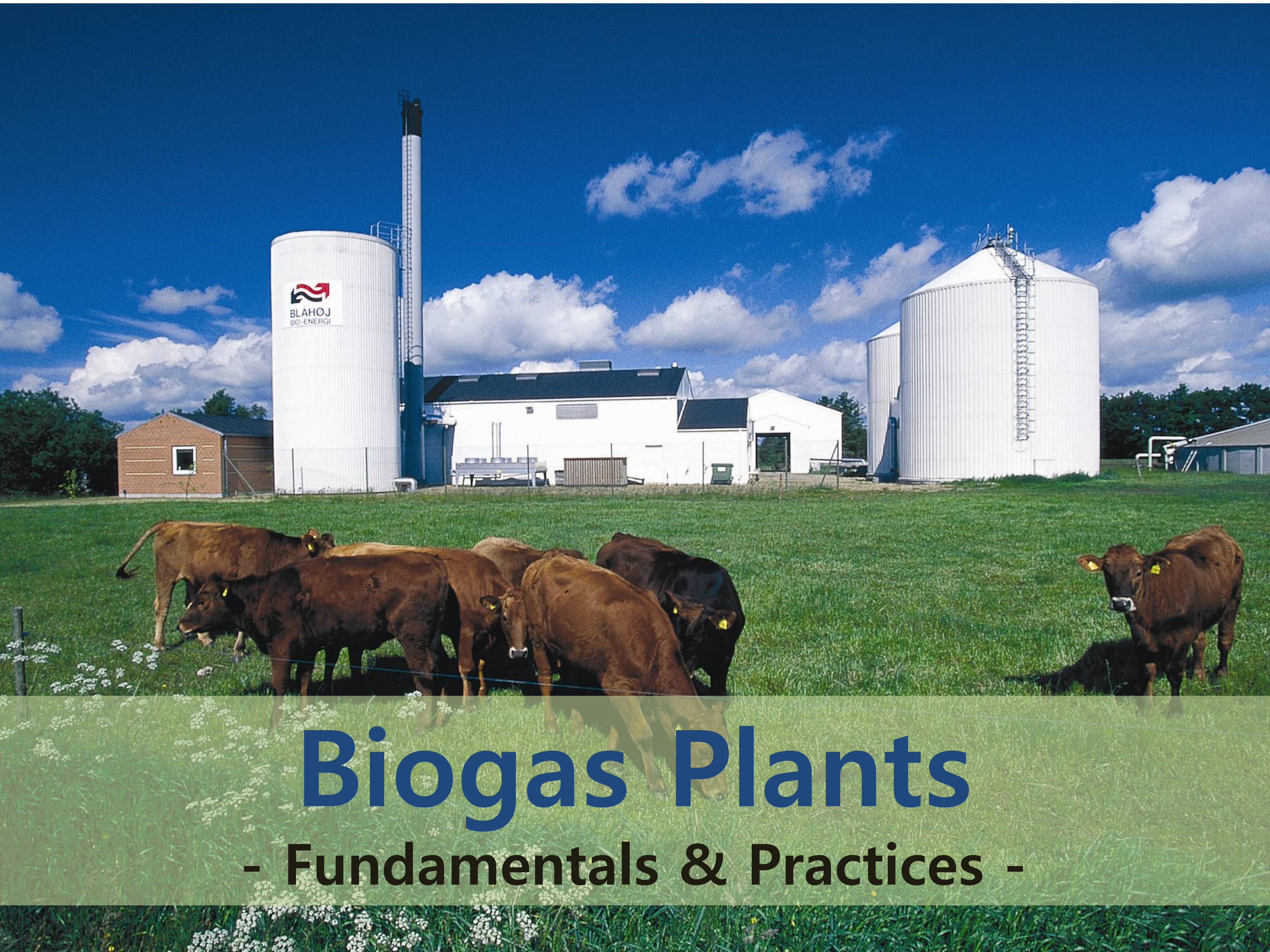


Methanobrevibacter smithii

Source: Prof. Chang D.J.

AD Configuration

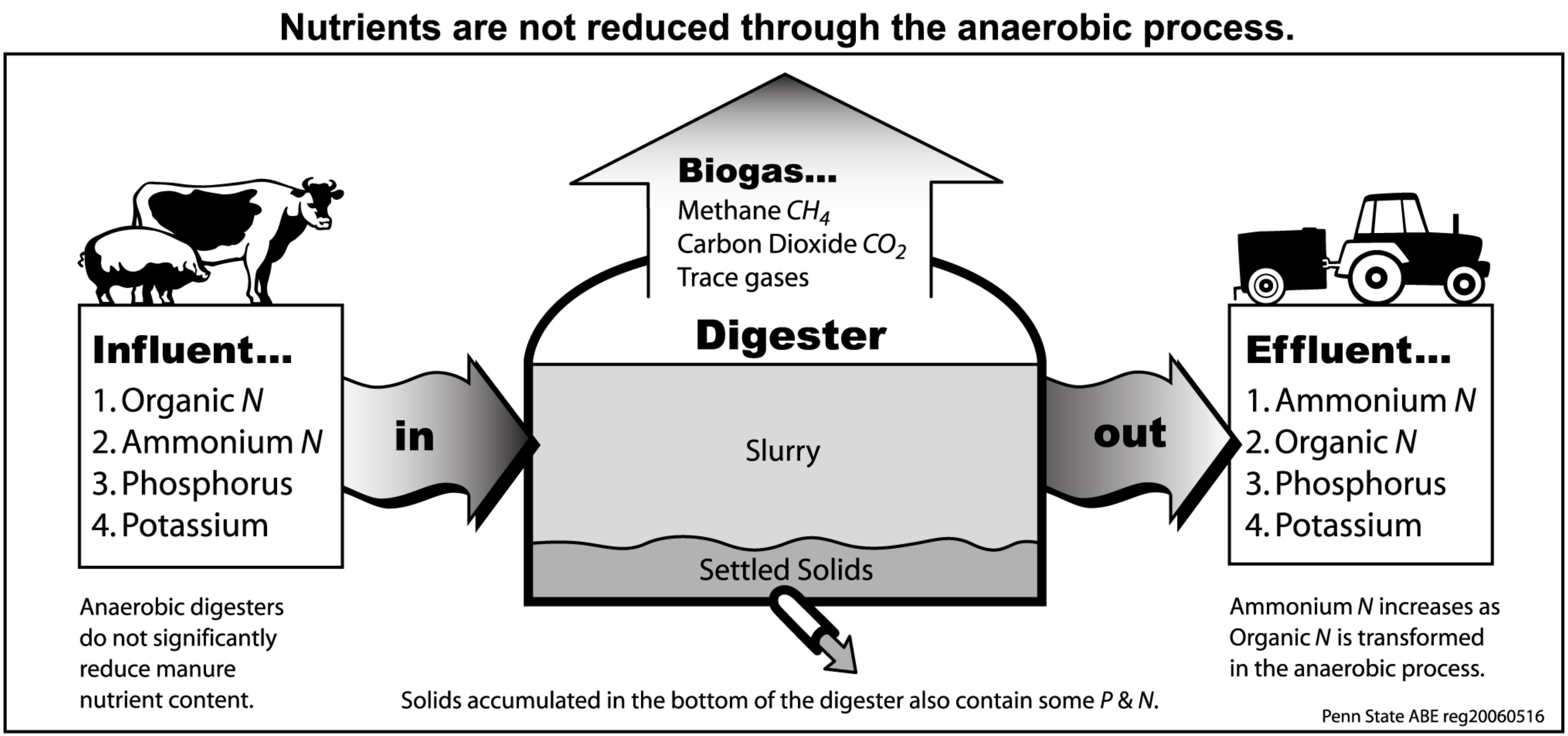
Flow Batch or continuous	**Temperature** Mesophilic or thermophilic
Solids content High solids or low solids	**Complexity** Single stage or multistage



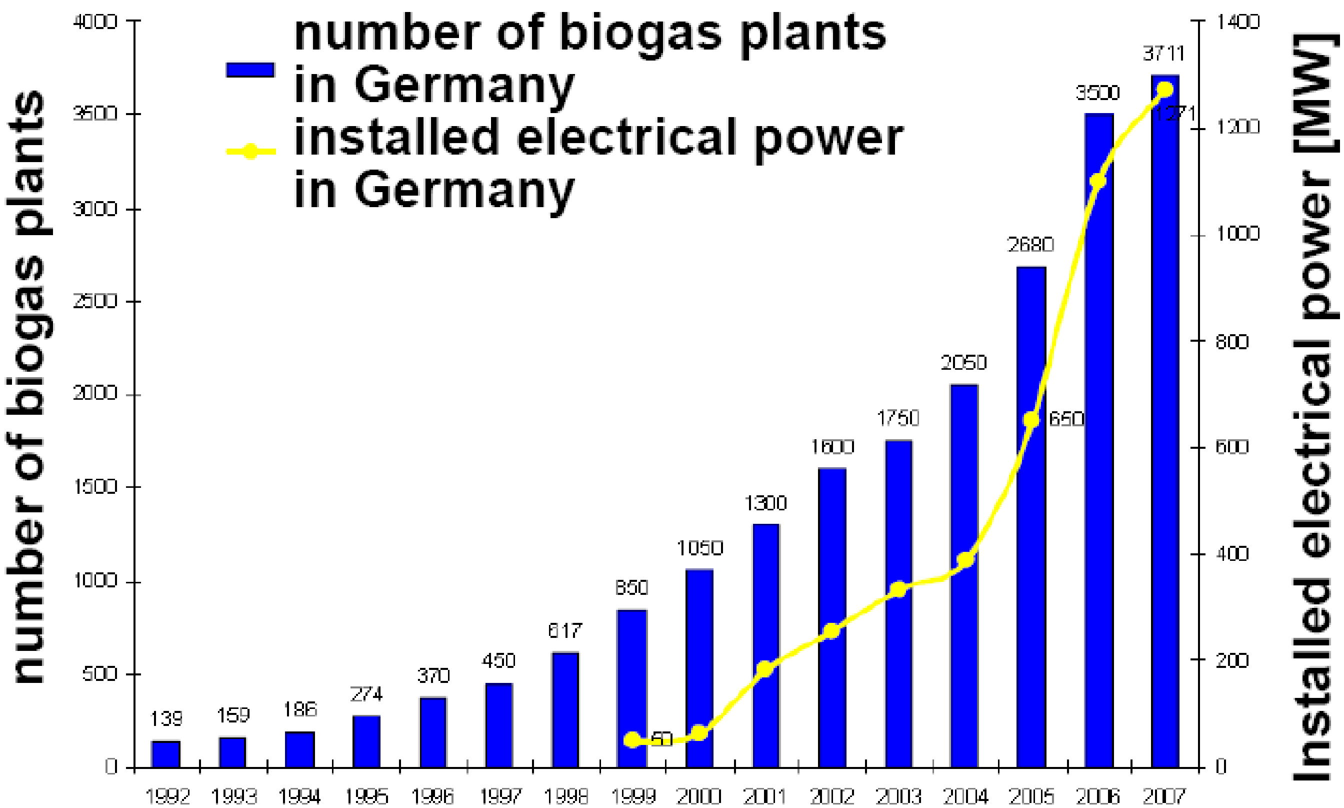
Biogas Plants

- Fundamentals & Practices -

How Do Anaerobic Digesters Work?

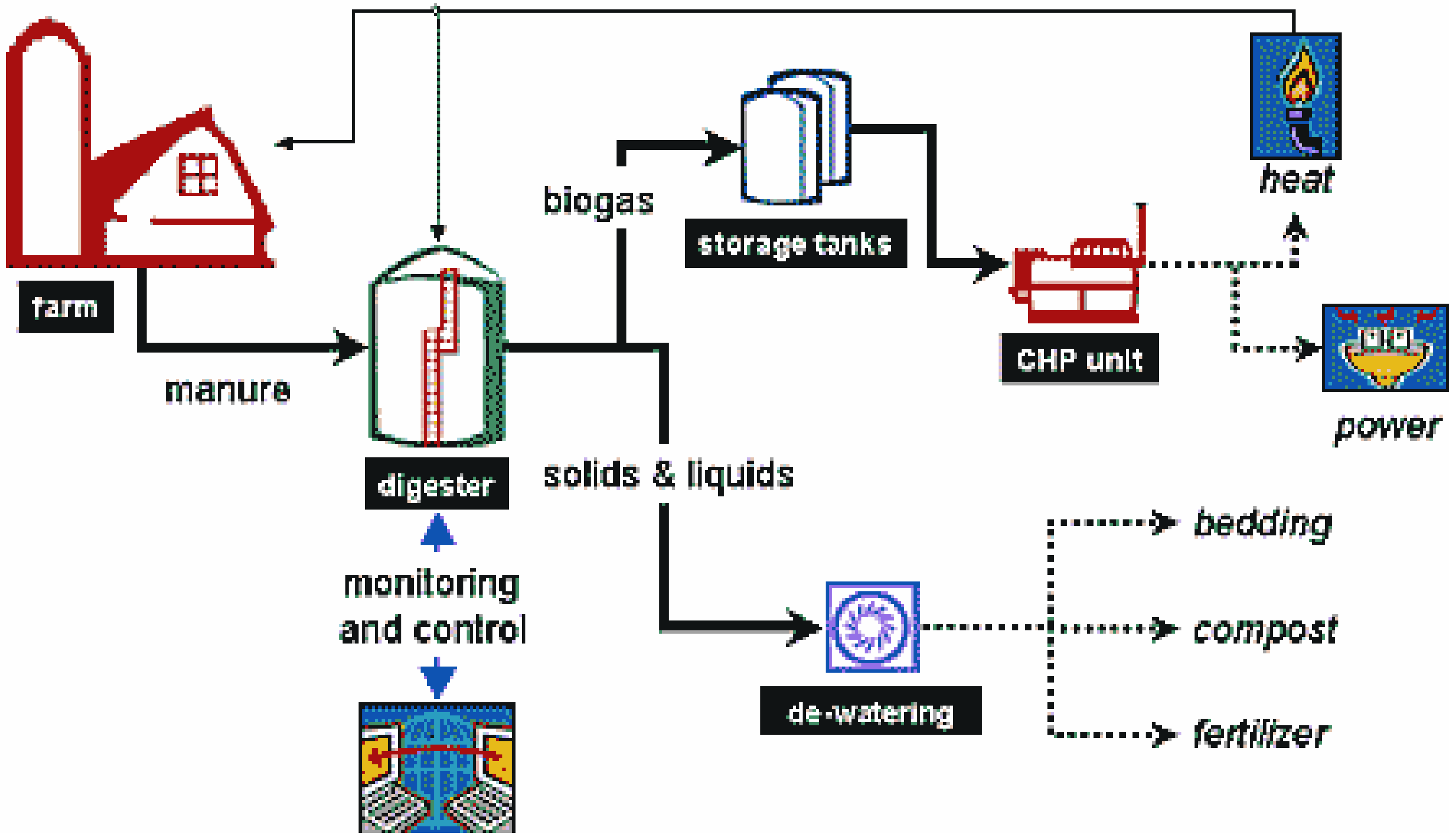




Source: Torsten Fischer
(Krieg & Fischer Ingenieure GmbH)

Biogas plant



Nutrients are not reduced through the AD process…

Biogas Plants:
Key Equipment

Pretreatment
Screen/
Hygienization tank

Anaerobic digester

Gas holder

CHP unit
or boiler

Biogas purification system

Safety device

Mixer

Pump

Heating system

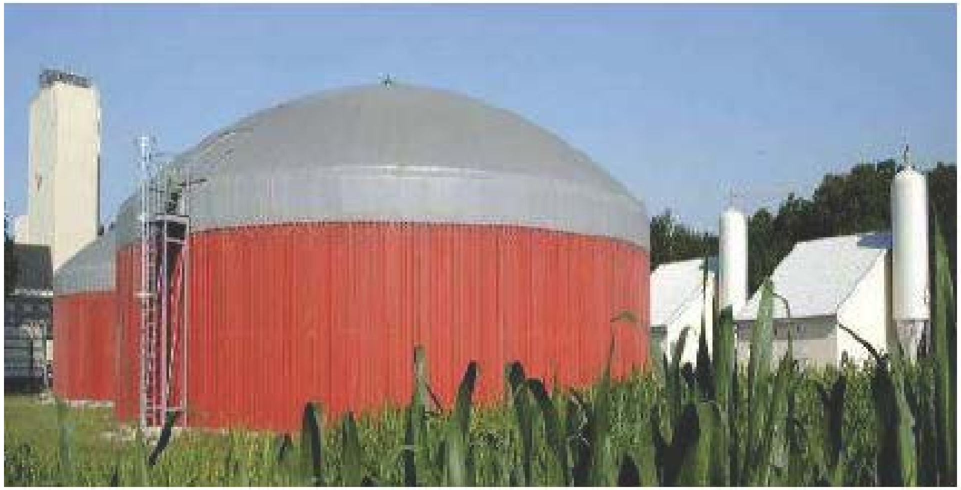
Feedstock

Source: German biogas association

Screening/sorting

Feeding

Digester Types



- Vertical digester
  - Different heights, diameter
  - Several digesters/stages possible
- Plug flow digester
  - Horizontal shaft
  - High organic loading rate
    - Dry digestion
- Combination plug flow vertical digester
  - Two (several) stages

Courtesy: Sustainable Energy Ireland

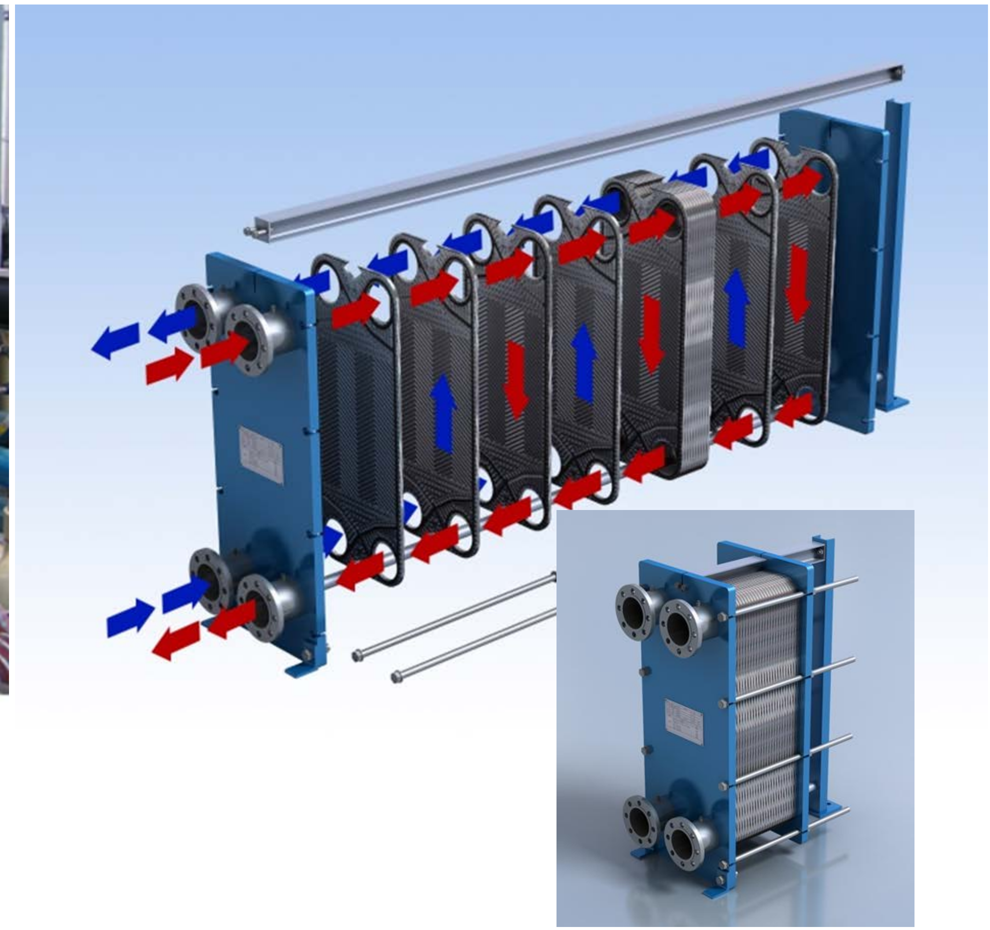
Mixer Types

Top mounted agitator for complete digester mixing

- Low energy
- Low mechanical problem

Heat Exchangers

Double-pipe heat exchangers



Serial wound HE

Plate HE….

We need a specialized HE for particle-rich waste(waters).

Pump Types

Courtesy: Sustainable Energy Ireland

Biogas Utilization

Biogas

Direct use

Local heating & electricity production

Microturbine

CHP unit

Boiler

Upgrade

Biomethane sold to public grid or grid owner

Car fuel

Fuel cell

CNG

CHP unit for Biogas

Combined Heat and Power

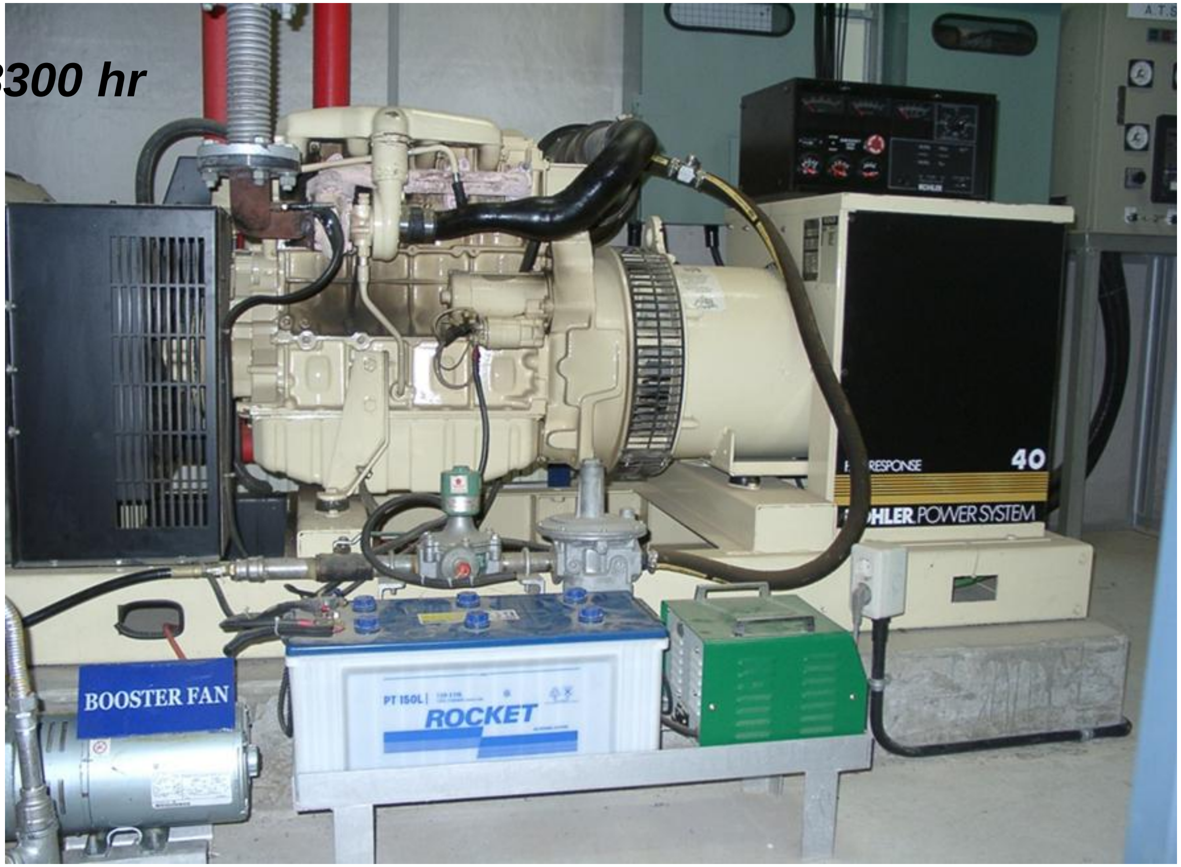
Modified Gas- or Diesel-engines

Dual fuel engines (diesel~10% + biogas 90%)

- ***50~2000kWp***
- ***Annual operating 7500~8300 hr***
- ***H2S, NH3 damage***

Efficiency rates:

- ***Electrical 30~42%***
- ***Thermal 25~50%***
- ***Overall up to 85%***



Containerized CHP unit for farm-scale biogas plant

Interconnection with the electricity grid.

Biogas Upgrading

Biogas purification			Biogas upgrade
H2O	H2S	Siloxane Removal (optional)	CO2 Removal

Biogas → H2O → H2S → Siloxane Removal (optional) → CO2 Removal → CH4 >95%

H2O:
Gas cooling
Water trap

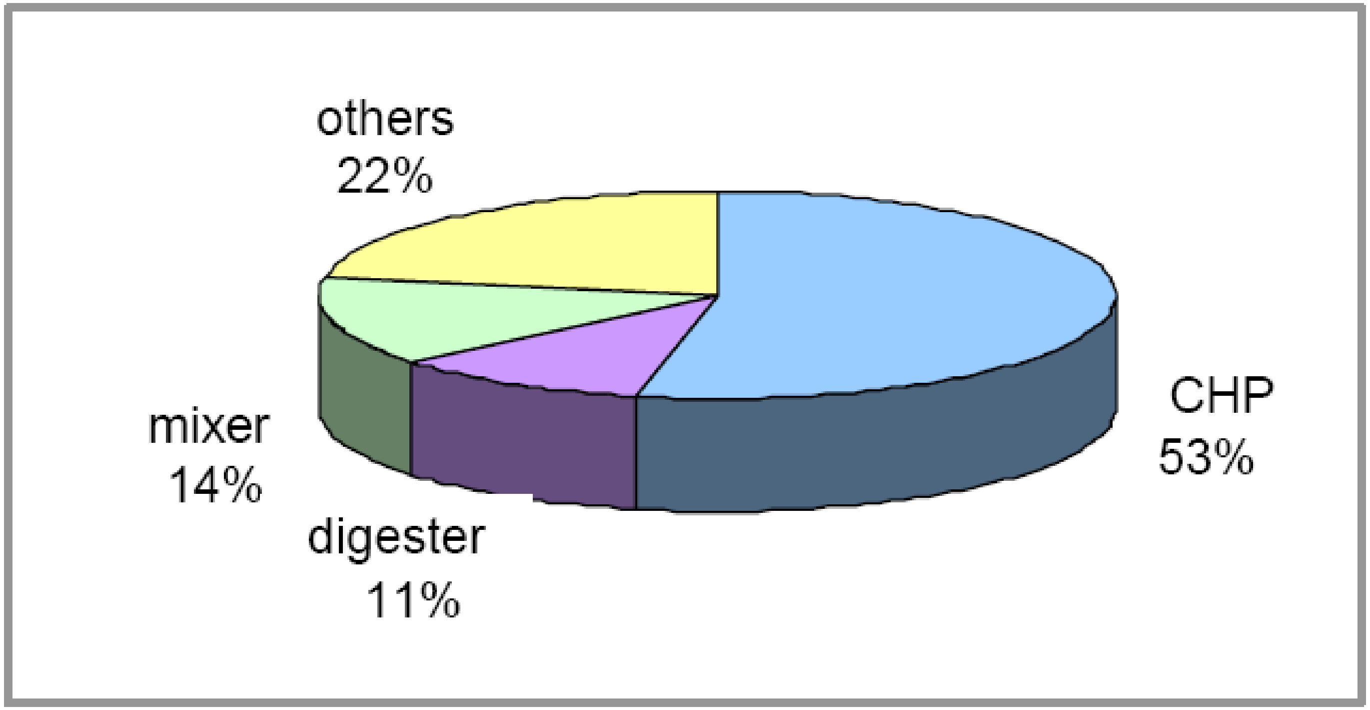
H2S:
FeCl3
Biofilter
Adsorption

CO2 Removal:
- Absorption: Water or amin scrubber
- Adsorption: Activated carbon
    - PSA (pressure swing adsorption)
- Membrane
- Cryogenic

Methane reforming
$CH_4 \rightarrow H_2$ with Pt catalyst

What is the most problematic?

Damages at different parts of the plant
- payments related to different plant parts



Marsh
GmbH

Experience of the insurance company
Source: Torsten Fischer

2

Case Study

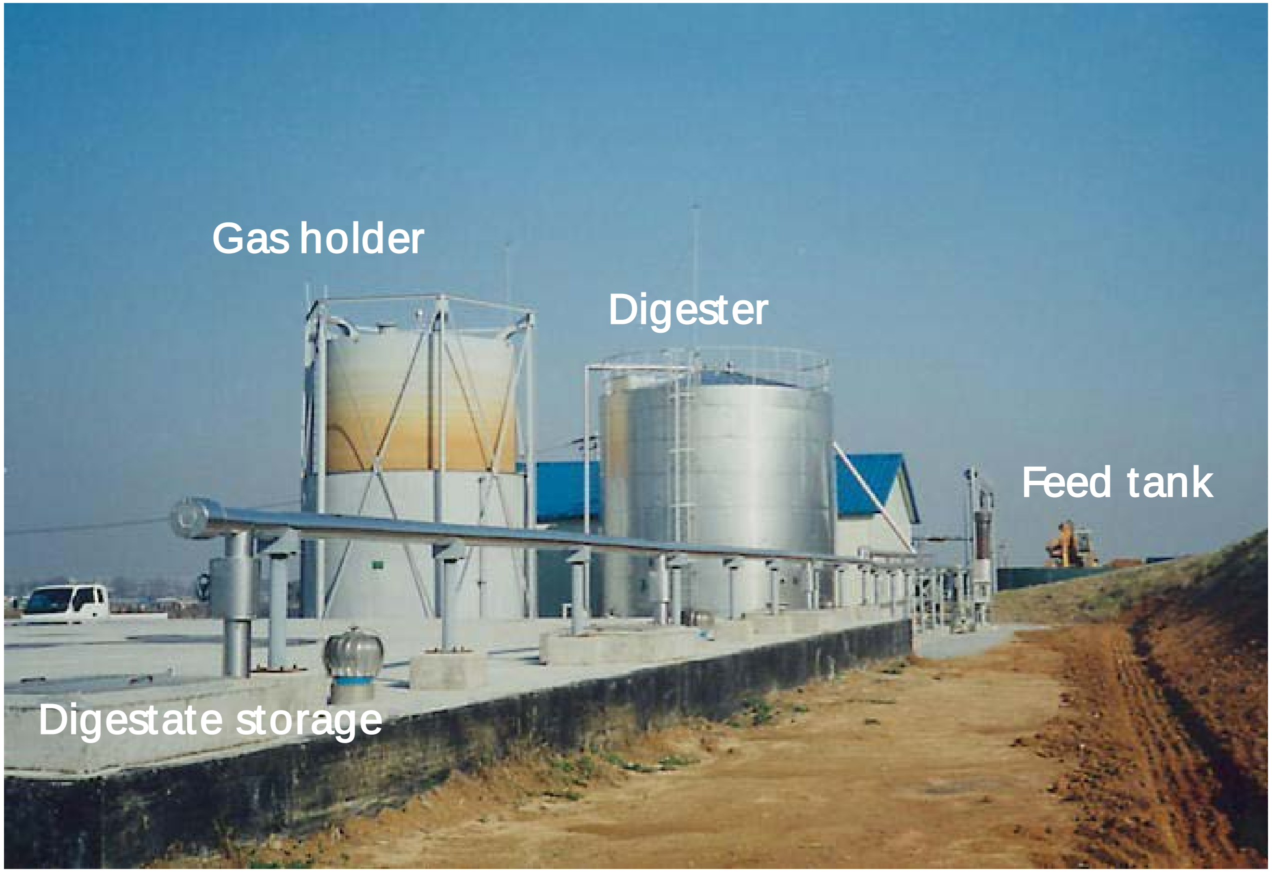
Lessons from biogas plant experiences

For Success of AD Operation

- ✓ Proper Heating
- ✓ Proper Mixing
- ✓ Proper pH
- ✓ Proper SRT

In some cases, mechanical aspect is more important than biological features for the successful operation of biogas plants.

Biogas plant (for swine manure)



- **Feedstock :**
  swine manure
- **run : 1999-2002**
- **Digester Vol. : 200 m^3**
- **AD + CHP(dual-fuel gas engine 37kW)**
- **New Excellent Technology(NET) certified**

Design & Construction: Rural Development Institute / Livestock Research Institute / Kolon Global Corp.

Design Parameters
(for swine manure)

Gas Yield (Biogas m^3/kg VS $_{added}$)	0.4-0.7 (0.47)
CH_4 (%)	60-75 (65)
VS/TS (%)	> 60
TS (%)	4-10 (6)
HRT (day)	15-20
OLR (kg VS/m^3-d)	0.5 – 6.0
Organic reduction rate (%)	50-70 (60)
Temperature(°C)	30-35
Digester type	Flat bottomed CSTR single stage AD
Heating	External heat exchanger
Mixing	Gas mixing + external hydraulic circulation
Biogas use	CHP (Dual-fuel type)
H2S removal	$FeCl_3$
Free ammonia (mg/L)	< 100

Anaerobic Digester Selection

(Mesophilic CSTR digester)

WHY Completely mixed?

- suitable for swine manure having high solids contents
- resistant to toxicant inhibitors (NH_3, disinfectant etc.)
- enhanced substrate-microbe contact

WHY Mesophilic?

- reduced heating requirement for winter season
- reduced ammonia toxicity

Biogas Yield

Mesophilic vs. Thermophilic ?

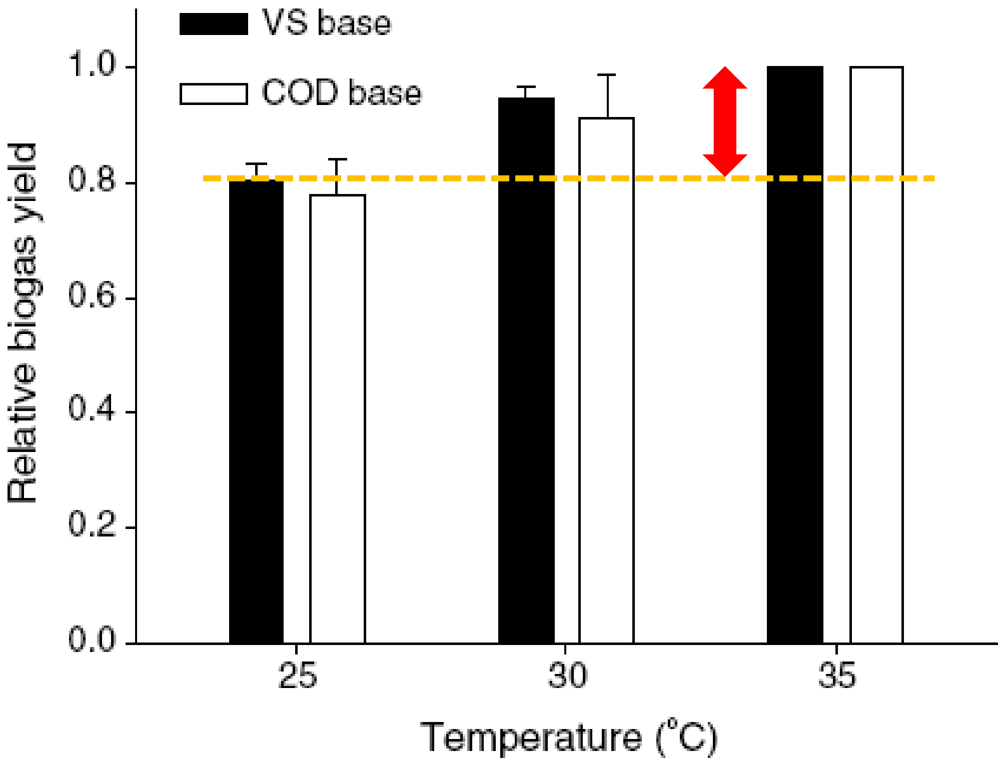


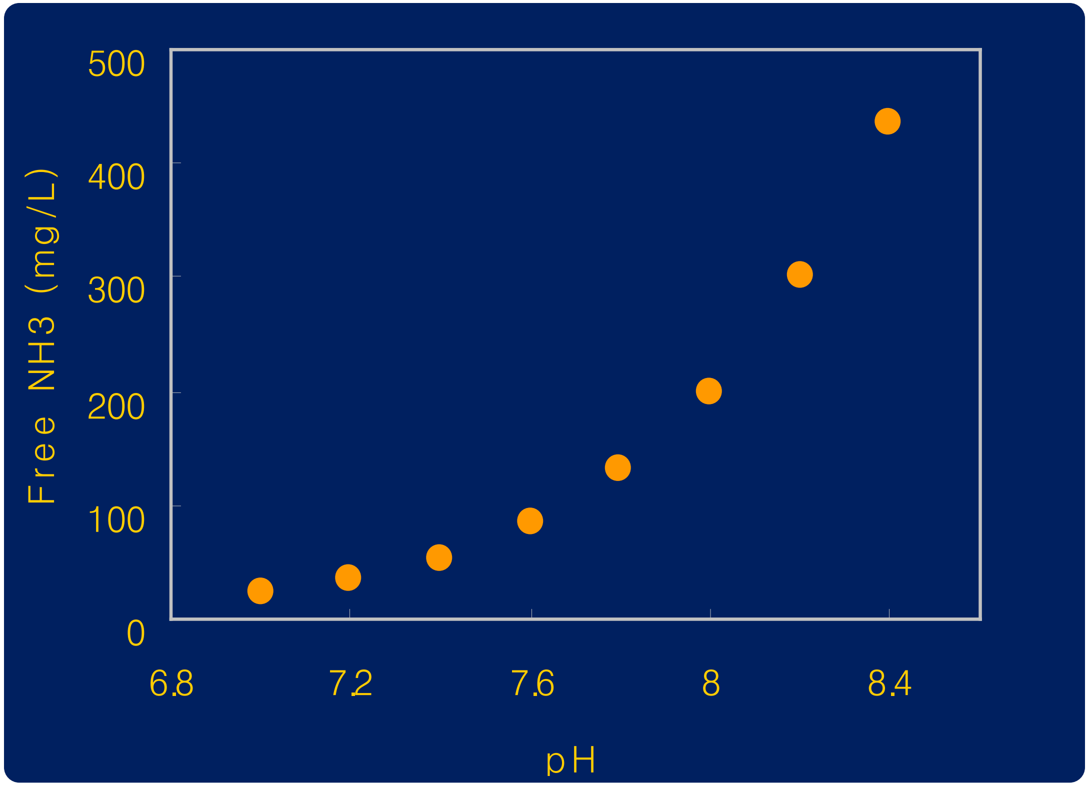
Fig. 3. Relative biogas yields (% of gas production at 35 °C, means of four feed loads) for various digester operating temperatures. The data are expressed as the mean ± SD ($n = 4$).

Chae et al., Biores. Technol., 2007

AD Heating Demand

60%	**Influent(feedstock) heating**
40%	**Compensation for digester heat loss**

Ammonia Inhibition



Free ammonia (NH3) vs pH

@ total ammonia concentration = 2000 mg/L, Temp. = 35 °C

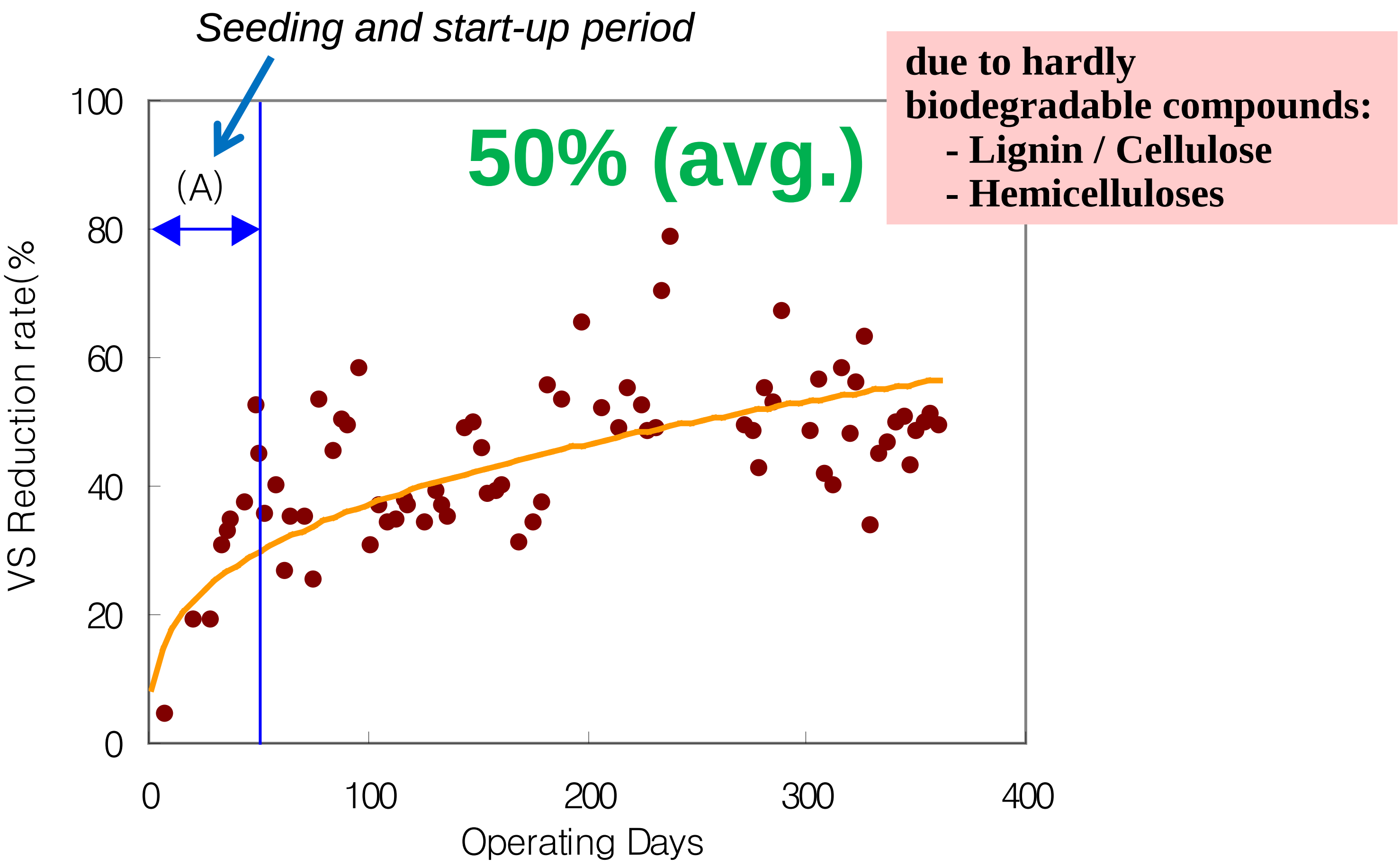
Temp (°C)	Free NH_3 (mg/L)
25	28
30	**39**
35	54
55	**177**

at T- NH_4 = 2000 mg/L, pH = 7.4

T-NH_4	Free NH_3 (mg/L)
1000	27
2000	54
3000	82
4000	109

at Temp. = 35 °C, pH = 7.4

VS reduction



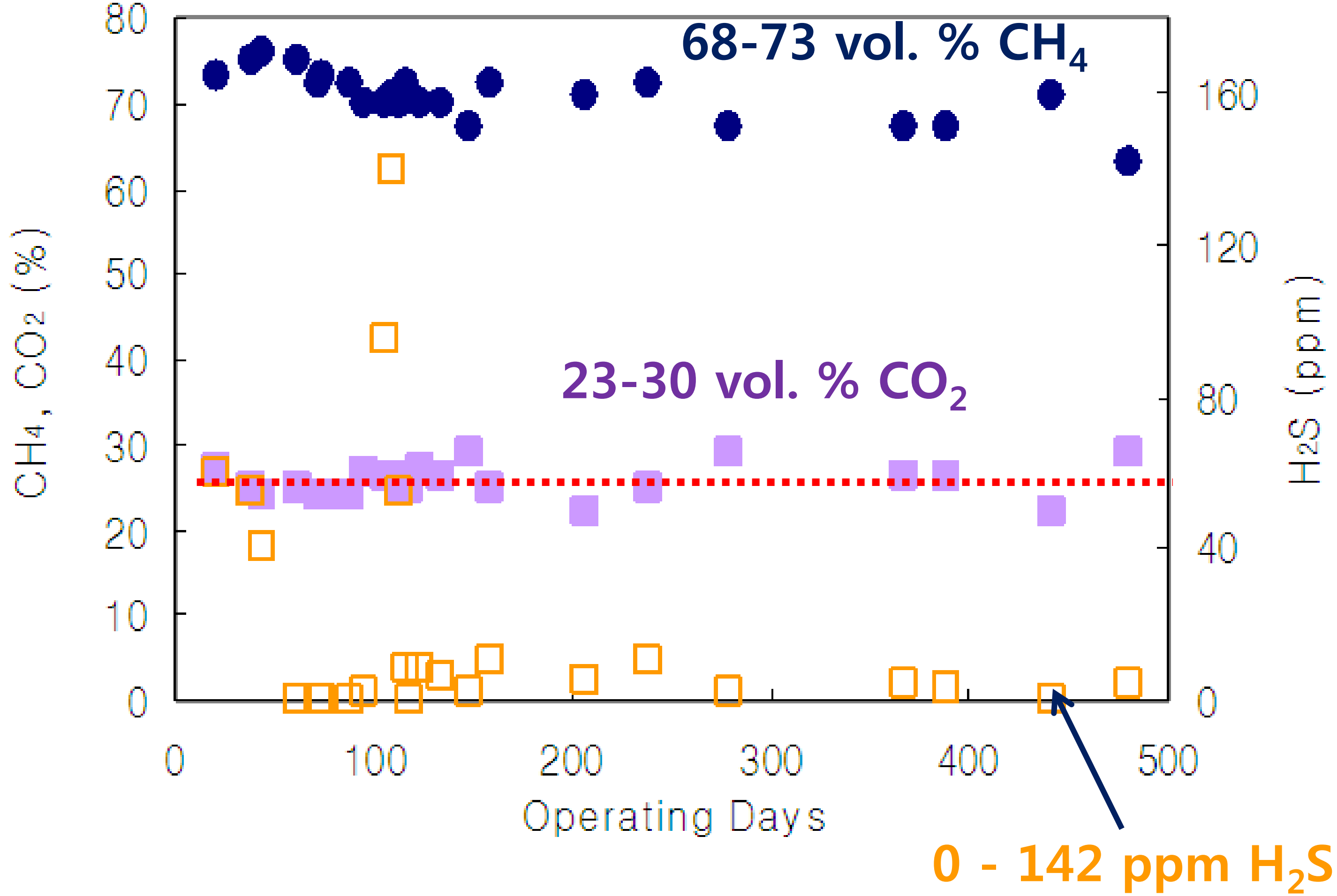
VS reduction of farm scale CSTR Biogas plant digesting swine manure

Characteristics of Influent Pig Slurry and Digester Effluent

Compounds	Raw Pig Slurry	Digester Effluent [a)]
pH	7.15-8.55	6.32-8.54
TS	3,750 – 40,800	750-1,500
VS	2,620-29,115	487-975
COD	4,530-44,800	764-3,740
SCOD	1,750-34,580	580-2,200
TN	500-3,561	-
NH_4^+-N	290-1,250	715-1,500
TP	120-580	-
PO_4^{3-}-P	60.5-480	15-152
Alk. as $CaCO_3$	1,742-7,882	2,966-6,606

All units in mg/L except pH

Biogas Composition



H_2S removal with ferric chloride dose:

$2Fe^{3+} + 3S^{2-} \rightarrow 2FeS + S$

Inconvenient Truth
of Digestate (liquid fertilizer)

In Germany,
All year round utilization

In Korea,
Only spring and fall (2 times)

Temperature Shock Effect

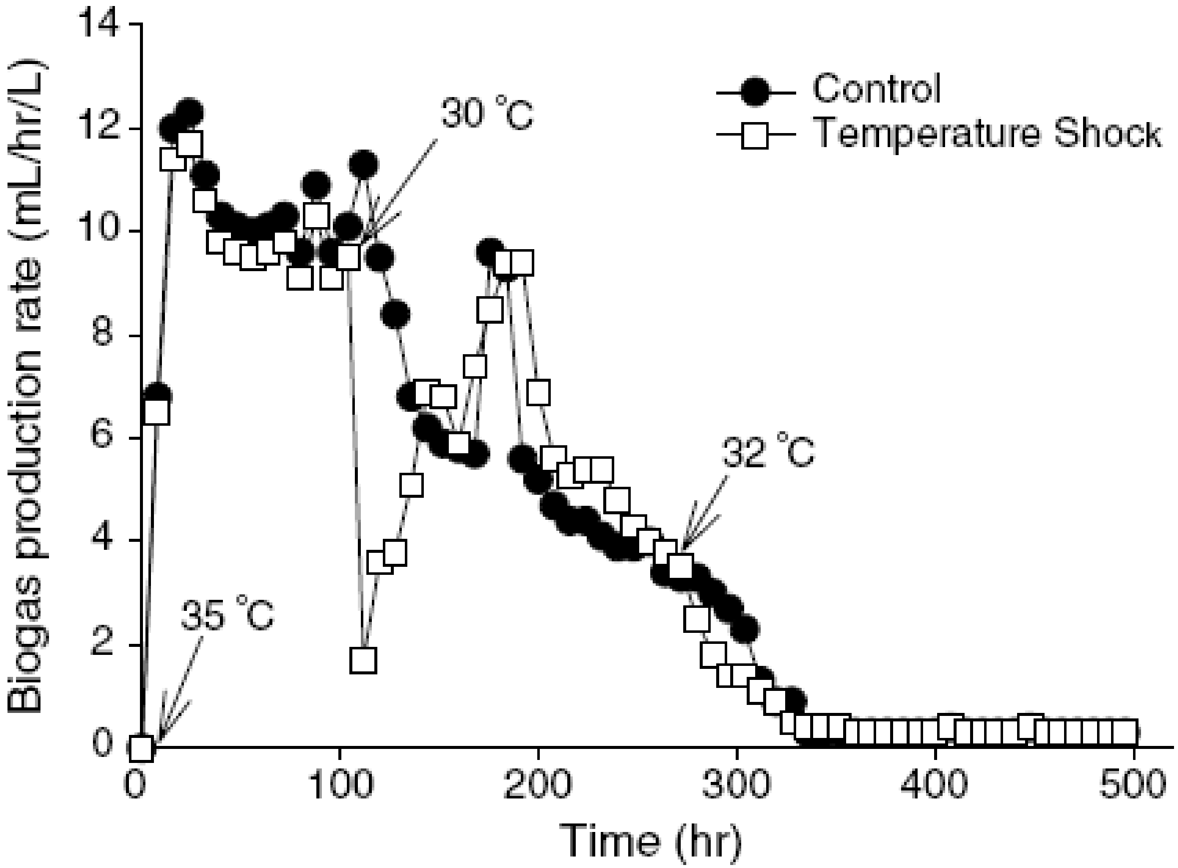


Fig. 5. Influence of temperature shock on the digestion of swine manure at a 20% (v/v) feed load.

Chae et al., Biores. Technol., 2007

Think Differently!!!

(Diverse choice for pipe materials)

(Courtesy Krieg & Fischer GmbH)

What Happen if you do not control struvite?

- Reduce flow capacity, foul pumps, and damage valves
- Occur after point of turbulence or pressure drop

(Courtesy enorca.blogspot.com)

Struvite encrusted roller

Struvite

- **Magnesium ammonium phosphate**

  $MgNH_4PO_4 \cdot 6H2O$
- White, yellowish (or brownish) white in color
- FW = 245.41
- Specific density = 1.7
- Very insoluble in water, pK_{so} = 12.6 – 13.15 at 25°C

$$\mathbf{MgNH_4PO_4.6H_2O \Leftrightarrow Mg^{2+} + NH_4^{+} + PO_4^{3-} + 6H_2O \qquad pK=12.6}$$

Struvite formation occurs when the conditions are such that the concentration product exceeds the struvite conditional solubility product

Struvite Control

Prevent formation by reducing reactant ion(s)

$Mg^{+2} + NH4^{+} + PO4^{-3} + 6\ H2O \rightarrow MgNH4PO4 \bullet 6H2O$

Minimize build-up by eliminating turbulence and/or using smooth pipe materials

Mechanical cleaning:

hydro-jetting / mechanical grinding

BUT Questionable Effectiveness…

Problems with Current Struvite Control Techniques

Reduce PO_4^{3-} with metallic salts

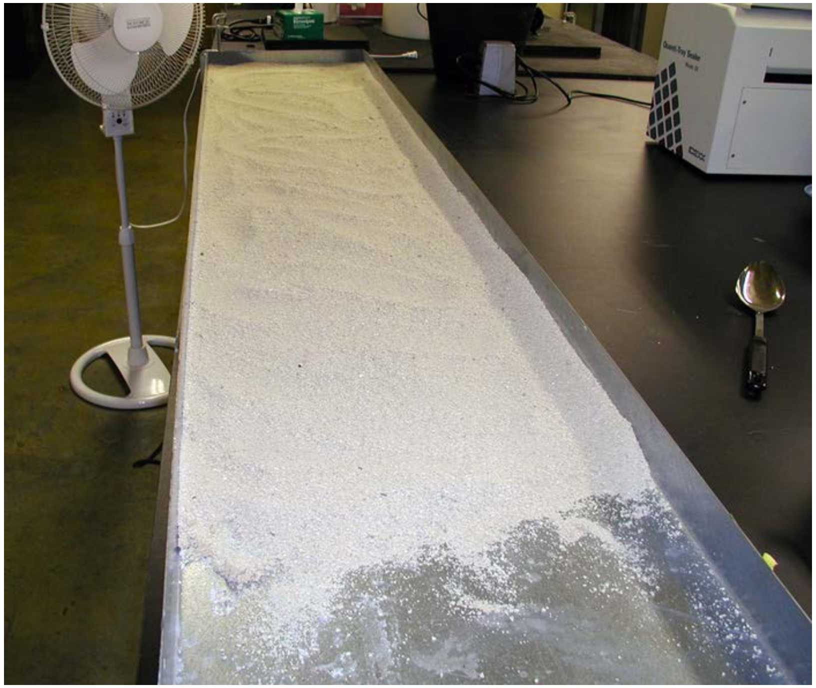
- Ferrous/ferric chloride and alum most common
- Requires large chemical dose to be effective
- Increases inorganic fraction in biosolids
- Increases risk of forming other deposits
  - Ferrous phosphate (vivianite) **$Fe_3(PO_4)_2 \cdot 8H_2O$**
  - Aluminum silicates

➔ Phosphate recovery from ferric phosphate salt(s) is nearly impossible

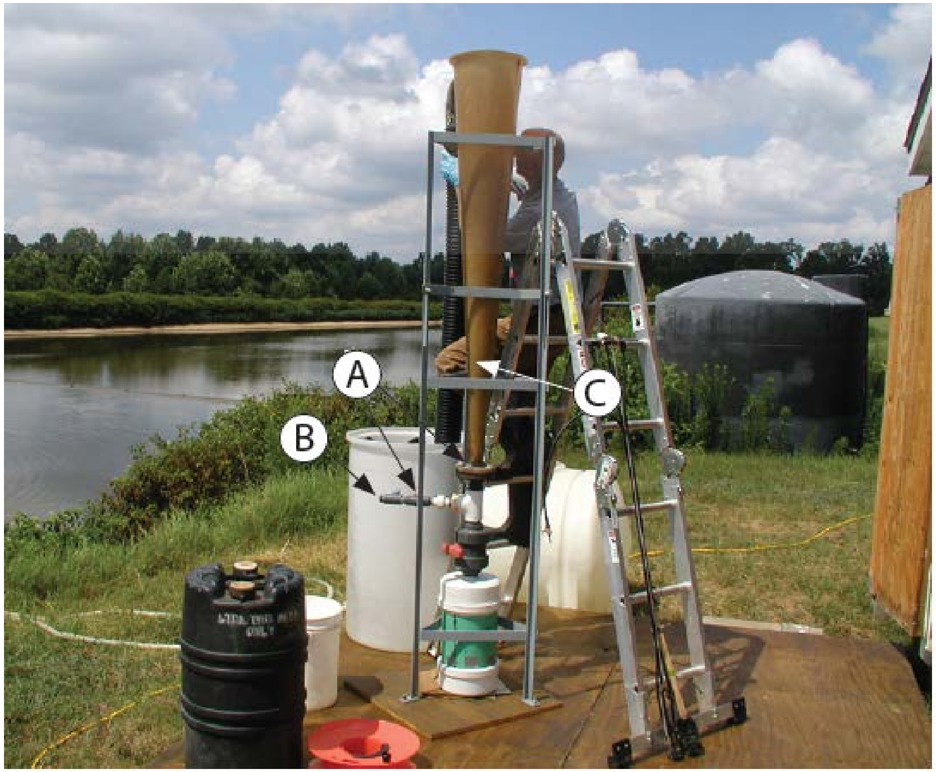
Lower pH with acid

- Large dose required for any significant change
- Increases risk of corrosion
- Requires handling of hazardous material

Struvite:
Slow-release fertilizer



Recovered struvite



gure 1. Stuvite crystallizer used for 1.4 gal/min. flow rate of ·vered digester liquid. A) Add chemicals for Mg and pH in-ease at bottom of crystalizer cone or in inflow line; B) Waste-ater inflow; C) Struvite crystals in bottom of cone

Design & Construction Failures

Overfilling of hydrolysis tank

(source: Krieg & Fischer GmbH)

…until the cover of the hydrolysis tank had been pushed up fluid pressure and blasted from the tank.

Our experience (leakage)

Design & Construction Failures

Y City AD for food waste leachate

Tubular UF membrane for solid separation

Strainer blockage

Explosion & Fire Damage

During start-up explosive methane/oxygen mixture exists.
Operator is not yet experienced with his biogas plant.

Damage during Start-up

Frankfurter Neue Presse

Startseite | Region | Nachrichten | Sport | Ratgeber | Freizeittipps

Rhein-Main/Hessen Frankfurt Vordertaunus Limburg-Lahn Wetterau Main-Taunus Usi

Explosion an der Biogasanlage

Einer der neuen Tanks für den Gärprozess in Ostheim ist gester ... ag in die Luft geflogen

Die Erweite ...

zwei Arbeite ...

Von Jürgen W. Niehof ...

Die Erweiterung der Biogasanlage in Ostheim sollte am 21. Dezember ans Netz gehen. Daraus wird nun wohl nichts. Bei einem Unfall wurden gestern zwei Arbeiter leicht verletzt.

Nidderau. Ein ohrenbetäubender Knall hat gestern um kurz nach 12 Uhr nicht nur die Bewohner von Ostheim hochschrecken lassen. Der Lärm war selbst im Nachbarstadtteil Windecken noch gut zu hören. Grund war die Explosion eines übergroßen Tanks der Biogasanlage am Ortsrand. Deshalb galt für die Feuerwehren aus allen Stadtteilen auch sofort Großalarm. Obwohl der Knall zunächst Böses erahnen ließ, hatten die Feuerwehrleute vor Ort dann doch nicht viel zu tun. Denn als die Einsatzkräfte wenig später eintrafen, brannten nur noch Kunststoffteile auf den Rändern des mächtigen Tanks.

Einer der vier Eigentümer der Ostheimer Biogasanlage, Stefan Bauer, zeigt die Teile, an denen vor der Explosion geschweißt wurde. Dahinter sind die Reste der Dachhülle zu erkennen, die durch die Explosion zerstört wurde. Foto: Jürgen W. Niehoff

Methane explosive limit (%)

Too rich
18~100%

100%

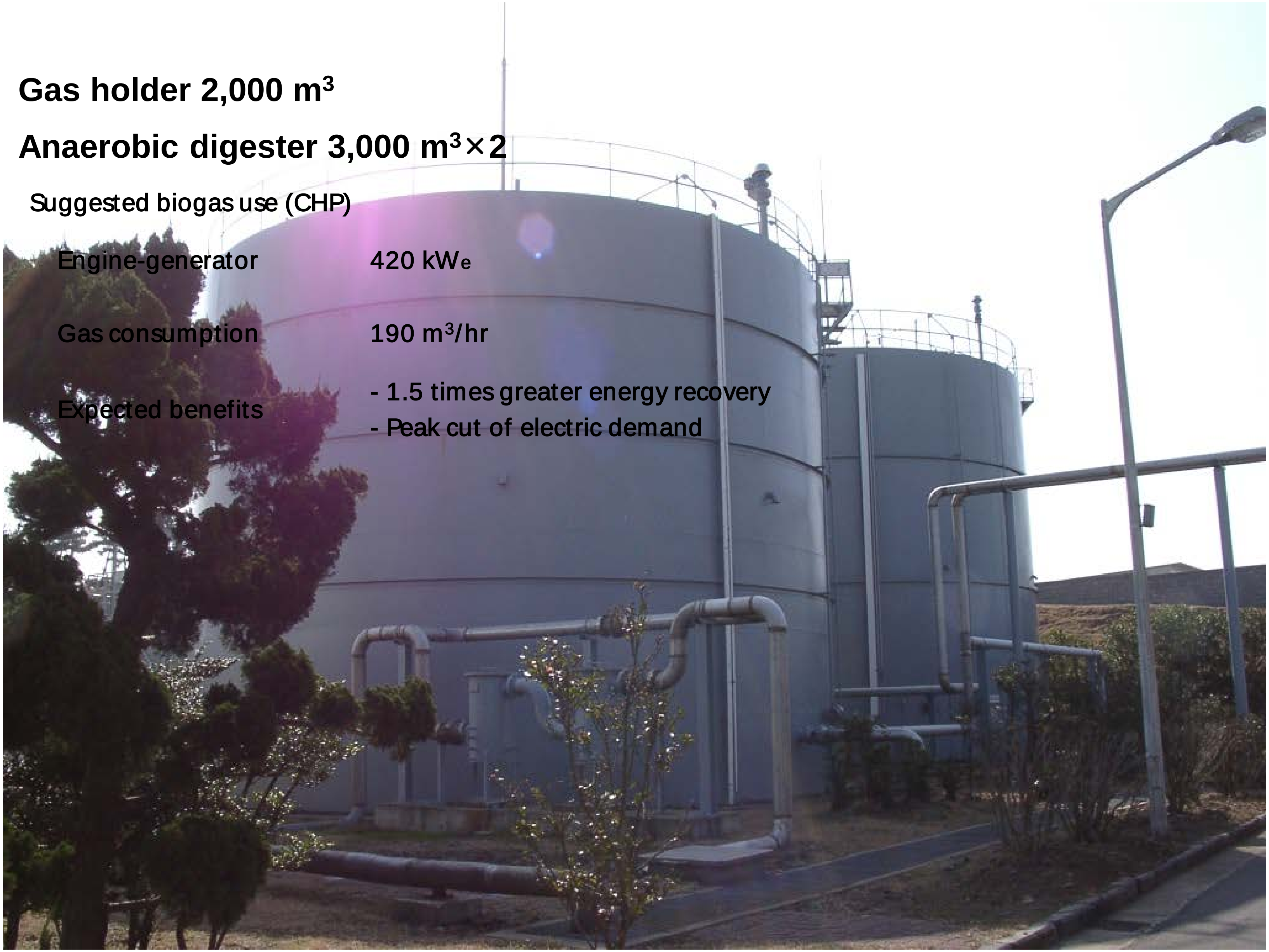
Flammable range:
4.4~17 vol.%

upper explosive limit:15-17%

lower explosive limit: 4.4-5%

Too lean:
< 4.4%

Explosion of J City biogas holder



Gas holder 2,000 m^3

Anaerobic digester 3,000 $m^3 \times 2$

Suggested biogas use (CHP)

Engine-generator	420 kW_e
Gas consumption	190 m^3/hr
Expected benefits	- 1.5 times greater energy recovery - Peak cut of electric demand

Summary:
AD Process for Korea

Feedstock

- Mono-giestion (single feedstock)
- Co-digestion (food waste + farm waste)

Temperature

- Mesophilic (30~40 ºC)
- Thermophilic (50~65 ºC)

Biogas utilization

- Boiler vs. CHP
- Upgrading

Digestion

- Dry (>25% DM)
- Wet (normal)

Plant design / Stage

- Batch
- Continuous (CSTR)
- Single- vs. Multi-stage

3

We need to know

Co-digestion

Anaerobic Co-digestion

Piggery wastewater

- High ammonia concentration
- High pH value (about 8.0)
- Energy depleted waste

Food waste

- High organic strength
- Low pH after hydrolysis and acidogenesis

Co-digestion

- Supplement micronutrients
- Improve buffering capacity
- Reduce ammonia inhibition
- Improve the organic strength

Source: Prof. Chang D.J.

Feedstock Characteristics

Parameter	Food waste			Piggery wastewater		
	Han and Shin (2004)	Zhang et al. (2007)	This study	Ahn et al. (2006)	Hansen et al. (1998, 1999)	This study
pH	--	---	--	6.37 ± 0.10	7.62 ± 0.02	6.64
TS (%)	**20.5**	**30.90 ± 0.07**	**18.1 ± 0.62**	**6.18 ± 0.04**	**--**	**5.95**
VS (%)	**19.5**	**26.35 ±0.14**	**17.1 ± 0.58**	**4.45 ± 0.02**	**4.5 ± 0.1**	**3.89**
VS/TS	0.95	85.30 ± 0.65	0.94± 0.0004	0.72	--	0.65
Total COD (g/L)	--	--	238.5 ± 3.83	130.8 ± 3.0	--	94.2
Soluble COD (g/L)	--	--	106.6 ± 5.28	59.7 ± 0.9	--	54.2
Carbohydrate (g/L)	--	--	151.7 ± 22.2	--	--	--
Lipid (g/L)	--	--	23.3 ± 0.45	20.1 ± 0.1	4.86	2.30
Carbon, C (% of TS)	51.4	46.78 ± 1.15	46.6738	--	--	--
Hydrogen, H (% of TS)	6.1	--	6.3894	--	--	--
Oxygen, O (% of TS)	38.9	--	36.3919	--	--	--
Nitrogen, N (% of TS)	3.5	3.16 ±0.22	3.5392	--	--	--
Sulfur, S (% of TS)	0.1	--	0.3299	--	--	--
TKN (N g/L)	--	--	5.42 ± 0.26	7.3 ± 0.1	6.6	7.6
TP (g/L)	--	--	1.49 ± 0.09	--	--	--
Ammonia-N (g/L)	--	--	--	4.8 ± 0.1	5.3 ± 0.1	4.95
Total protein (g/L)	--	--	--	15.8 ± 0.9	8.13	16.6
Alkalinity ($CaCO_3$ g/L	--	--	--	--	--	--
C/N	14.7	14.6	13.2	6.72	--	4.35

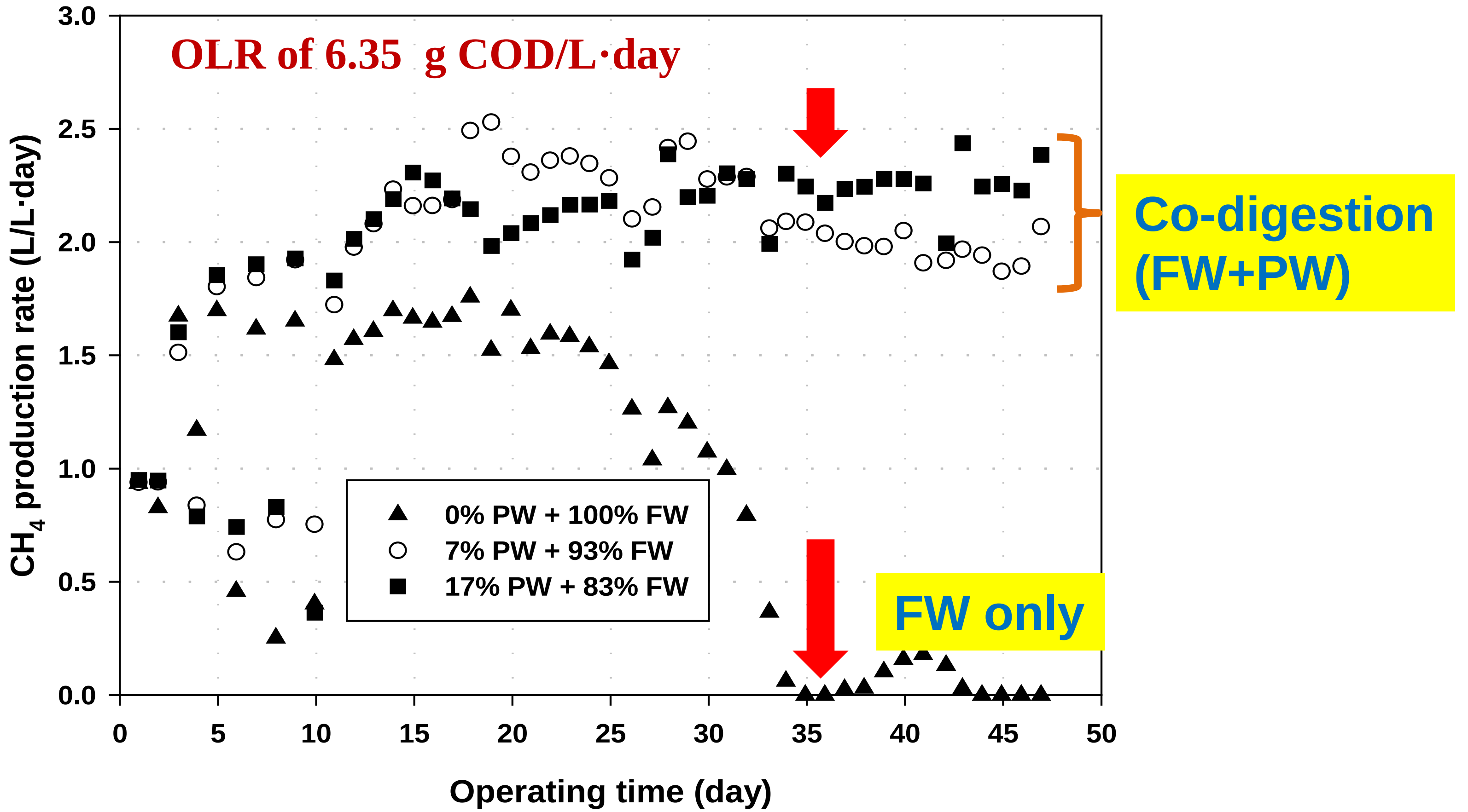
Source: Prof. Chang D.J.

Metal Element Levels in Food Wastes and Piggery Wastewaters

Property (mg/L)	Food waste			Piggery wastewater		
	Zhu et al. (2008)	Zhang et al. (2007)	This study	Moral et al. (2008)	Creamer et al. (2010)	This study
Sodium (Na)	143 mg/L	--	3547.65	900 ± 520	155	606.65
Magnesium (Mg)	12.5	453±32	144.92	144.92	551	672.15
Aluminium (Al)	--	1202±396	10.01	--	--	41.28
Potassium (K)	160	2913±356	3389	--	501	3956.82
Calcium (Ca)	38	2160±290	274.20	--	--	1775.03
Chromium (Cr)	--	3±1	0.403	1.10 ± 1.15	--	0.169
Manganese (Mn)	0.12	60±30	2.2294	25 ± 32	45.1	24.9328
Iron (Fe)	**1.35**	**766±402**	**7.36**	**127 ± 160**	**177.6**	**98.91**
Cobalt (Co)	**--**	**--**	**nd**	**0.14 ± 0.16**	**--**	**0.1188**
Nickel (Ni)	**--**	**2±1**	**0.4417**	**0.94 ± 0.94**	**0.6**	**0.4542**
Copper (Cu)	0.17	31±1	7.0927	42 ± 51	13.7	39.1763
Zinc (Zn)	0.36	76±22	19.1965	172 ± 176	133.2	154.5396
Molybdenum(Mo)	**0.01**	**--**	**0.0585**	**--**	**--**	**0.418.7**
Cadmium (Cd)	--	<1	0.0531	0.10 ± 0.09	0.1	0.0142
Lead (Pb)	--	4±3	0.4073	0.65 ± 0.55	--	0.3348

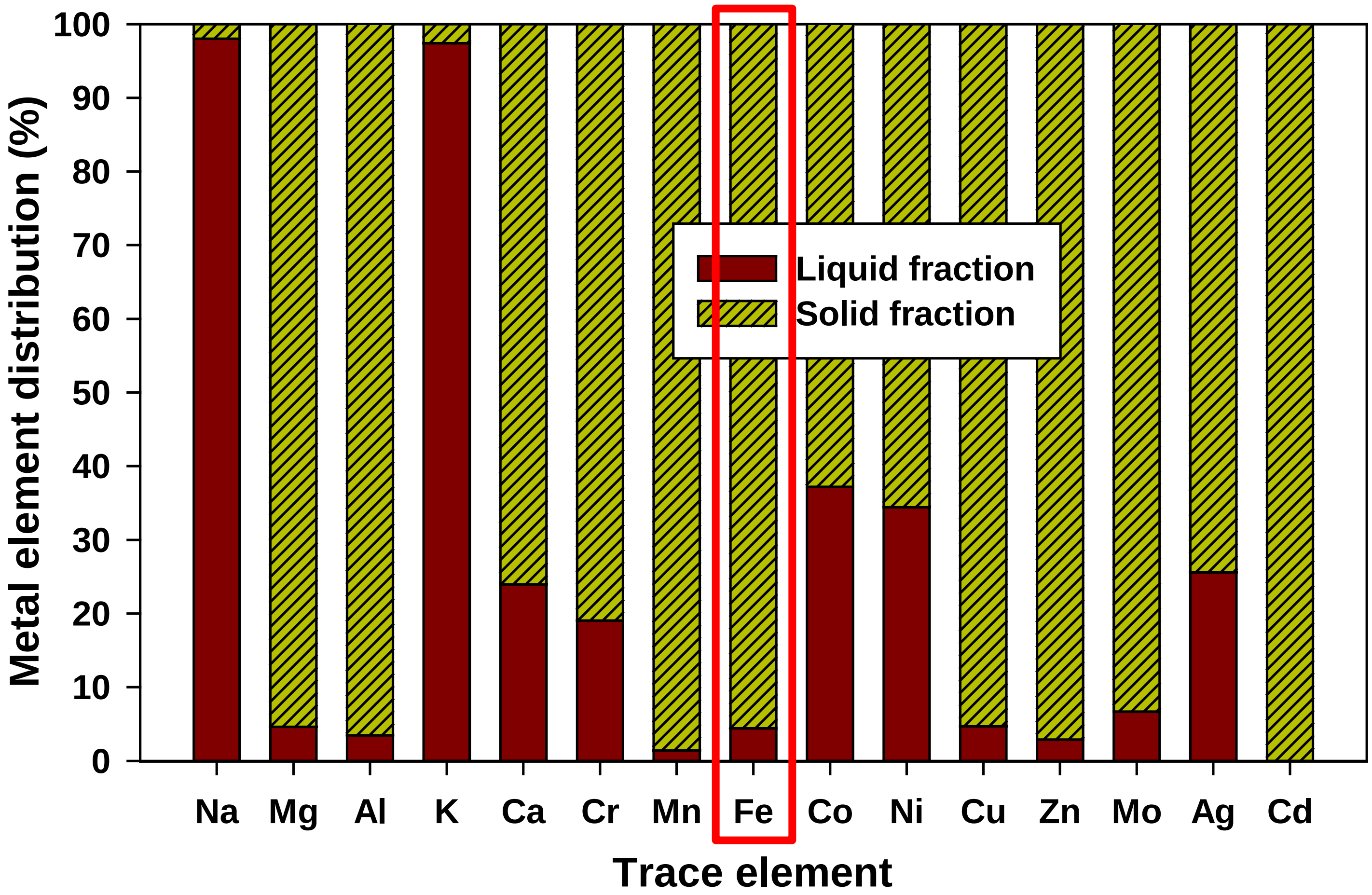
Source: Prof. Chang D.J.

Anaerobic Co-digestion of Food Waste and Piggery Wastewater



- The addition of piggery wastewater increased the stability of anaerobic digestion of food waste.
- Some substances from piggery wastewater help the process performance.

Metal Elements Distribution in Solid Fraction and Liquid Fraction of Piggery Wastewater



It's highly possible that trace elements in the solid fraction contributed the enhanced anaerobic digestion of food waste

Thanks to
Mr. Torsten Fischer

for sharing his valuable knowledge and materials.
Krieg & Fischer Ingenieure GmbH

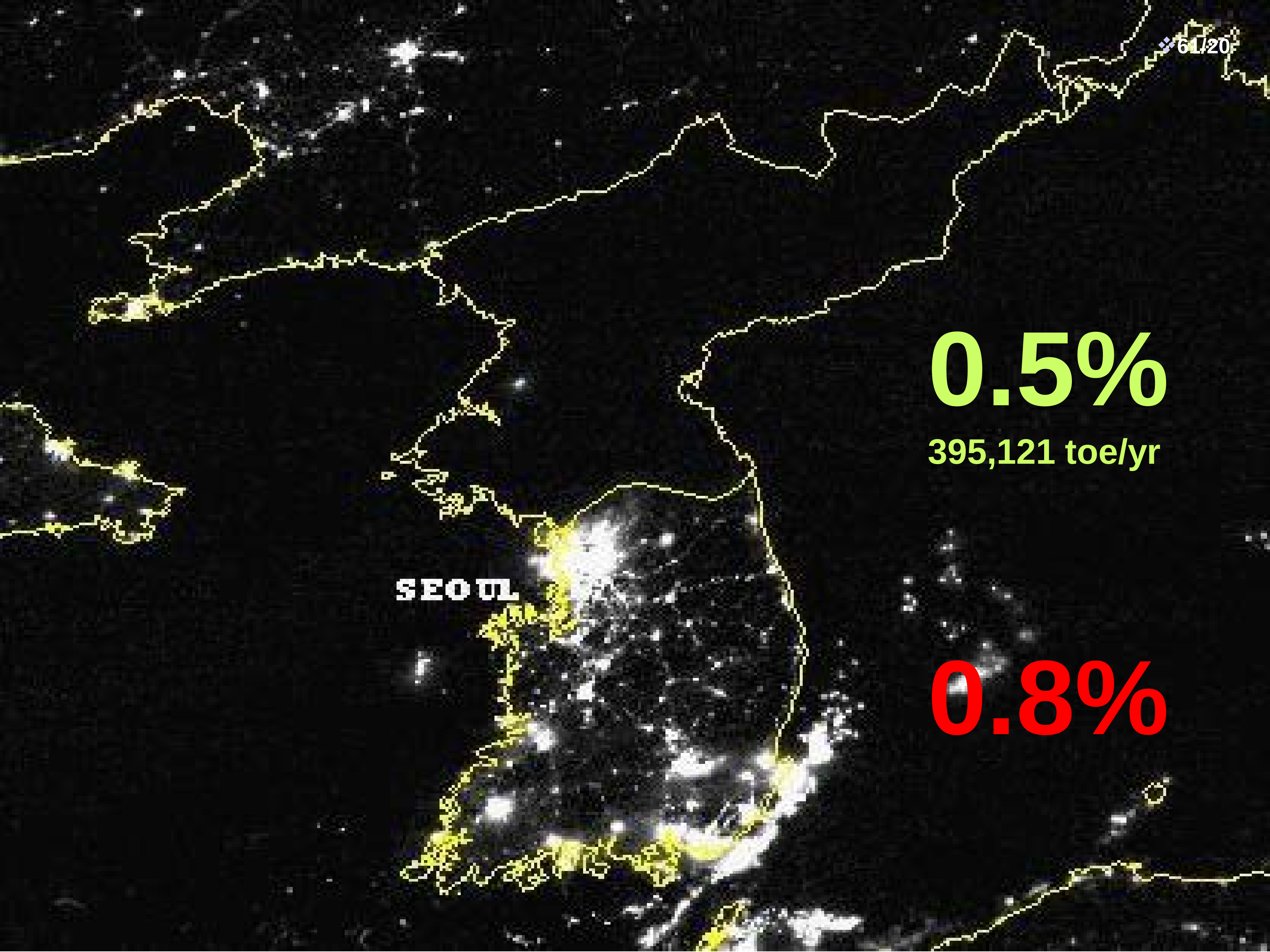
Thanks to
Prof. Chang D.J. (MyoungJi Univ.)

for sharing his valuable materials for co-digestion.

4

For energy self-sufficiency of WWTPs

Renewable Energy Technologies


0.5%
395,121 toe/yr
SEOUL
0.8%

Energy Self-sufficiency

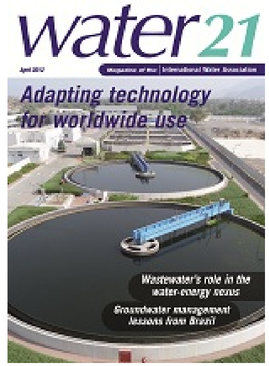
ENERGY SAVINGS 10-20% (fine bubble controlled aeration, energy efficient motors and pumps)	RENEWABLE ENERGIES 5-10% (wind power, photovoltaic, solar thermal power, geothermal power)
ENERGIES FROM SEWAGE FLOWS 2 – 10% (hydro-turbines, heat pumps, in-sewer heat exchangers)	SLUDGES 40 → 60-80% (anaerobic sludge digestion, pre-treatment to increase digestability)

HOW?

Figure 6: Major components of the 'positive energy plant' – zones where the energy efficiency of wastewater treatment can be improved.

Concluding remarks

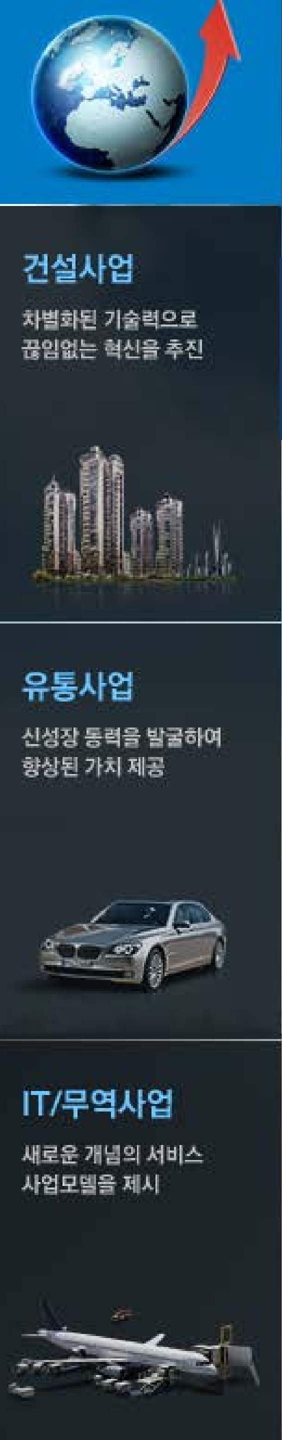
The current configuration of urban water management systems means that significant quantities of water and energy are consumed and nutrients are inefficiently managed. Historically, water and energy have been managed independently, but in the City of the Future the whole water cycle should



Water21, April 2012, p16, Lazarova, Choo, and Cornel

You will see more details

during the field trip next class...



KOLON GLOBAL

Thank you very much!

ckj@kolon.com

Status of organic waste to energy technologies

2013. 10. 28

DOHWA Engineering Co., LTD.

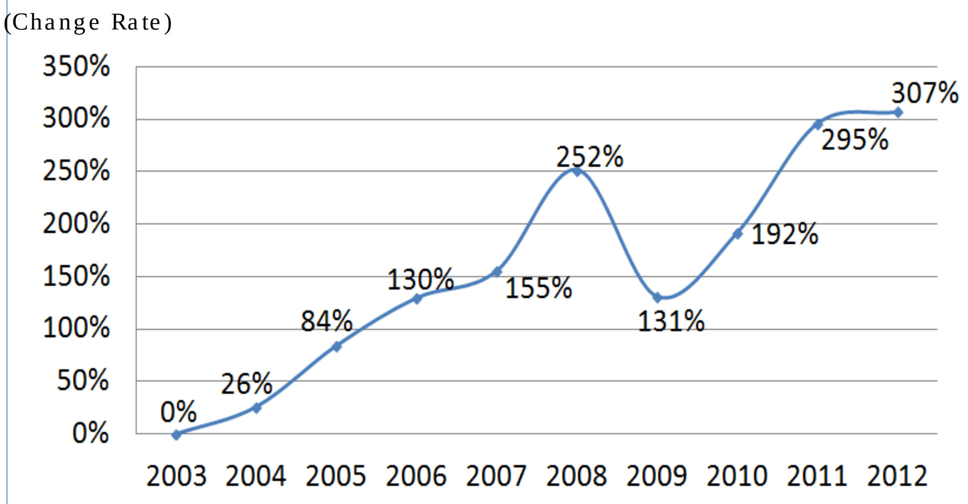
Contents

1. Policy and Trend of Renewable Energy

DOHWA
Dohwa Consulting Engineers Co.,LTD.

Background of Renewable Energy

Annual change in oil prices



International oil price rapidly increase recently 3 years

Year	Cost ($/bbl)
2003	26.80
2004	33.77
2005	49.37
2006	61.55
2007	68.43
2008	94.29
2009	61.92
2010	78.13
2011	105.98
2012	109.03

- International oil price is 107.93 $/bbl(2013. 09)
- 10th largest energy consumer of the world ⇨ relies on imports for 97%

EU	The goal of renewable energy supply in 2020 is 20 % of total energy 34 % of generation , 10 % of transportation fuel
Japan	The goal of renewable energy supply in 2020 is 20 % of total energy (MOE, ' 10.1) (Reopen to give solar energy subsidy(' 09.1) Mandatory for purchase remain solar energy (' 09.11)
USA	Provide renewable energy which is 25% of eletric power in 2025 (Announcement of Obama Government)
China	The goal of renewable energy supply in 2020 is 15% of Primary Energy (300GW of Water, 30GW of Wind, 1.8GW of Solar, 30GW of Biomass) Develop and supply plan of Wind, solar, water etc.
Germany	The gold of renewable energy supply in 2020 is 18% of Final Energy (30% of generation amount)

Div.	USA	Japan	Germany	Denmark	UK	Korea
Supply rate('07)	5.0%	3.4%	8.6%	18.1%	2.4%	2.4%
Goal	10.9%('30)	20%('20)	18%('20)	30%('20)	15%('20)	11%('30)

Data : Energy Balance of OECD Countries('09), IEA

Set the goal of renewable energy supply and under continuous efforts

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R&D Strategy of Major Advance Countries

" Establish New Growth Power Driving Strategy through Innovational Energy Technology"

America

- American Recovery and Reinvestment Act('09.2)

  26 billion dollars of budget for ARPA- E

*470% of Budget of DOE is increased compare to 2008

Japan

- New National Energy Strategy ('06.5)
  Improve 30% of energy efficiency, and achieve 40% of oil development by 2030
- Announcement of Cool Earth ('08.4)
  Announced 21 Innovation technology

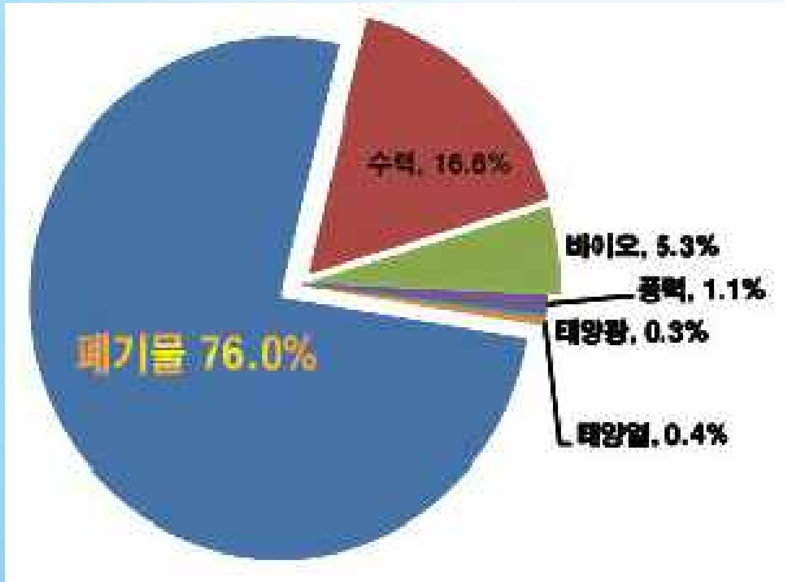
E U

- An Energy Policy for Europe('07.1)
  Improve energy efficiency
- SET Plan('07. 11)
  Long term plan for clean energy society based on low carbon technology

Focus the capability Nation securing energy technology to prepare climate changes and dominating the global market

Policy of Renewable Energy in Domestic

<Composition of Renewable Energy>



- Renewable energy using Bio is 5.3% of total energy
- Plan to increase rate of bio- energy up to 30% by 2030
- Production cost of bio energy among national renewable energy is similar with 10% of solar and 70% of wind

(단위 : Won/ kwh)

Div.	Solar	Wind	Water	Waste	Bio
Unit cost of production	716	107	70	71	75

Establish goal plan in supply structure of Bio- Energy among renewable energy

Policy Change of Organic Waste in Domestic

Past

No separate organic waste

Landfill treatment

Organic waste landfill

Leachate degenerate

Permit sea disposal

Sea Enviornent Pollution

Ban on Sea disposal of sludge in 2012

London Dumping Convention

ban on sea disposal of leachate in 2013

Present

Revised plan for total management of 2nd national waste (2007. 7, MOE)

- Expend organic waste re- utilize facility
- Diversify organic waste treatment technology facility

Total plan for waste to energy(2008. 5, MOE)

- Organize legislation for promoting waste energization
- Divide country into 4 areas to build energy town

Green growth plan in environment industry(2009. 1, MOE)

- Propel organic waste to bio – gas
- Provide gas and generation using bio- gas

Plan of wasted resource and biomass to energy (2009. 7, MOE)

- Manage climate changes
- Secure new growth power through technology development

Change in paradigm for management policy of making resource recirculation society

2. Treatment Technology of Organic Waste

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Treatment Technology of Organic Waste in Domestic

Feeds	Installation cost is cheap but expensive production cost , odor from dehydration process and difficult to look for source of fodder demand
Compost	Many facilities are already installed because of easy access, but low additional value of by- product and need a wide area
Combine to sewage treatment	Low installation cost because of using the existing sewage plant, but low operation result and need high- level treatment process

"Waste to Energy"
National policy change

Anaerobic Energization	Low odor and possible to be energization by manufacturing bio- gas Low operation cost , preparing for climate changes and suitable for low carbons policy

Change into Anaerobic energization is coincide with government policy

3. Characteristic of Organic Waste

Characteristic of Organic Waste in Domestic

Organic waste

Div.	Moisture (%)	TS (%)	VS (%)	VS/TS (%)
K city	82.35	17.65	14.33	81.19
D city	83.49	16.51	14.29	86.55
I city	76.26	23.77	17.45	73.41
Literature	74 ~ 85	15 ~ 26	13 ~ 19	73 ~ 86

Organic waste leachate

Div.	BOD (mg/L)	COD (mg/L)	SS (mg/L)	T-N (mg/L)	T-P (mg/L)
K city	97,856	138,417	68,042	8,289	672
I city	83,617	141,393	42,653	3,246	498
Literature	61,097 ~ 82,501	136,570 ~ 160,146	16,385 ~ 50,984	2,527 ~ 2,835	226 ~ 656

Data : K city, D city, I city, basic design report,
literature : feasibility study of biogas development using organic waste, 2008, SLC

Moisture and VS rate is high, High concentration leachate is generated

Characterization of Organic Waste in Domestic

Moisture

- Eating habit, High moisture
- Odor generation because high moisture content

Organic matter

- Fast hydrolysis and acidification of organic matter
- High biodegradability (removal rate of VS : over 80%)

Appropriate Treatment of Organic waste!!

Physical composition

- High load by deviation per days and months
- Need to pretreatment facility by foreign material

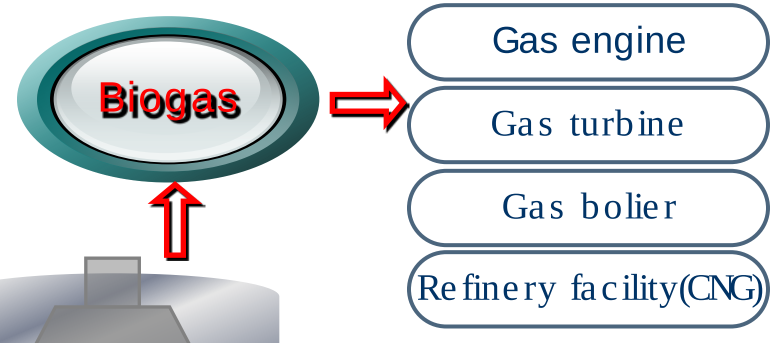
Salt concentration

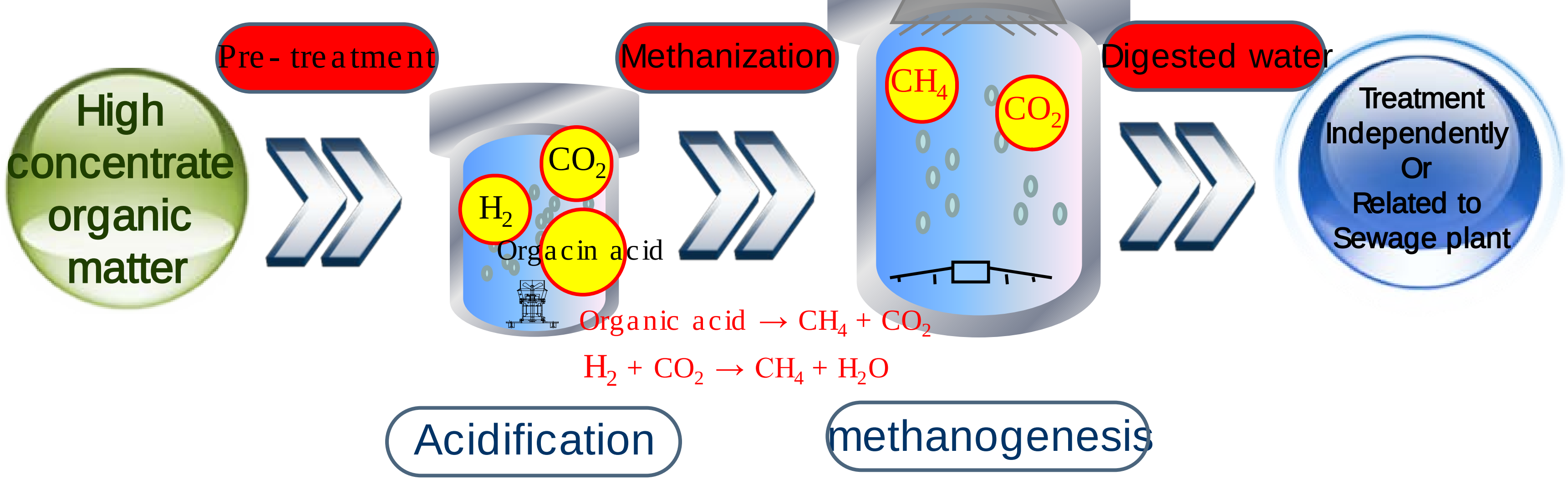
- Consistant amount of salinity
- Low Influence to process

Need high efficiency energization facility

Concept of anaerobic digestion technology

- Biogas generation : 50～120m³/ton
- Biogas generation of leachate : 80m³/ton
- Biogas generation of livestock : 20m³/ton





Biogas is generated by anaerobic digestion process

Input & Pre- Treatment Process

Organic waste import

Organic waste storage

Crushing, Seperating

Hydration(wet)

Dehydration(dry)

Anaerobic digestor

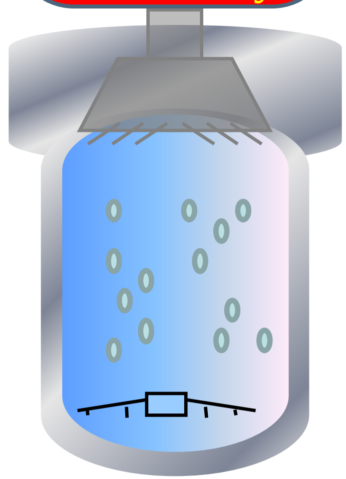
Process for micro- organism to be easy to use

Anaerobic Digestion Process Types

Input method
SBR (sequencing batch reactor)
CFR (continuous flow reactor)

Digestion
Single Tank
Double Tank

HRT : 20- 30days



Anaerobic digestor

SS(mg/l)
Wet digestion : less than 10%
Dry digestion: more than 20%

Temp. in tank
Middle : 35℃
High : 55℃

Select Anaerobic digestion process according to operation condition

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Operating Condition of Anaerobic Digestor

Div.	Condition	Remarks
Temp.	middle: 30~ 40℃ high: 50~ 60℃	Additional heating cost of reactor when temperature increases
HRT	15~ 30 days	CSTR process
pH	Near 7.0	Optimal condition of methanogen
ORP	Less than - 300 mV	Organic carbon’s reduction condition
Removal rate of VS	70~ 85%	Differences depend on characteristics of organic waste
Removal rate of COD	40~ 95%	Big differences depend on characteristics of organic waste

Basic conditions to maintain high activity of Anaerobic micro- organism

Biogas Utilization Process

Desulfurization

Dehumidification

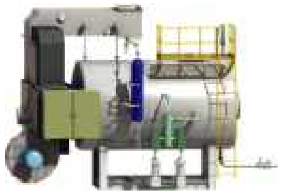
Gas storage tank

Refine

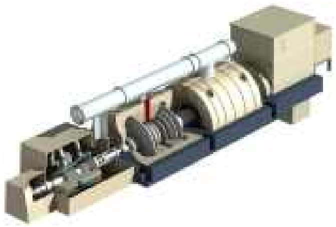
Remove siloxane

Fuel of Vehicle

Gas boiler



Generation of gas turbine

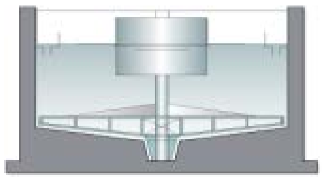


Generated biogas can be utilized to various energy sources

Waste water treatment process

Storage tank

Flocculation tank



Physical treatment
(floatation,precipitation)

Dehydration of sludge

Combine sewage treat.

Discharge

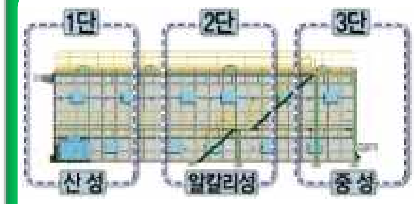
Digested waste water are treated independently or ties to sewage plant

Odor Treatment Process

High Concentration (Input area)

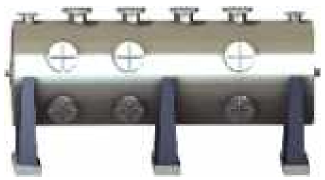
Burnning

Chemical treatment

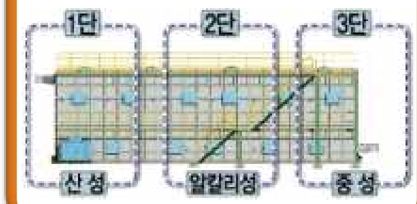


Low Concentration (Rooms)

Bio fillter



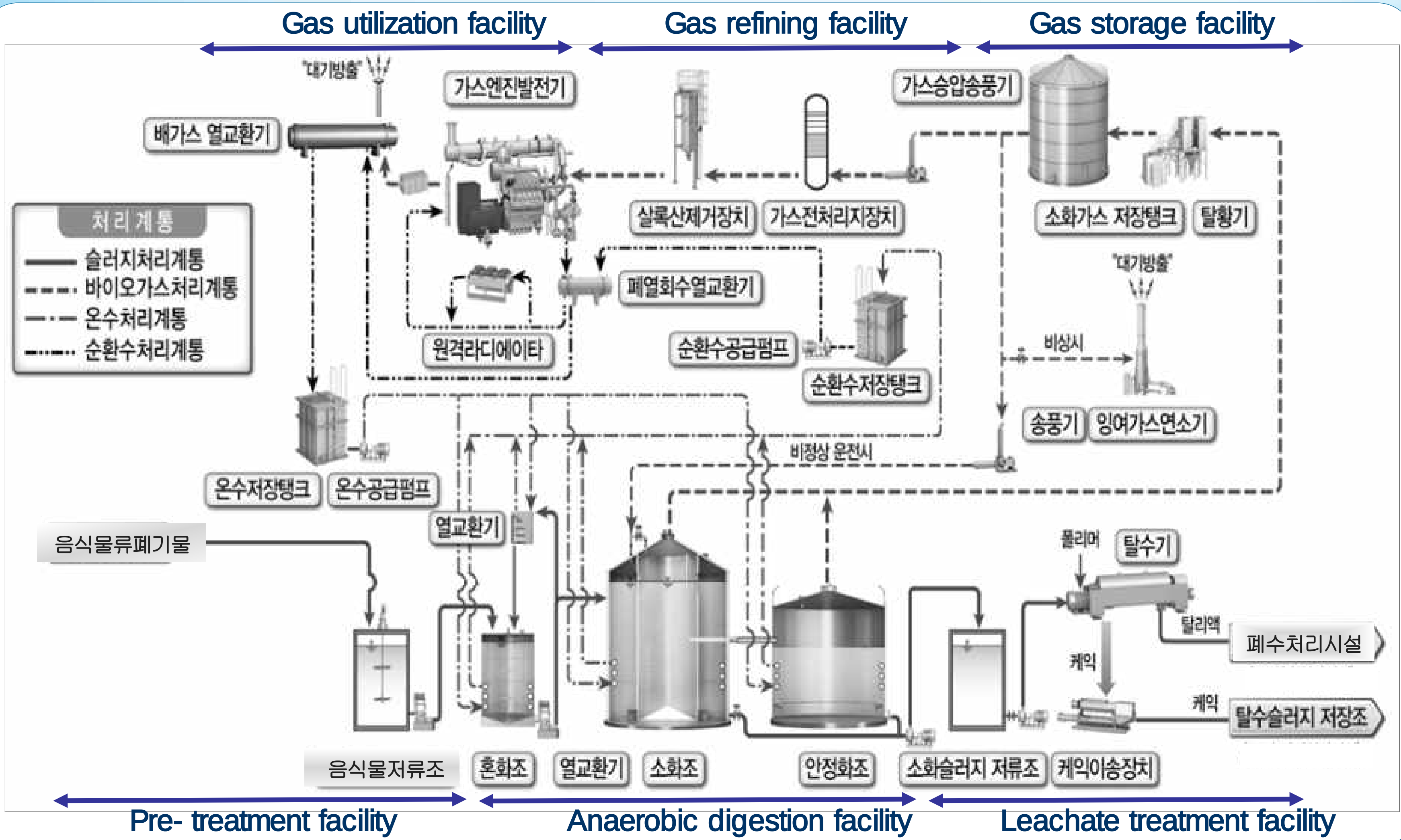
Chemical treatment



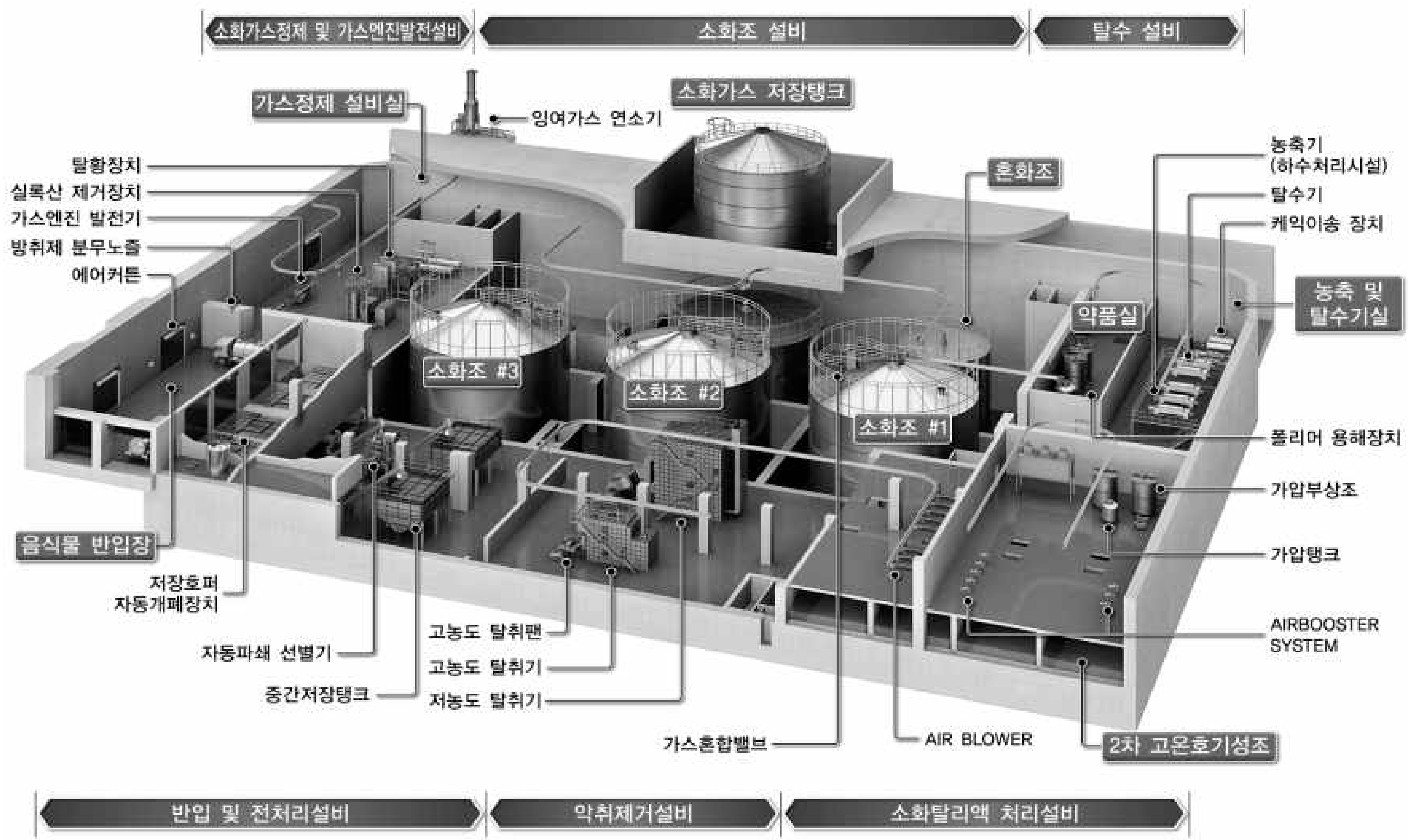
Removal odor by separating high and low concentration

5. Example of Organic waste to energy in domestic

Process diagram



Case of underground(P city- Private investment business)



Introduction Techniques of Domestic

Div.	Dae-woo	Seo-hee	Hallasanup	Ecoday
Technology	Own technology	OWS(Belgium)	OWS(Belgium)	Own technology
Name	DASB	Dranco Process	Double wet middle temp. digestor	E.PFR-2 SYSTM
Waste	Leachate, livestock waste water	Organic waste	Organic waste, livestock waste water	Organic waste, Leachate
Process	Double wet	Single dry	Double wet	Double wet
Temp.	middle(35~ 40℃)	high(55± 2℃)/ middle(35± 2℃)	middle(within 35℃)	middle(within 35℃)
Time	25 ~ 30 days	Within 30 days	(1^{st} 3 ~ 5days, 2^{nd} 15 ~ 20days)	Within 15 days
CH_4	Within 60%	60 ~ 70%	60 ~ 75%	Within 75%
Character of process	No-power stirring by gas pressure	No hydrolysis process	pH control by returned discharge water	High load, Fast treatment
Result	•Nambu waste treatment 1,700㎥(leachate) •Asan(100 ton/day)	•Busan(200 ton/day) •Dongdaemun(98 ton/d)	•Paju(30 ton/day) •milyang(20 ton/day) •Sokcho(20 ton/day)	•Paju(30 ton/day)

Introduction Techniques of Overseas

Div.		ARROWBIO	BTA	OWS	HESE
Technology		Own technology	Own technology	Own technology	Own technology
Name		Double wet anaerobic	Single and double wet anaerobic	DRANCO Process	Double wet anaerobic digestion
Waste		Organic Waste	Organic waste, livestock waste, sludge	Organic waste	Organic waste, livestock waste
	Method	Double wet	Single dry, double wet	Single dry, double wet	Double wet
	Temp.	middle(35~ 40℃)	middle(35~ 40℃)	high(50~ 65℃)	middle(within 35℃)
	Time	HRT : 1 ~ 3days SRT : 80 ~ 90days	Single : 14 ~ 16days Double : 5 ~ 7days	15 ~ 30days	19days
	CH_4	81%	65 ~ 75%	50 ~ 60%	Within 60%
Characteristic of process		UASB	No- power stirring by gas pressure	Directly supply steam to reactor	Maintain Aerobic at hydrolysis
Performance		•Tel Aviv, Israel(100 Ton/day)	•Kirchstockach, Germany(20,000 Ton/yr) etc.	•Rome, Italy (40,000Ton/yr) •Leonberg, Germany (30,000 Ton/yr) etc.	•Leicestershire, UK (40,000 Ton/yr) etc.

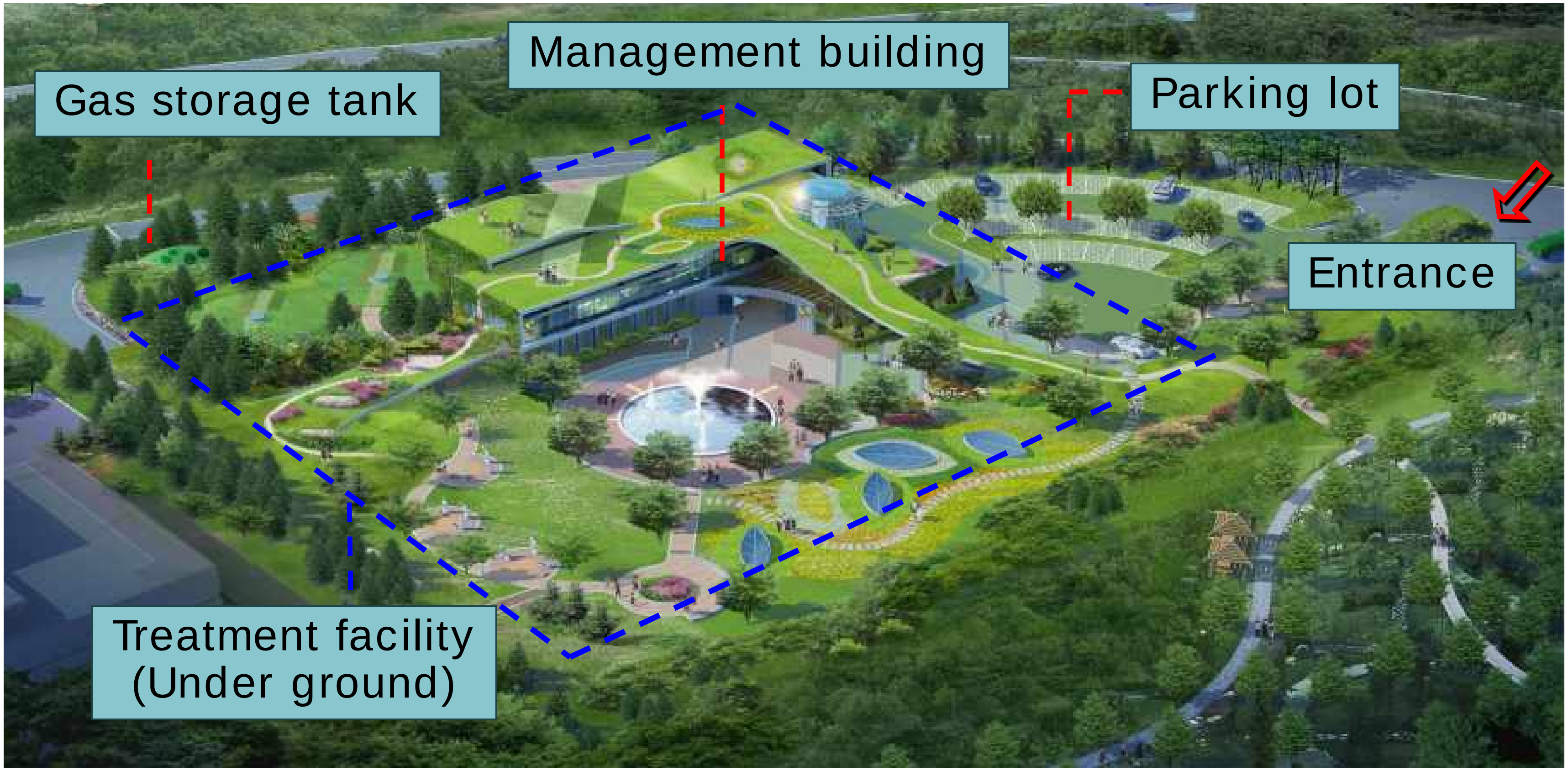
Cases of Organic Waste to Biogas in Domestic

Div.	Gwangju	SLC	Dongdaemun gu
Picture			
Capacity (Ton/day)	150	1,300	98
Completion	2007. 02	2008. 04	2010. 10
Treatment	Leachate	Leachate	Organic waste
Utilization of biogas	Heat reactor	Heat reactor and air conditioning and heating	Electronic and steam generation for onsite
Anaerobic Process	Wet high temp.	Wet double phase	Dry single phase
Remarks	Anaerobic digestion of organic waste leachate	Largest in national of anaerobic digestor	Undergrounding and Making park

Project Plan of Organic Waste to Biogas

Local Government	Treatment	Period (year)	Capacity (T/d)	Case of underground
Sokcho	Organic waste	09-10	40	-
Daegu	Organic waste	09-12	300	Treatment facility(underground), Park(ground)
Goyang	Organic waste	09-12	260	Treatment facility(underground), Park(ground)
Kimhae	Leachate	09-12	100	-
Jinju	Leachate	10-11	150	-
Unpyoung	Organic waste	10-12	100	Treatment facility(underground), Park(ground)
Gwangju	Leachate	10-12	300	Treatment facility(underground), Park(ground)
Ulsan	Leachate, Livestock	10-12	150	-
Chungju	Leachate	10-12	200	-

Case of Changing Facility into Park(K city- 300 Ton/ day, Detail design)



Possible to make the park being designed with efficiency and environment friendly

Case of Changing Facility into Park
(P city- 200 ton/ day, on going private investment business)

Thank you

Waste to Energy

Status of Biomass Fired Power plant

2013. 11. 4

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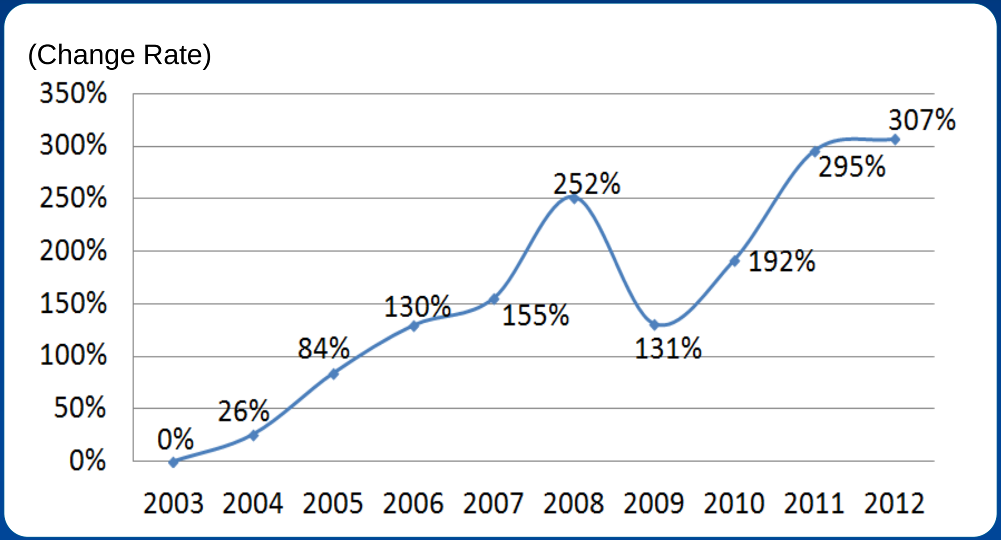
CONTENTS

Ⅰ. POLICY and TREND of RENEWABLE ENERGY

Ⅰ. POLICY and TREND of RENEWABLE ENERGY

Background of Renewable Energy is

Annual change in oil prices



International oil price rapidly increase recently 3 years

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- **International oil price is 107.93 $/bbl(2013. 09)**
- **10th largest energy consumer of the world ⇒ relies on imports for 97%**

EU	The goal of renewable energy supply in 2020 is 20 % of total energy 34 % of generation , 10 % of transportation fuel
Japan	The goal of renewable energy supply in 2020 is 20 % of total energy (MOE, '10.1) Reopen to give solar energy subsidy('09.1) Mandatory for purchase remain solar energy ('09.11)
USA	Provide renewable energy which is 25% of eletric power in 2025 (Announcement of Obama Government)
Chaina	The goal of renewable energy supply in 2020 is 15% of Primary Energy (300GW of Water, 30GW of Wind, 1.8GW of Solar, 30GW of Biomass) Develop and supply plan of Wind, solar, water etc.
Germany	The gold of renewable energy supply in 2020 is 18% of Final Energy (30% of generation amount)

Div.	USA	Japan	Germany	Denmark	UK	Korea
Supply rate('07)	5.0%	3.4%	8.6%	18.1%	2.4%	2.4%
Goal	10.9%('30)	20%('20)	18%('20)	30%('20)	15%('20)	11%('30)

Data : Energy Balance of OECD Countries('09), IEA

Set the goal of renewable energy supply and under continuous efforts

R&D Strategy of Major Advance Countries

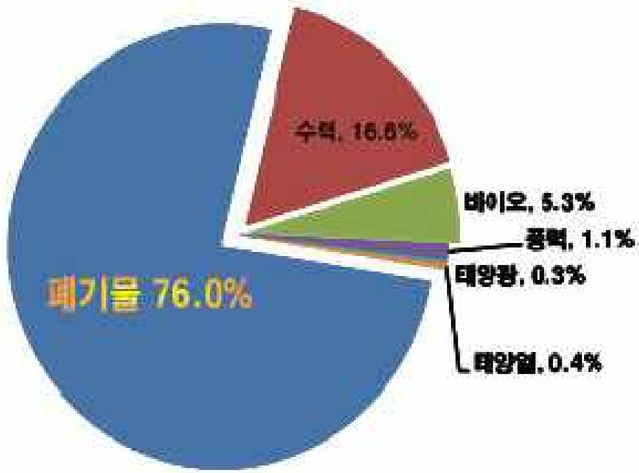
"Establish New Growth Power Driving Strategy through Innovational Energy Technology"

America	Japan	E U
➢ American Recovery and Reinvestment Act('09.2) 26 billion dollars of budget for ARPA-E *470% of Budget of DOE is increased compare to 2008	➢ New National Energy Strategy ('06.5) Improve 30% of energy efficiency, and achieve 40% of oil development by 2030 ➢ Announcement of Cool Earth ('08.4) Announced 21 Innovation technology	➢ An Energy Policy for Europe('07.1) Improve energy efficiency ➢ SET Plan('07. 11) Long term plan for clean energy society based on low carbon technology

Focus the capability Nation securing energy technology to prepare climate changes and dominating the global market

Policy of Renewable Energy in Domestic

<Composition of Renewable Energy>

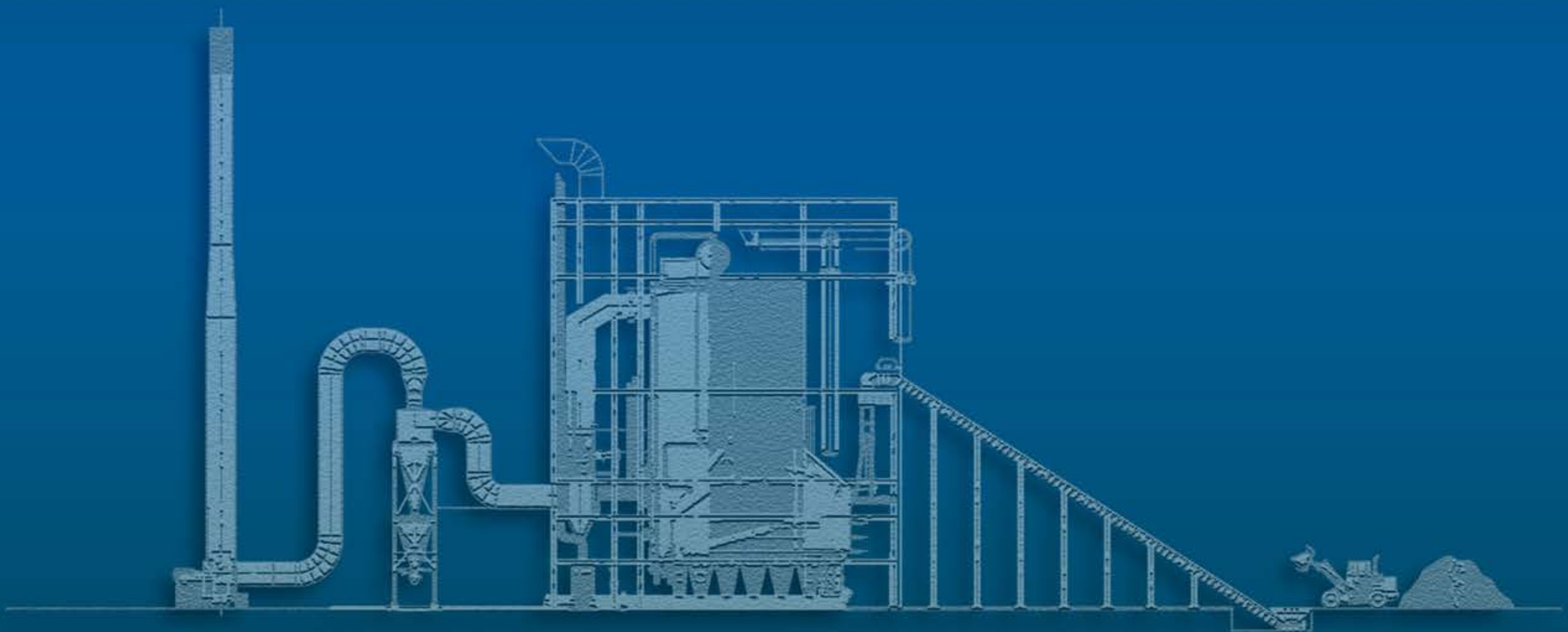


- **Renewable energy using Bio is 5.3% of total energy**
- **Plan to increase rate of bio-energy up to 30% by 2030**
- **Production cost of bio energy among national renewable energy is similar with 10% of solar and 70% of wind**

Div.	Solar	Wind	Water	Waste	Bio
Unit cost of production	716	107	70	71	75

Establish goal plan in supply structure
of Bio-Energy among renewable energy

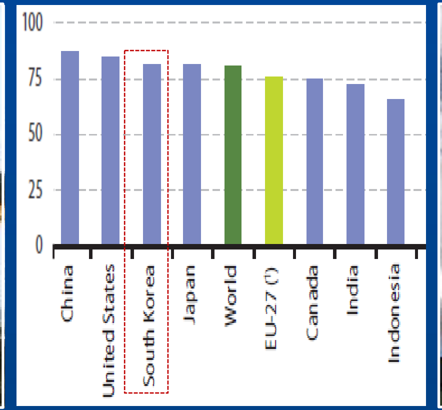
Ⅱ. BIOMASS as CLEAN ENERGY



Ⅱ. BIOMASS as CLEAN ENERGY

Alternative Clean Energy in Domestic

- To address global warming, the development of alternative clean energy source like biomass must accelerate to reduce our dependence on fossil fuel.
- Korean power demand ranked third place of electricity consumption rate among global top 8 major countries (International Energy Agency(IEA))
- A steep increase of power demand especially on specific time (summer and winter) can lead to electricity crisis like Blackouts



Domestic Policy for Alternative Clean Energy

- Government needed alternative clean energy and introduced the "Renewable Energy Portfolio Standard(RPS) " to satisfy power demand and reduce greenhouse gas emissions and opened the new RECs(Renewable Energy Certificates) market
  - –RPS duty supply: 2.0% by 2012, 2.5% by 2013, 3.0% by 2014, 10% after 2022 of total electricity generated
  - –2012year result: KEPCO subsidiaries(6 companies) are carrying out 64% (3,808 GWh out of total 5,911 GWh)

◆ REC Performance in 2012

Unit(GWh)

Generator	Total amount of duty (photavoltaic)	Performance result		Implementation delay	Penalty (0.1 billion won)
		Self-supply	Outside purchase		
Kosep(남동)	834(43)	62(18)	302(23)	470(2)	105
Komipo(중부)	738(43)	89(6)	303(36)	346(1)	59
Kowepo(서부)	761(43)	72(6)	366(33)	323(4)	45
Kospo(남부)	834(43)	115(13)	451(29)	268(1)	8
EWP(동서)	734(43)	72(13)	351(30)	311(0)	44
KHNP(한수원)	2,010(43)	1,291(2)	333(37)	386(4)	0
Total	5,911(258)	1,702(58)	2,106(188)	2,103(12)	261

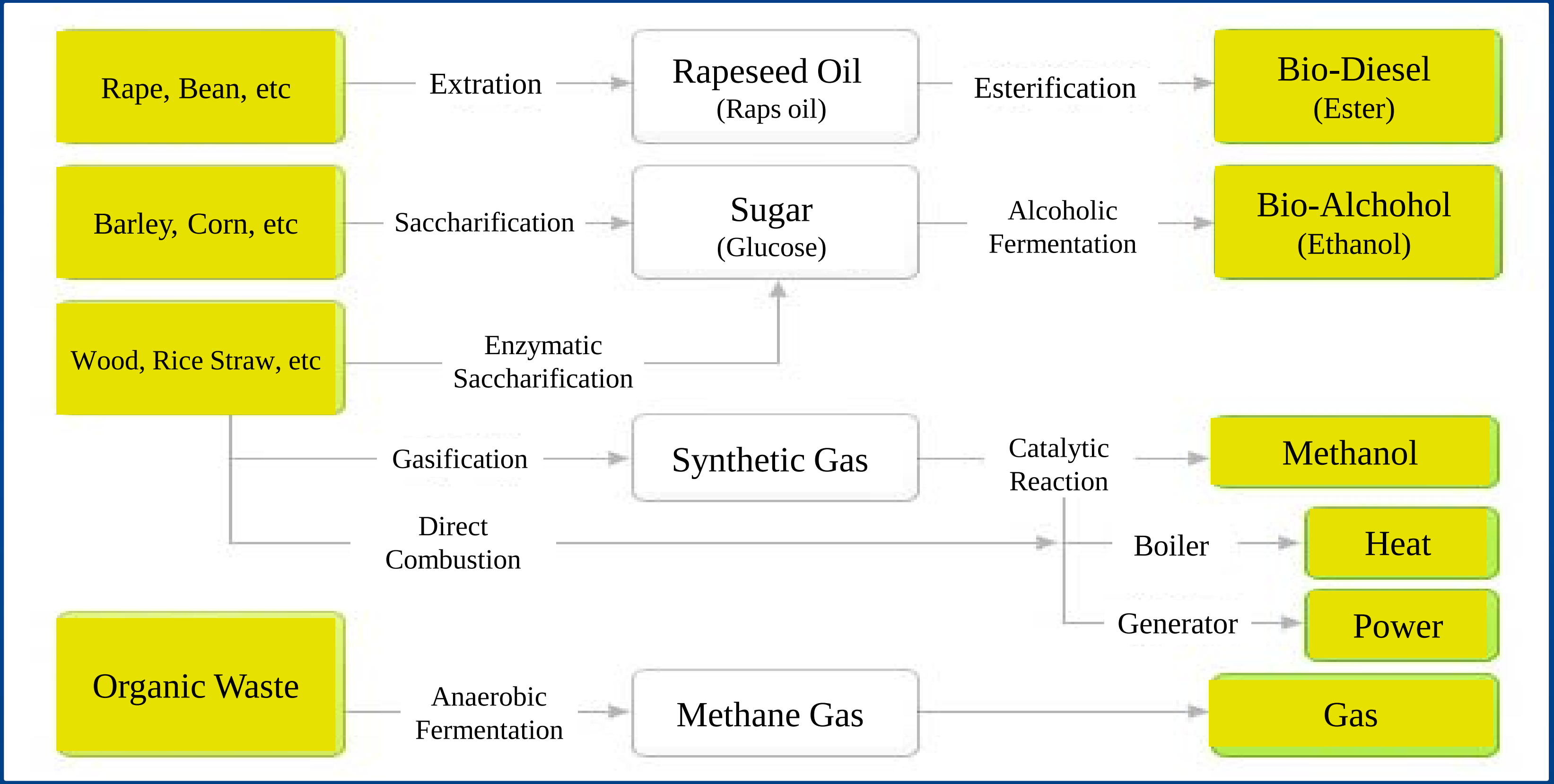
⇒ Increased using biomass fuel for the effective implementation of the RPS to avoid penalty

Biomass?

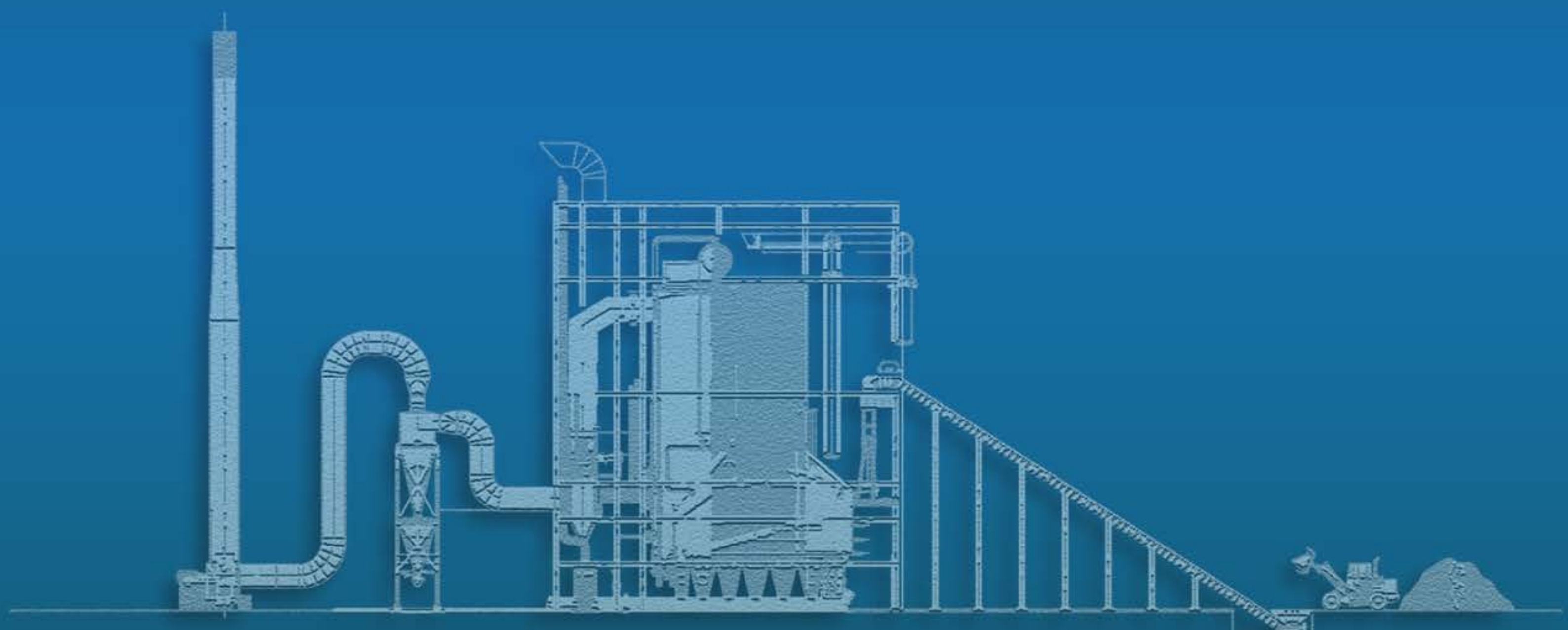
- Biomass is derived from sources of various types, such as agricultural, forestry, fishery, stockbreeding, and waste resources, and the technologies to use those various types also vary widely.

Biomass as a Renewable Energy Source

- Biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel, wood chip, pellet, biodiesel, bioethanol and biogas.



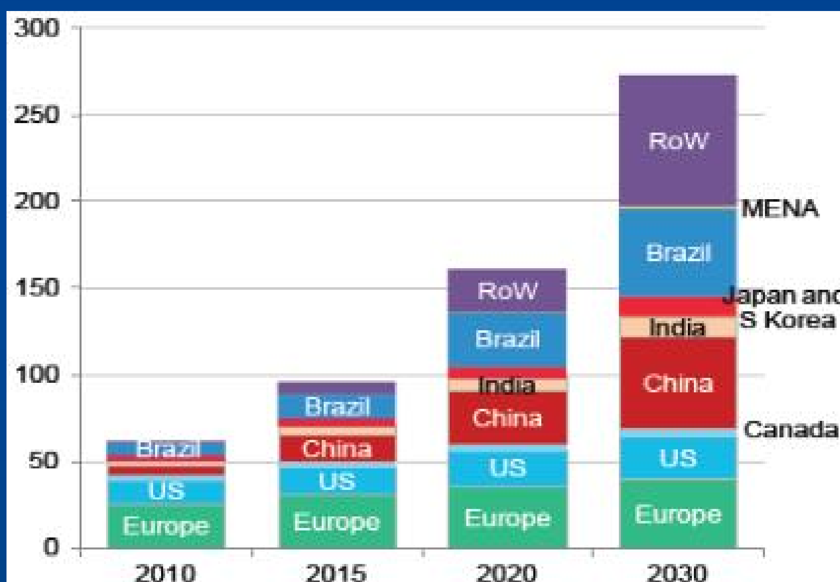
Ⅲ. BIOMASS ENERGY MARKET OUTLOOK

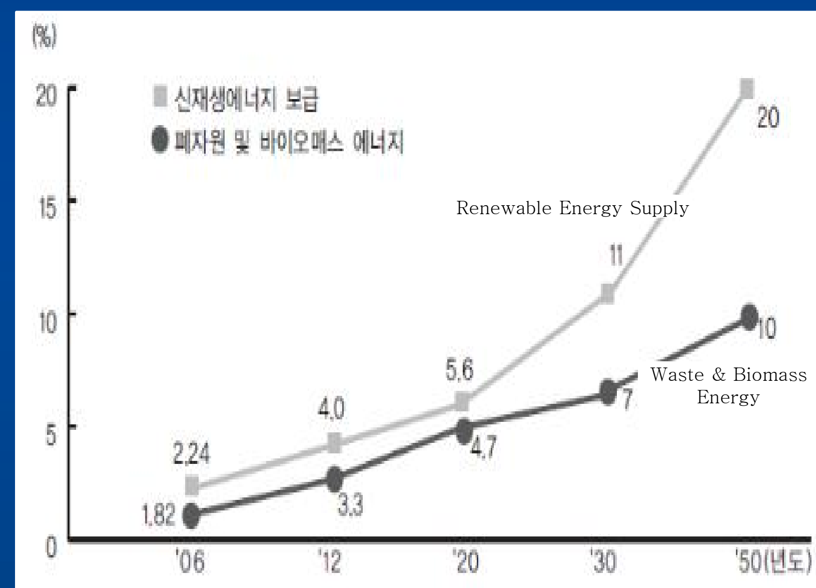


Ⅲ. BIOMASS ENERGY MARKET OUTLOOK

Biomass Energy Demand Forecast (1)

- All over the world, biomass power plant is expected to continue high rate of increase by planning to supply 150GW around developing countries and BRICs such as Brazil, India, China and other countries by 2020.





Biomass Energy Demand Forecast (2)

- Korea completed the test of mixed fuel power plant of biomass energy and plans to mixed fuel in available plants with 3~10% of biomass content.

Coal Power Plant

Biomass Fuel

Biomass Mixed Fuel Plant

(unit : 1,000TOE)

Remark	2020	2030	2050
Primary Energy Demand Forecast	287,976	300,417	373,872
Long-term goal of renewable energy supply	5.6%(16,241)	11.0%(33,027)	20.0%(74,774)
Goal of waste resources and biomass energy supply	4.7%(13,383)	7.0%(21,000)	10.0%(37,387)

Secure Biomass Fuel

- Biomass production capacity is only 10,000 tons/year in domestic (requirement : 3.2 million tons)
- Indonesia has a lot of various forest resources
- Korean private capital are investing on Indonesian forest resources for long-term development with high technology.

Region	Company Name	Production	Area(10,000ha)
Sumatra	PT. HAN	Wood pellet	3.3
Zawa	National Forestry Cooperatives Federation	Timber	1.0
Central Kalimantan	Korindo	Wood pellet	6.0
	Taeyoung Global	Timber	6.0
Southern Kalimantan	SK Networks co., Ltd.	Timber	3.0
	National Forestry Cooperatives Federation	Wood pellet, Timber	8.0
Papua	Korindo	Palm oil, Timber	16.0
	LG International Corp.	Timber	17.0

※ source : Korea-Indonesia Forest Cooperation Center internal data(2012)

- Recently Biomass Fuel Global Market is expanding.
- Construction of Biomass Power Plant is increasing world-wide as well Korea.

IV. BIOMASS ENERGY TECHNOLOGY TRENDs

IV. BIOMASS ENERGY TECHNOLOGY TRENDs

Biomass Energy Production Technology

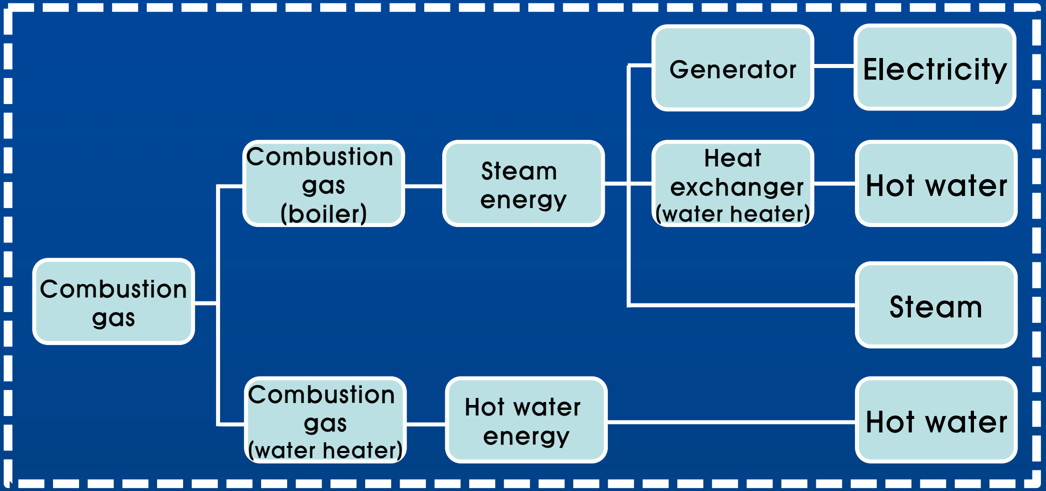
- Biomass energy production technology is divided into biogas production, solid derived fuel, bio-derived fuel technologies

  → solid derived fuel has been the most available in domestic.

- Solid derived fuel technology includes both Solid Refused Fuel(SRF) technology to manufacture wood pellets or charcoal and direct combustion technology to produce hot water and electricity by burning SRF.

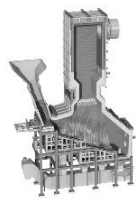
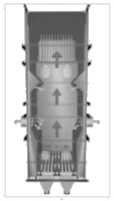
Heat Recovery Forms by Direct Combustion

- In direct combustion facility, 3 forms(electricity, hot water, steam) are applied for heat recovery.



Types of Biomass Boiler

- Boiler has been most widely used in biomass energy conversion of direct combustion method.
- The forms of boiler are stoker grate, circulation fluidized–bed and bubble fluidized–bed.

Division	Type	Fundamentals	Remarks
Stoker Grate		• Incineration take place by air coming from the bottom on stoker grate placing fuel.	Europe
Circulation Fluidized–Bed		• Fluidized bed will circulate externally by repeating discharge and supply of sand.	Domestic
Bubble Fluidized–Bed		• Fuel will incinerate quickly on bubled sand bed by mixing with air injected by perforated plate at the bottom of the furnace.	Japan

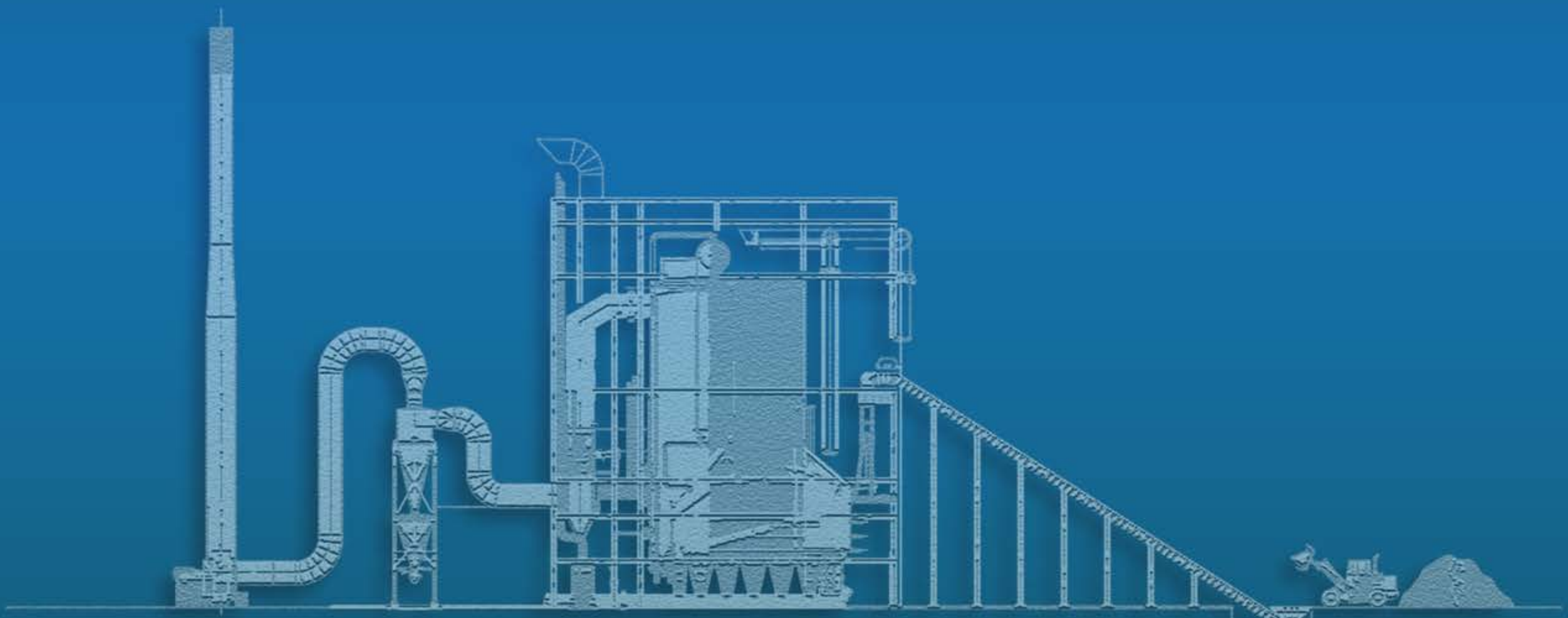
KTH Biomass Fired Power Plant

2013. 11. 11

Dohwa Consulting Engineers Co., LTD.

CONTENTS

I. Summary



Ⅰ. Summary

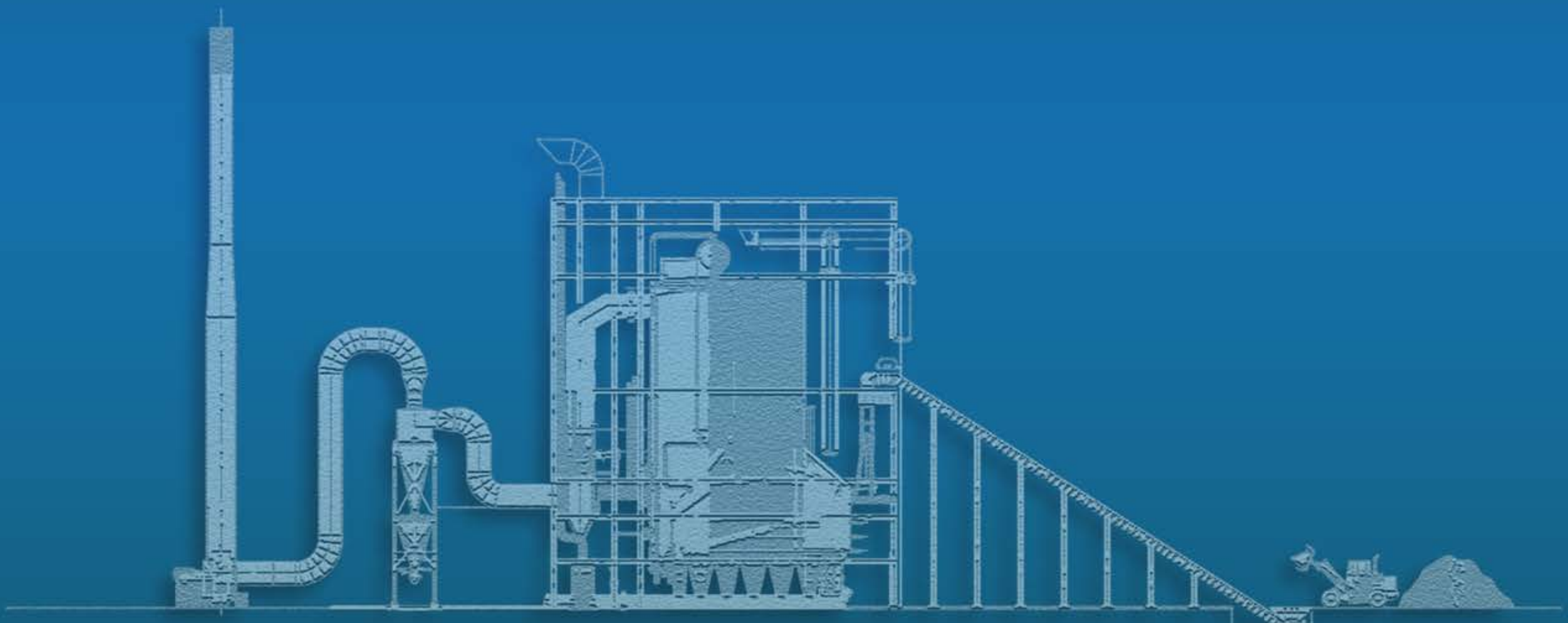
Project	KTH Biomass fired Power Plant
Location	Kumai, Kalimantan, Indonesia
Site Area	About 10,000㎡
Facilities	Boiler Capacity : 33 Ton/hr Power Capacity : 7.3MW(Net 6.5MW)
Client	PT Korintiga Hutani(Korindo Group + OJI Paper)
Duty Scope	EPC Work
Total EPC Amount	USD 23,000,000
Period of Project	2011. 08. 29 ~ 2013. 03. 31 (19Months)

Ⅰ. Summary

Location

- **Kumai, Kalimantan, Indonesia**

Ⅱ. Project Process



Ⅱ. Project Process

- 2010. 08. 28. : Submit Technical Proposal
- 2010. 11. 16. : Submit Commercial Proposal
- 2011. 02. 10. : Negotiation
- 2011. 05. 10. : Awarding
- 2011. 07. 21. : Contract EPC
- 2011. 09. 01. : Basic & Detail Design Start
- 2012. 04. 25. : Submit Final Detailed Design
- 2012. 05. 30. : Finished Pile Work
- 2012. 06. 20. : Shipping Material(Equipment, Raw Material etc.)
- 2012. 08. 18. : Start to Install Equipment
- 2013. 02. 10. : Mechanical Completion
- 2013. 03. 31. : Commissioning Complete

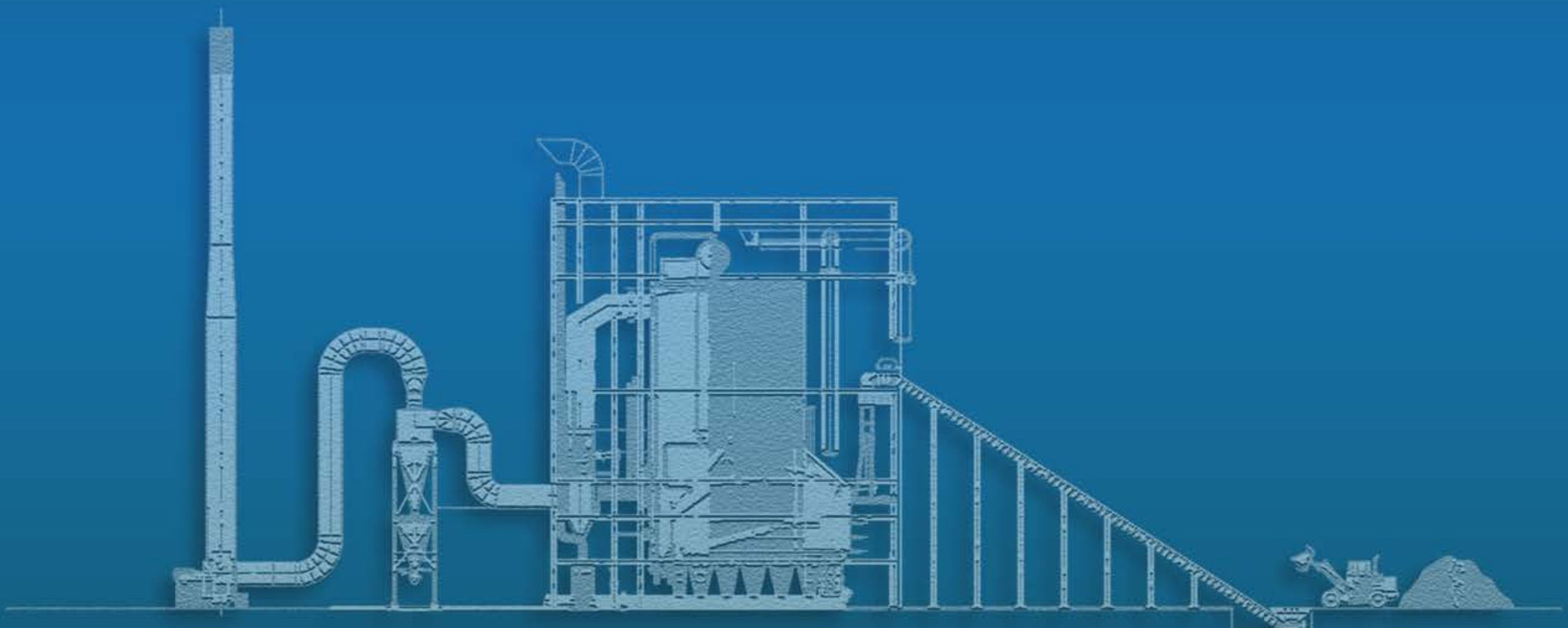
Ⅱ. Project Process

Project Schedule

Actual :
Plan :

ITEM	DESCRIPTION	2012								2013		
		5	6	7	8	9	10	11	12	1	2	3
PREPARATION	MOBILIZATION	10	50	85	100	100	100	100	100	100	100	100
	SITE OFFICE & MESS	75	100	100	100	100	100	100	100	100	100	100
	MATERIAL HANDLING				35	100	100	100	100	100	100	100
MECHANICAL	BOILER				5	10.15	33.2	75.55	92.13	96.86	96.86	100
	STG						9.75	21.6	64.76	94.79	100	100
	FUEL & ASH HANDLING									57	100	100
	FLUE GAS TREATMENT					15	59.67	80.9	81.3	92.18	100	100
	WATER TREATMENT							20.8	73.22	95.94	100	100
	COOLING TOWER				5	10	10	40	46	[illegible]	100	100
	AIR COMPRESSOR									12	100	100
	TANK						2.5	53.9	92.45	100	100	100
	BFP						45	100	100	100	100	100
	PUMPS							22.65	[illegible]	85	100	100
	CRANE								60	97.5	100	100
	CHEMICAL DOSING & SAMPLING							50	100	100	100	100
	STEEL STRUCTURE				7.5	40	75	87.5	97.5	100	100	100
PIPING	PIPING				2.5	15	31.41	44.2	65.17	81.81	100	100
	INSULATION									30	90	100
ELECTRICAL	TRANSFORMER									50	100	100
	SWITCHGEAR & MCC								7.5	77.5	100	100
	DC & UPS SYSTEM									50	100	100
	CABLE TRAY & CONDUIT							32.5	62.5	88.75	100	100
	GROUNDING SYSTEM					40	70	92.5	98.75	100	100	100
	PAGING									2.5	100	100
	CABLE									10	100	100
	PLC									75	100	1000
INSTRUMENT	FIELD INSTRUMENT								15	75	100	100
	TUBING & WIRING									37.5	87.5	100
TEST	TEST & COMMISSIONING										37.5	100

Ⅲ. Equipment List up & drawings



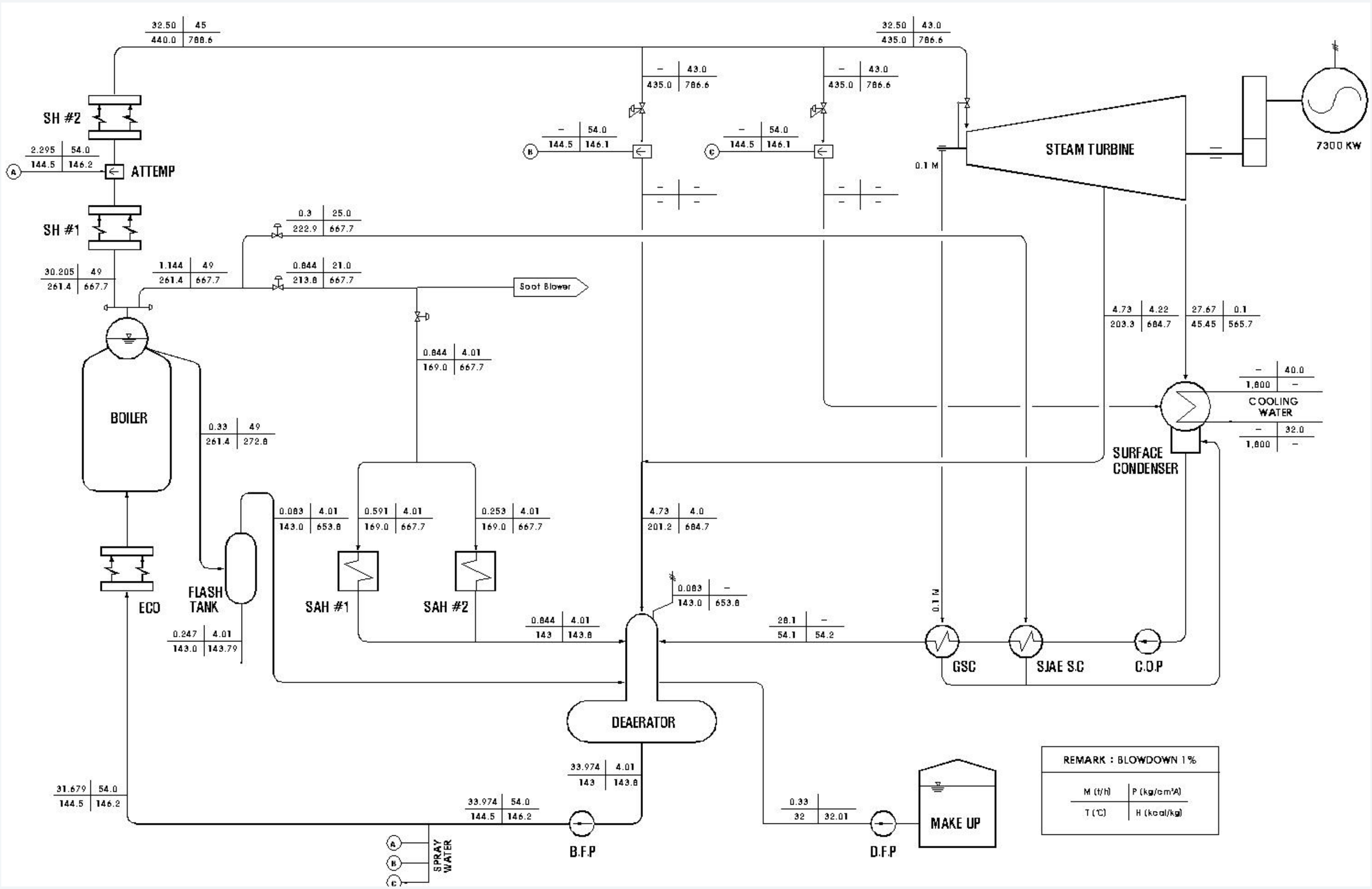
Ⅲ. Equipment List up & drawings

Equipment list

Description	Capacity	Remarks
Stoker Grate (Standardkessel GmbH in Germany)	• Fuel : Bark Chip • Design Firing Capacity : 27.3 MW • Design Fuel Flow : 10.8 t/h • Fining Efficiency : 98% • Annual Fuel Throughput : 165,000 ton/a • Annual Operation Hours : 8,000 h/a	
Boiler (Sookook Corporation In Korea)	• Boiler steam flow (MCR) : 32,760 kg/hr • Super heater outlet temperature: 45 kg/㎠.a • Boiler steam temperature: 440 ℃ • Boiler efficiency: 86 % • Fuel(bark) consumption base on LHV : 2,184kcal/kg, 11,283 kg/hr	
Steam Turbine (Shinnippon in Japan)	• Inlet steam - Pressure : 43 kg/㎠.a - Temperature : 435 ℃ - Flow : 32,460 kg/h • Exhaust steam - Pressure : 0.1 kg/㎠a - Temperature : 45.45 ℃ - Flow : 27,770 kg/h • Output at generator terminal : 7.3MW	

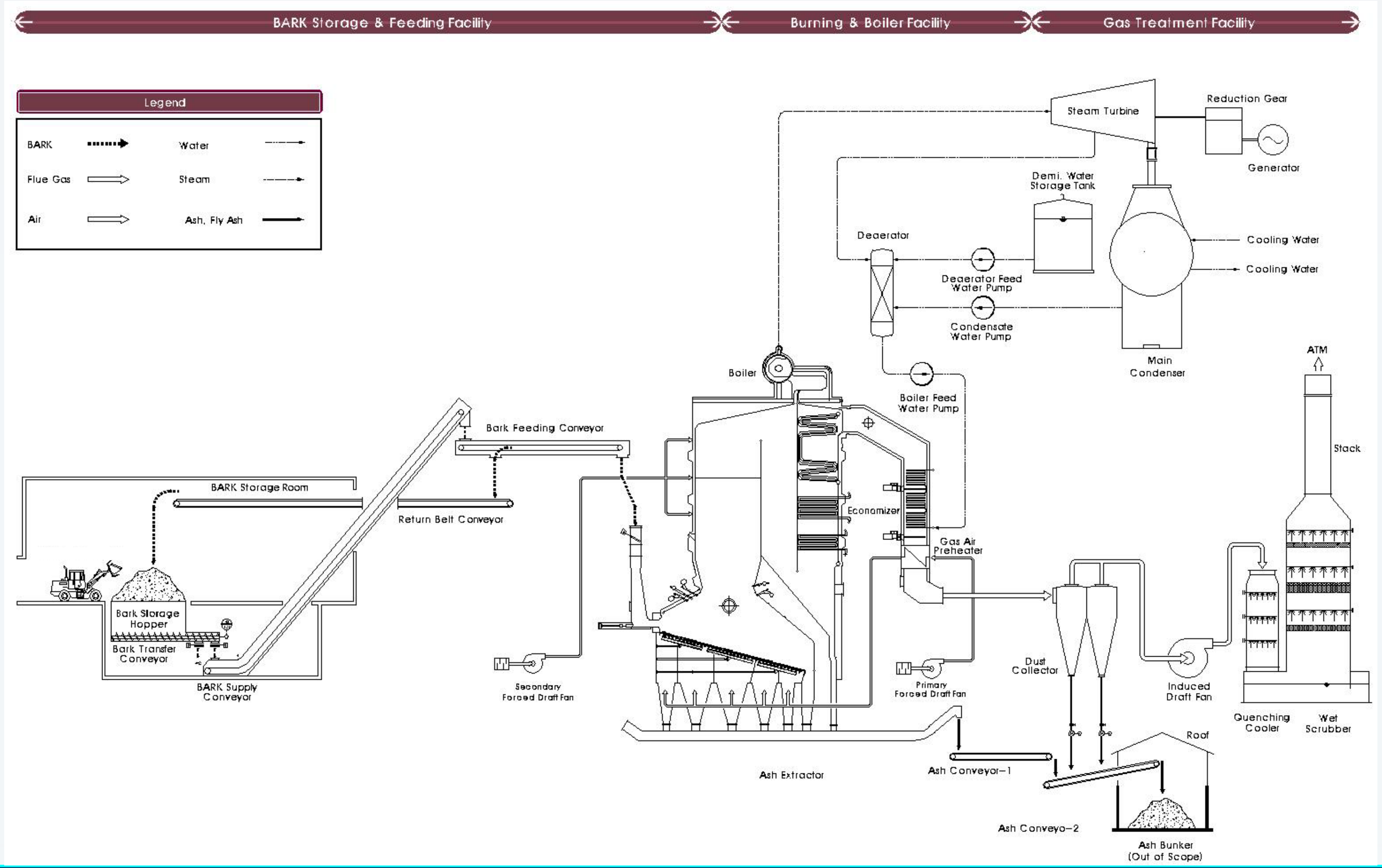
Ⅲ. Equipment List up & drawings

Heat Balance Diagram(Blowdown 1%)



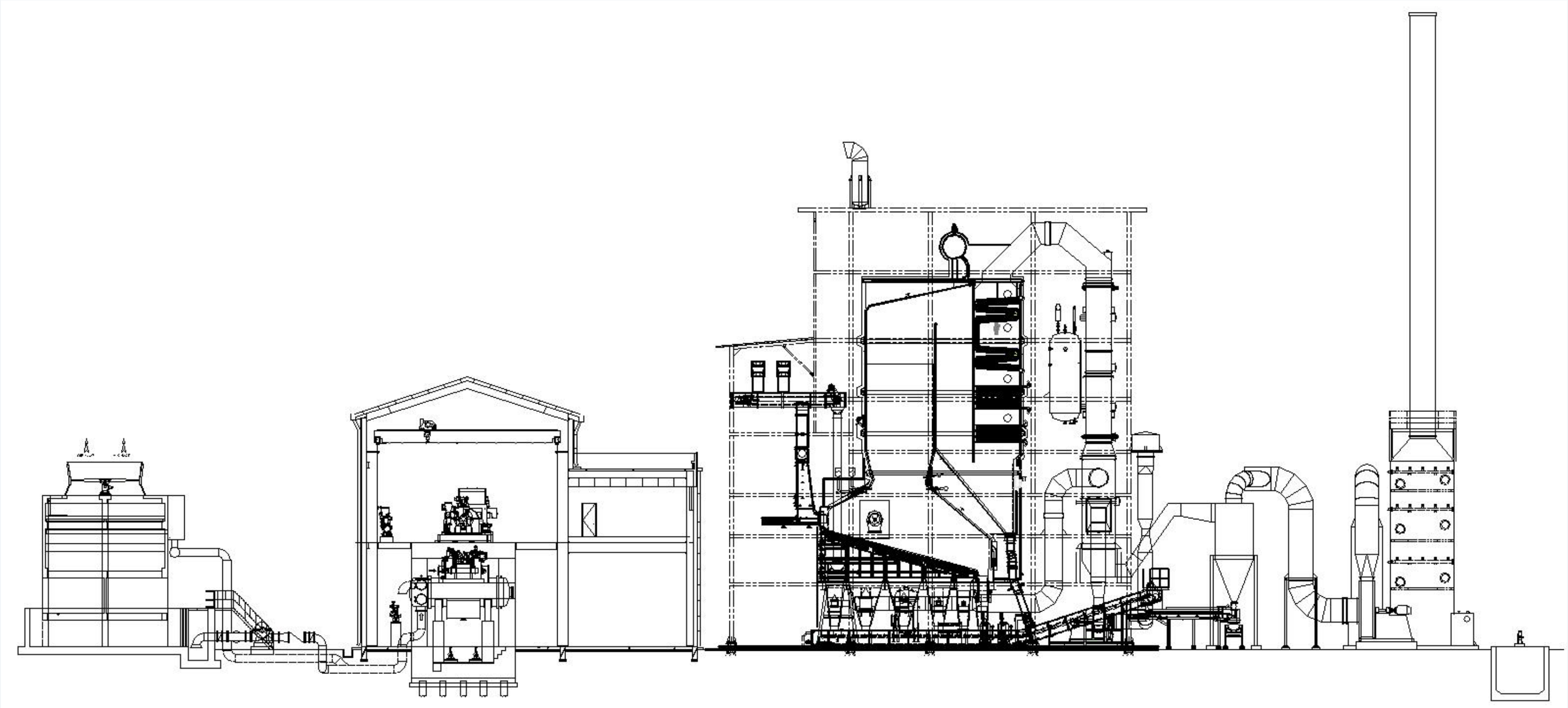
Ⅲ. Equipment List up & drawings

Process Flow Diagram



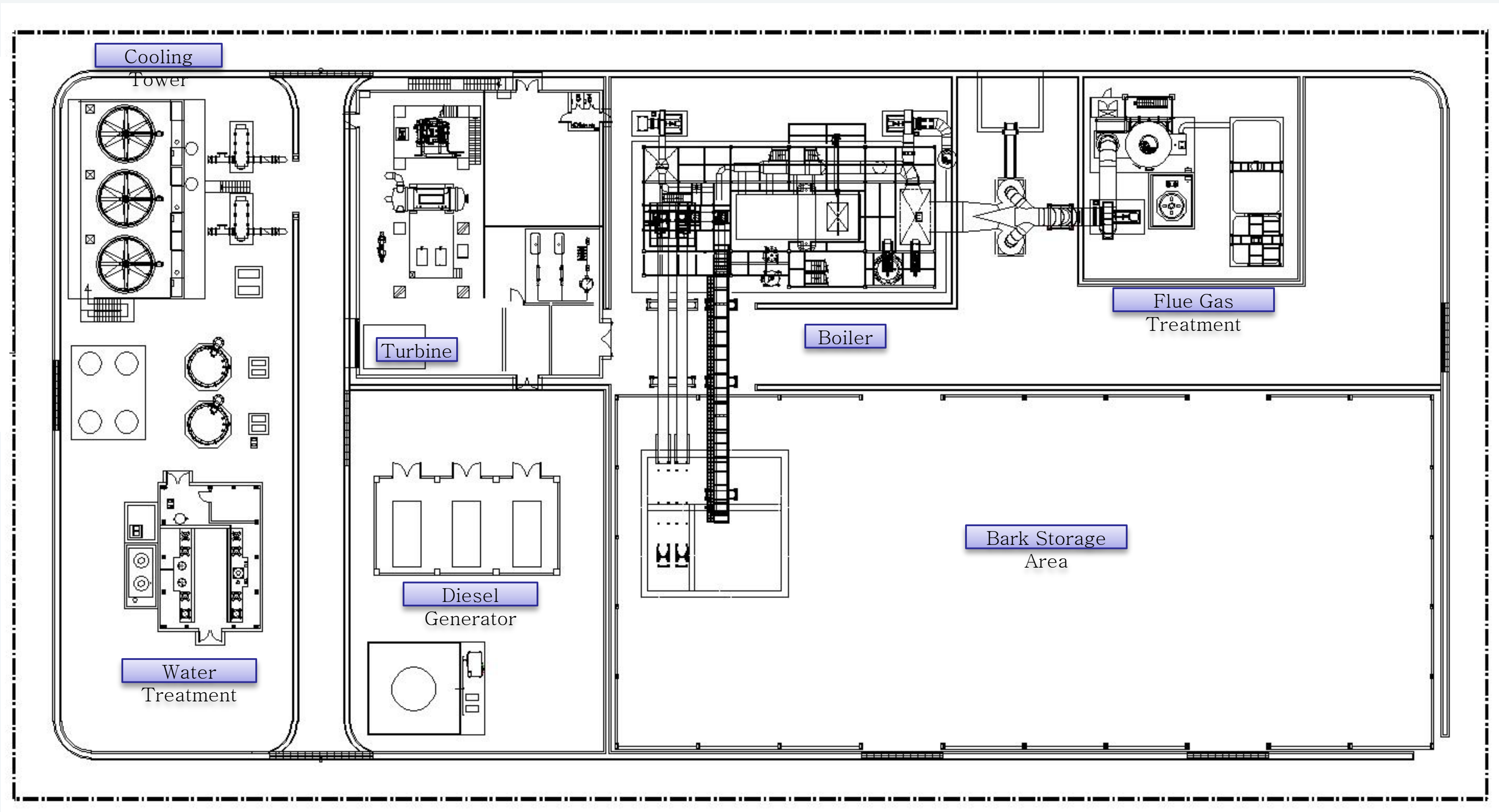
Ⅲ. Equipment List up & drawings

Section View



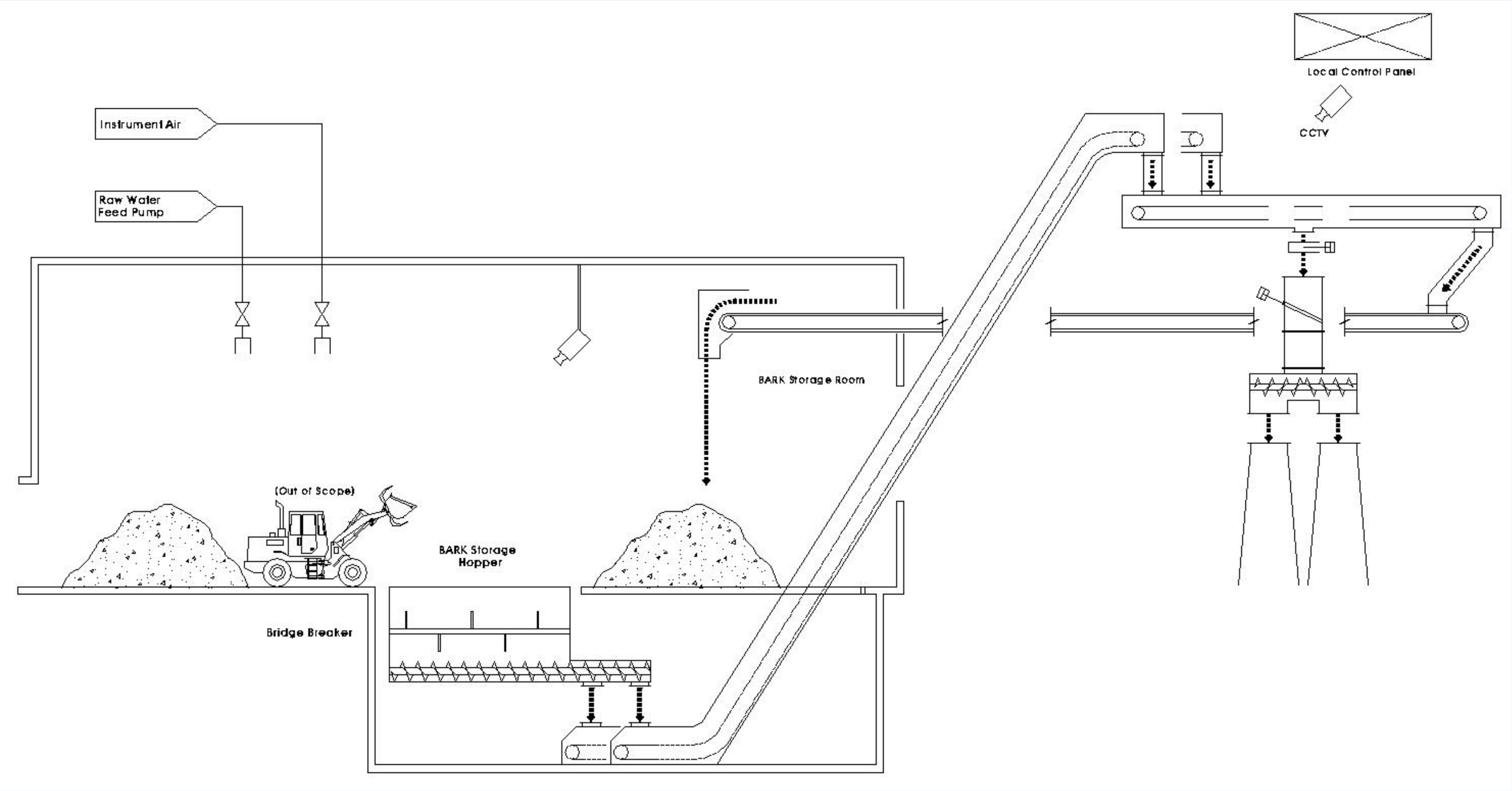
Ⅲ. Equipment List up & drawings

Plot Plan



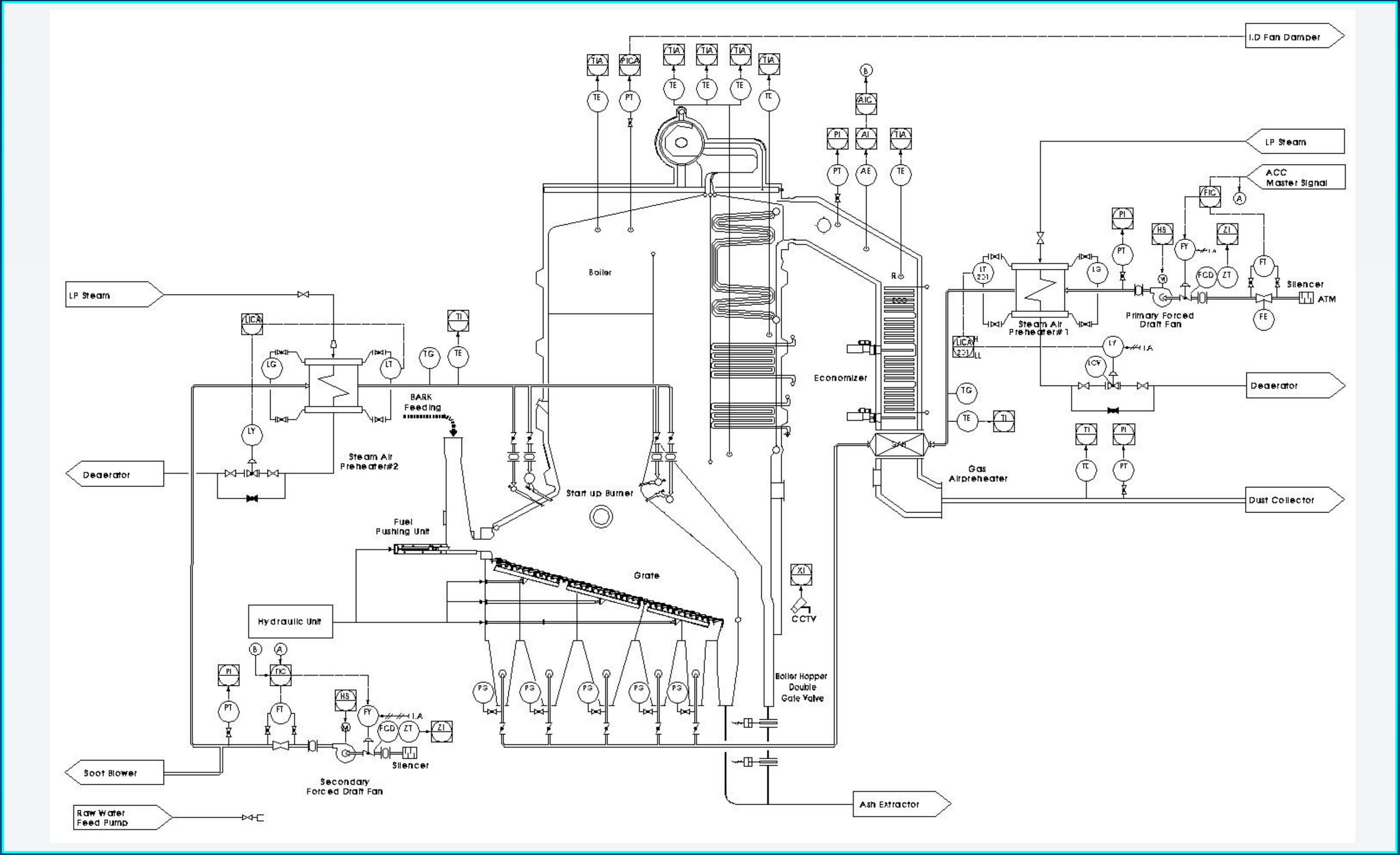
Ⅲ. Equipment List up & drawings

P&ID : Fuel Handling System



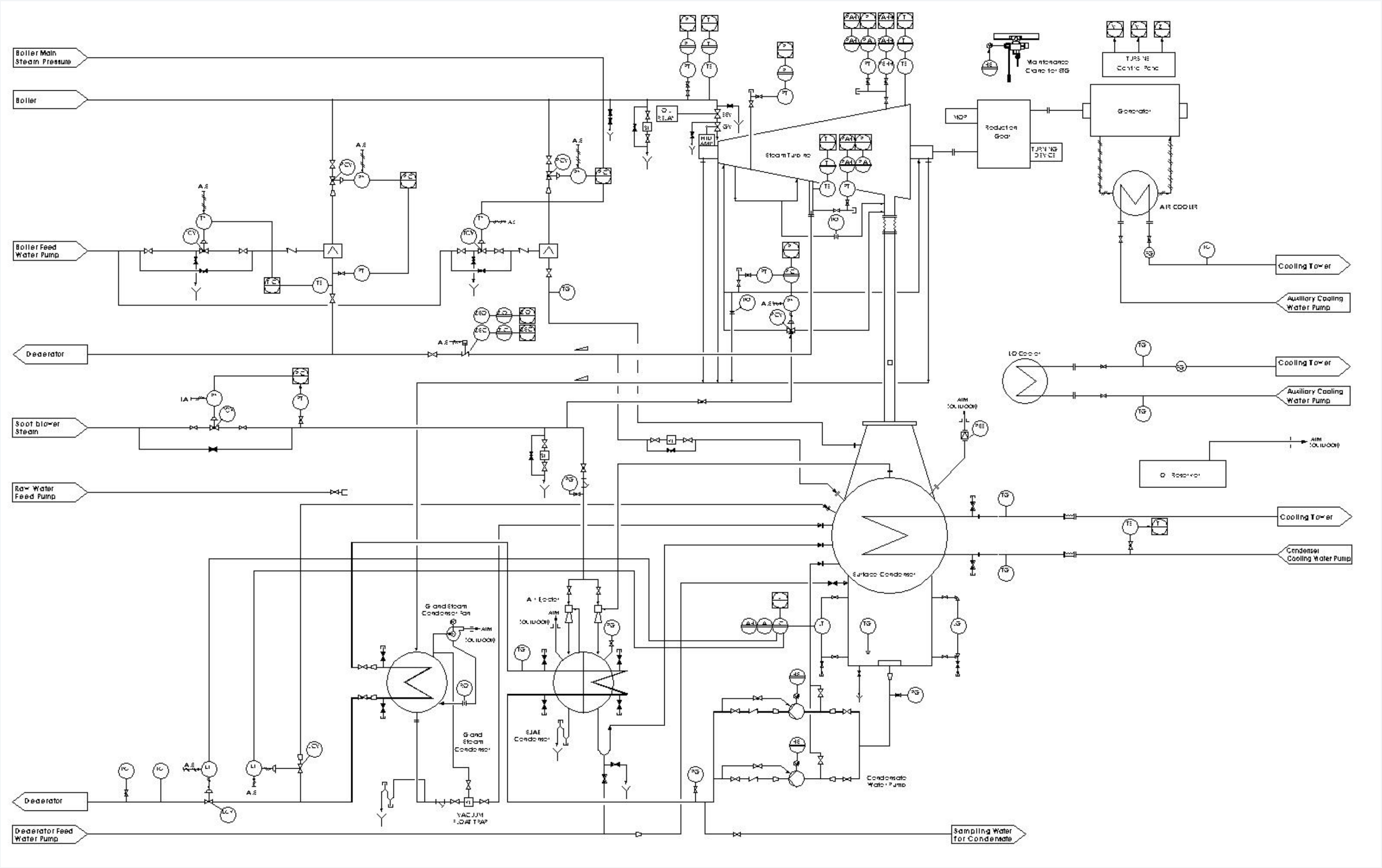
Ⅲ. Equipment List up & drawings

P&ID : Boiler System



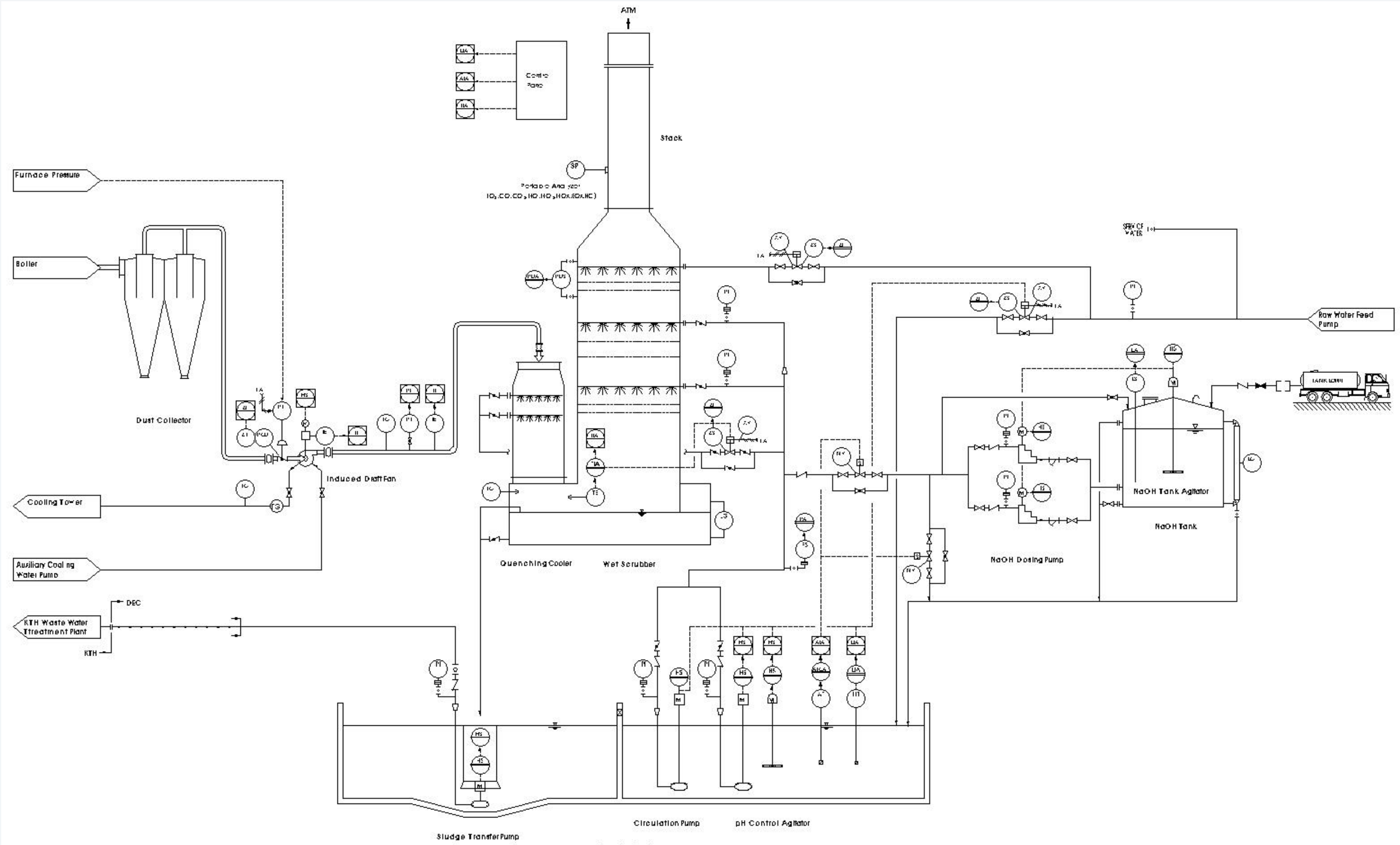
Ⅲ. Equipment List up & drawings

P&ID : Steam Turbine & Condensate System



Ⅲ. Equipment List up & drawings

P&ID : Flue Gas Treatment System



Ⅳ. Shipping & Inspection

Ⅳ. Shipping & Inspection

Shipping

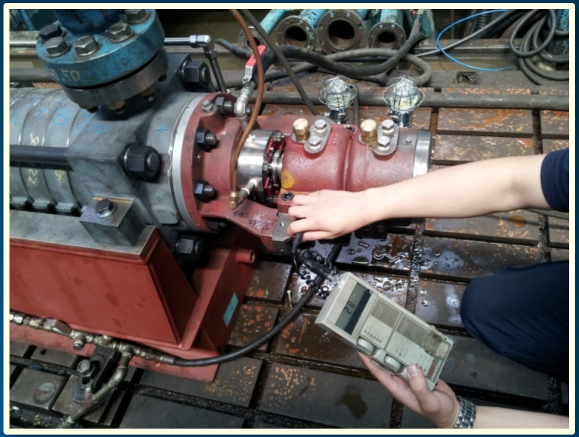




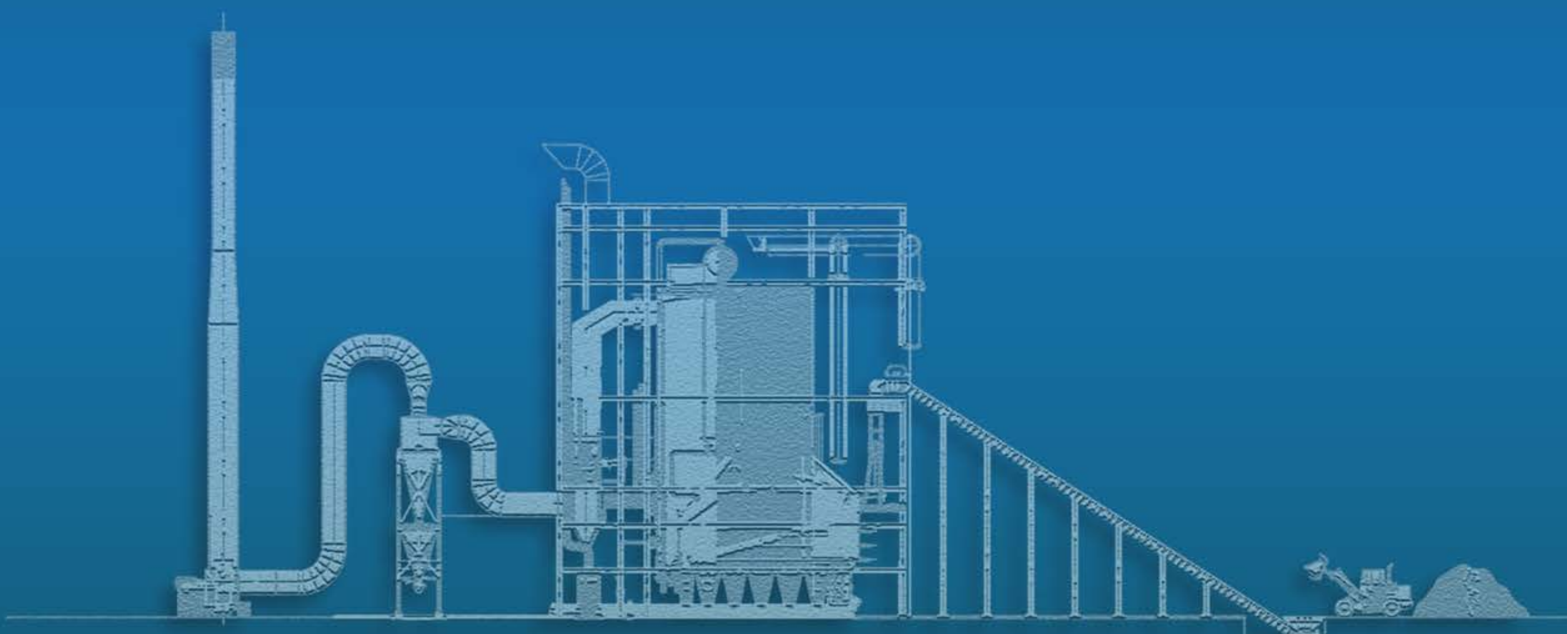

Ⅳ. Shipping & Inspection

Inspections






Ⅴ. Construction



V. Construction

- **Pile Punching & Head Treatment**

- **Reinforcement Work**

- **Column Reinforcement Arrangement Work**

- **Boiler Steel Structure Erection**

V. Construction

- **STG 1st Slab - Install of Floor Post & Forms**

V. Construction

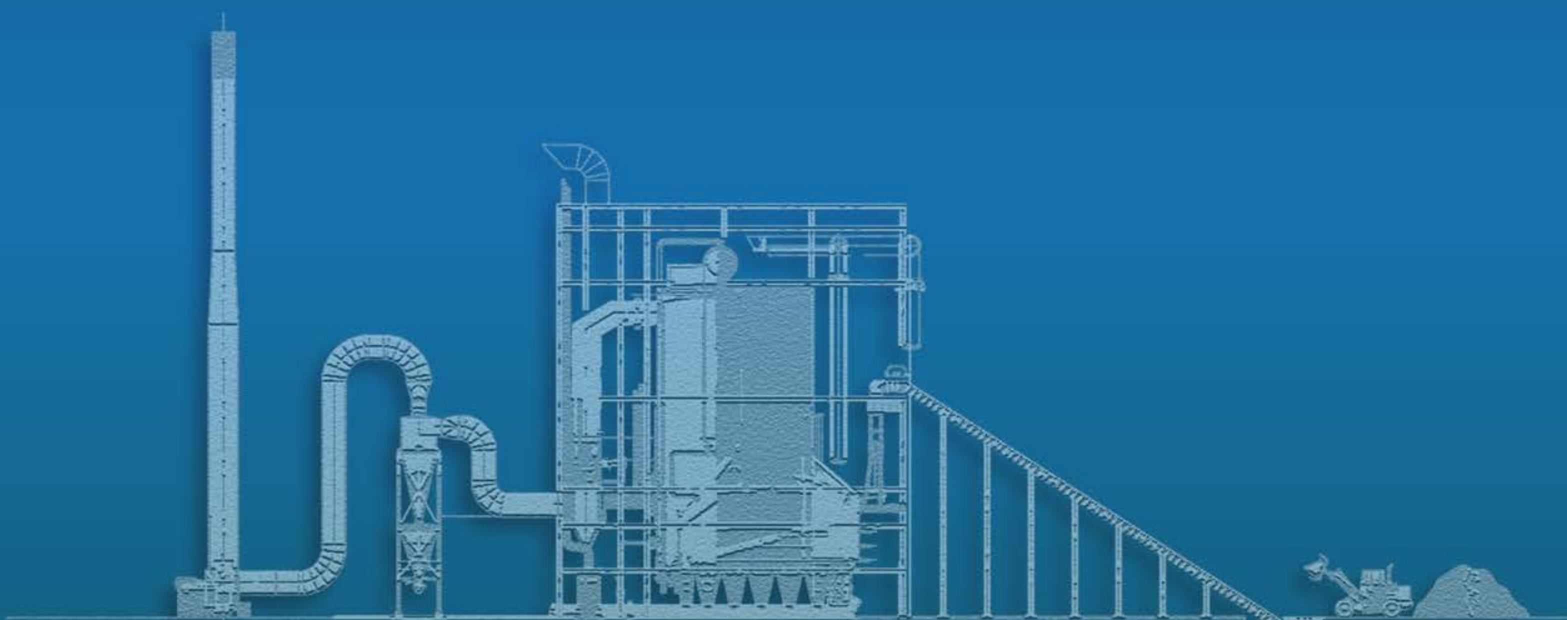
- STG Foundation - Removal of Forms

- Erection Boiler

- Cleaning Access Floor For Control Room(STG Building)

- Install Formwork for Cooling Tower

Ⅵ. Commissioning



VI. Commissioning

- **After Completion of Commissioning**

Thank you.

Organic waste-to-energy: Reduction and Recycling

Ki-Hoon Kang

Technology R&D Institute

DAELIM Industrial Co., Ltd.

Nov. 11, 2013

【 Contents 】

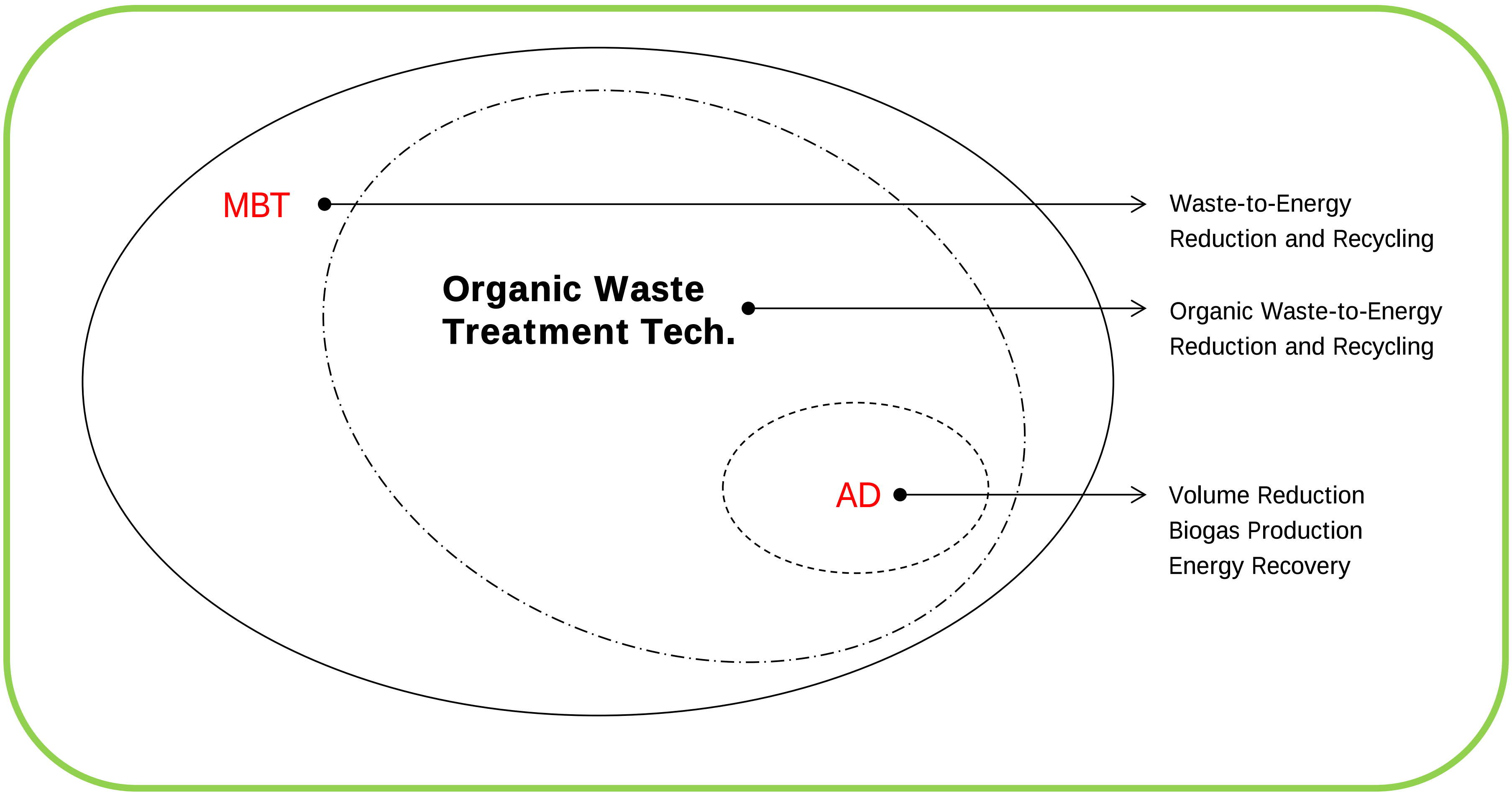
DAELIM

RELATION OF THE TECHNOLOGIES in this material

Abbreviation

MBT Mechanical-Biological Treatment

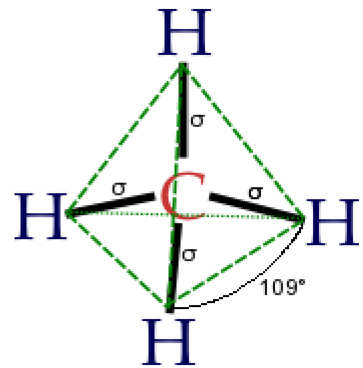
AD Anaerobic Digestion



Introduction

DEFINITION

- Organic compounds and organic materials
  - Matters in its various forms that contain C & H atoms
  - Structure of organic methane molecule: the simplest hydrocarbon compound



- Important constituents of many products including plastics, drugs, petrochemicals, food, explosive material, and paints.

- In this material, we limit meaning of term "organic waste" which is anything that comes from plants, animals or by-products from facilities that is biodegradable such as food waste or sludge.

Introduction

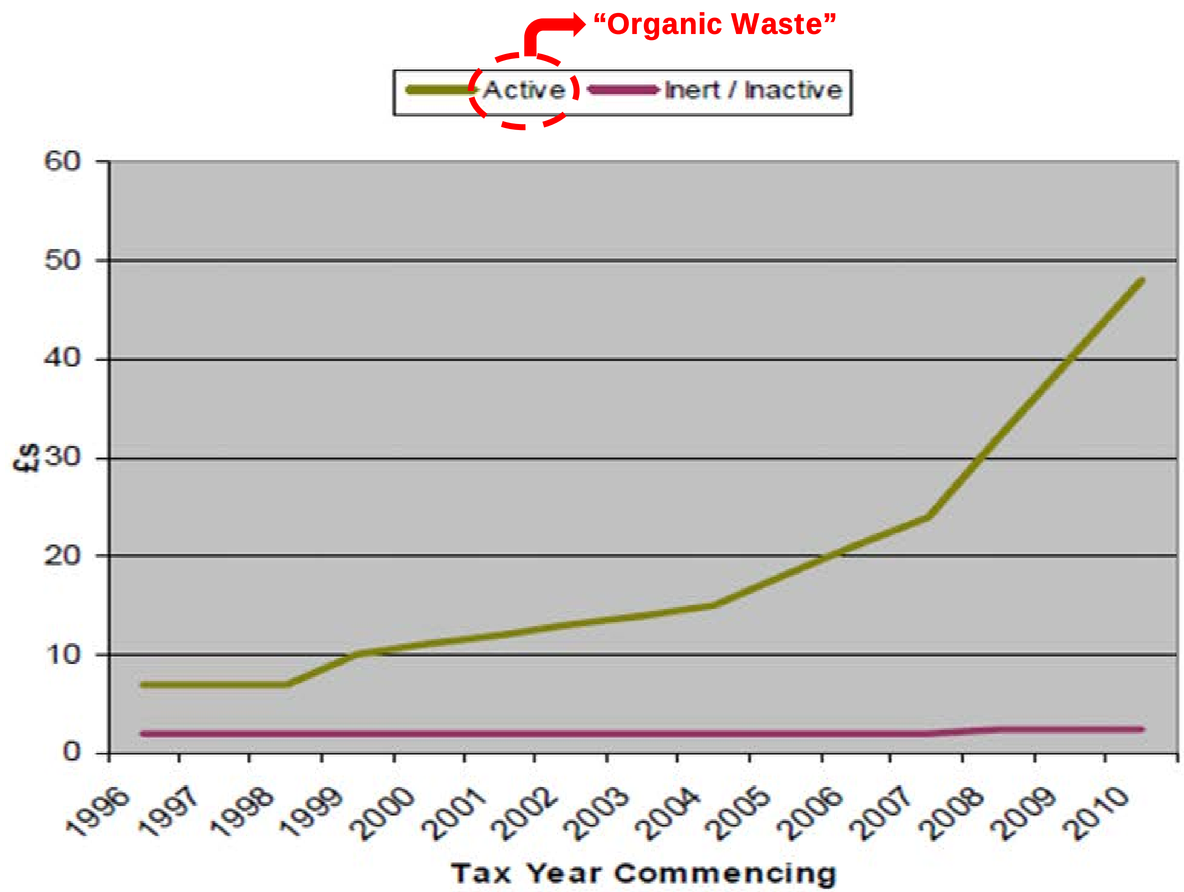
THE PROBLEM

- The main problem is the sheer volume of waste being produced and how we deal with it.
- The disposal of waste activated sludge (WAS) has been one of major issues.
  - Generation rate in Korea : 8,292 ton/day (2009)
  - expected to increase to 10,936 ton/day by 2013
- WAS comprises 19% of the total amount of industrial waste production, which causes a big burden environmentally as well as economically.
- Although ocean dumping had been major disposal method of WAS in Korea, an appropriate alternative is required due to the prevention of ocean dumping.

DAELIM

Introduction

- In England, landfill tax is differentiated between un-treated active waste and treated residual inert
  - In 2011, £56/ton for active waste, £8/ton for inert residual



Introduction

THE SOLUTION

- More appropriate and sustainable approaches to waste need to be adopted.
  To be sustainable we need to move the emphasis toward a system that makes use of low-tech, low-energy systems.

- It is focused on waste reduction and recycling.

✓ **Waste minimization** is an approach that aims to reduce the production of waste through education and the adoption of improved processes.

✓ **Recycling**, separating certain materials within the waste stream and reprocessing them. The recycling of many materials is currently not financially viable.

✓ **Waste processing** is treatment and recovery (use) of materials or energy from waste through thermal, chemical, or biological means.

Recycling as Resource (MBT)

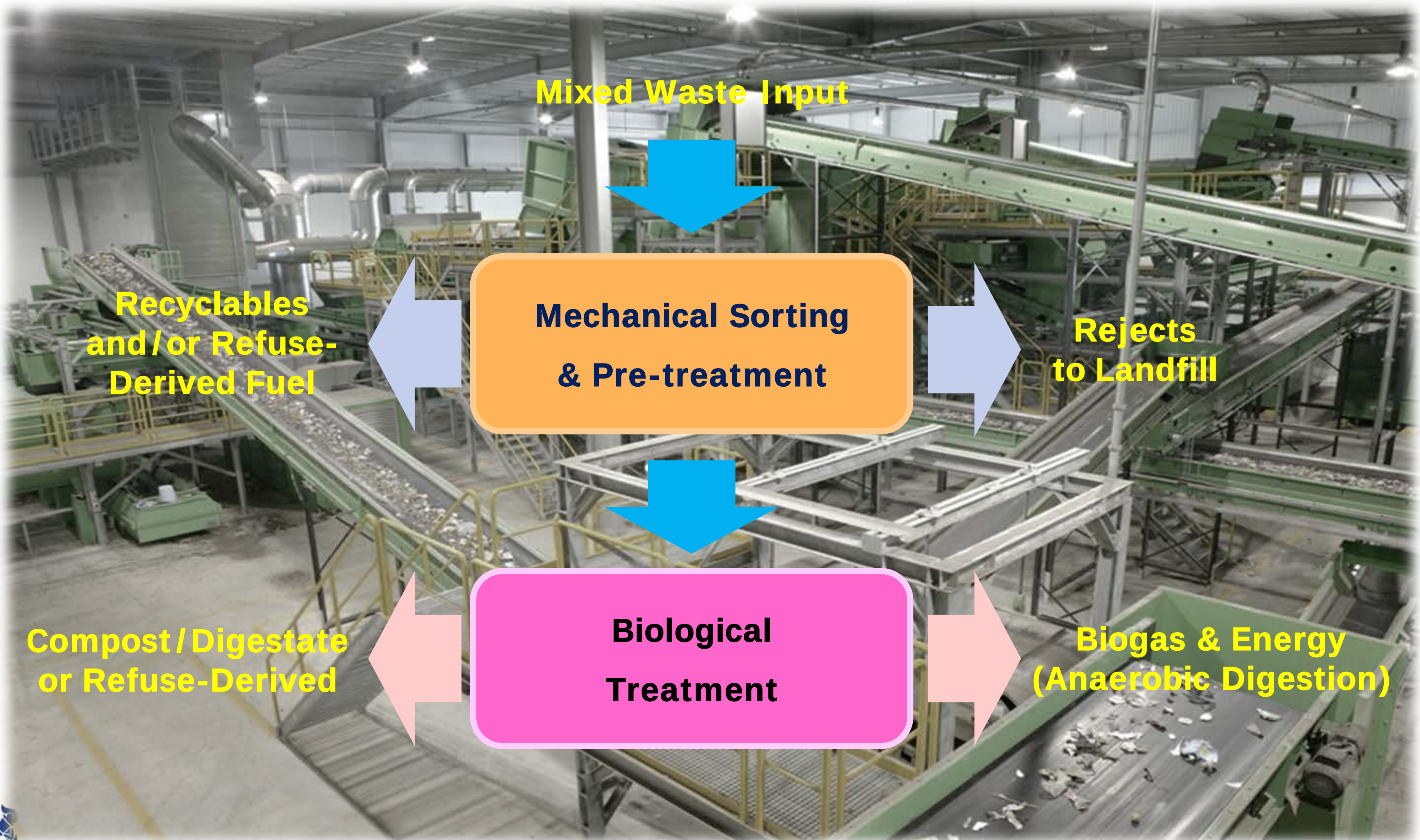
MBT OVERVIEW

- MBT was started to developed in Germany
  - as an alternative of MSW pretreatment prior to landfill
  - in compliance with EU Landfill Directive (1999/31/EC)
  - stepwise reduction of the landfilling of biodegradable waste

- MBT in Germany (2010)
  - 46 MBT plants with a capacity of 6 mil. Mg/y are operating.
  - Approx. 25% of MSW are treated by MBT
  - The realized process concepts are varying strongly and can not compared easily.

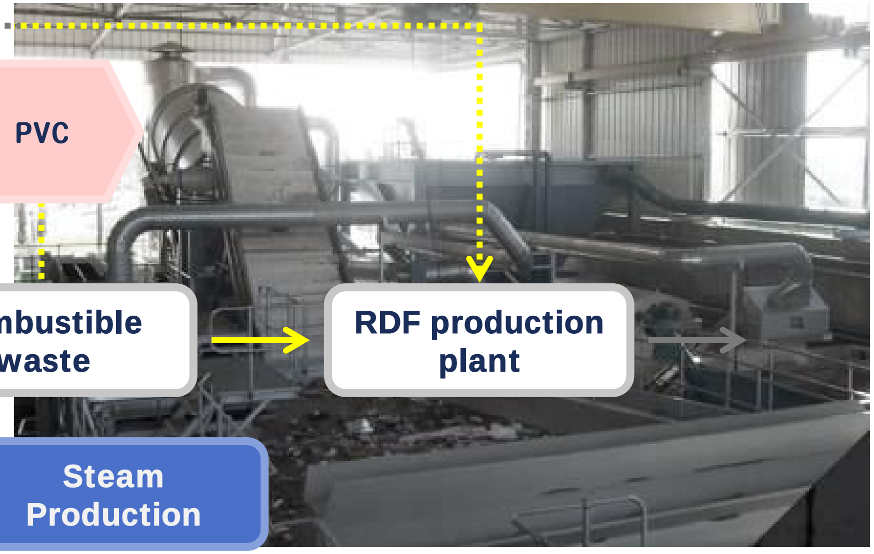
- MBT in Europe
  - 330 MBT plants were constructed during 2005 to 2011
  - Within next 5 yrs No. of MBT plants will be increased to 450 plants

CONCEPTS OF MBT PROCESS



Recycling as Resources (MBT)

Mechanical Treatment (MT)

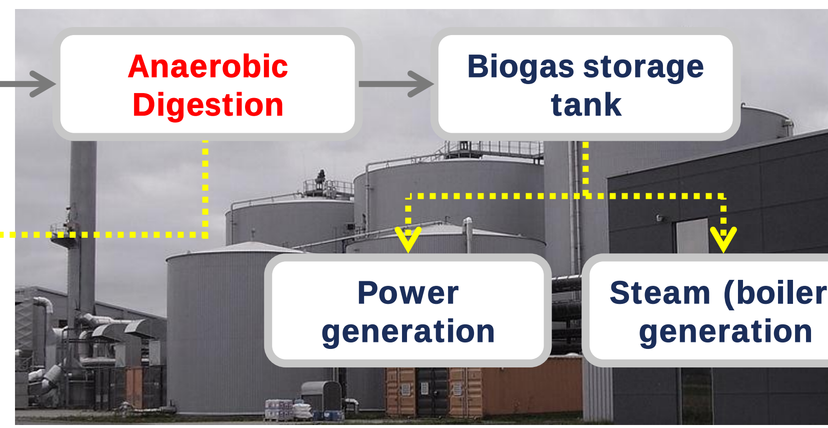


Biological treatment | Waste plastics | Glass bottle | Garment, paper | PVC

Living waste → Manual or Auto sorting → Combustible waste → RDF production plant

RDF (solid fuel) → Power Plant → Steam Production

Biological Treatment (BT)



Organic Waste → Separation of foreign matters → Crushing → Anaerobic Digestion → Biogas storage tank

Biogas storage tank → Power generation

Biogas storage tank → Steam (boiler) generation

Anaerobic Digestion → De-hydration

Wastewater treatment | De-hydration

De-hydration | Fertilizer

GOALS OF MBT

Abbreviation

LFG	Landfill Gas
RDF	Refuse Derived Fuel
SRF	Solid Refuse Fuel

- Volume reduction of landfilling wastes

  to minimize the necessary landfill capacity and to prolong the operating life of a landfill.

- Reduction of the biodegradable fraction of landfilling wastes

  so that the uncontrolled LFG generation is minimized as far as possible.

- Reduction of dangerous substances

  which will be leached in the landfill and can be led to a groundwater contamination

- Recovery of materials and energy

  Metals, RDF/SRF, Biogas

"The process concepts will be changed by the principal goal of localities"

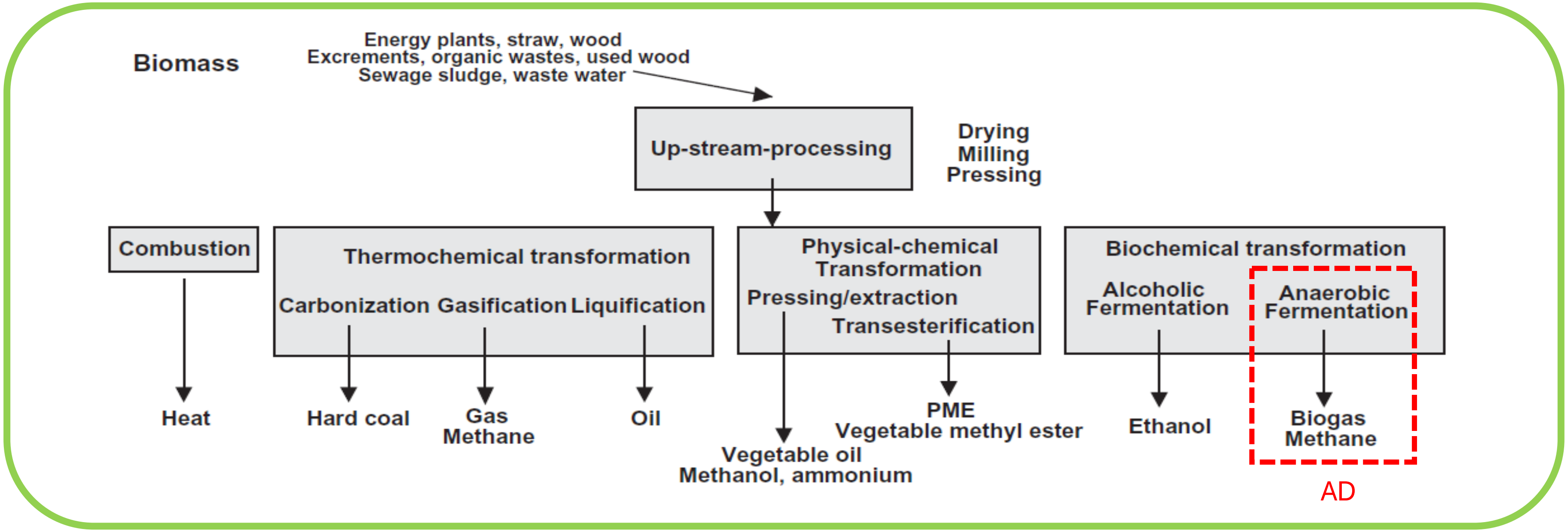
Waste–to–Biogas

TECHNOLOGIES

Abbreviation

AD Anaerobic Digestion

- There are several processes to transform organic waste into solid, liquid, or gaseous secondary energy sources and reduce its mass.
- Processes : combustion, thermochemical transformation via carbonization, liquefaction or gasification, physico-chemical transformation by compression, extraction, trans-esterification, and biochemical transformation by fermentation with alcohol or anaerobic digestion



[Applied technologies to transform biomass(organic waste) into secondary energy sources]

THEORY

- The theoretical maximum yield of methane: assuming the elementary composition as a base

$$C_cH_hO_oN_nS_s + yH_2O \rightarrow xCH_4 + (c - x)\ CO_2 + nNH_3 + sH_2S$$

where, $x = 0.125\ (4c + h - 2o - 3n + 2s)$

$y = 0.250\ (4c - h - 2o + 3n + 2s)$

or, simplified:

$$C_cH_hO_o \rightarrow (2c + 8h - 4o)\ CH_4$$

- Environmental requirements

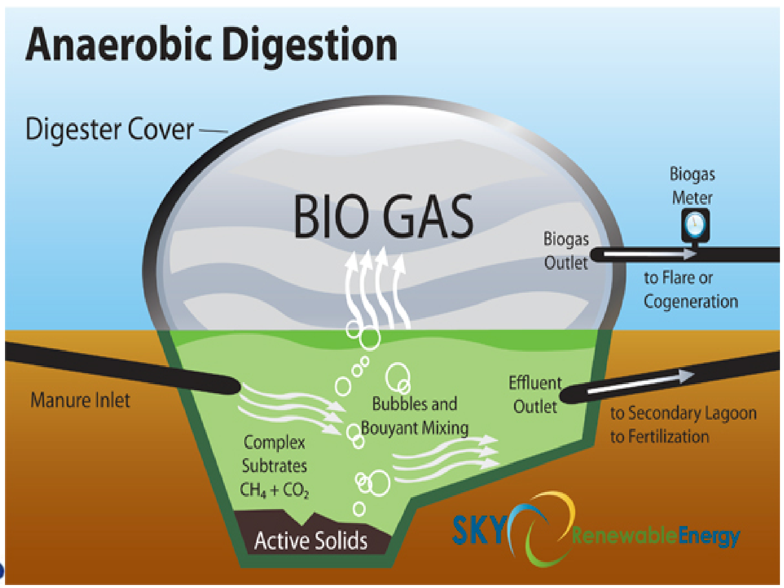
Parameter	Hydrolysis/acidogenesis	Methane formation
Temperature (°C)	25–35	Mesophilic: 32–42 Thermophilic: 50–58
pH value	5.2–6.3	6.7–7.5
C:N ratio	10–45	20–30
DM content (%)	<40	<30%
Redox potential (mV)	+400 to −300	<−250
Required C:N:P:S ratio	500:15:5:3	600:15:5:3
Trace elements	No special requirements	Essential: Ni, Co, Mo, Se

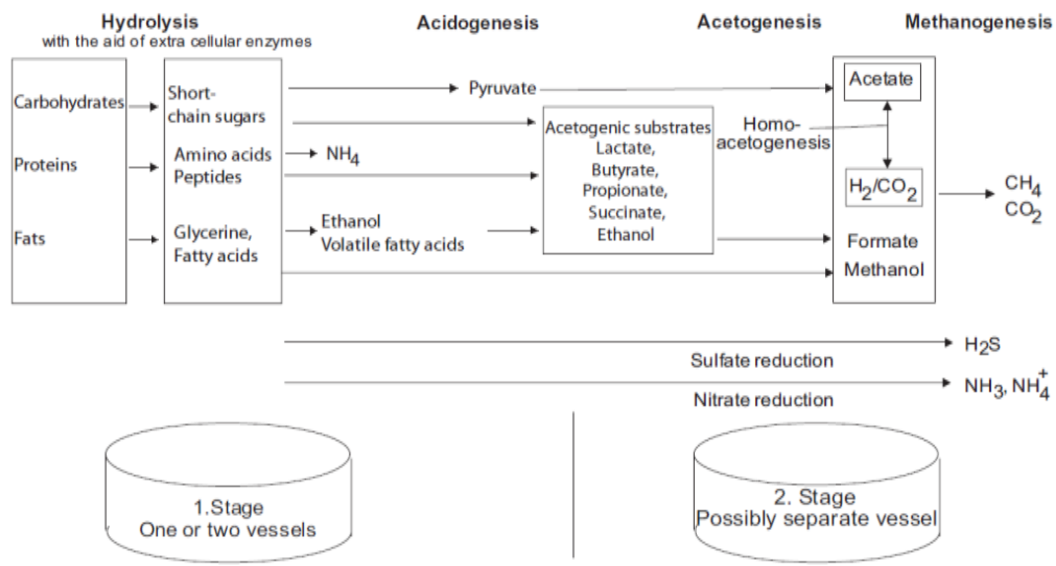
Abbreviation

AD Anaerobic Digestion

ANAEROBIC DIGESTION (AD)

- Methane fermentation : hydrolysis, acidogenesis, acetogenesis, and methanation
- The individual phases : partly stand in syntrophic interrelation and place different requirements on the environment
- Two stages: the first 2 phases and the last 2 phases are linked closely with each other





DAELIM

Abbreviation

AD Anaerobic Digestion

AD REACTORS

- Low-rate anaerobic reactors
  - Anaerobic pond
  - Septic tank
  - Imhoff tank
  - Standard rate anaerobic digester

Slurry type bioreactor, temperature, mixing, SRT or other environmental conditions are not regulated. <u>Loading : 1-2 kg COD/m^3-day</u>

- High-rate anaerobic reactors
  - Anaerobic contact process
  - Anaerobic filter (AF)
  - Upflow anaerobic sludge blanket (UASB)
  - Fluidized bed reactor
  - Hybrid reactor: UASB/AF
  - Anaerobic sequencing batch reactor (ASBR)

Able to retain very high concentration of active biomass in the reactor. Thus extremely high SRT could be maintained irrespective of HRT. <u>Loading: 5-20 kg COD/m^3-d</u>

Abbreviation

AD Anaerobic Digestion
SRT Solids Retention Time

AD DESIGN

- Design based on volumetric organic loading rate (VOLR)

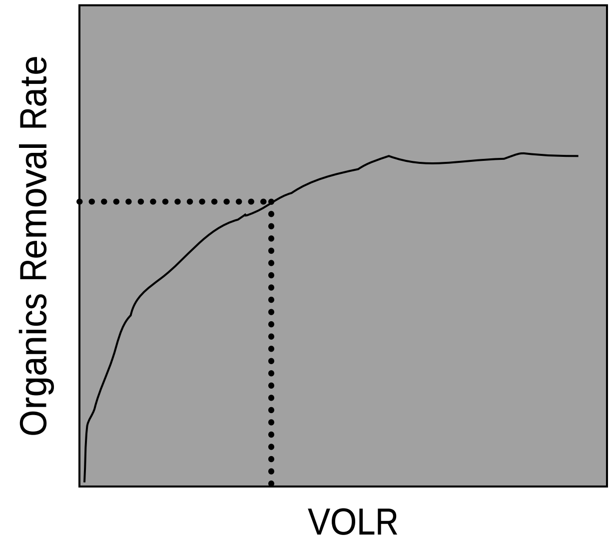
$$VOLR = \frac{S_o \cdot Q}{V}$$

VOLR : Volumetric organic loading rate (kg COD/m^3-day)

S_o : Wastewater biodegradable COD (mg/L)

Q : Wastewater flow rate (m^3/day)

V : Bioreactor volume (m^3)

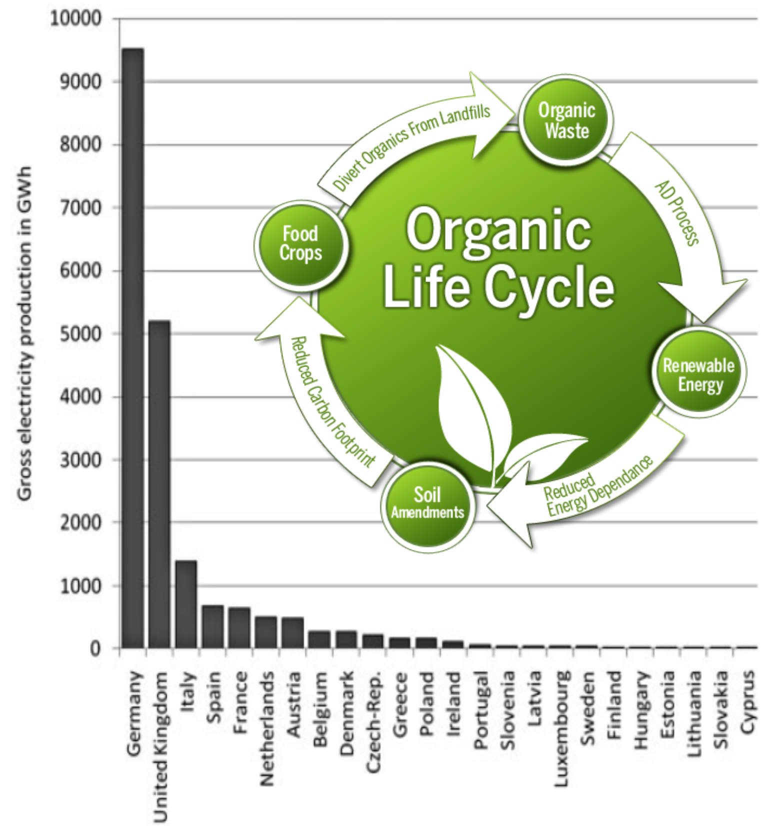


- S_o and Q can be measured easily and are known upfront VOLR can be selected!
- How do we select VOLR?
  - Conducting a pilot scale studies
  - Find out removal efficiency at different VOLRs
  - Select VOLR based on desired efficiency
- Other important design factor : SRT

BIOGAS COMPOSITION PRODUCED BY AD

- The gas components: specified to the plant and substrate and should be checked regularly on a long-term basis

Component	Content	Effect
CO_2	25–50% by vol.	Lowers the calorific value
		Increases the methane number and the anti-knock properties of engines
		Causes corrosion (low concentrated carbon acid). if the gas is wet
		Damages alkali fuel cells
H_2S	0–0.5% by vol.	Corrosive effect in equipment and piping systems (stress corrosion); many manufacturers of engines therefore set an upper limit of 0.05 by vol.%
		SO_2 emissions after burners or H_2S emissions with imperfect combustion – upper limit 0.1 by vol.%
		Spoils catalysts
NH_3	0–0.05% by vol.	NO_x emissions after burners damage fuel cells
		Increases the anti-knock properties of engines
Water vapor	1–5% by vol.	Causes corrosion of equipment and piping systems
		Condensates damage instruments and plants
		Risk of freezing of piping systems and nozzles
Dust	>5 μm	Blocks nozzles and fuel cells
N_2	0–5% by vol.	Lowers the calorific value
		Increases the anti-knock properties of engines
Siloxanes	0–50 mg Nm^{-3}	Act like an abrasive and damages engines



[Gross electricity production from biogas in Europe in GWh in 2007]

Pretreatment Methods

for Enhanced Biogas Production

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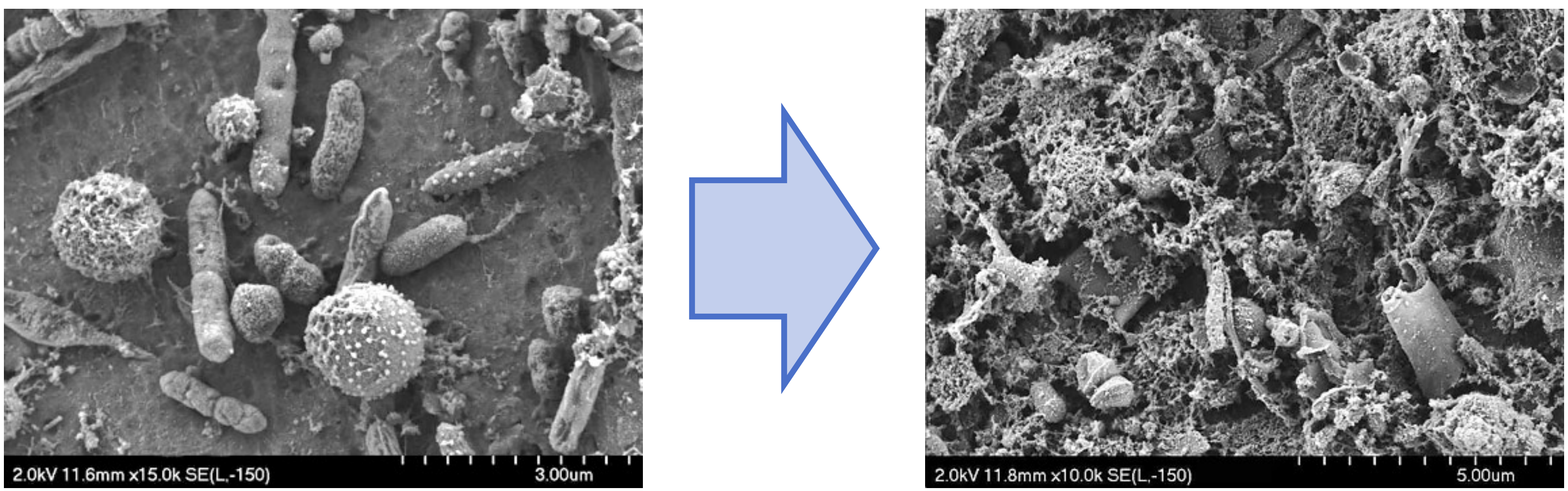
Pretreatment Methods for Enhanced Biogas Production

P. L. McCarty at Stanford University

- Looking for a way to improve anaerobic digestion (in the late 1970s)
  - Primary Sludge (PS) : easily digested
  - Waste Activated Sludge (WAS) : only 1/3 can be digested
- Waste Activated Sludge : mostly consisted of microbial cells
  - Protection by cell walls, most cellular material is unavailable to anaerobic microbes.
- Pretreatment Methods : focused on ‘Cell Lysis”
  - Volatile solids reduction (VSR) can be increased 2~3 times.
  - Biogas production can be doubled.



Methods of Cell Lysis

- High temperature (Hydrolysis)
  - Cambi^{TM} by Cambi AS, Norway : 165°C at 6 bar for 20~30 min
  - Exelys^{TM} by Veolia, France : 165°C at 9 bar for 30 min

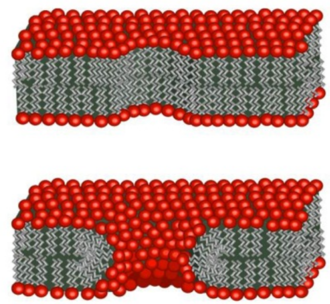
- High Pressure
  - MicroSludge® by Paradigm Environment, Canada : homogenizer (60 bar)

- Physical Force
  - OpenCel® by OpenCel LLC, Atlanta : focused pulse
  - Ultrasound homogenizer

- Others : high or low pH, chemical oxidation, etc.

Cambi^{TM}

MicroSludge® Homogenizer



OpenCel® (pores on cell well)

Carbon source production from sludge using Cell Lysis

- Methanol alternatives as C source for denitrification
  - Reduced sludge production & reduced
  - Utilization as C source has 10 times its value making biogas
    - ⇒ Reduced greenhouse gas emission
    - ⇒ Reduced O&M cost

Major Issues on Pretreatment of Sludge

- Cost can be higher than the benefit it can provide !!
  - Benefit (increased biogas production) should be greater than CAPEX + OPEX.
  - There are various unforeseeable and hidden costs.

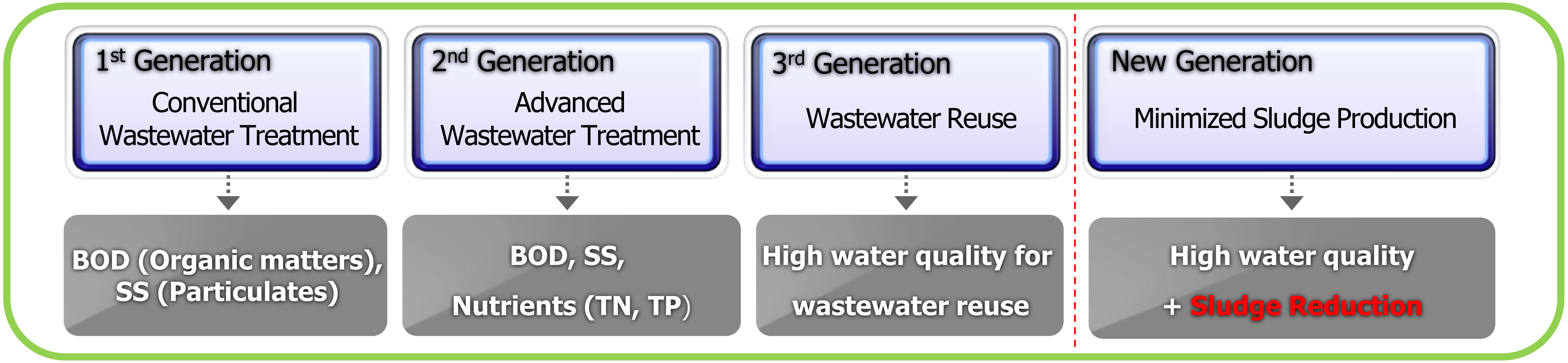
Reduction

of Sludge Production

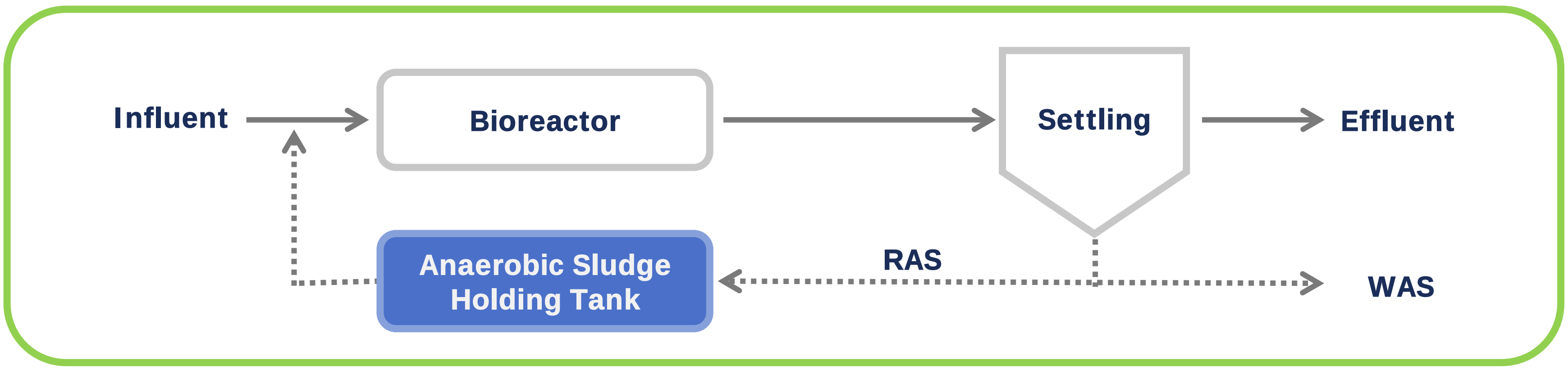
Reduction of Sludge Production

Paradigm Shift

- New technology for source reduction during wastewater treatment by manipulating microbial growth kinetics



- Process Diagram



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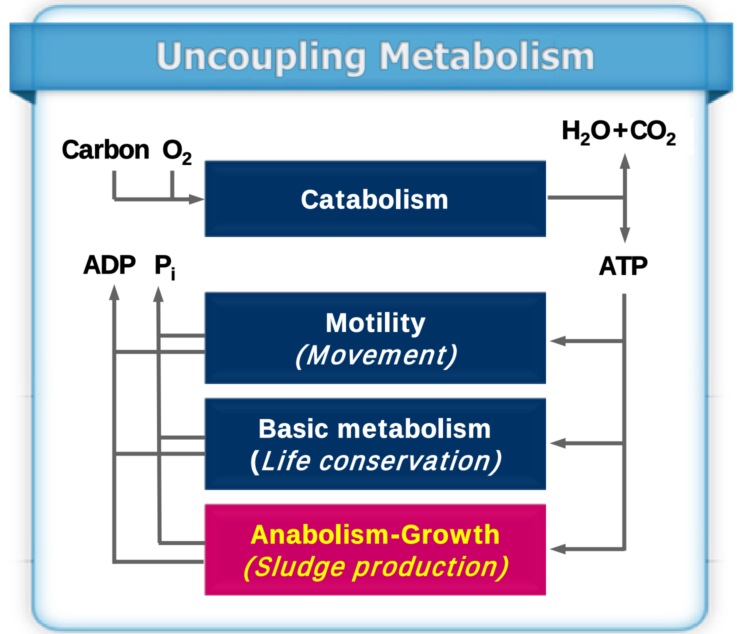
Possible Explanation Uncoupling M

PRINCIPLE OF SLUDGE REDUCTION

- The abrupt change in growth environments
  - Uncoupling metabolism occurs
  - Yield reduction while maintaining substrate uptake rate
  - The reduction of ATP production in microbial cells

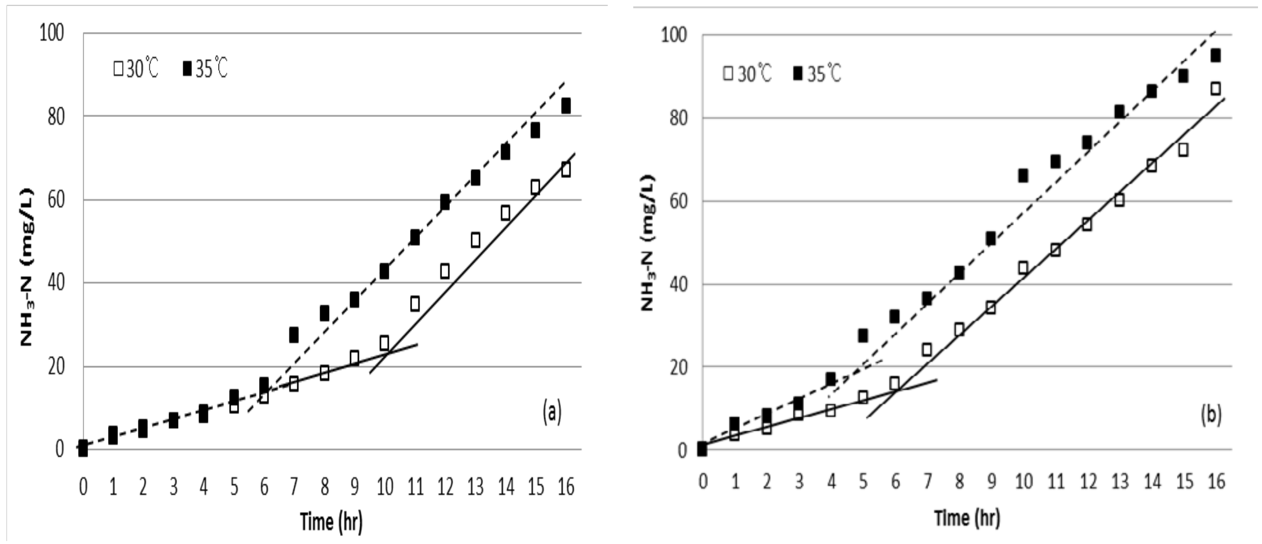


EXPERIMENTAL RESULTS_ Optimal HRT

The concentrations of NH_3-N with time by incubation of the settled sludge at 30°C and 35°C

(a) MLSS = 5,000 mg/L

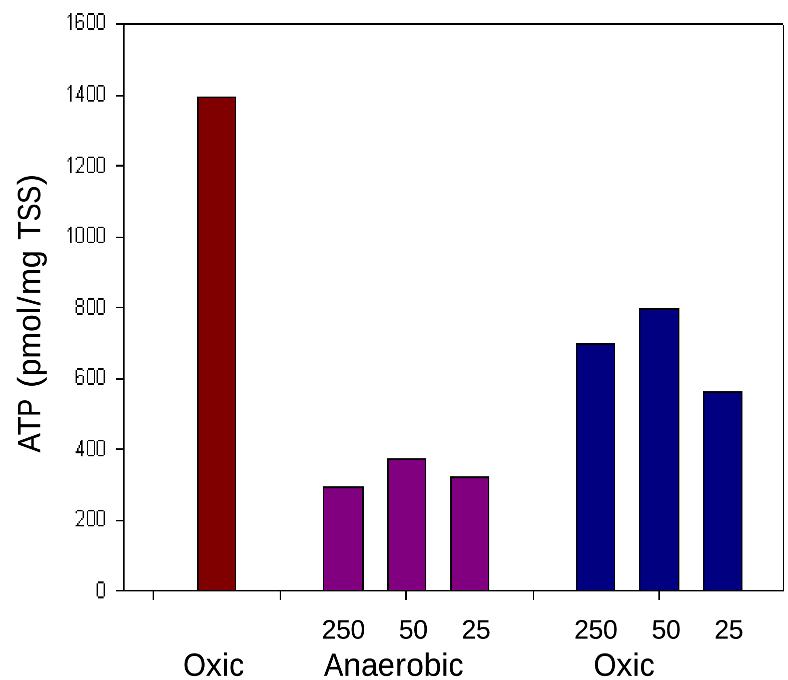
(b) MLSS = 10,000 mg/L



- Increase in the release rate = the increased degradation of microbial cells
- Optimal point : the start of full-fledged endogenous phase at each experimental as the optimal hydraulic retention time for SHT.

EXPERIMENTAL RESULTS_ Metabolism

- Oxic-Anaerobic-Oxic (The change in growth environments)

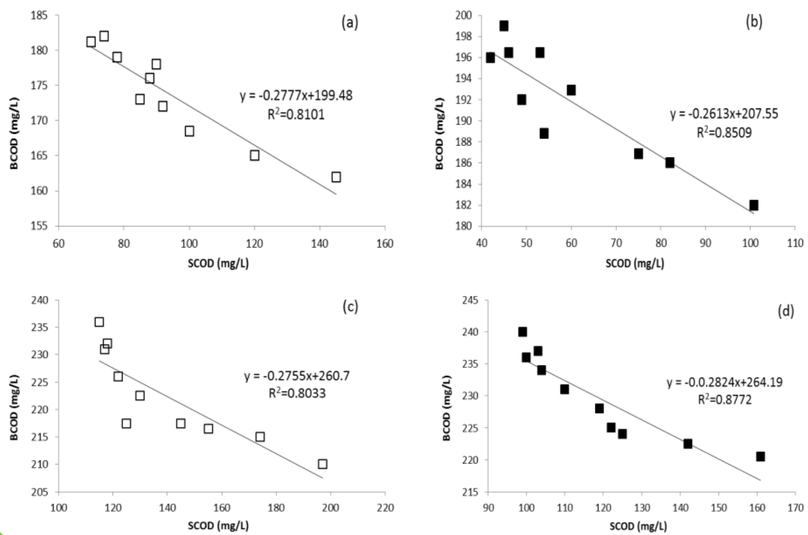


Abbreviation

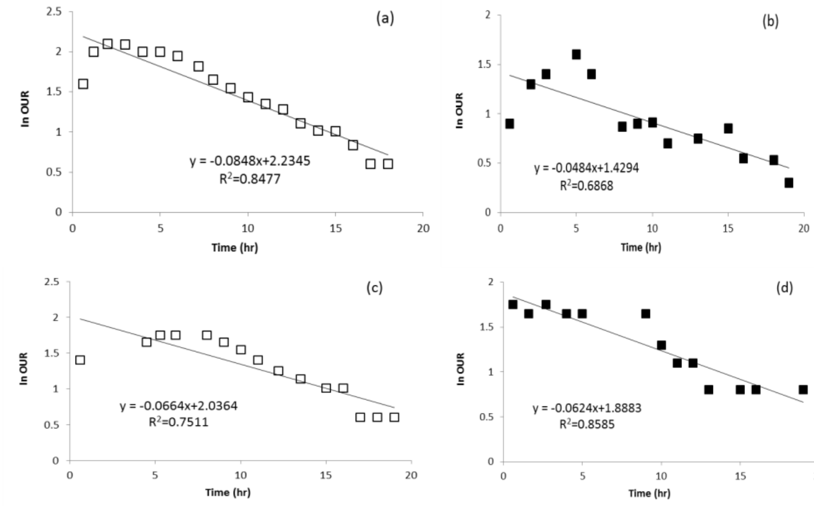
CAS	Conventional Activated Sludge
SHT	Sludge Holding Tank

EXPERIMENTAL RESULTS_ Kinetic parameters

- Y_H estimation



- b_H estimation

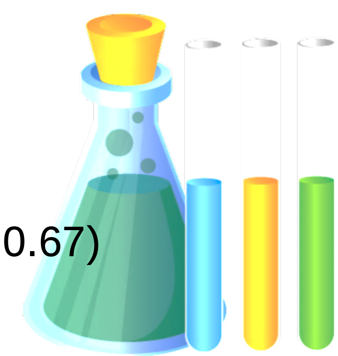


- Conditions & Results

Experiment		(a)	(b)	(c)	(d)
SHT operation condition	MLSS (mg/L)	5,000		10,000	
	Temp. (°C)	30	35	30	35
Y_H		0.27	0.26	0.28	0.27
b_H (day^{-1})		0.11	0.06	0.09	0.08

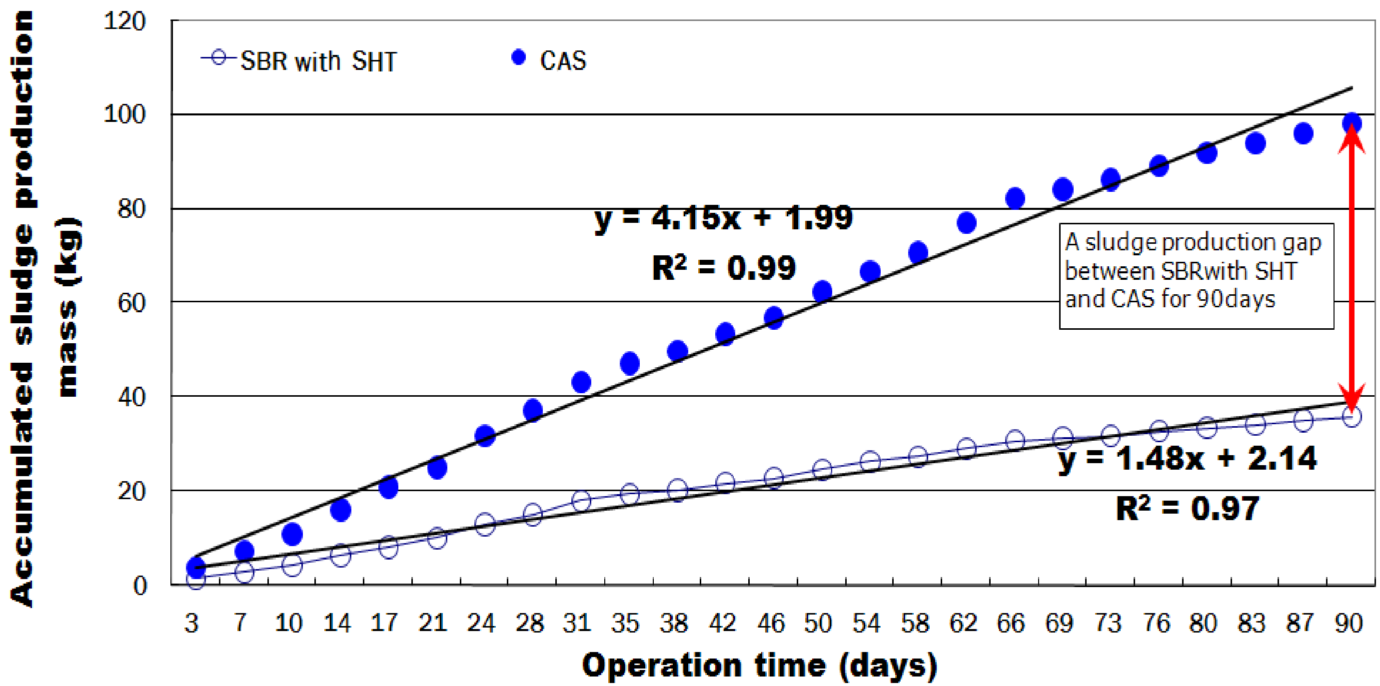
The average values of kinetic parameters

- $Y_{H.avg.}$ = 0.27 (CAS ⇨ 0.67)
- $b_{H.avg.}$ = 0.085 day^{-1}



EFFICIENCY

- WAS production rate can be reduced by **63.5%** compared to conventional process with no deterioration of treatment efficiency.



Reduction of Sludge Production

Abbreviation

CAS Conventional Activated Sludge
STP Sewage Treatment Plant
GHG Green House Gas
GT Green Technology

EFFECT OF TECHNOLOGY

- Excess Sludge Production : Reduction of 63.5% compared to CAS

- Operating costs of STP : Reduction of 30% operating costs

- GHG & Energy

  : Eco-friendly to reduce GHG and energy that occur in sludge treatment.

Discharge coefficient for CO_2

5.3×10^{-2} **[Unit : ton GHG / ton sludge]**

Process	Reduction rate	Weight reduction (Criterion : 100 ton sludge)	Weight reduction Of GHG
e-Tris	63.5 %	63.5 ton sludge	3.4 ton GHC

DAELIM

Q & A

Energy Management in Wastewater Treatment Facility

Nov. 25. 2013

Dr. Hee-Jun Kim

R&D Center, Chief/Director

JIU Corporation

I Background

Current Status

❖ Current Status of Sewage Treatment Facilities in Korea

- Number of sewage treatment facilities : 528 (in 2012)

  (Facilities with capacity lower than 500 m^3/day are not included)
- Total amounts of sewage treated in facilities : 25 million m^3/day
- 65 facilities have anaerobic digester, but only 57 facilities operate digesters actively
- Anaerobic digestion (AD) efficiency is quite lower than those in other countries

❖ AD Efficiency and Sludge Reduction Data in Some Facilities in Korea

Facility	Anaerobic Digester Volume (m^3)	Digestion Efficiency (%)	Sludge Reduction (%)
A	82,776	35.3	27.3
B	17,500	37.3	14.4
C	25,120	25.1	35.9
D	7,234	47.3	68.0
E	7,551	23.8	44.2
F	12,565	42.3	29.1
G	2,154	50.3	30.7

Note) $$\text{Anaerobic Digestion Efficiency} = \left(1 - \frac{FS_{in} \times VS_{out}}{FS_{out} \times VS_{in}}\right) \times 100$$

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Current Status

Energy Consumption in Sewage Treatment Facilities

- Annual energy consumption in sewage treatment facilities : 395,121 TOE (in 2007)
- Among them, electric use occupies 98.6%
- Electric use per flow : 0.29 kWh/m^3
- Electric use per BOD removal : 2.353 (kWh/kg BOD)
- Faction of electricity used in sewage treatment facilities reaches 0.5% of national electricity usage.
- Energy self-sufficiency of sewage treatment facilities is only 0.8%

Note) TOE : Tonnage of Oil Equivalent, the amount of energy released by burning one tonne of crude oil
≈ approximately 42 GJ (10^7 Kcal)

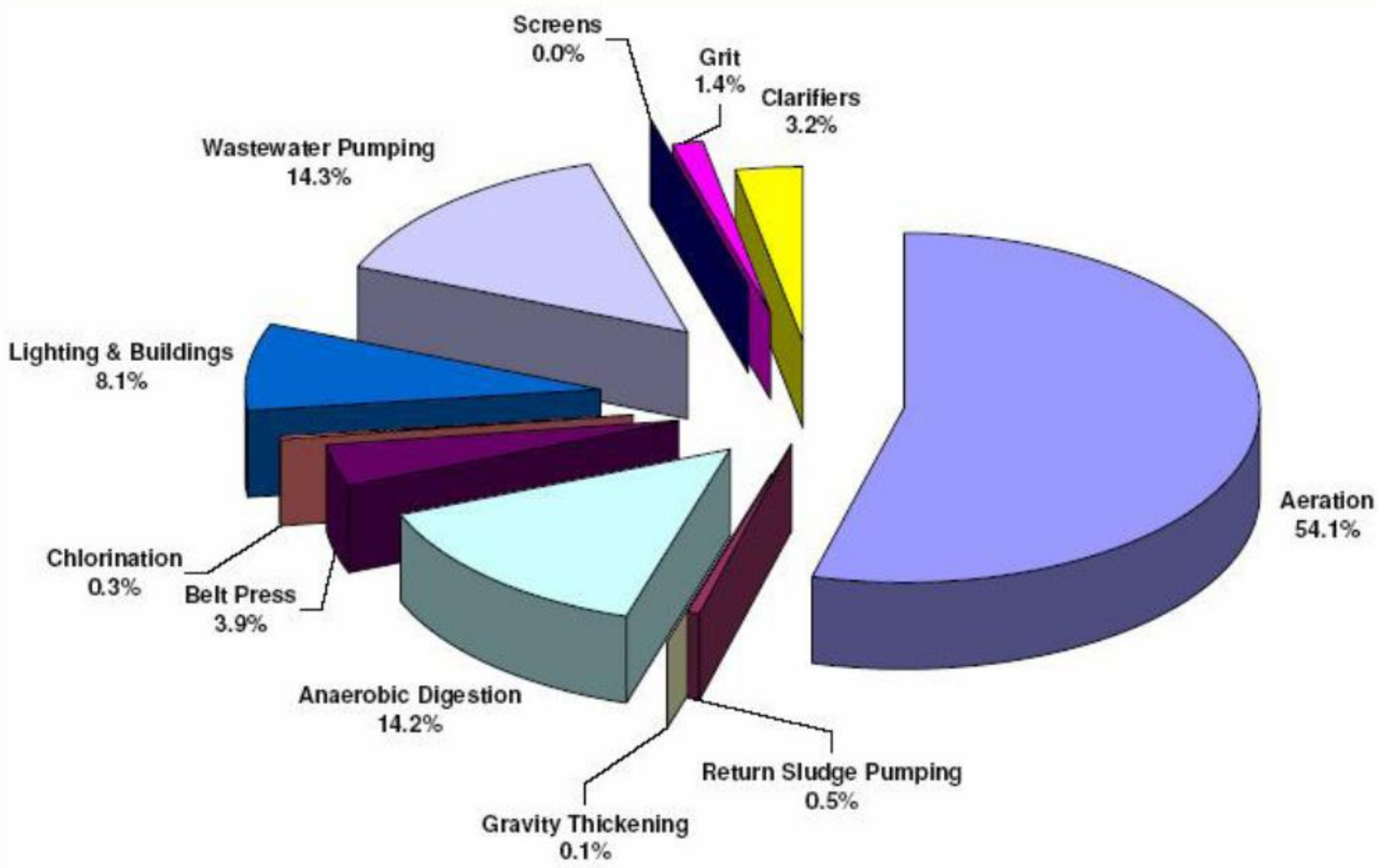
Note) Energy self-sufficiency : (Renewable Energy production + Energy saving)/Annual electric use

Energy Consumption in sewage treatment operations (2008)

Energy related operation	Aeration	Sewage pumping	Dewatering	Sludge pumping	Discharge pumping	Anaerobic Digestion (mixing)	Thickening, screen, etc.
Fraction (%)	40.1	21.3	6.4	3.6	2.3	1.4	23.9

Energy Used in Wastewater Treatment (US)

❖ Energy Consumption in sewage treatment with AS Process



Electricity Requirements for Activated Sludge Wastewater

Derived from data from the Water Environment Energy Conservation Task Force *Energy Conservation in Wastewater Treatment*

Electricity Use by Process (in kWh/MG)

	1 MGD (≈ 3,786 m³/d)	10 MGD (≈ 37,852 m³/d)	100 MGD (≈ 378,520 m³/d)
Wastewater Pumping	171	140	118
Screens	2	1	1
Aerated Grit Removal	49	13	12
Primary Clarifiers	15	16	16
Aeration	532	532	532
Biological Nitrification	346	345	340
Return Sludge Pumping	54	51	38
Secondary Clarifiers	15	16	15
Chemical Addition	80	55	42
Filter Feed Pumping	143	82	67
Filtration	137	39	34
Thickening	6	203	131
Digestion	1,200	170	155
Dewatering	0	46	25
Chlorination	1	3	3
Lighting and Buildings	200	80	30
Total Process	**2,951**	**1,792**	**1,559**

(from WEF M.O.P No. 32, "Energy Conservation in Water and Wastewater Facilities")

Electricity Used in WWTF

❖ Annual Electric Use in Sewage Treatment Facilities

Year	2002	2003	2004	2005	2006	2007	2008	2009
Annual Expenses (million won)	365,084	424,366	468,660	511,082	584,635	649,582	696,934	782,225
Annual Electricity Cost (million won)	77,330	85,914	95,404	102,264	112,786	125,090	137,611	156,139
Electricity/Total (%)	21.2	20.2	20.4	20.0	19.3	19.3	19.7	20.0
Electricity Cost Growth (%)	-	11.1	11.0	7.2	10.3	10.9	10.0	13.5

❖ Electric Use in Sewage Treatment Facility with Different Capacity

Capacity (m^3/d)	Number of Facilities	Total Electric Cost (thousand won /year)	Average Electric Cost (thousand won /year)	Electricity Cost per Sewage Flow (won/m^3)	Electricity Consumption (kwh)	Electric Use per Flow (kwh/m^3)
500 ~ 1,000	53	965,566	18,218	114.2	10,683,210	1.26
1,000 ~ 5,000	102	4,391,042	44,354	72.7	71,014,710	1.18
5,000 ~ 10,000	47	4,679,909	99,573	56.5	59,632,253	0.72
10,000 ~ 50,000	87	20,331,289	239,191	37.8	331,990,571	0.62
50,000 ~ 100,000	23	10,044,406	436,713	25.7	325,614,887	0.83
100,000 ~ 500,000	33	43,710,493	1,324,560	23.2	863,180,857	0.46
500,000 ~	14	57,850,387	4,132,171	17.5	847,361,345	0.26

Note) Average annual electric consumption of 1 household(4 persons) in Seoul city is about 4,800 kwh.

Basic Plan for Energy Self-Sufficiency

❖ **Basic Plan for Energy Self-Sufficiency in Sewage Treatment Facilities**

Main Goal

Energy Self-Sufficiency in Sewage Treatment Facilities in year 2030

: 50% in 343 facilities

Phase 1 ('10 ~ '15)

- Energy self-sufficiency 18%
- Completion of biogas (16.4%) and small hydro power (0.6%) introduction
- Energy saving, solar power and wind power introduction (1%)

Phase 2 ('16 ~ '20)

- Energy self-sufficiency 30%
- Expansion of energy saving (2%) and solar power production (4.6%)
- Completion of wind power introduction (5.4%)

Phase 3 ('21 ~ '30)

- Energy self-sufficiency 50%
- Completion of energy saving (2%) and solar power production project (18%)

(Ministry of Environment, 2010)

Basic Plan for Energy Self-Sufficiency

❖ Some Strategies for Upgrade Energy Self-Sufficiency

Promoting Energy Saving

- Energy efficient operation
- Replacement to energy efficient equipments

Utilization of Unused Energy

- Improvement of biogas production and utilization
- Expansion of beneficial usage of small hydro power and heat energy in wastewater

Production of Natural Energy

- Expansion of solar power and wind power

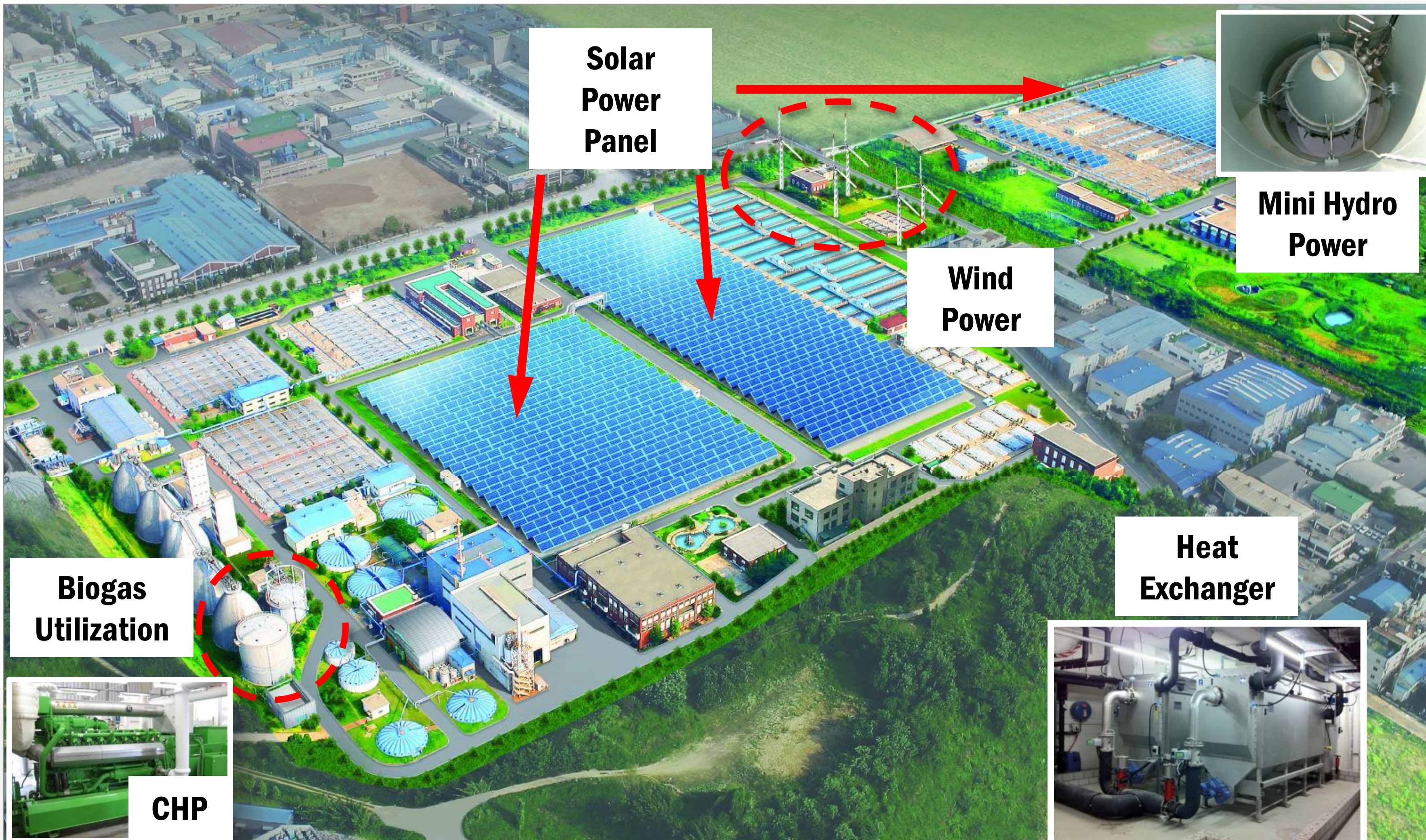
Basis Setting for Energy Self-Sufficiency

- Planning energy self-sufficiency scheme for every treatment facilities
- R&D, education, campaign for low-carbon green growth

(Ministry of Environment, 2010)

Upgrading Energy Self-Sufficiency Example

- Energy Self-Sufficiency Planning in Ansan WWTF, Korea



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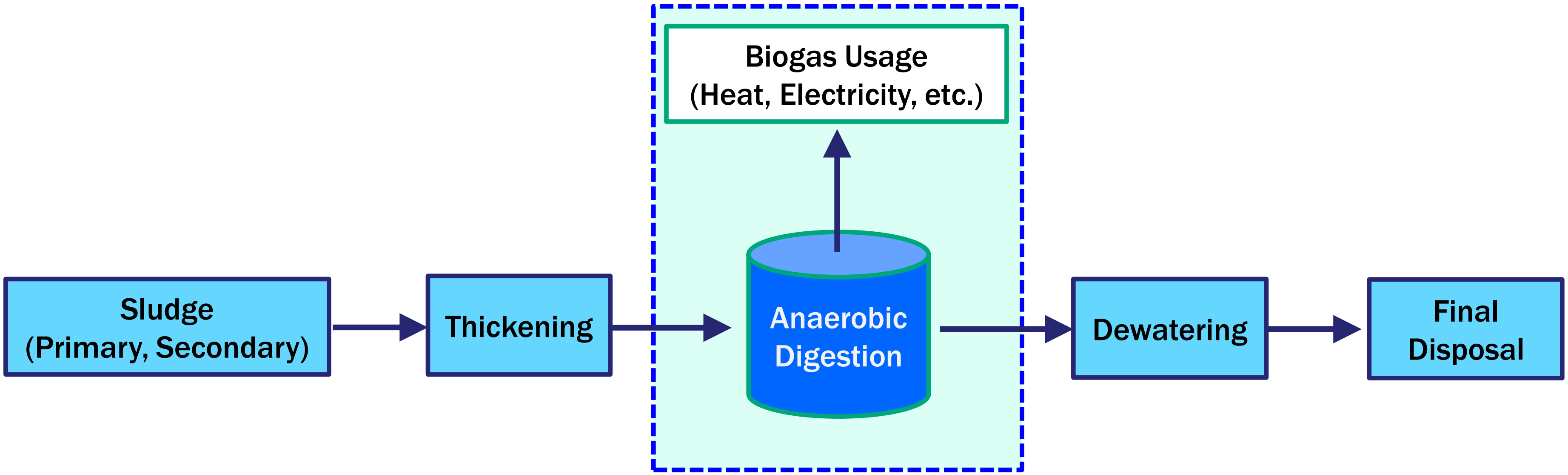
Ⅱ Session 1

Is Anaerobic Digestion Always Economical in WWTF?

Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Boundary



Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Criteia

Benefit/Cost Ratio (B/C ratio)

$$B/C = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} / \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

- t : time
- n : period, 20 years for sludge treatment facility
- r : discount rate (5.5%)
- Present value of project benefits / present value of project costs
- If B/C ≥ 1.0, the project is judged to be worthwhile in economic terms

Calculation of B/C ratio

Period	Cost						Benefit		
	Construction (million won)	Personnel Expenses (thousand won/ year)	Electricity (thousand won/ year)	Heating Energy (thousand won/ year)	Maintenance (thousand won/ year)	Sum (million won)	Biogas Usage (thousand won/ year)	Sludge Cake Reduction (thousand won/ year)	Sum (million won)
1	17,944	52,718	73,075	272,583	50,402		625,856	219,612	
2		49,970	69,265	258,373	47,774		593,228	208,163	
3		47,365	65,654	244,903	45,283		562,302	197,311	
.		.	.	.	.		.	.	
.		.	.	.	.		.	.	
.		.	.	.	.		.	.	
19		20,110	27,875	103,981	19,227		238,743	83,774	
20		19,062	26,422	98,560	18,224		226,296	79,407	
	17,944	664,654	921,300	3,436,638	635,447	23,602	7,890,575	2,768,791	10,659

- B/C ratio = 23,602/5,676 = 0.45

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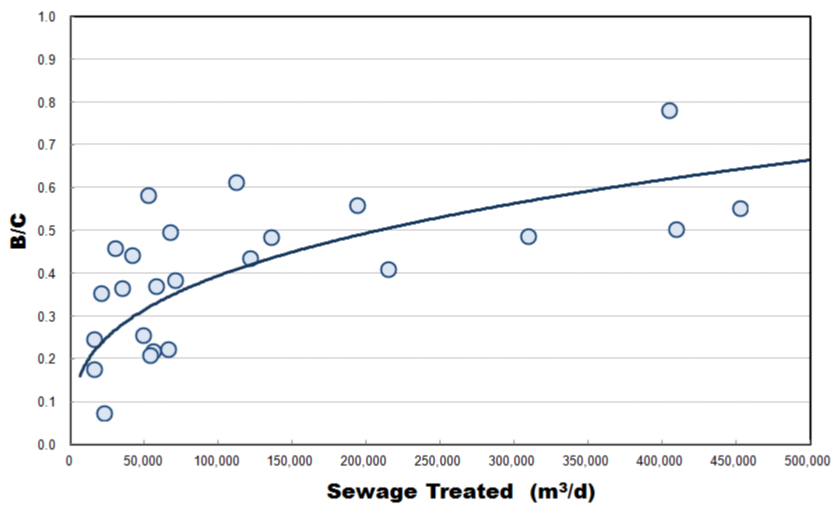
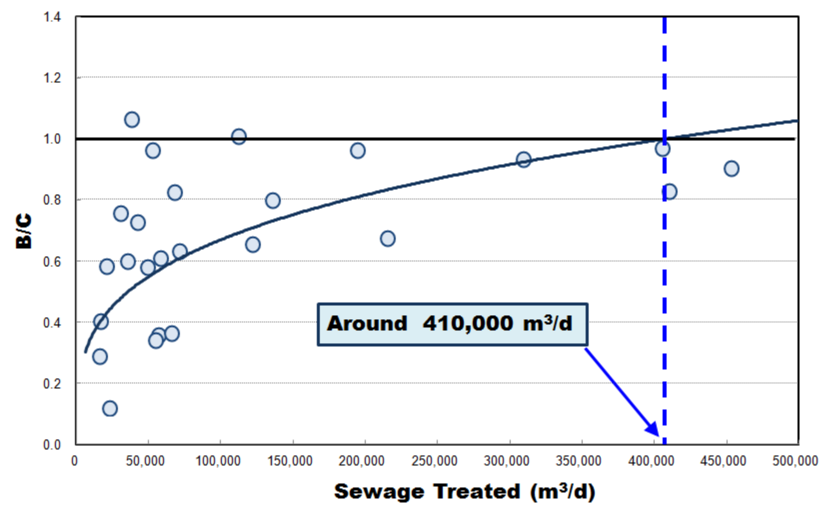
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Digestion Efficiency



<Digestion Efficiency 27%>



<Digestion Efficiency 45%>

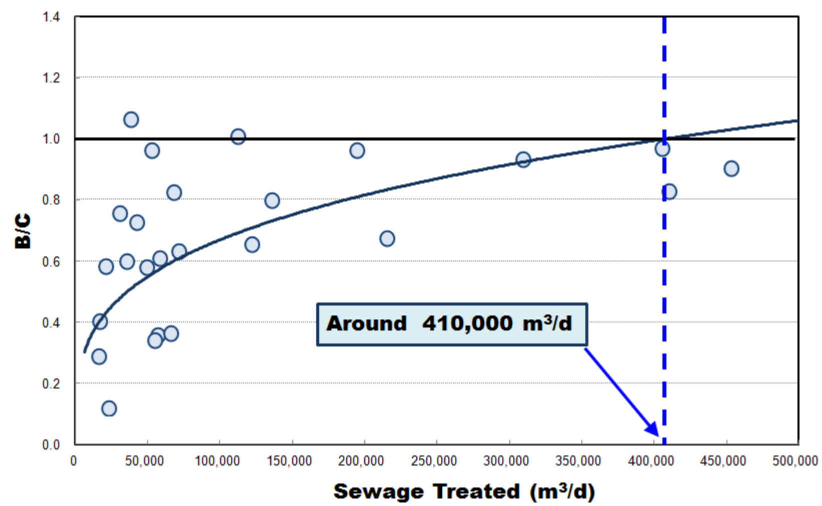
Note) 27% is average digestion efficiencies of 24 sewage treatment facilities

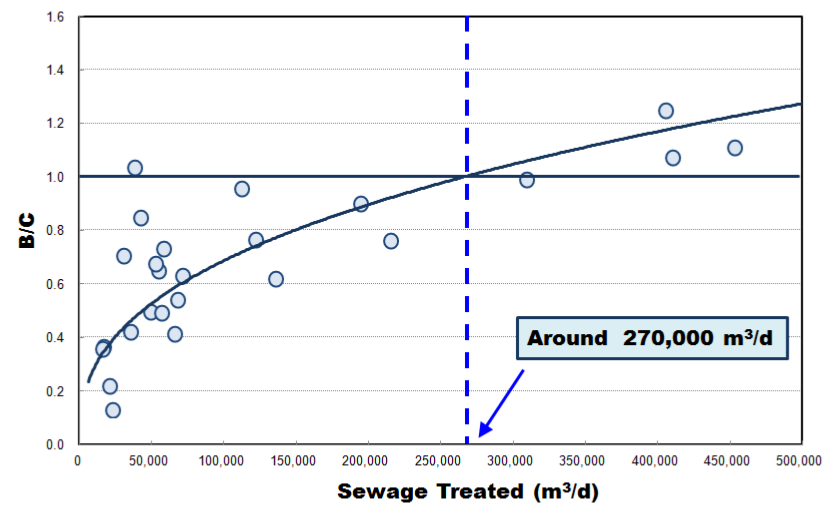
- At 27% of digestion efficiency, there was no facility with B/C ratio over 1.0.
- At 45% of digestion efficiency, B/C ratio exceeds 1.0 at wastewater treatment capacity over 410,000 m^3/d.
- Increase in digestion efficiency raise B/C ratio due to the biogas production increase and reduction in sludge cake production.

Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Final Disposal Cost





<Using individual final disposal cost>

<Using average final disposal cost>

Note 1) Anaerobic digestion efficiency was assumed to be 45% at all treatment facilities

Note 2) Final disposal cost

Carbonization	: 116,000 won/cake ton	Incineration	: 87,000 won/cake ton
Drying	: 100,000 won/cake ton	Solidification	: 63,000 won/cake ton
Average	: 91,000 won/cake ton		

- With average final disposal cost, the treatment capacity with B/C ratio 1.0 reduces to 270,000 m^3/d.
- Final disposal cost largely affects on B/C.

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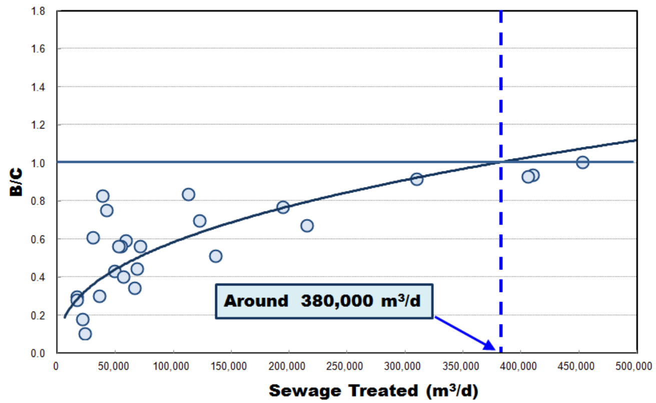
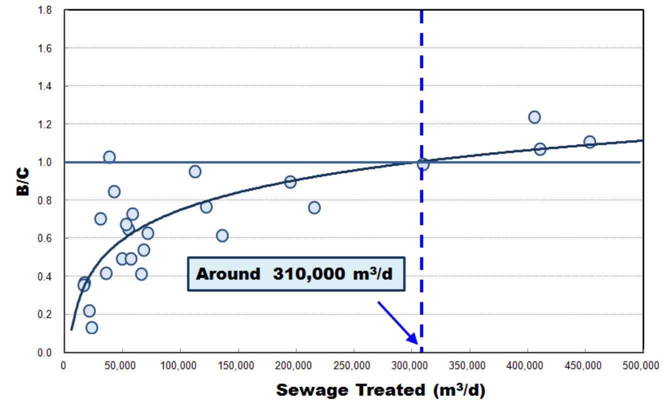
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

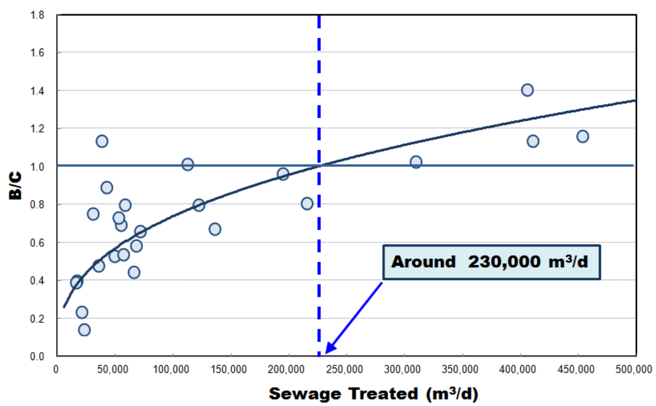
Effect of Final Disposal Methods



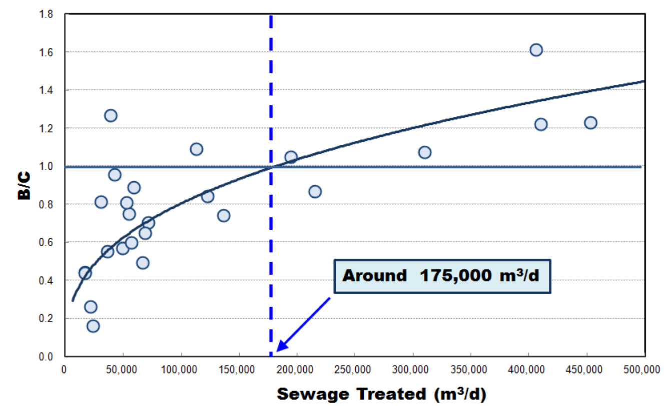
<Solidification>



<Incineration>



<Drying>



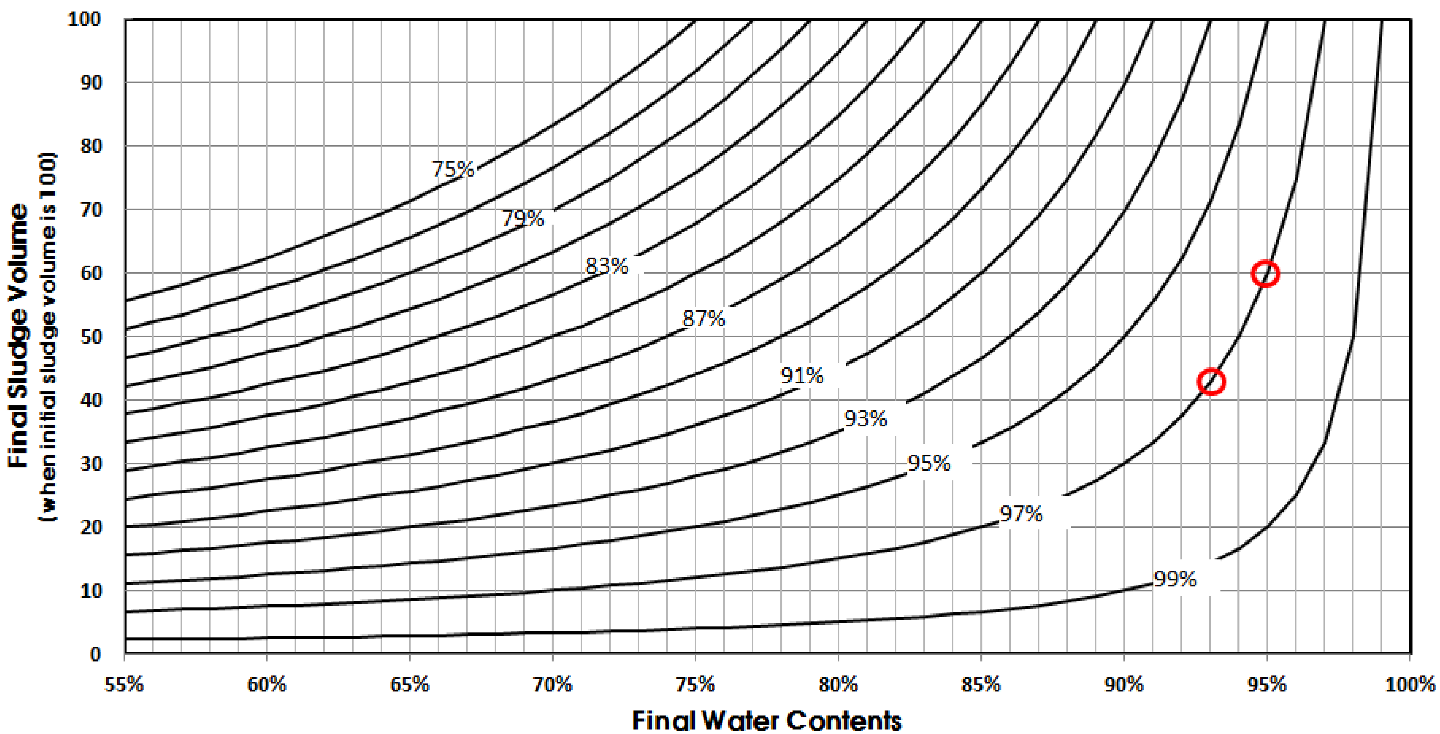
<Carbonization>

- AD installation is more economical at the facility using carbonization as the final sludge disposal option.

Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Sludge Thickening before AD

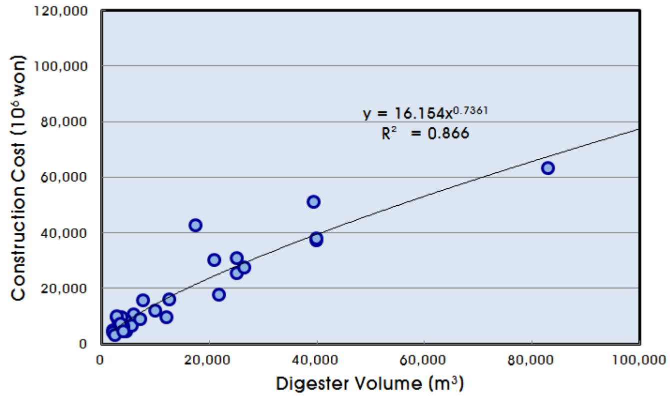


- Average water contents (W.C) of influent sludge is about 97%.
- If W.C of sludge is reduced to 95% or 93%, the volume of sludge will be 60% or 42% of initial sludge volume, respectively. → We can build smaller anaerobic digester

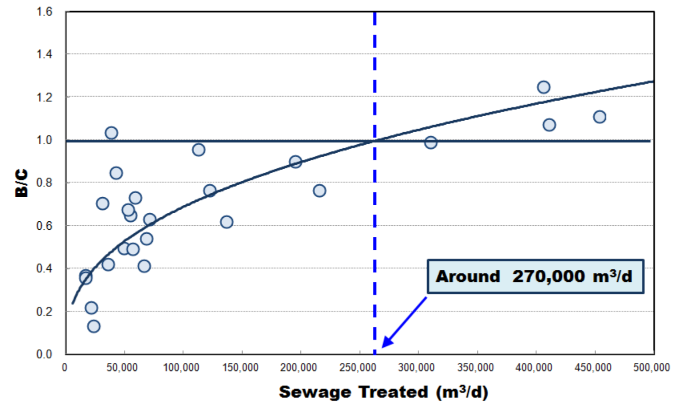
Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

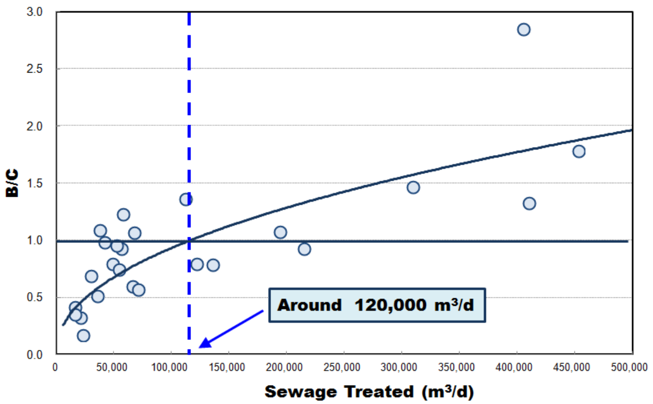
Effect of Sludge Thickening before AD



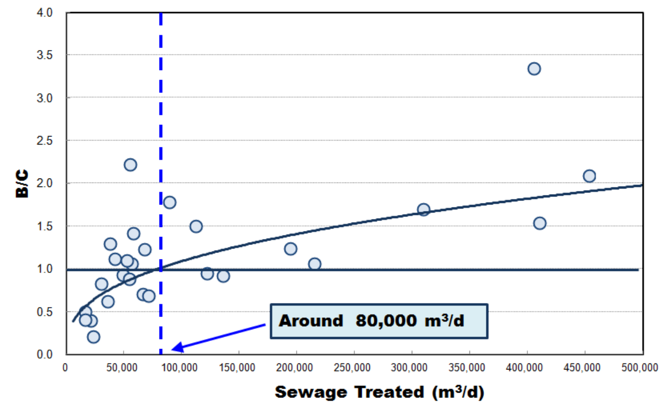
<AD construction cost vs AD volume>



<Water Content : 97%>



<Water Content : 95%>



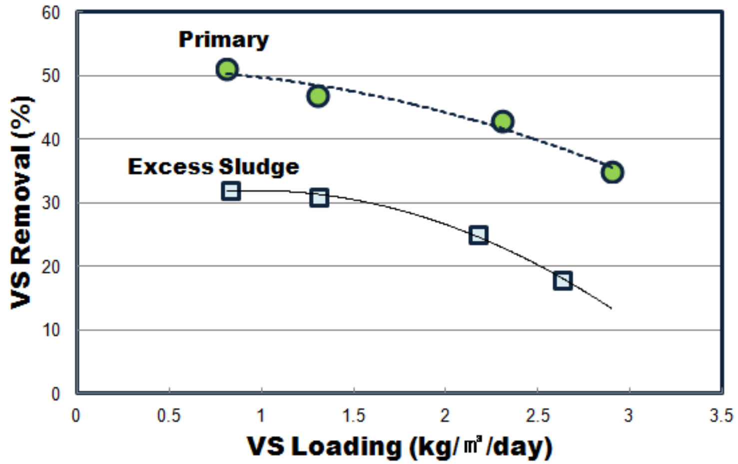
<Water Content : 93%>

- Higher solids contents leads to smaller capacity reaching B/C = 1.0 due to the lower construction cost.

Cost Benefit Analysis of AD Installation

❖ Cost Benefit Analysis Results

Effect of Sludge Thickening on VS Removal



- Higher VS loading can deteriorate anaerobic digestion efficiency.

❖ Some Findings from Cost Benefit Analysis Results

- There's specific anaerobic digestion capacity that can achieve economical benefit under given operational condition.
- If you want to gain economical benefit with smaller anaerobic digester (i.e. lower initial investment), mainly consider the measures to increase solids contents in sludge and anaerobic digestion efficiency.

Energy Management in Wastewater Treatment Facility

Dec. 02. 2013

Dr. Hee-Jun Kim

R&D Center, Chief/Director

JIU Corporation

Ⅲ Session 2

How to Improve Energy Self-Sufficiency in WWTF?

Basic Strategies

❖ Energy Self-Sufficiency

Definition

$$\text{Energy self-sufficiency} = \frac{(\text{Renewable Energy production} + \text{Energy saving})}{\text{Annual electric use}}$$

Basic Strategies to Enhance Energy Self-Sufficiency

- Improve renewable energy production

  : mainly, enhancing biogas production in AD

  (co-digestion of food waste or night soil can be considered)

  : introducing solar power, small hydropower, wind power, etc.

- Focus on biggest energy consumers at WWTF (aeration, pumping, etc)
- Tailor operations to meet seasonal and diurnal changes
- Consider equipment life and energy usage to guide repair and replacement

Pretreatment Before Anaerobic Digestion

❖ What Can We Expect from Pretreatment Before Anaerobic Digestion

- Faster hydrolysis of particulate
- Decrease of retention time in anaerobic digestion
- Enhancement of biogas production
- Improvement of dewatering characteristic of sludge

❖ Types of Pretreatment Methods

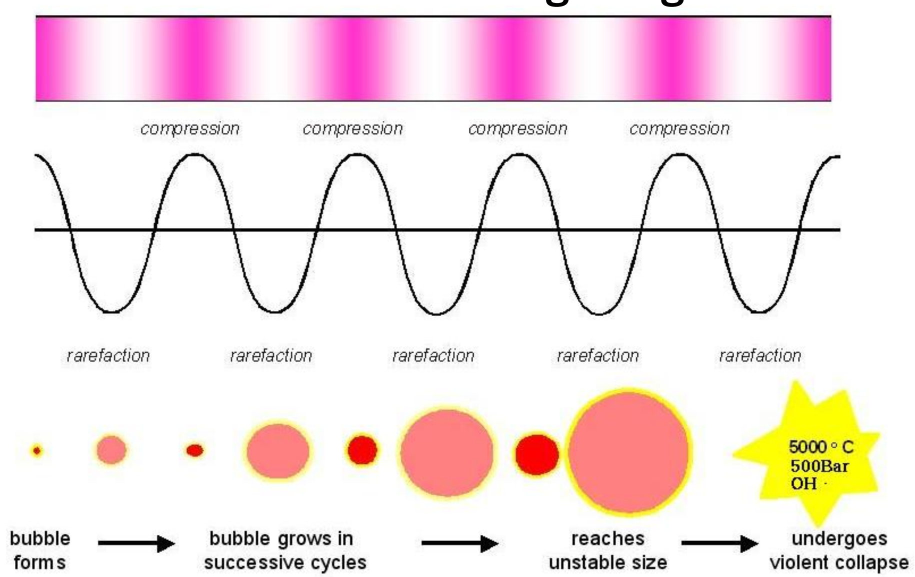
- Mechanical : homogenizer, stirred ball mills, **cavitation**, etc.
- Chemical : alkaline/acid hydrolysis, ozonation
- Biological : enzyme addition, thermophilic bacteria injection, etc.
- Thermal : **thermal hydrolysis** & Freeze-Thawing
- Combined : thermal-chemical, ultrasonic-chemical, etc.
- Others : electron beam, microwave, **focused pulsed electricity** etc.

Ultrasonic Pretreatment

❖ Principles

- At the lower end of ultrasound (20kHz to 10MHz), the compaction and rarefraction waves generated by ultrasound lead to the formation of cavitation bubbles in the fluid, which implode creating high mechanical shear forces.
- The implosions create localized hot spots (temperatures up to 5,000°C) and pressures up to 500 bar (7,250 psig) and jet-stream (400 km/hr)

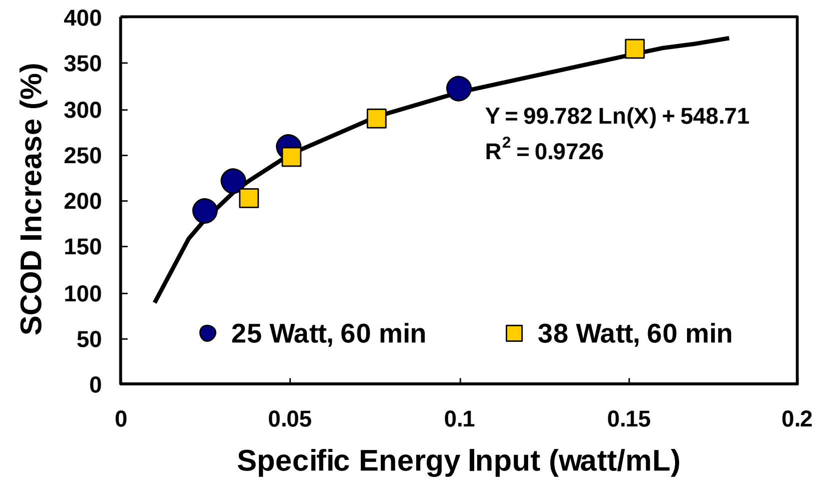
  → Shear forces can be used for disintegrating solids in the fluid



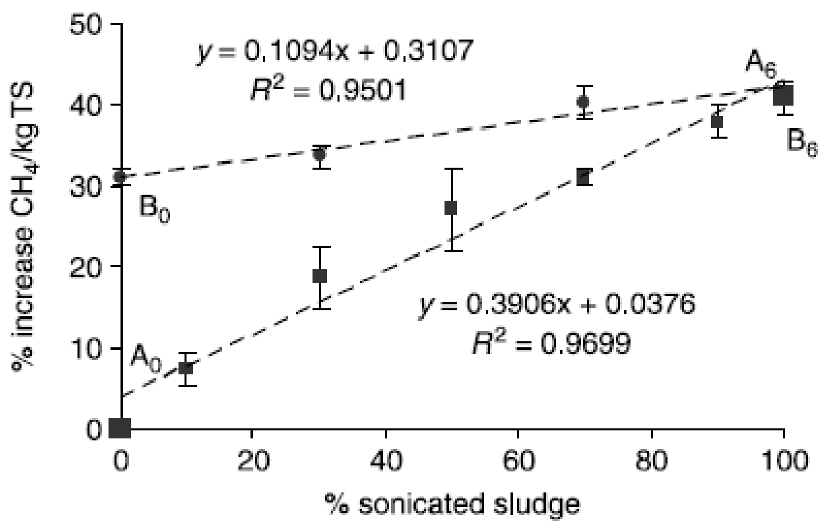
Ultrasonic Pretreatment

❖ Principles

Human hearing		16Hz - 18kHz
Conventional power ultrasound		20kHz - 100kHz
Extended range for sonochemistry		20kHz - 2MHz
Diagnostic ultrasound		5MHz - 10MHz

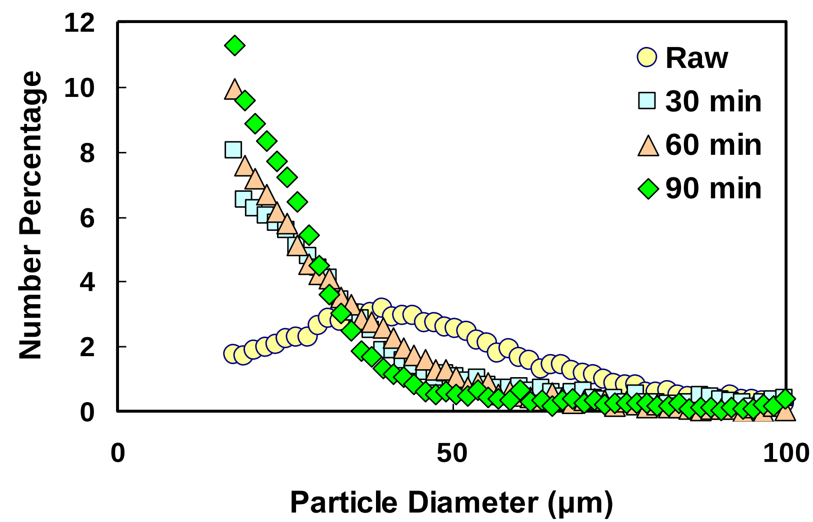


<Effect of energy input on SCOD increase>



<Sonicated sludge fraction in AD vs methane production>

(Perez-Elvira et al, 2010)



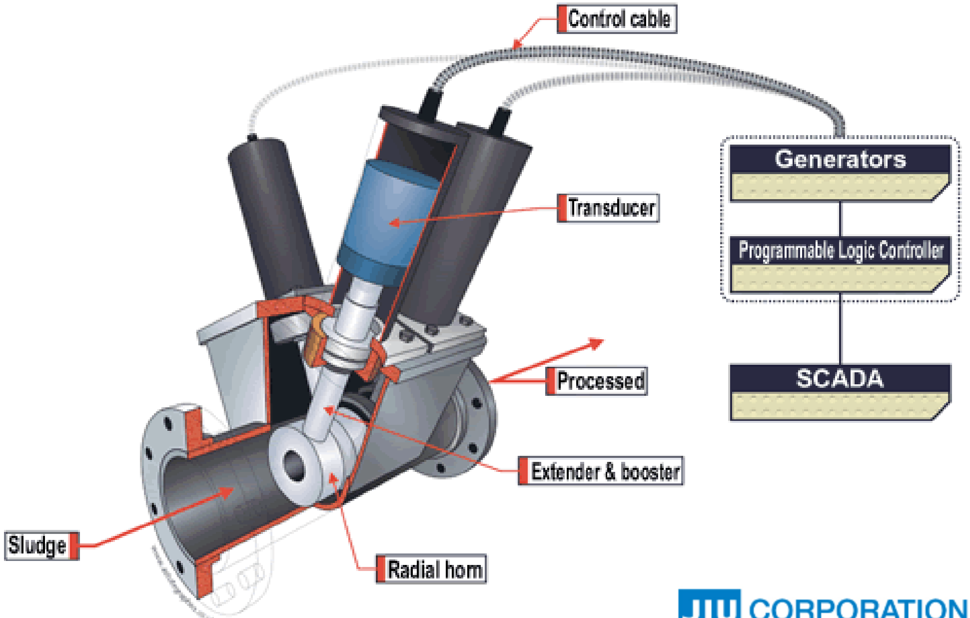
<Effect of sonication time on particle size>

Ultrasonic Pretreatment

❖ Commercial Process - Sonix

Description

- English company, Sonico
- Usually 3 to 5 sonotrodes are installed in 1 unit (6kW/unit)
- VS reduction and gas production increase by up to 30 ~ 50%

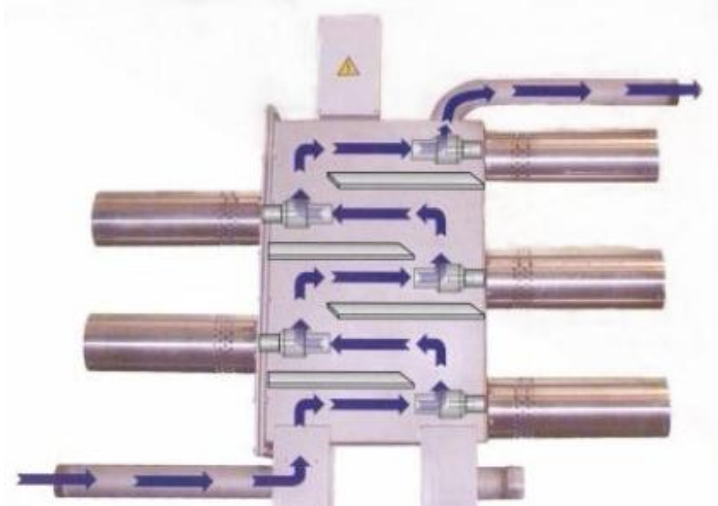


Ultrasonic Pretreatment

❖ Commercial Process - Ultrawaves

Description

- German company, Ultrawaves
- Usually 5 sonotrodes are installed in 1 unit (2kW/unit)
- WAS treatment fraction is 30 to 50%
- Ultrasound energy : 0.04 ~ 0.05 kWh/kg DS
- VS reduction and gas production increase by up to 20 ~ 50%
- Applied in one Korean WWTF (Ulsan Yongyeon)



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Ultrasonic Pretreatment

❖ Commercial Process – Reverse Flow Disintegration Unit

Description

- Austrian company, VTA Technologie GmbH
- Sewage sludge continuously flows top down through the disintegration reactor
- Mixing with agitator installed in reactor (30 ~ 120rpm)
- Disintegration degree can be controlled with the residence time of the sludge in the reactor, the flow rate, the rotation speed of the agitator and the energy input of the integrated ultrasonic elements
- VS reduction and gas production increase by up to 20～50%

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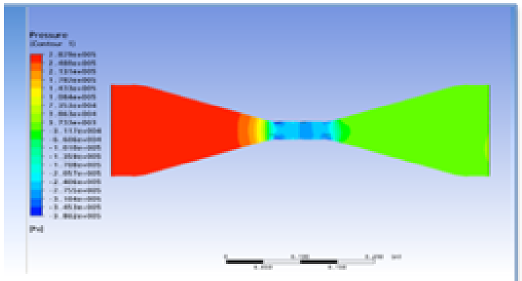
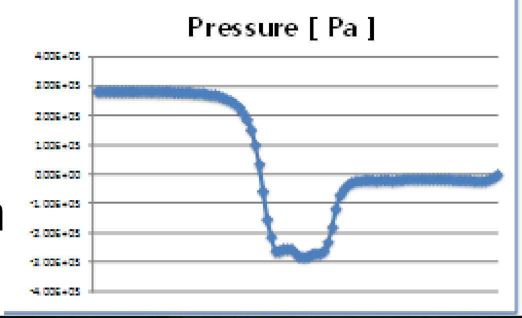
Hydrodynamic Cavitation Pretreatment

❖ Commercial Process – Crown Disintegration





Description

- German company, Biogest
- Cavitation bubbles produced in the constriction region (venturi throat) due to the pressure drop below vapour pressure and rapidly collapses (implosion) in the expansion region → producing shock waves
- Homogenizer, progressive cavity pump, disintegrator and control panel
- Gas production increase by up to 30%

Thermal Pretreatment

❖ Commercial Process - Cambi Process

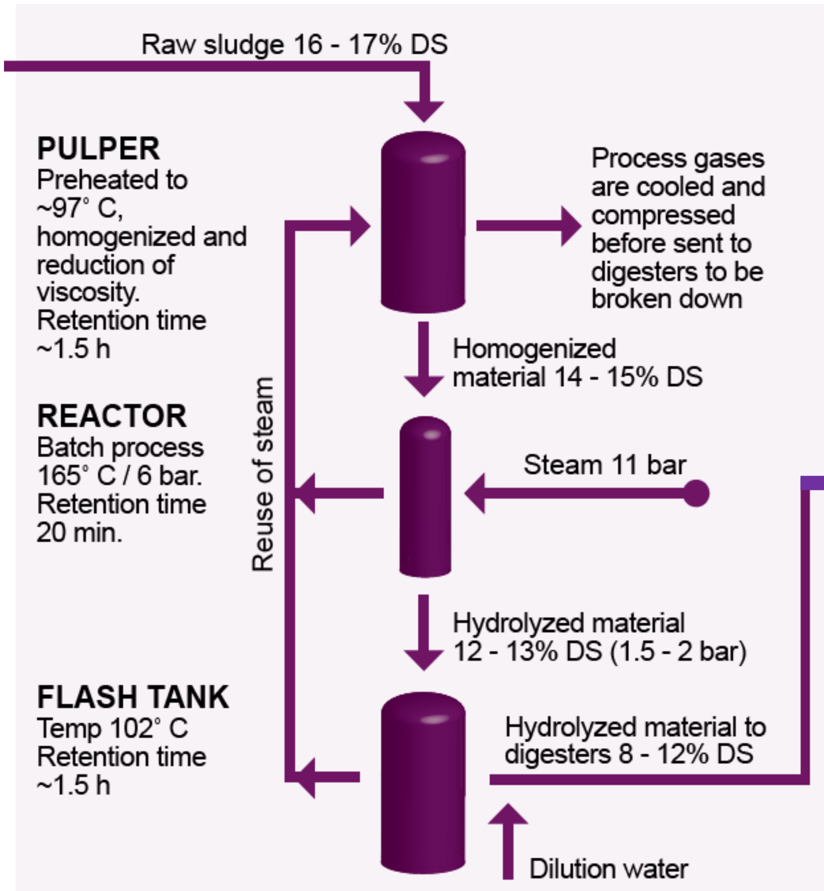
Description

- Norwegian company, Cambi
- First full scale demonstration plant

  : HIAS WWTP in Hamar, Norway
- Using high-pressure steam : 6 bar, 165°C
- Process configuration

  : Pulper – Reactor – Flash Tank
- Batch process
- Need pre-dewatering process

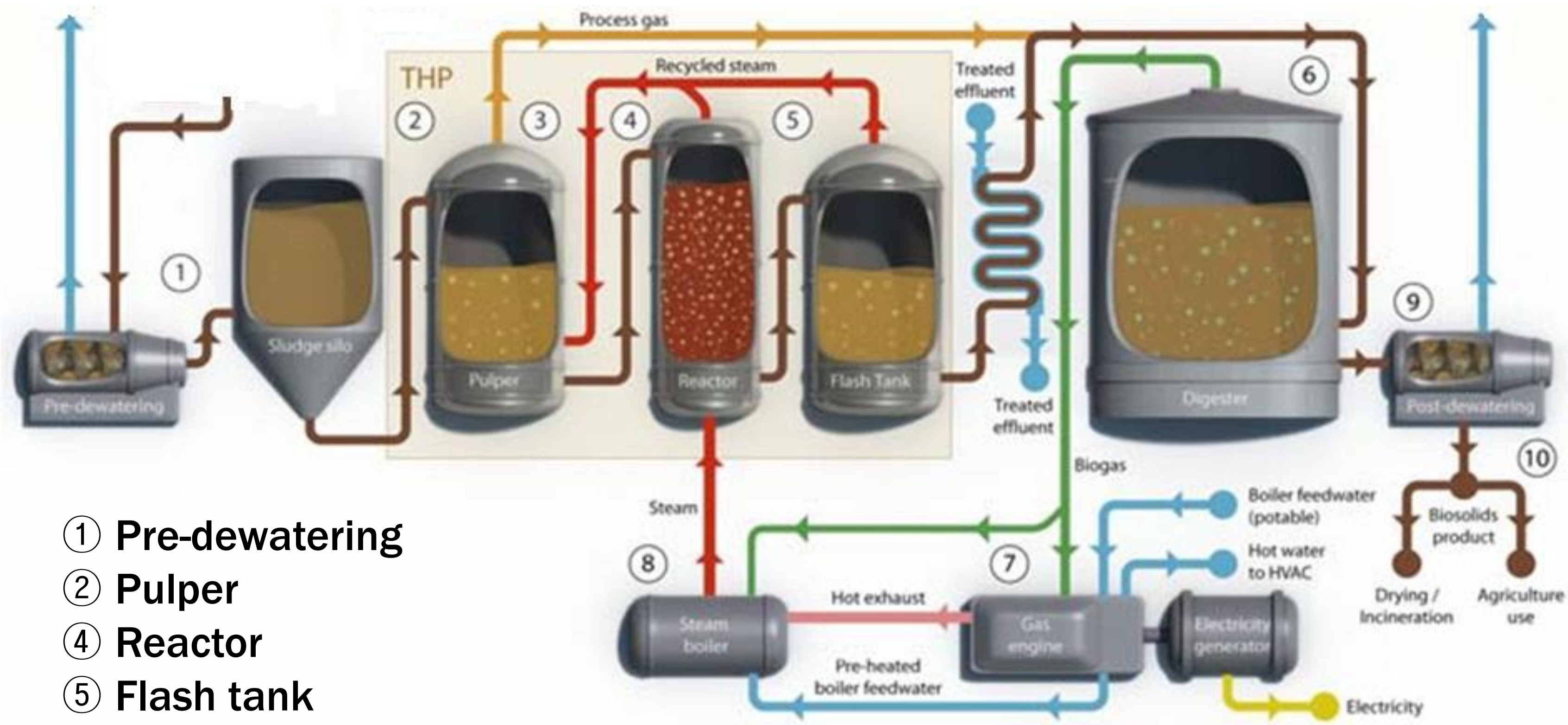
  : TS contents 16 ~ 17%
- Increase gas production up to 30 ~ 100%



Thermal Pretreatment

❖ Commercial Process - Cambi Process

- Flow Diagram

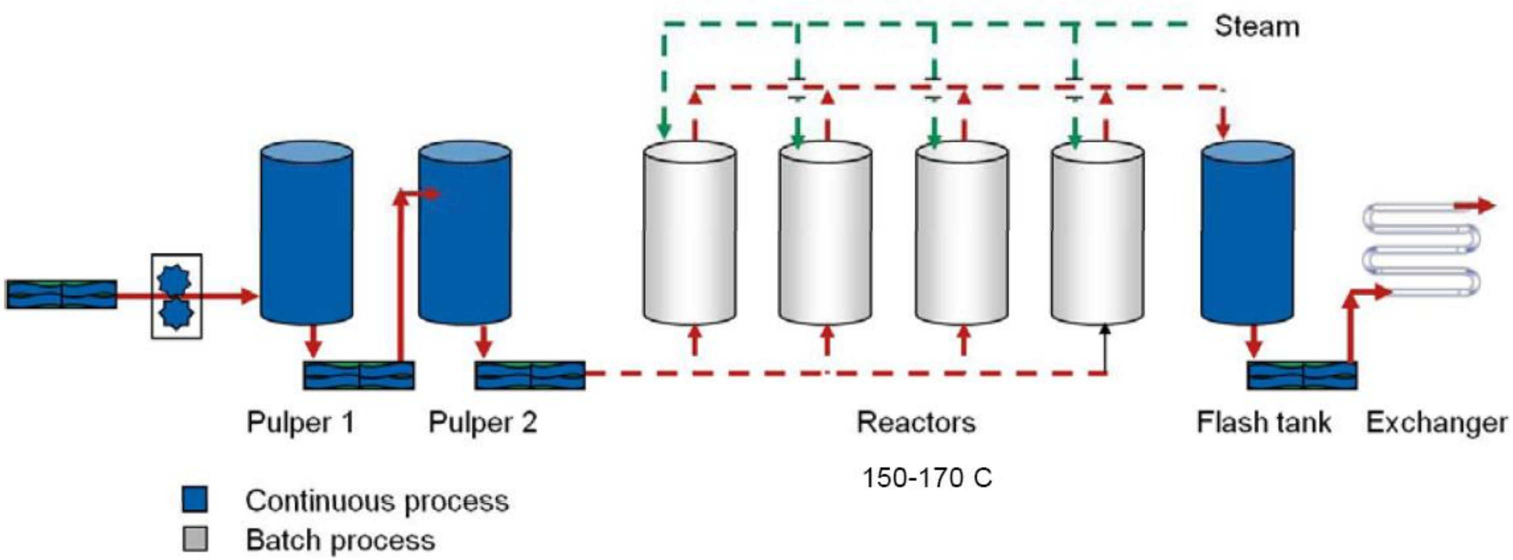


① Pre-dewatering
② Pulper
④ Reactor
⑤ Flash tank

Thermal Pretreatment

❖ Commercial Process - Cambi Process

- Operation



	15 min	15 min	30 min		15 min	15 min
Reactor 1	Fill	Steam In	React		Steam out	Empty
Reactor 2	Empty	Fill	Steam In	React		Steam out
Reactor 3	Steam out	Empty	Fill	Steam In	React	

Thermal Pretreatment

❖ Commercial Process - Biothelys Process

Description

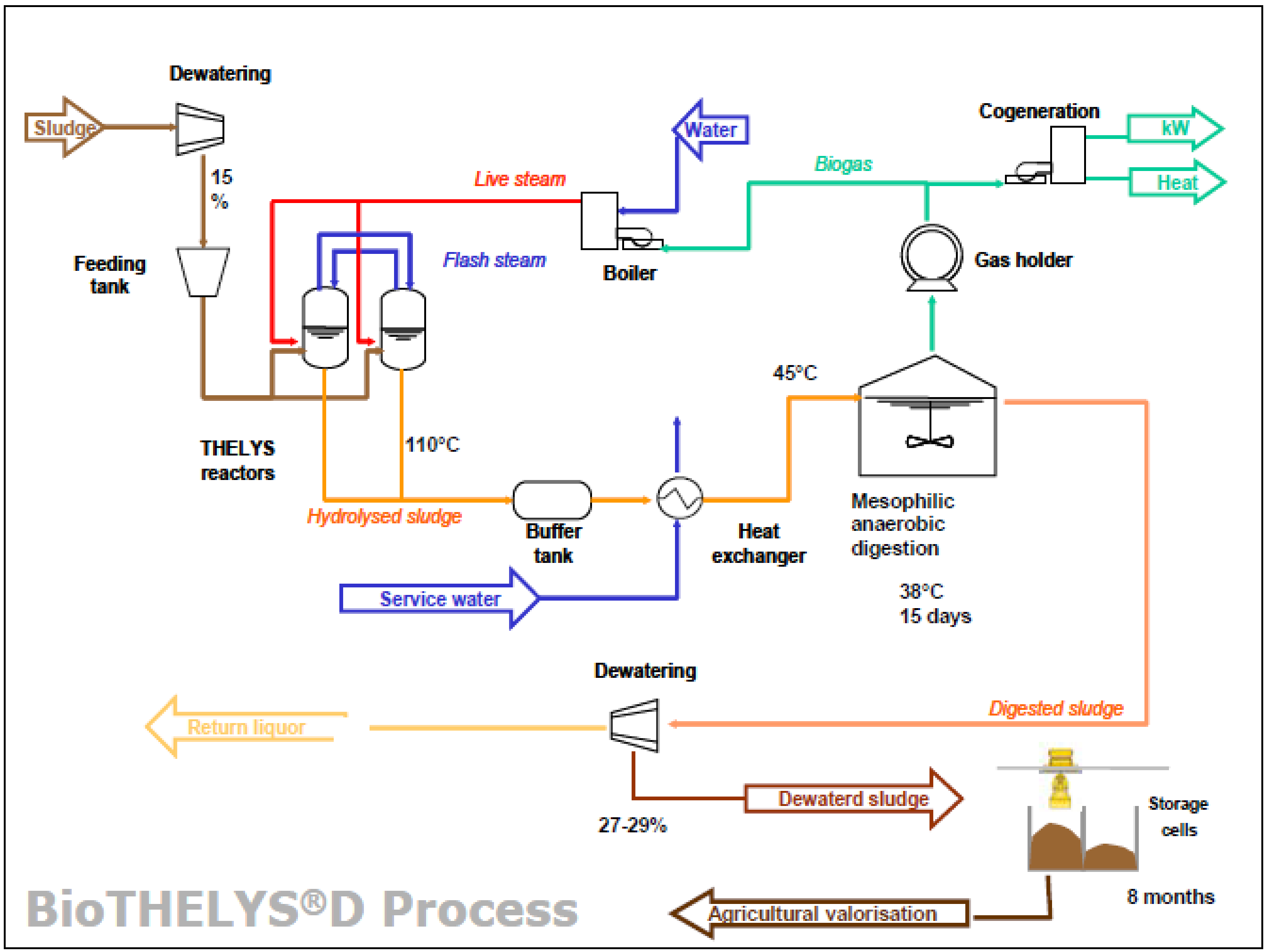
- French company, Veolia
- Thermal hydrolysis (Thelys process) + anaerobic digestion
- Using high-pressure steam (7 ~ 9 bar, 150 ~ 170°C)
- Batch process
- Retention time 30 ~ 60 min
- Need pre-dewatering process

  : TS contents around 15%
- Reduce quantity of sludge production by up to 80%
- Tergnier (1,600ton DS/y) WWTF, France

Thermal Pretreatment

❖ Commercial Process - Biothelys Process

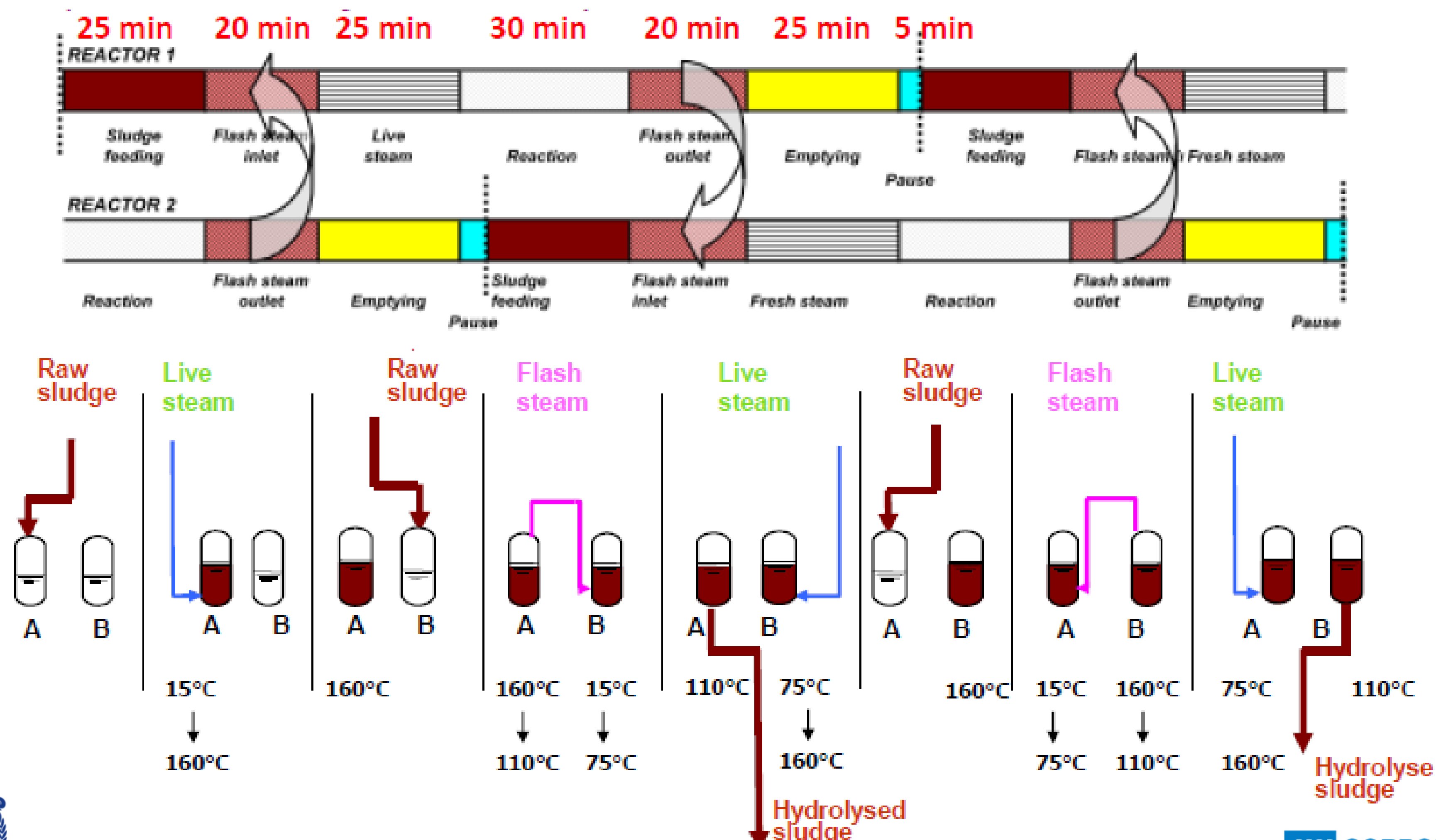
Flow Diagram



Thermal Pretreatment

❖ Commercial Process - Biothelys Process

Operation



Thermal Pretreatment

❖ Commercial Process - Exelys Process

Description

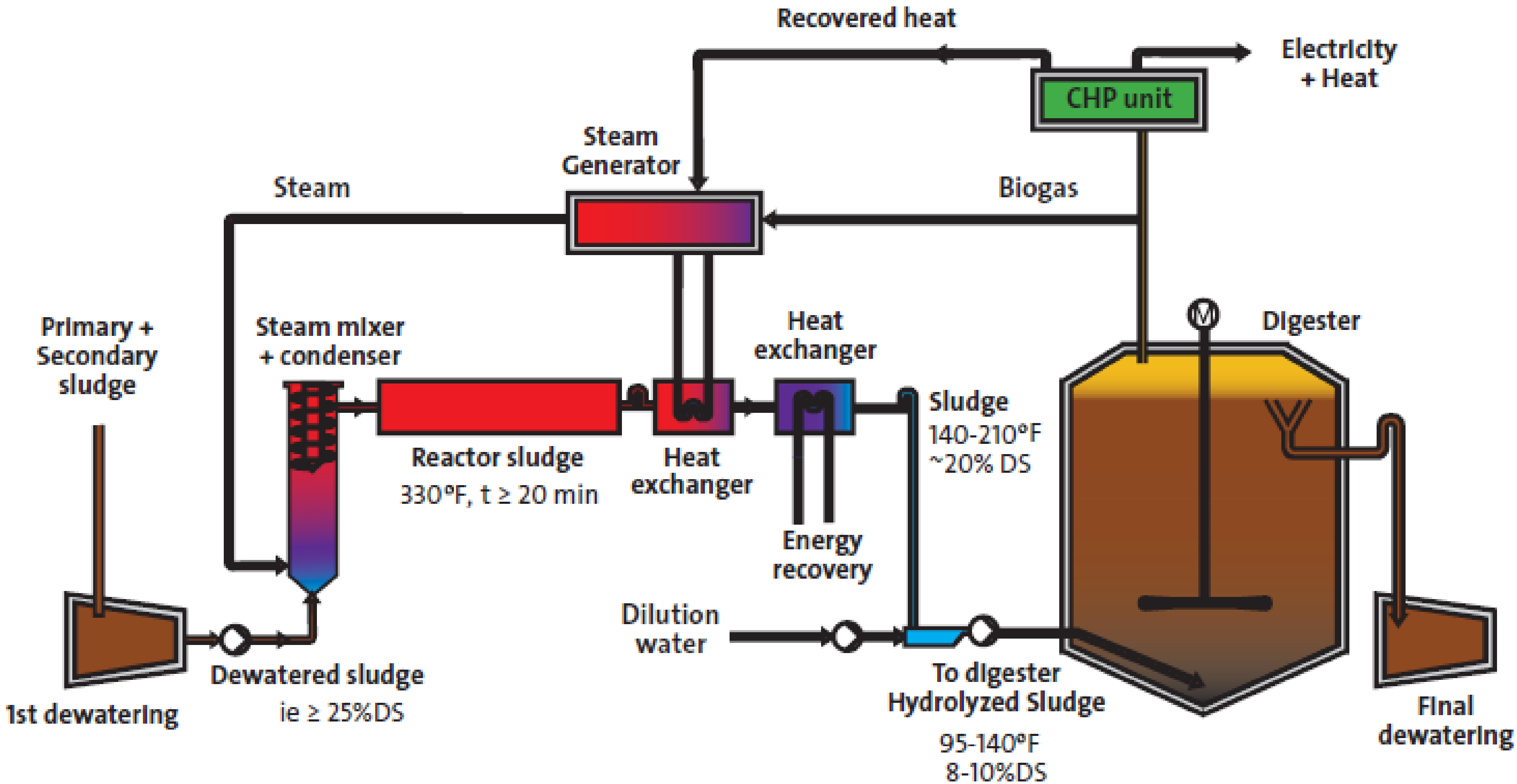
- French company, Veolia
- Using high-pressure steam (9 bar, 165°C)
- Tube type reactor : plug flow
- Continuous process
- Need pre-dewatering process

  : TS contents over 22%
- Increase gas production up to 20 ~ 40%

Thermal Pretreatment

❖ Commercial Process - Exelys Process

- Flow Diagram



Electric Pulse Pretreatment

❖ Commercial Process – OpenCel Process

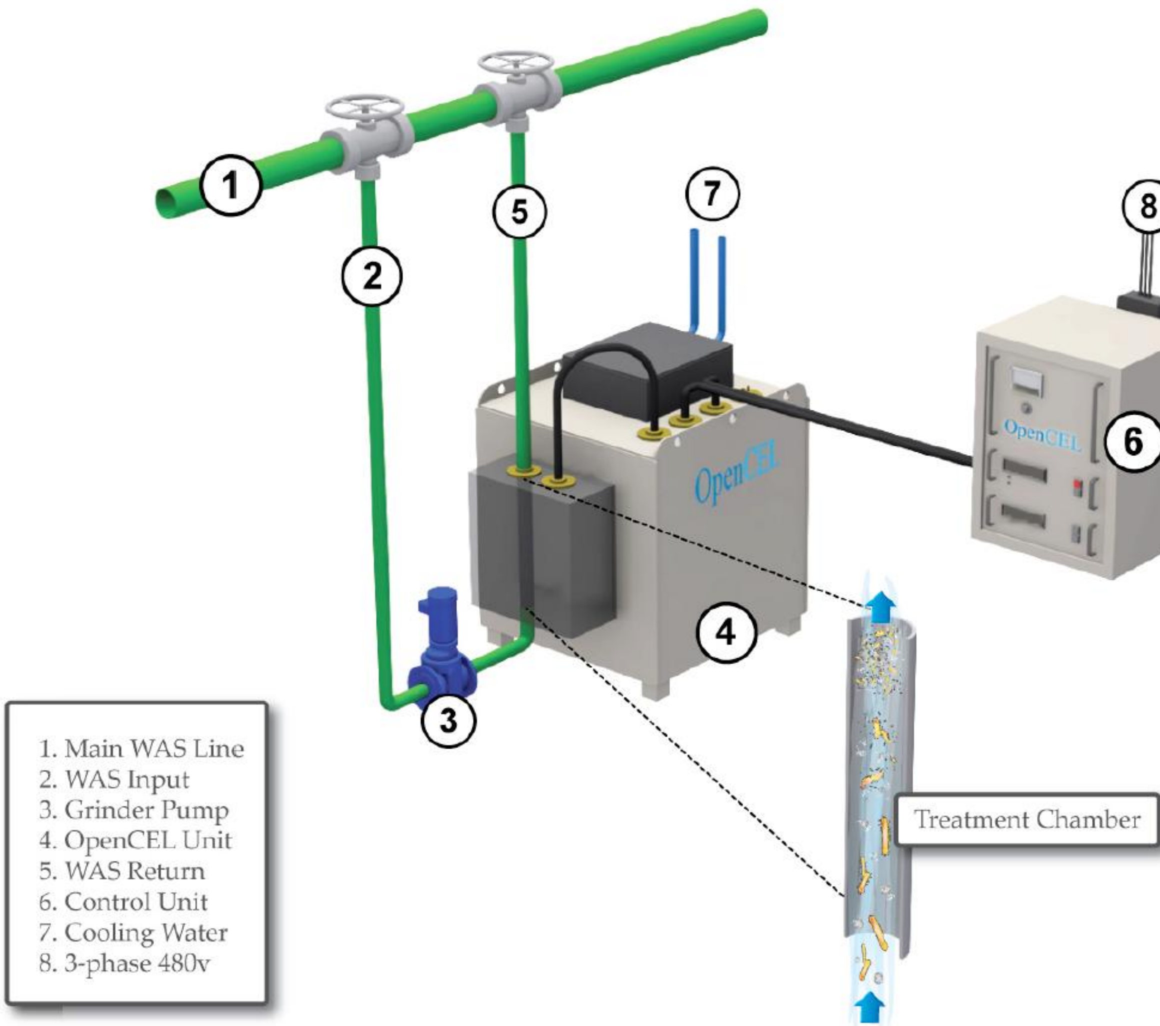
Description

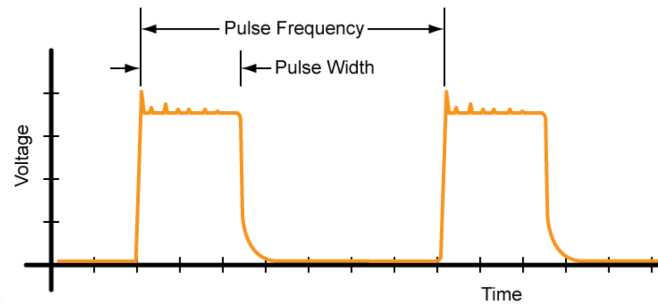
- American company, OpenCel
- Using pulsed electric field (PEF) technology to the sludge to achieve a process known as irreversible "electroporation"
- Electroporation : the pores in the microorganisms cell wall open in the pulsing electric field $\rightarrow$ when higher electrical power is applied the pores, they do not close in a reversible fashion. Instead, the cell membranes become permeable to the influx of small molecules from carrier medium, leading to swelling and rupture of the cell
- Pre-thickening is required : TS 6%
- Increase gas production up to 30 ~ 50%

Electric Pulse Pretreatment

❖ Commercial Process - OpenCel Process

- Sludge Treatment in OpenCel Process





Key operating parameters

Field Strength	Pulse Duration	Pulse Interval
15 to 100 kV/cm	2 to 15 µs	2 to 10 kHz

Combined Pretreatment

❖ Commercial Process – Microsludge Process

Description

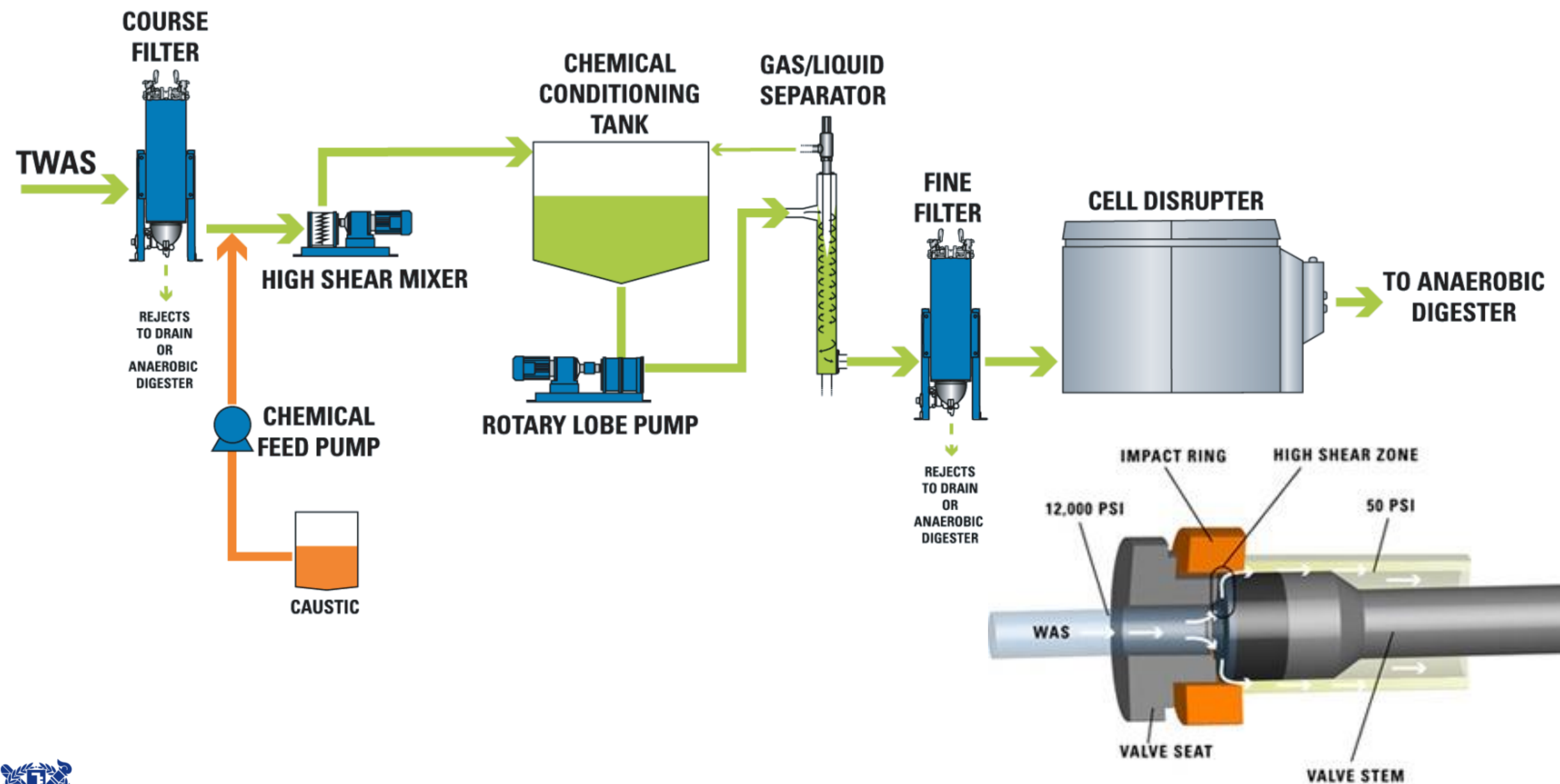
- Canadian company, Paradigm
- Chemical + mechanical process
- Alkaline treatment with NaOH : pH 8~9
- Screening(800μm) before mechanical treatment
- Pressure drop : 12,000 psi (≈ 816 atm) to 50 psi
- VSR in AD after pretreatment : 78%

  (with HRT 13day)
- Canada Chilliwack WWTF

Combined Pretreatment

❖ Commercial Process – Microsludge Process

- Flow Diagram



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Combined Pretreatment

❖ Commercial Process – Microsludge Process

- Example O&M Costs of Microsludge for WAS Pretreatment before AD

Item	Unit Cost	Unit	Cost/dry ton TWAS (4% TS)[1]	Cost/dry ton TWAS (6% TS)[2]
Electricity	\$0.06	/kWh	(\$46)	(\$30)
Caustic	\$0.60	/L	(\$13)	(\$9)
Maintenance			(\$15)	(\$10)
Total O&M			(\$73)	(\$50)
Natural gas offset	\$8.50	/GJ	\$78	\$78
Heat from homogenization	\$8.50	/GJ	\$18	\$12
Biosolids Management Savings	\$120	dt	\$49	\$49
Total Savings			\$145	\$139
Net O&M Value			\$72	\$90

[1] Based on data from Chilliwack WWTP trial. Assumes CH_4 at 64%, biosolids management at \$30/wt, 25% TS cake. Does not include cost of handling screenings. Performance assumptions to be adjusted based on final data from Los Angeles trial.
[2] Estimated

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Pretreatment Comparison

❖ Comparison between Some Pretreatment Methods

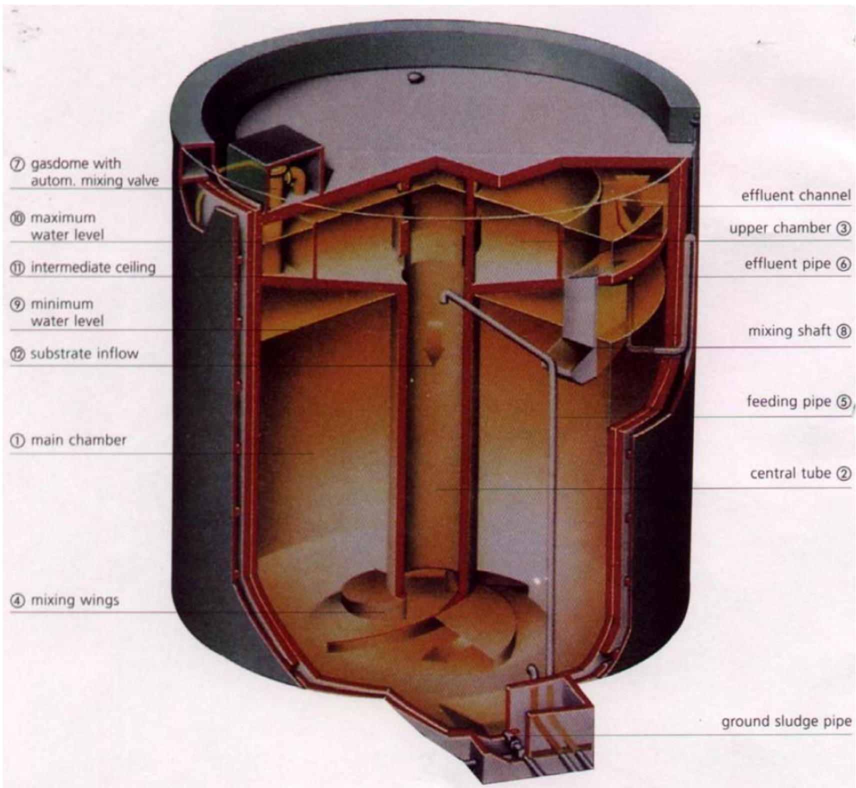
Methods	Heat treatment	Ultrasonic	Ozonization	Cavitation
Outlines	Use of enhancing dehydration through releasing water in a cell by heating at high temperature and pressor condition	Use of ultrasonic cavitation caused by ultrasonic generator	Adjustment of direct reaction by ozone and indirect reaction with OH-radical produced through a degradation by ozone	Usage of cavitation produced by a turbulent flow of liquid
Sludge reduction	60~70%	30~50%	30~40%	20~80%
Advantages	• Excellent dehydration • Extinction of bacteria and filamentous fungus • High rate of sludge removal	• Simple facility • Small facility area • Low cost for construction of reactor	• Extinction of bacteria and filamentous fungus • Improvement of sludge precipitation and dehydration • No chemical reagents	• Possibility of sludge homogenization
Dis- advantages	• High cost of operation and maintenance	• No intermittent operation but only continuous operation • Need of a double cover for a shock noise	• Low economical efficiency for excess ozone treatment • A fluctuation of treatment efficiency by pH	• Low persistence • Large power consumption

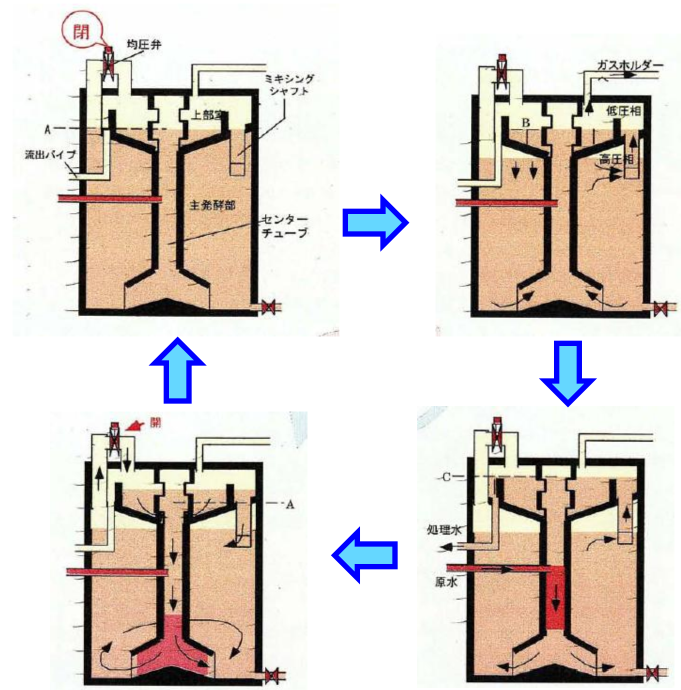
(Namgung and Chon, 2010)

Energy Saving in Process Configuration

❖ Saving Mixing Energy in Anaerobic Digestion

Biogas Induced Mixing Arrangement (BIMA)



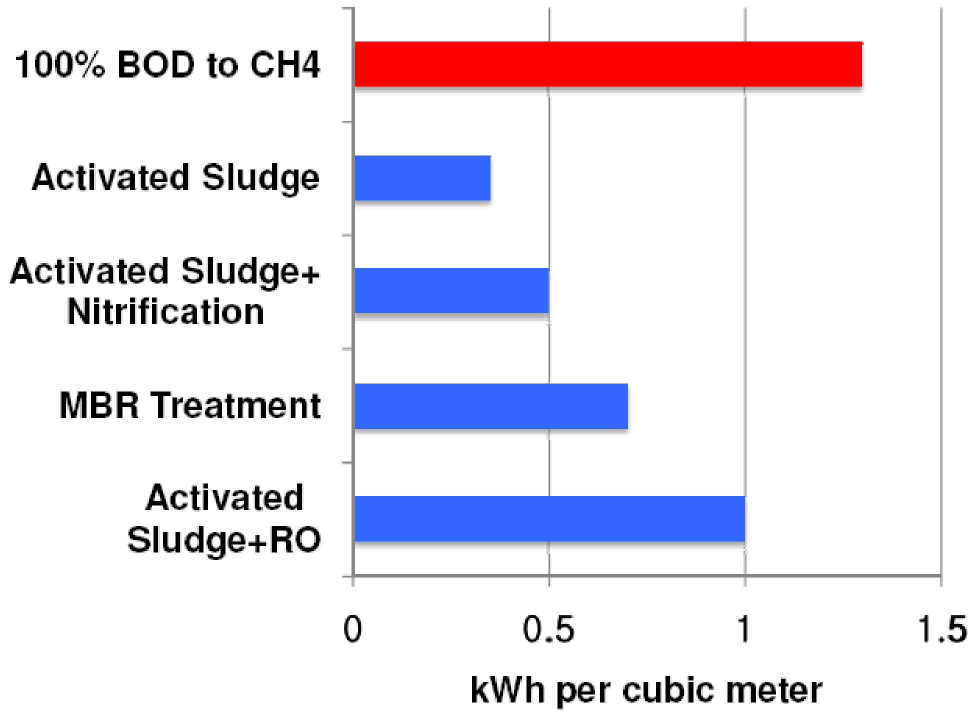


- Self-mixing hydraulic digester systems → No need for mechanical equipment such as agitator, circulation pumps or gas injection for mixing the digester contents.
- The 2-chamber system uses the produced biogas to create a level difference in the chambers
- The turbulent mixing occurs against the biogas production in intervals of 4-10 times a day.

Energy Saving in Process Configuration

❖ Anaerobic Treatment of Wastewater

- Energy Consumption or Production



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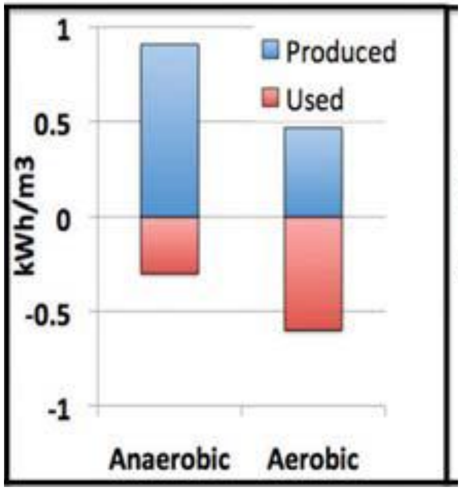
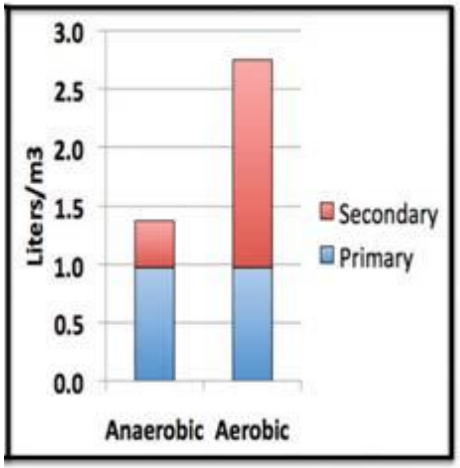


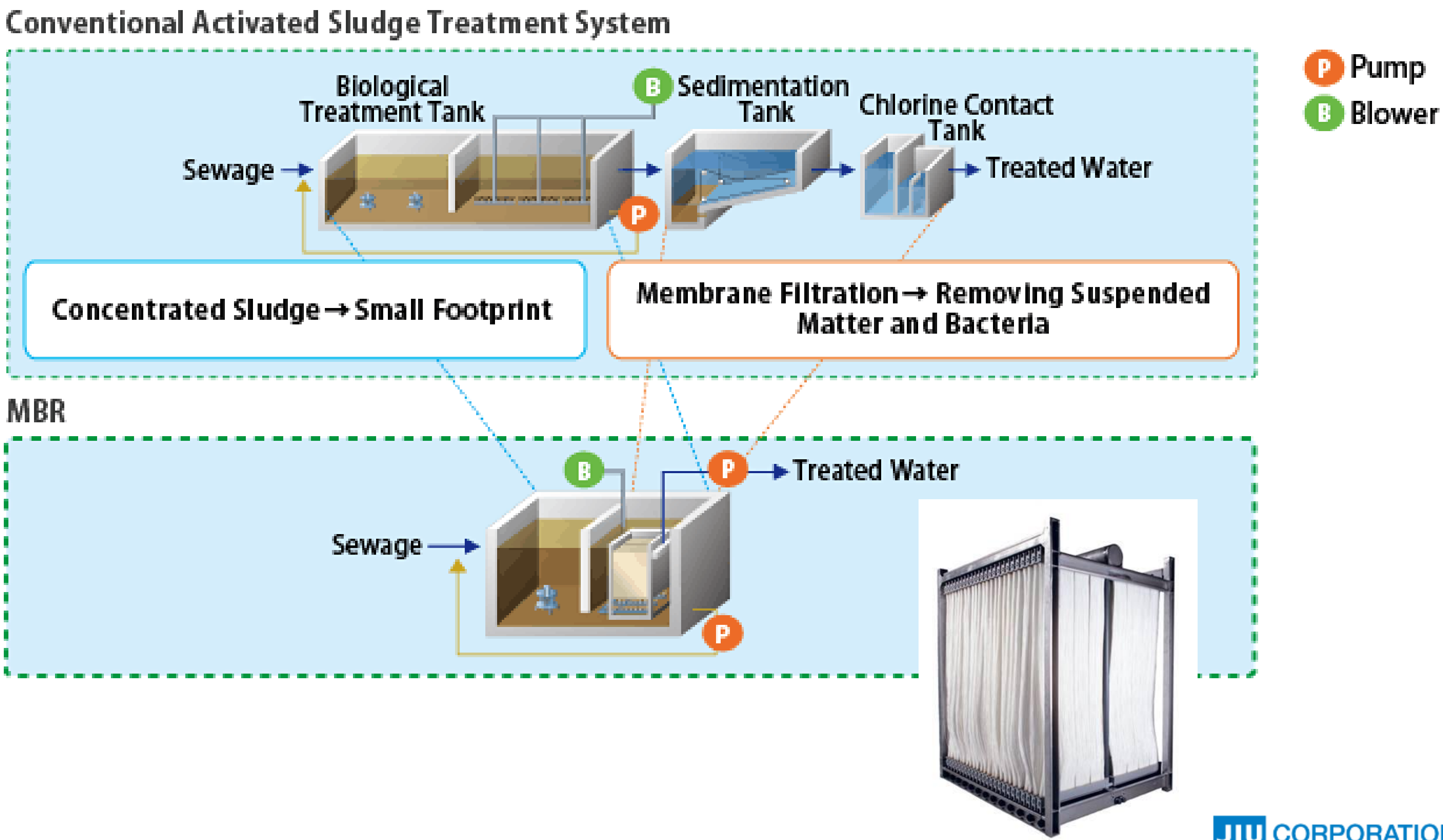
<Sludge>



Energy Saving through Tailored Operation

❖ Saving Aeration Energy in MBR Process

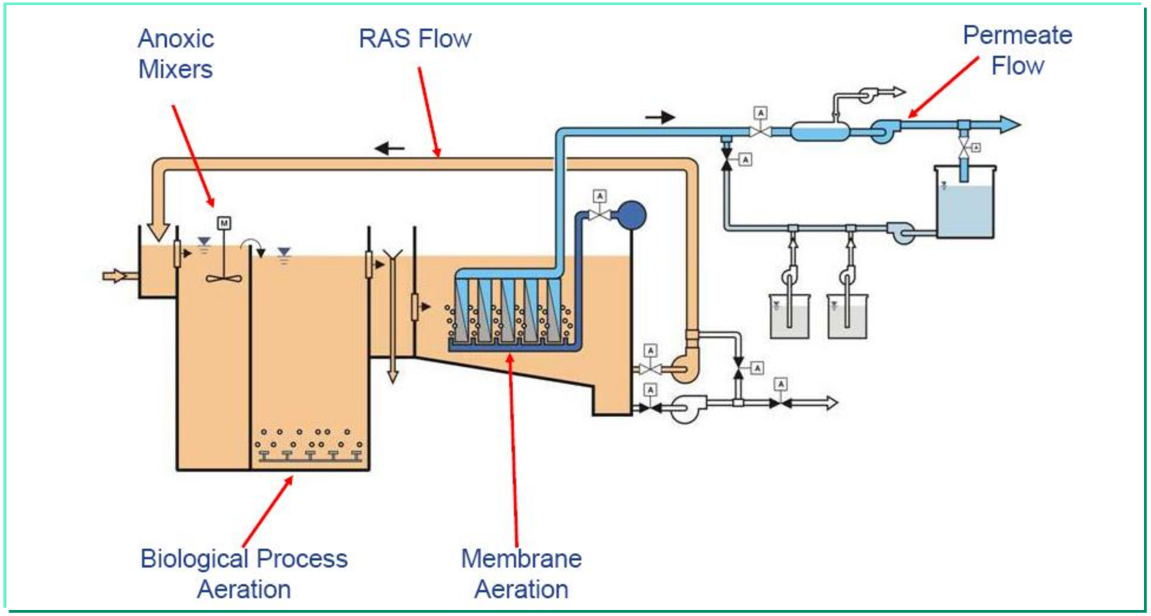
- A Basic MBR Process

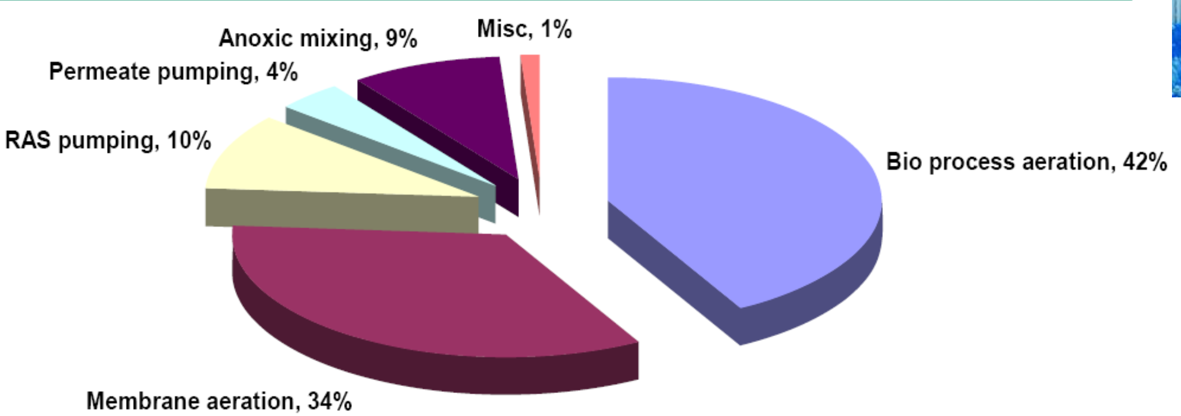


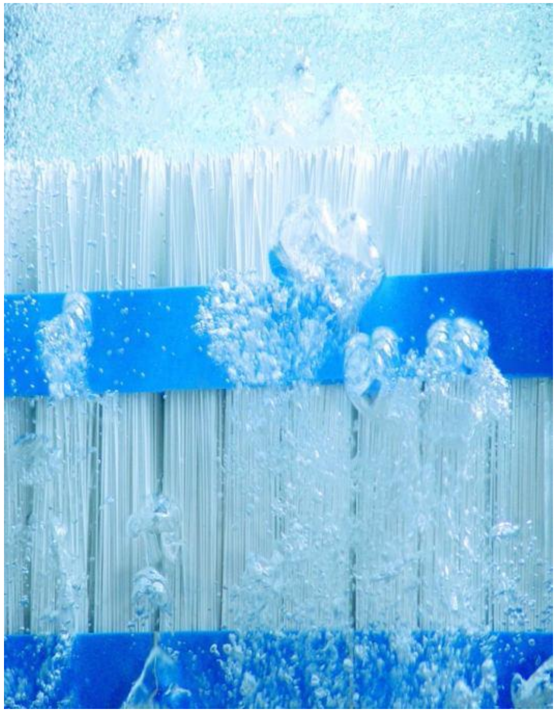
Energy Saving through Tailored Operation

❖ Saving Aeration Energy in MBR Process

- Energy User in MBR System





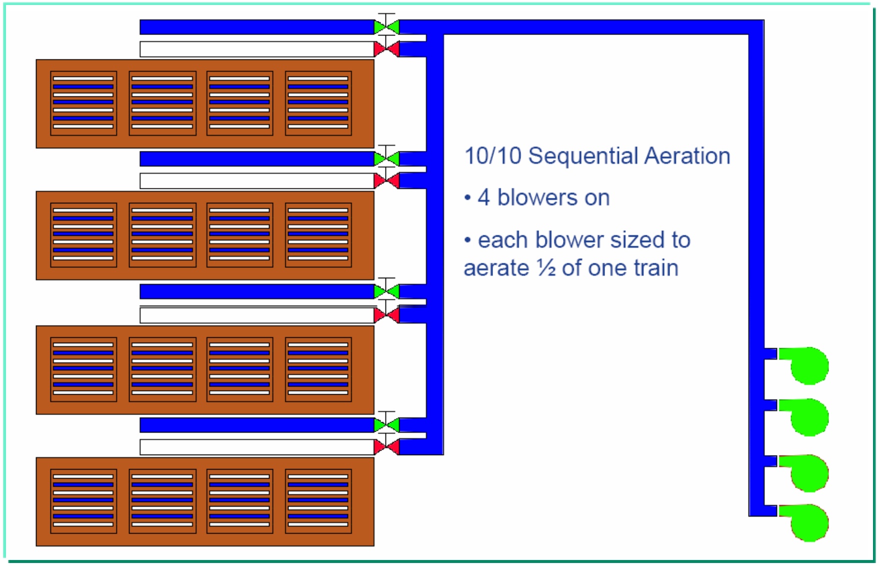


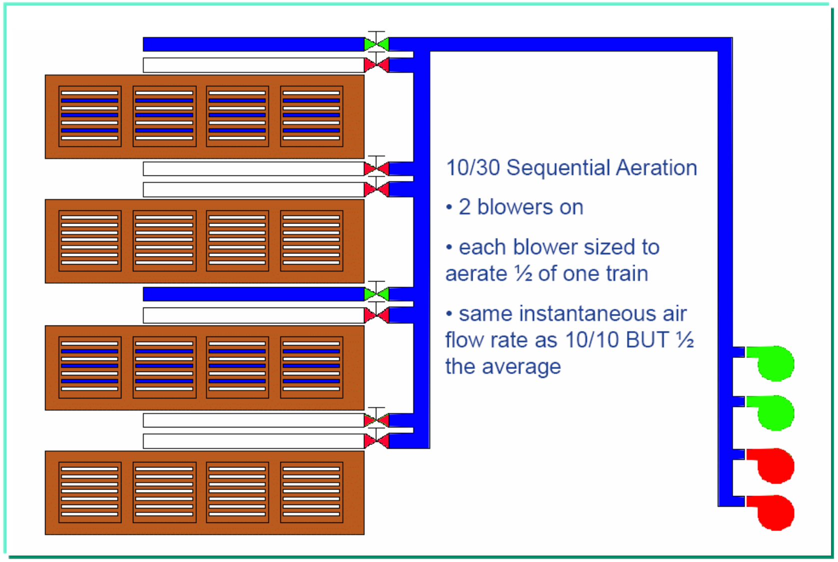
<Air scouring>

Energy Saving through Tailored Operation

❖ Strategy for Air Scouring

10/10 Air Scour and 10/30 Air Scour (GE, Zenon)





- 10/10 air scour : cycled air on and off in 10 second intervals
- 10/30 air scour
  - for 10 seconds, 24 of the 48 modules in a given cassette receive air scour. For the next 10 seconds this cassette does not receive air scour, but air scour is being used in other cassettes. For the next 10 seconds, the other 24 modules in the cassette receive air scour. For the last 10 seconds of the cycle, the cassettes do not receive air scour. A given cassette receives air ½ the time, and a given module receives air ¼ of the time. 50% savings compared to 10/10.
- Maintain 10/10 aeration at or above average daily flow
- Run at 10/30 aeration below average daily flow

Other Energy Saving Measures

❖ Replacement to Energy Saving Equipments

Oxygen Requirements in Biological processes

- BOD oxidation

  : For solids retention times of 5-10 days, the kg of oxygen per kg of BOD usually varies from 0.92-1.07. A conservative value of 1.1 kg O_2/kg BOD is used on occasion. Higher values are valid for long detention times with low organic loadings and additional sludge oxidation.
- Ammonia oxidation

  : Usually one kg of ammonia requires 4.3-4.6 kg of oxygen.
- Endogenous respiration

  : 0.05-0.15 kg O_2/kg MLVSS/d
- DO concentration maintenance for side-stream (internal and external recycle, etc.) loading
- The AOR(actual oxygen requirement) demand is the sum of the above sources
- SOR : standard oxygen requirement

Other Energy Saving Measures

❖ Replacement to Energy Saving Equipments

Oxygen Requirements in Biological processes

$$SOR = \frac{AOR \cdot Csat_{20}}{\left[\beta \cdot Csat_T \left(\frac{P_{field}}{P_{msi}}\right) - DO_{field}\right] \alpha \cdot \theta^{T-20}} \quad (1)$$

Where AOR = actual oxygen requirements (field conditions)

SOR = standard oxygen requirements (standard conditions)

$$\alpha = \frac{KL_a \text{ waste water}}{KL_a \text{ tap water}}$$

β = saturation factor

P_{field} = barometric pressure at the treatment site

P_{msi} = barometric pressure at mean sea level

T = operating temperature of wastewater (°C)

C_{sat20} = surface DO saturation concentration at 20°C and standard conditions for the particular aeration equipment at the design submergence

C_{satT} = Surface DO saturation concentration at design temperature T and 14.7 PSIA for the particular equipment at the submergence

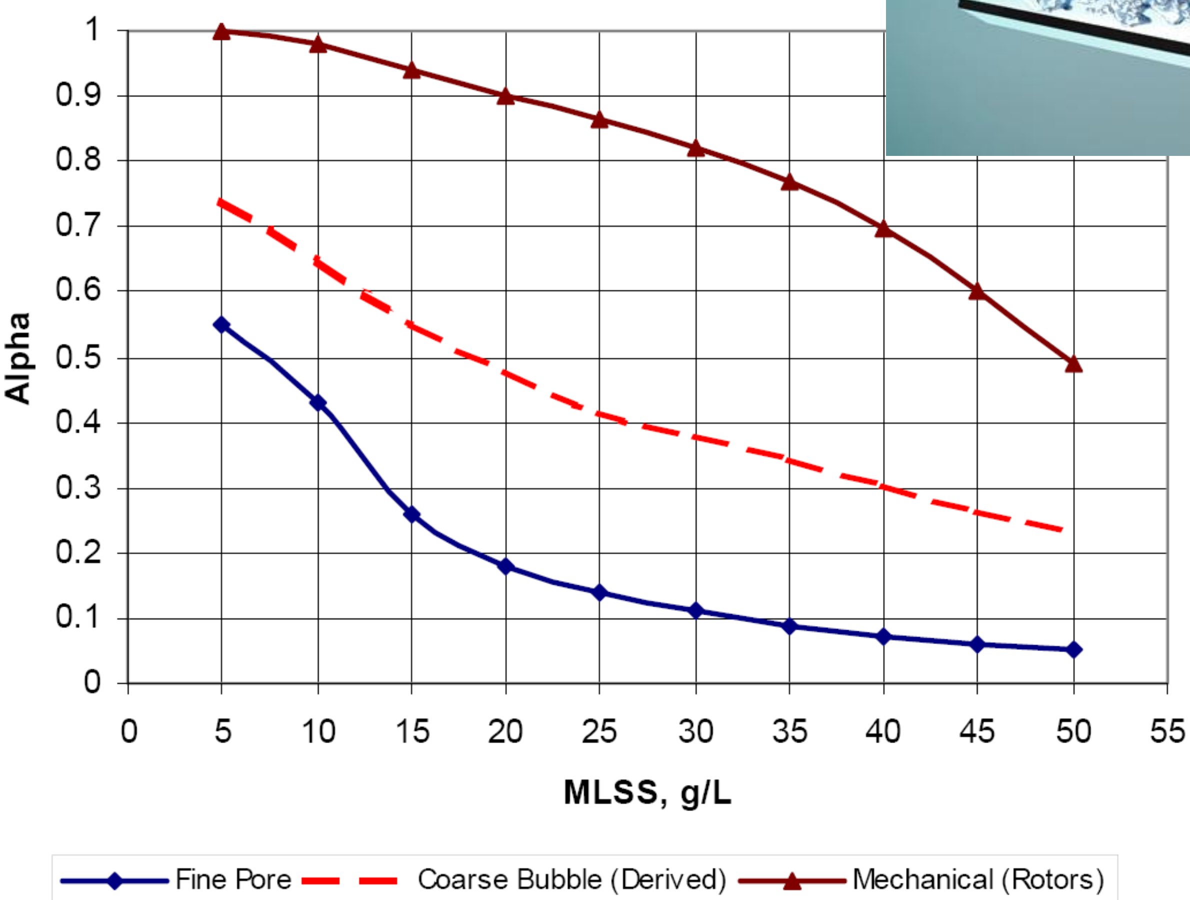
DO_{field} = dissolved oxygen in wastewater

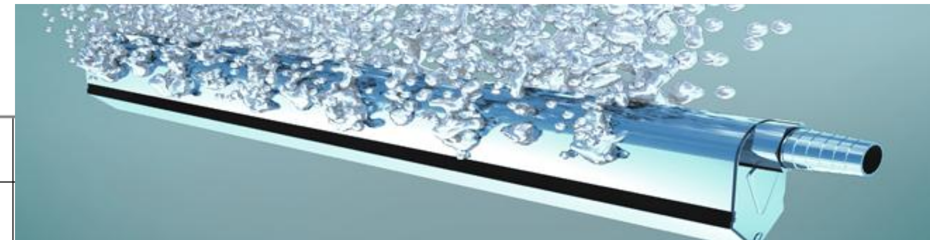
θ = temperature correction factor

Other Energy Saving Measures

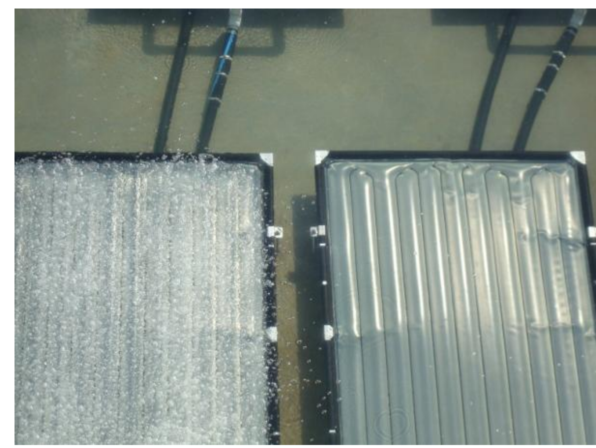
❖ Replacement to Energy Saving Equipments

- Effect of Aeration Methods





<Coarse bubble aerator>



<Ultra-fine pore membrane diffuser>

Other Energy Saving Measures

❖ Replacement to Energy Saving Equipments

Pulsed Air Mixing of Anoxic and Anaerobic Zones - BioMIx

- Efficient mixing in anaerobic and anoxic zones with no significant oxygen transfer.
- Intermittent release of bursts of compressed air at the bottom of the water column zones.
- Testing at F. Wayne Hill Water Resource Center in Buford, GA to compare effectiveness, compatibility with anaerobic and anoxic environments, and power requirements vs. a conventional submersible propeller mixer.
  - Dye tracer tests showed similar mixing for the BioMIx and submersible mixer systems.
  - Continuous oxidation reduction potential (ORP) measurements over periods of 12 to 28 hours showed 95th percentile ORP values of less than -150 millivolts (mv), which is indicative of anaerobic environments.
  - Power analyzer readings taken simultaneously showed that energy (in kW) required to mix one anaerobic cell using the BioMIx system was 45 percent less than the energy required by a submersible mixer.

<Typical BioMIx installation>

Other Energy Saving Measures

❖ Replacement to Energy Saving Equipments

- Light Tubes

- Utilize energy saving light tubes, save about 1/3-1/4 electricity use

Thank You for Your Attention!

Questions or Comments ?

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