환경부 KEITI 한국환경산업기술원

Application of Food Waste to Biogas Energy Plant

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HYUNDAI ENGINEERING & CONSTRUCTION

COWEB 유기성폐자원에너지화사업단 Center for Organic Wastes to Energy Business

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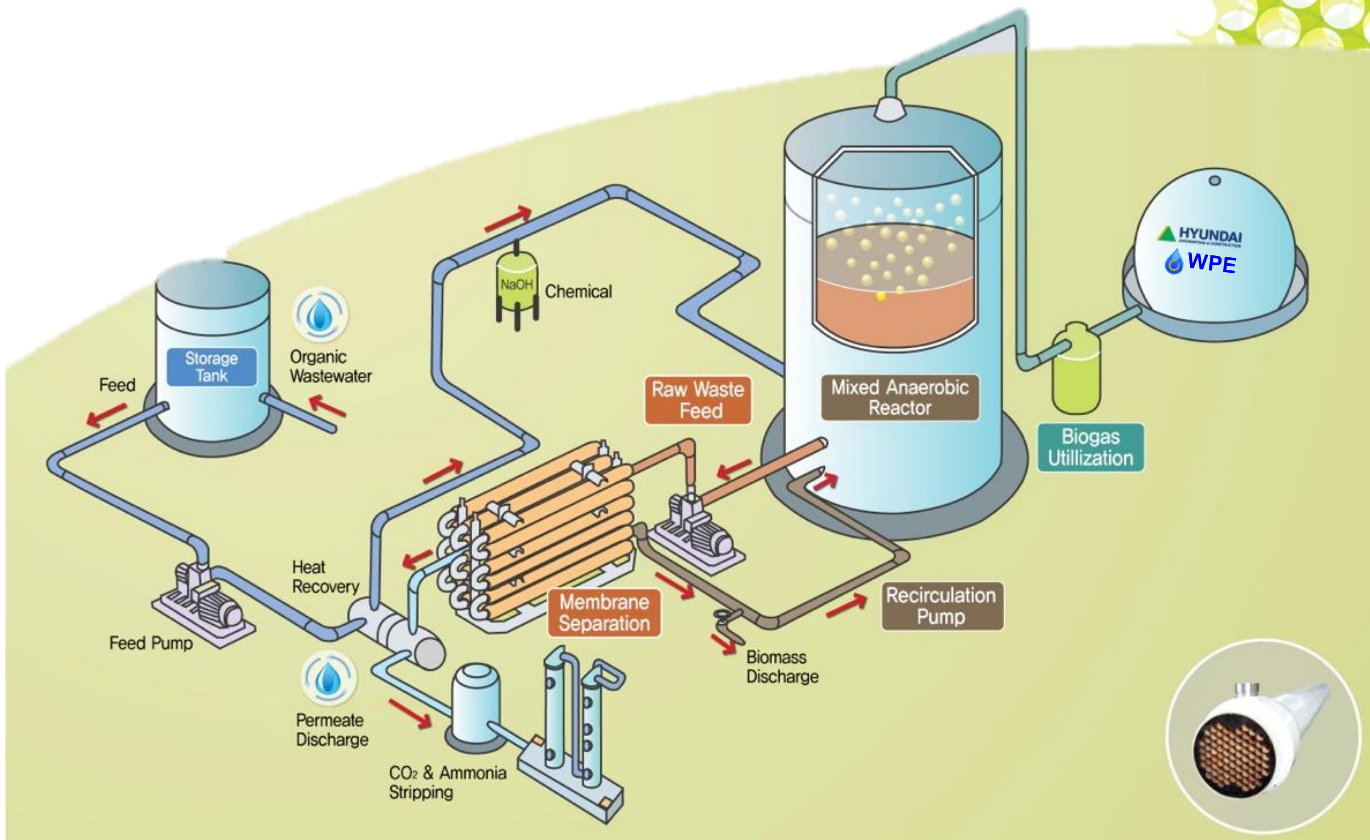
INOVATION
for Eco-SUSTAINABILITY

"Harvesting
Clean Energy & Clean Water from Wastewater"



Talk outline

1. Value of Organic Wastes
2. Anaerobic Digestion description.
3. Stage of Biogradation
4. See Hyundai Biogas Plant (AnMBR; HAnDs)
5. Field Application of AnMBR

Characteristics of Organic Wastes in Korea

High Volatile Solid Content

- Readily biodegradable
  → Easy corruption
- Renewable energy source

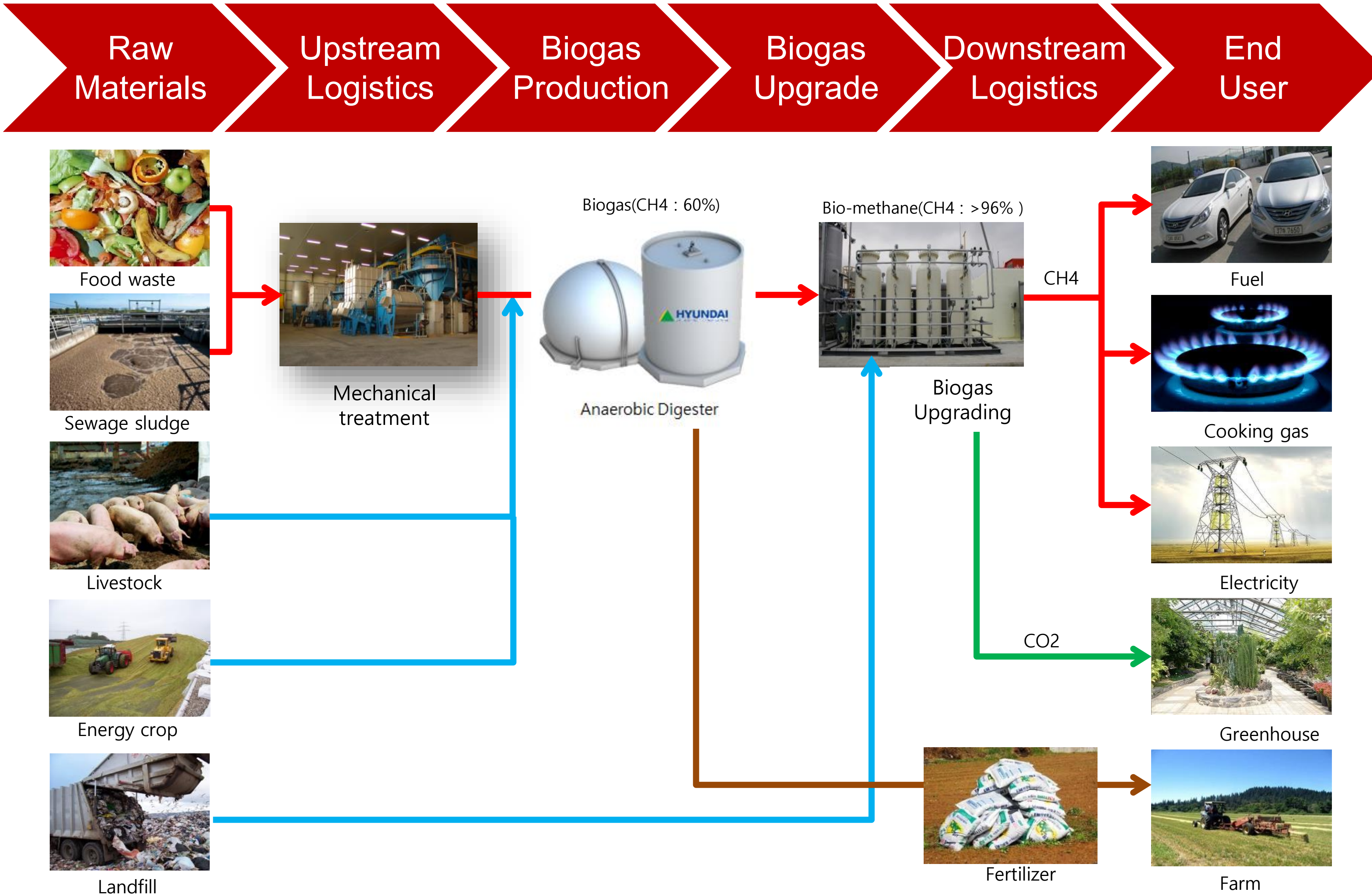
High Moisture Contents

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

Heterogeneous

- Heterogeneous feedstock
- Necessity of pretreatment
- Hard to apply microbial treatment techniques

Value Chain

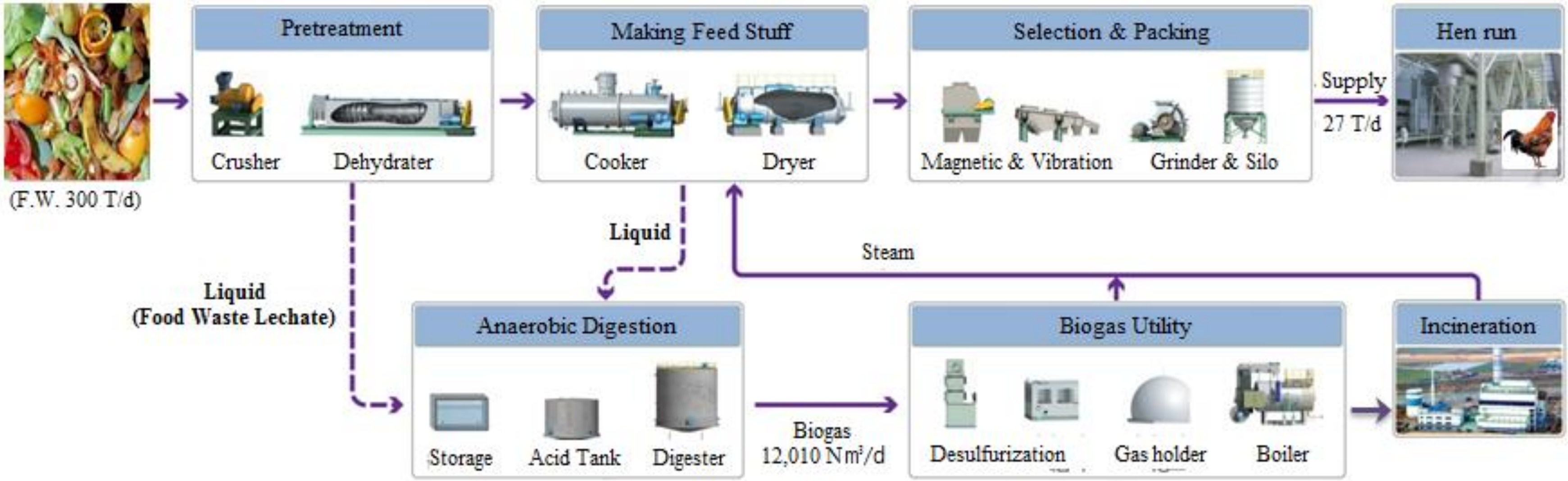

Raw Materials
Upstream Logistics
Biogas Production
Biogas Upgrade
Downstream Logistics
End User
Food waste
Sewage sludge
Livestock
Energy crop
Landfill
Mechanical treatment
Biogas(CH4 : 60%)
HYUNDAI
Anaerobic Digester
Bio-methane(CH4 : >96%)
Biogas Upgrading
CH4
CO2
Fertilizer
Fuel
Cooking gas
Electricity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

Value Chain

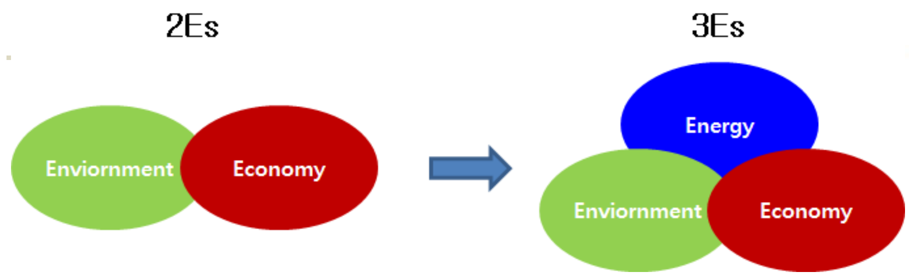
- Food waste made into feed stuff for hen run, Liquid to biogas digestion

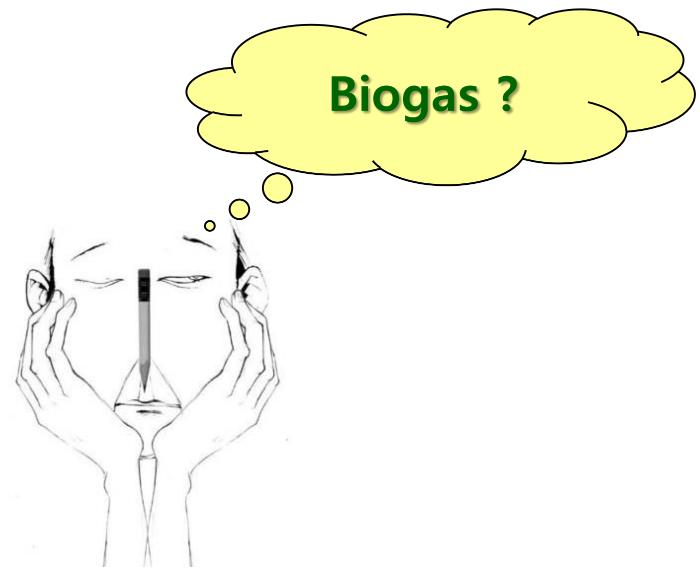
GuangJu (Food Waste 300 t/d)

- Feed stuff facility : 100 t/d
- Anaerobic Digestion : 260 t/d
- AD Type : Conventional Two stage



Paradigm of organic wastes treatment





Anaerobic Digestion

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

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

- 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

- 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.

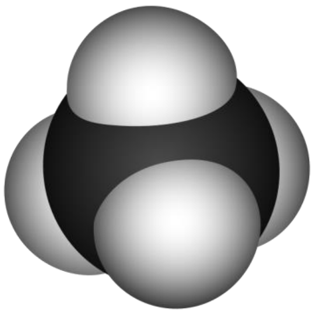
Acidogenesis

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

- 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.

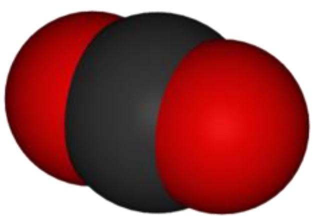
What is Biogas ?

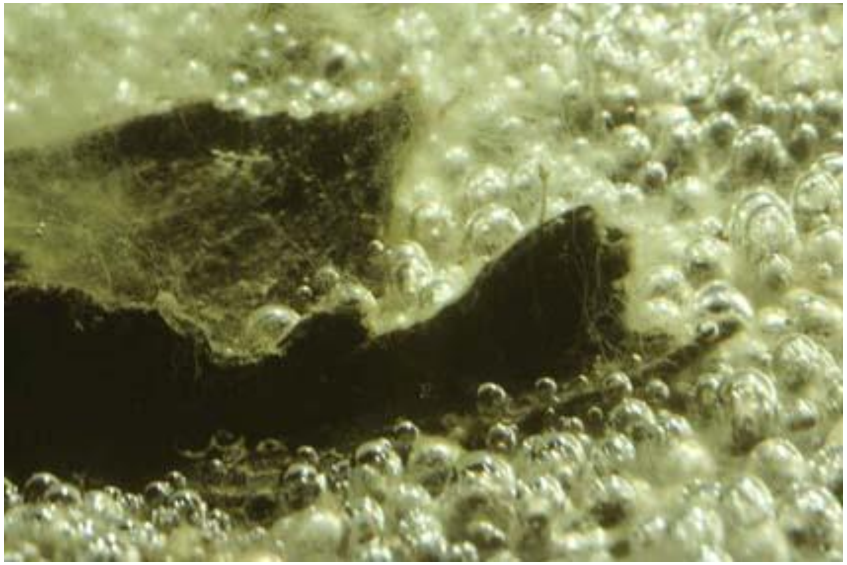
- A mixture of methane and carbon dioxide



CH_4

CO_2





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

What is this?

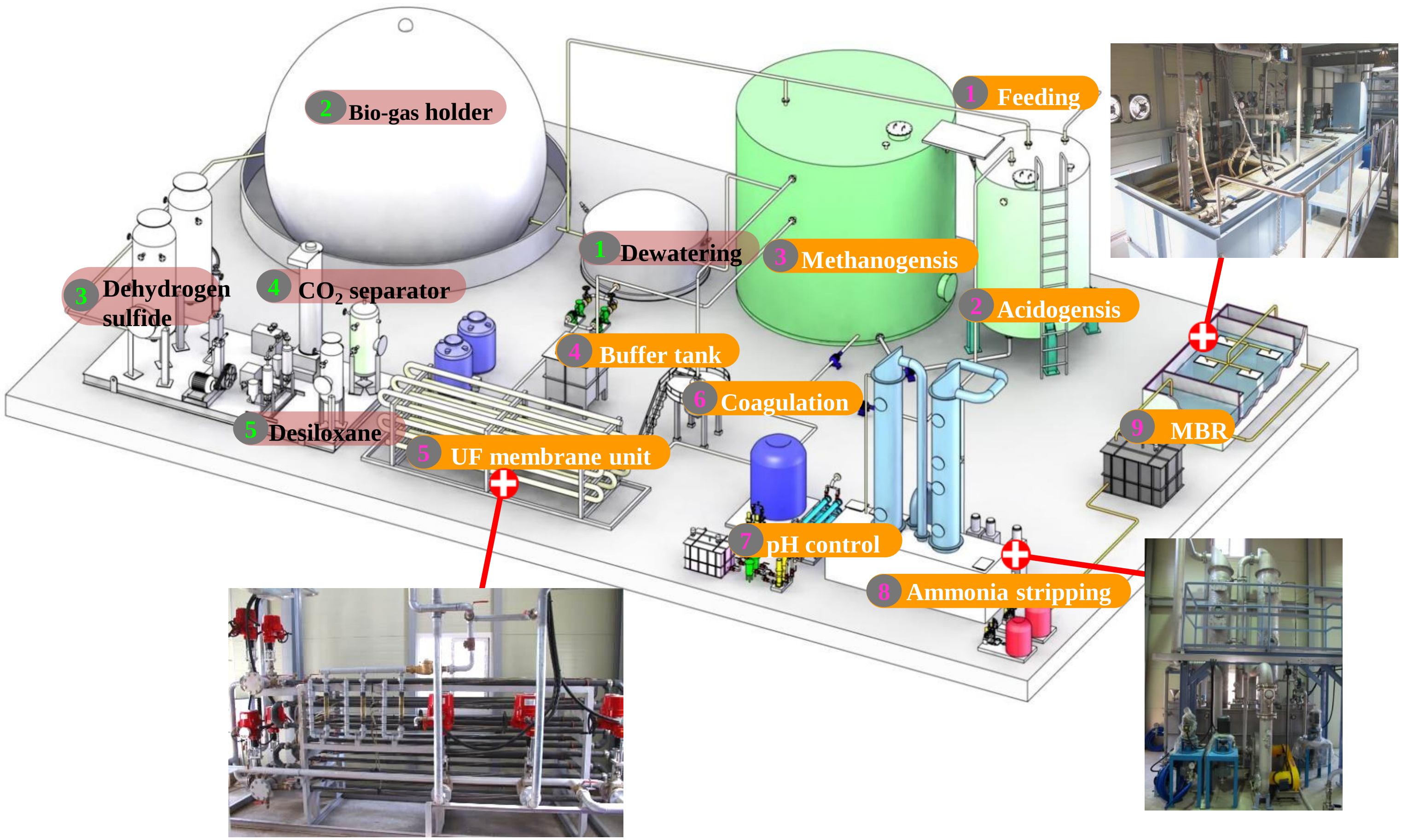
Potential of Biogas

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

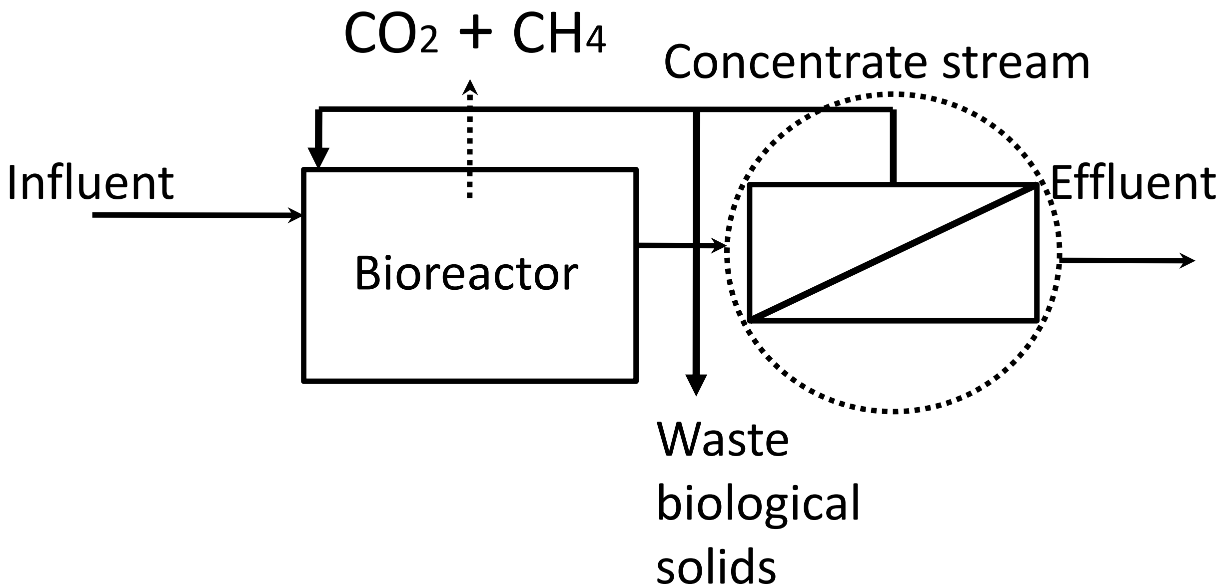
Pilot-plant of AnMBR : HAnDs

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

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

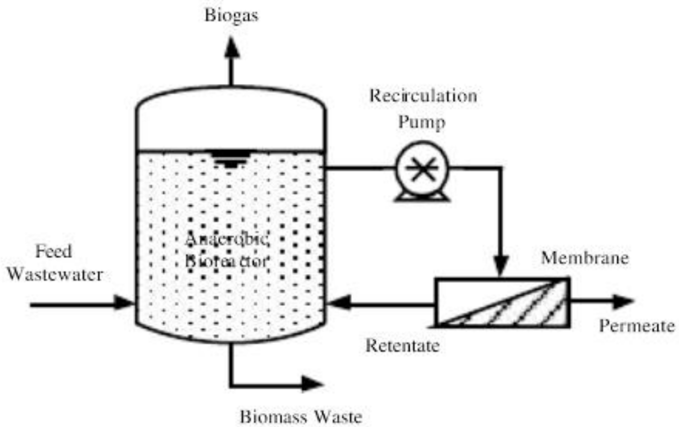


Anaerobic Membrane Bioreactor(AnMBR)

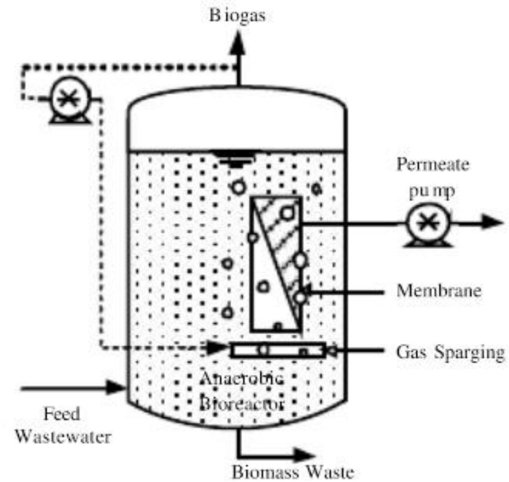


- Providing long SRT needed while operating at short HRT as required to reduce reactor size
- Pressurized type use more since membrane cleaning is easier to perform

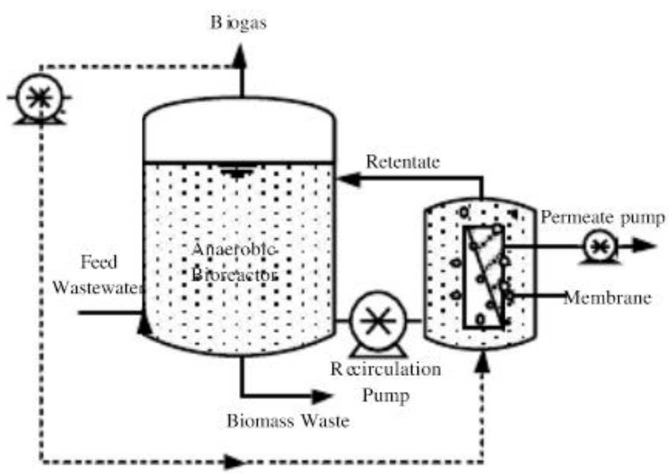
Types of AnMBR



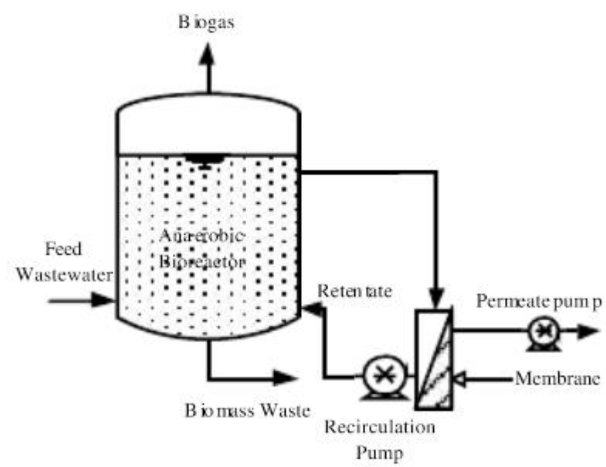
(a) External cross-flow



(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

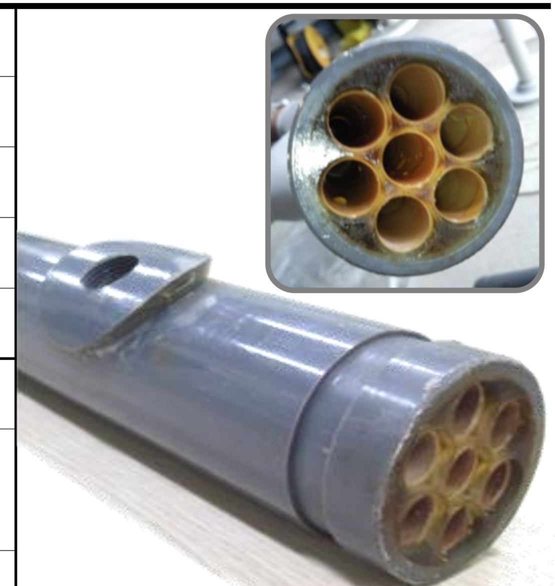
Type of wastewater	Scale[a]	Temp. (℃)	Membrane Material	Pore size[c]	Membrane area (m^2)	TMP (kPa)	linear velocity ($m. s^{-1}$)	Initial flux ($L. m^{-2}. h^{-1}$)	Final flux ($L. m^{-2}. h^{-1}$)	Reference
Wheat starch	P	40	-	18,000 D	144	690	-[d]	-	14~25	Butcher et al, 1989 Choate et al, 1983
Brewery 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

Picture of Plant

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



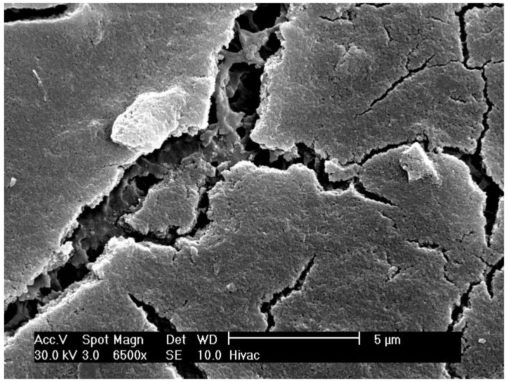
Why Crossflow Membrane ?

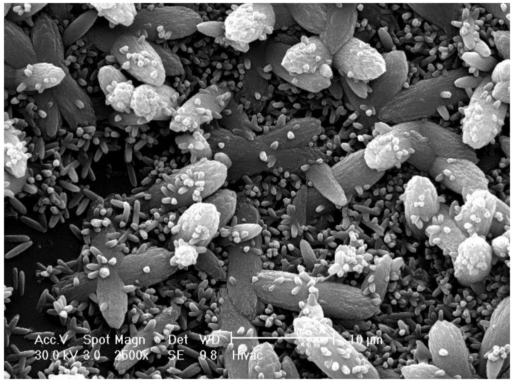
- Flat-sheet membranes can only be installed in a submerged tank, which client pays to build
- For membrane cleaning, the entire membrane tank must be drained, halting treatment of wastewater
- Crossflow membranes are installed on skids with minimal footprints, and require no storage tank of any kind
- 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

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)





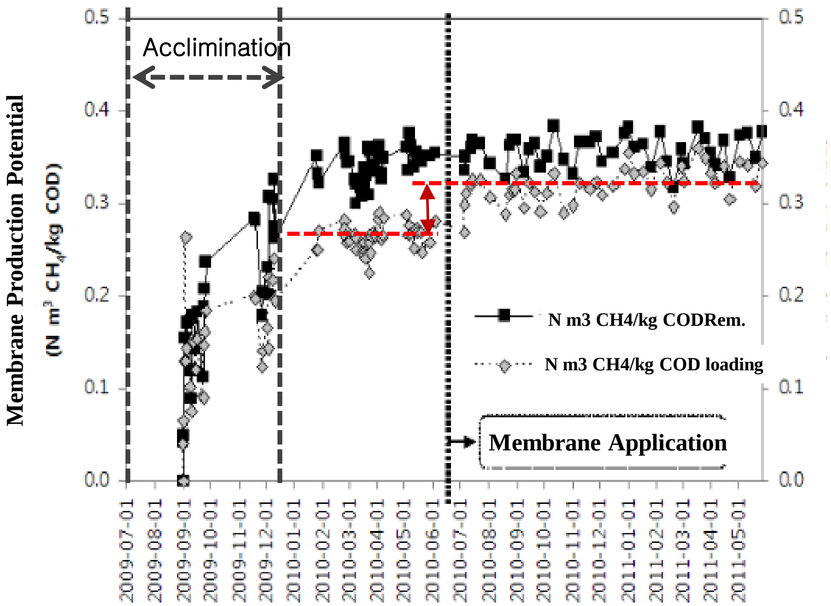
Characteristics of Food Waste Leachate

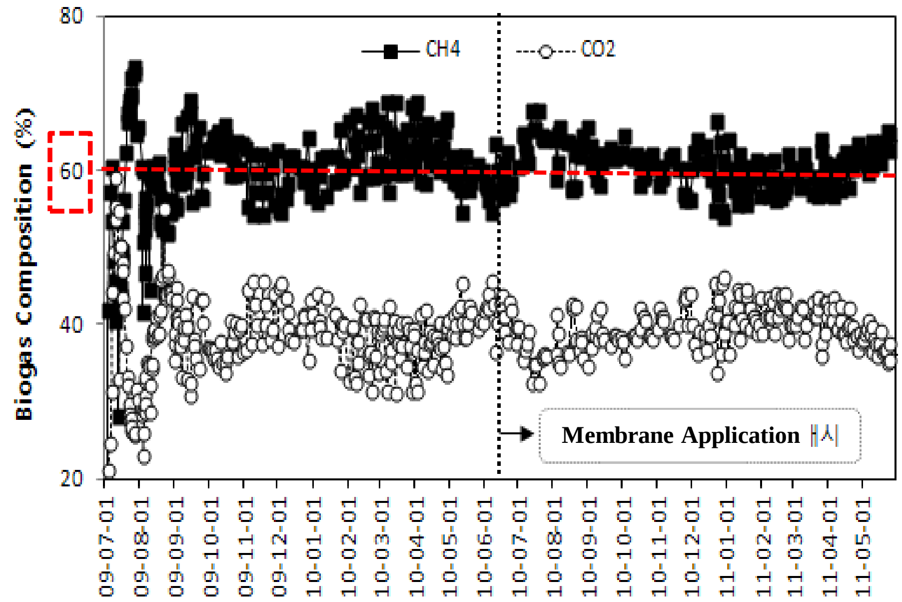
Water Quality through HAnDS® process

(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)

Biogas Production Potential and Compostion





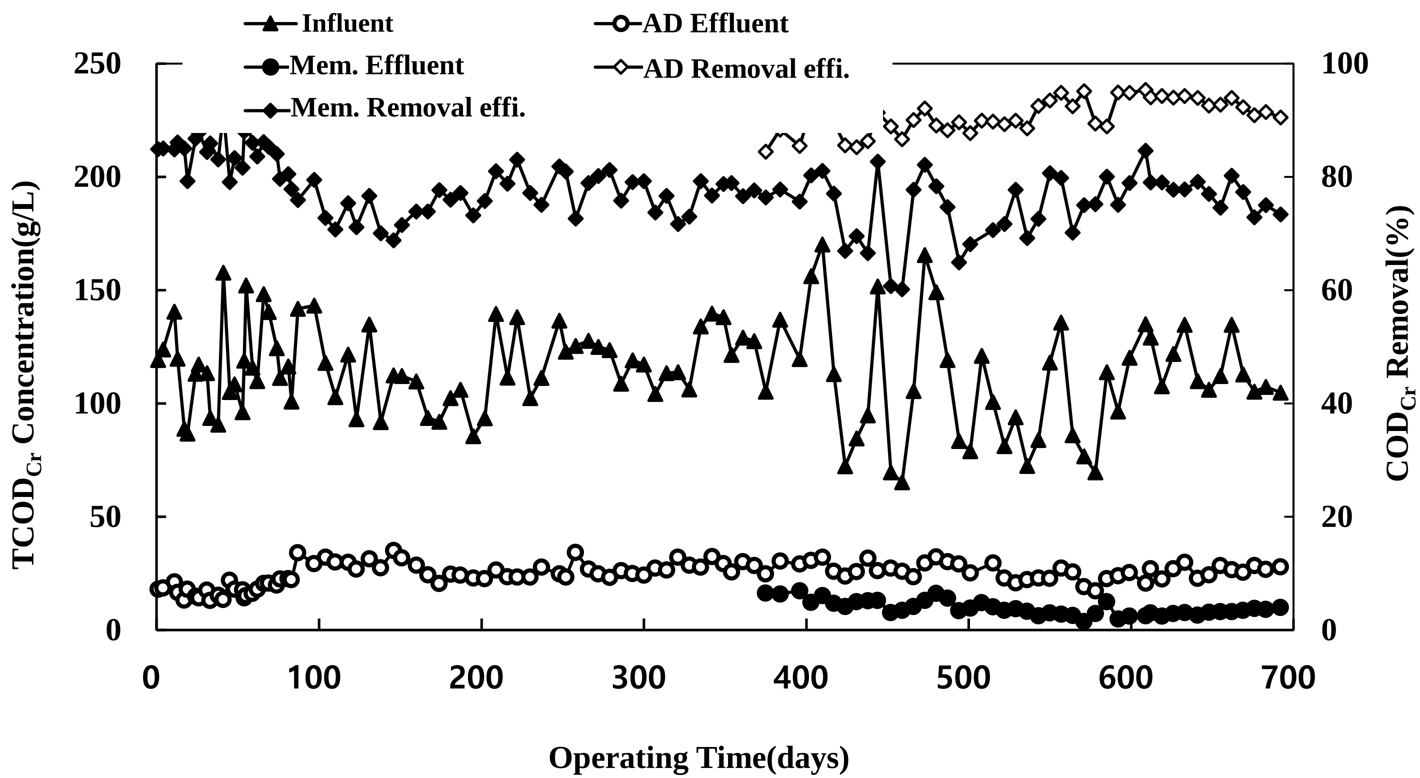
(단위 : Nm^3 CH_4/kg COD)

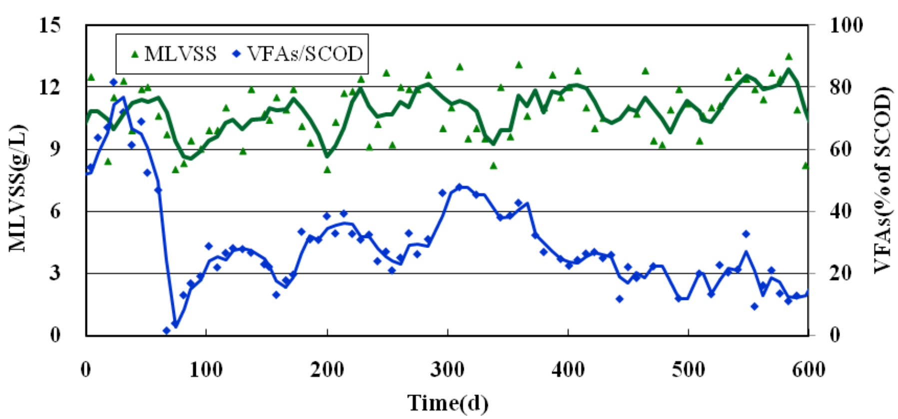
	Before	After	Variation
CH_4 production/ CODloading	0.28 (0.25~0.29)	0.32 (0.29~0.36)	△22.1%
CH_4 production/ CODRem.	0.34 (0.30~0.38)	0.36 (0.32~0.38)	△6.0%

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}

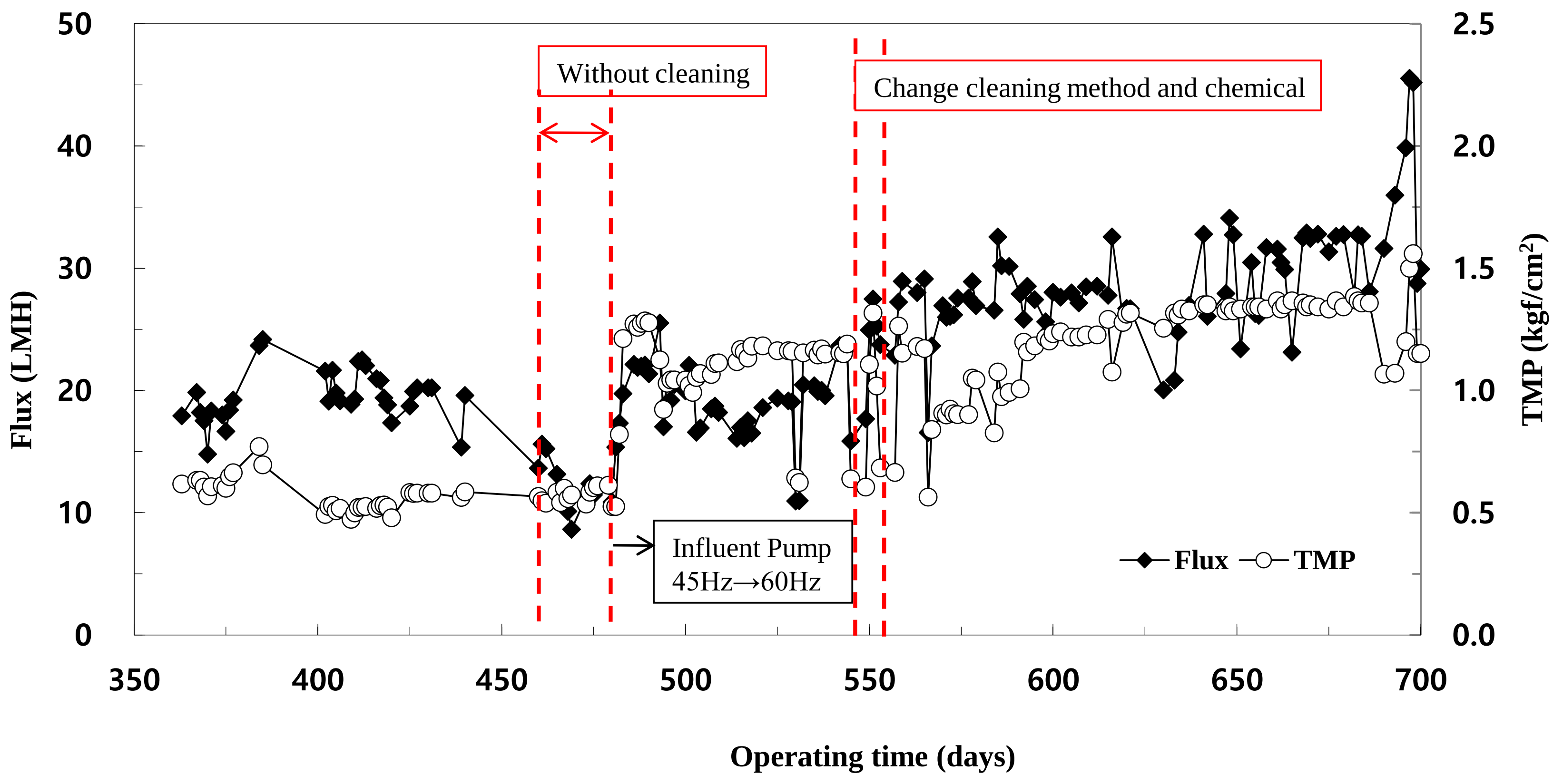
COD Removal Efficiency



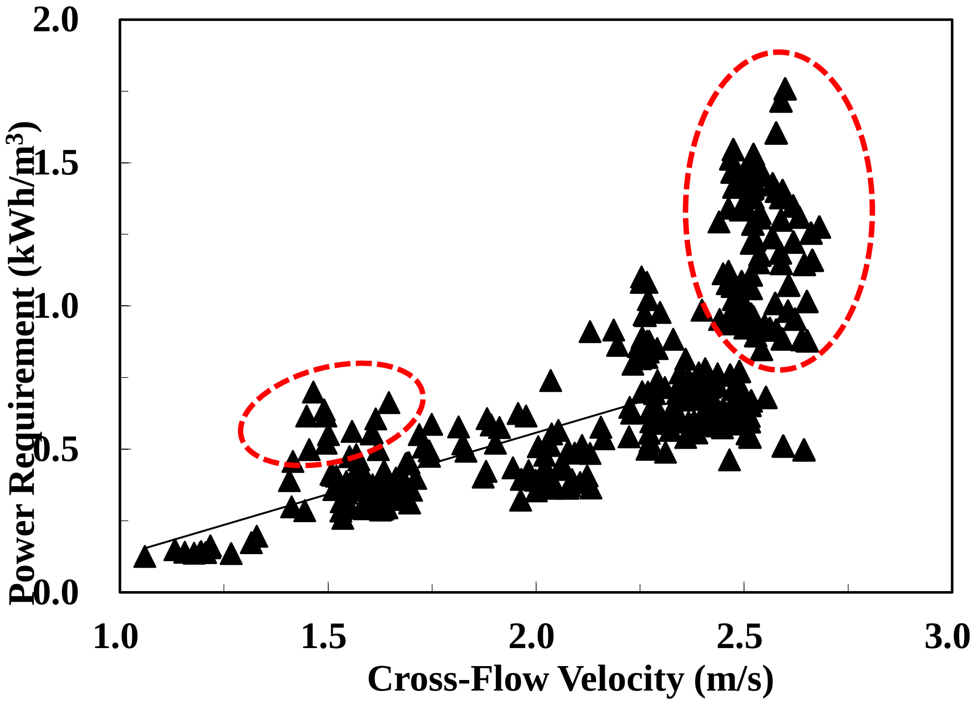


MLVSS has been increasing continuously since the digester was integrated with UF membrane

Variation of Flux and TMP in AnMBR



Relationship between Cross-flow velocity and Power Requirement in AnMBR



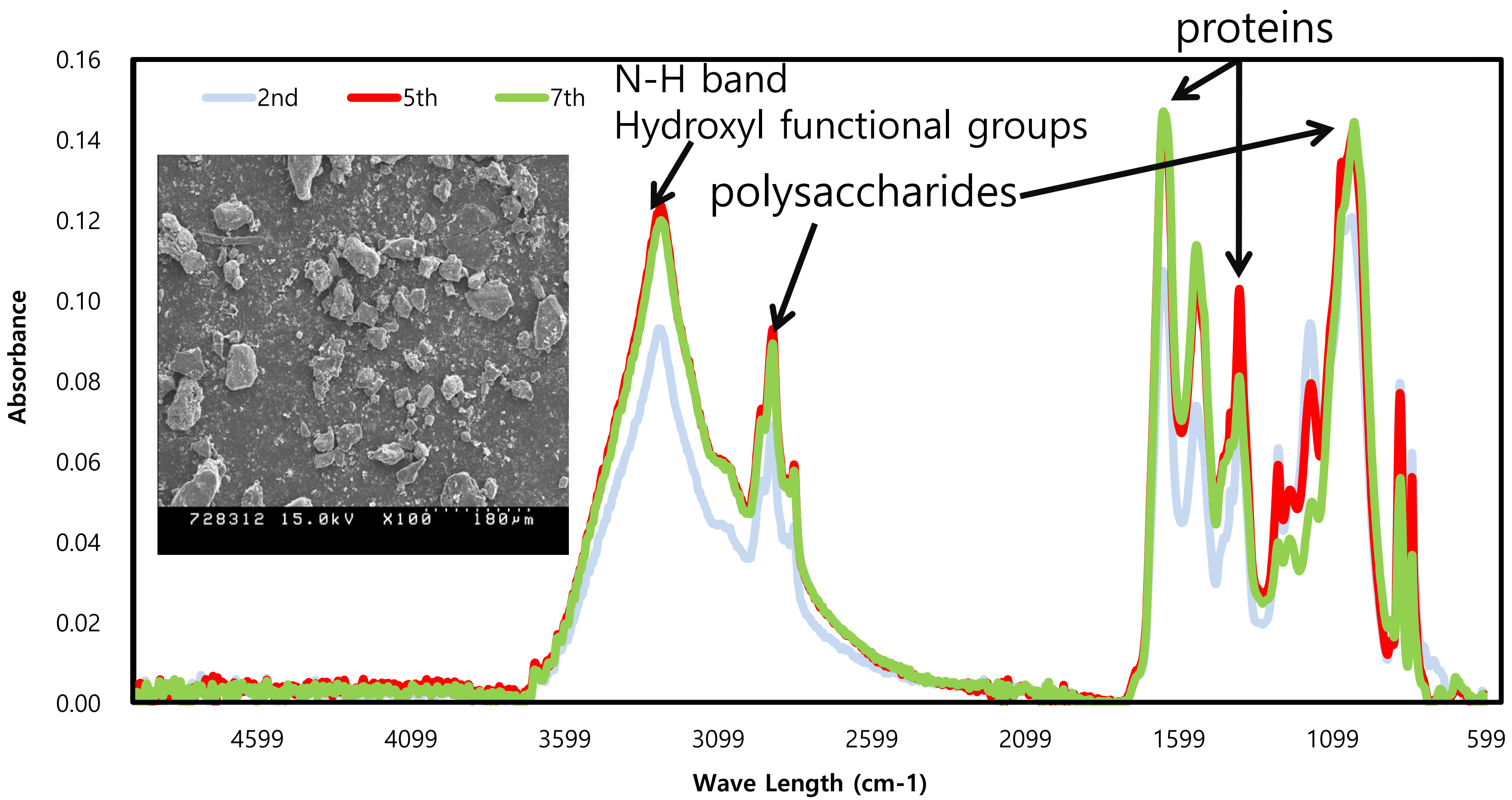
$$P = \frac{QE}{1000}$$

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

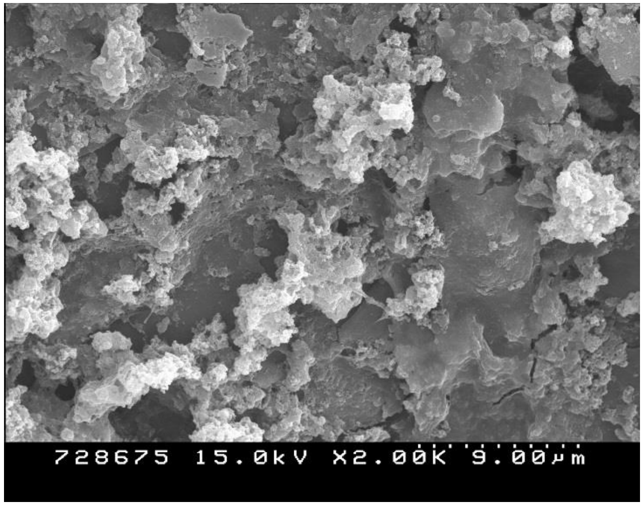
Source by Kim, J.H., MaCarty, P.L.(2011)

- 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



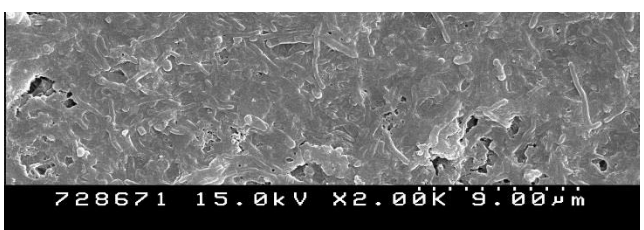
after NaOCl chemical cleaning

	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

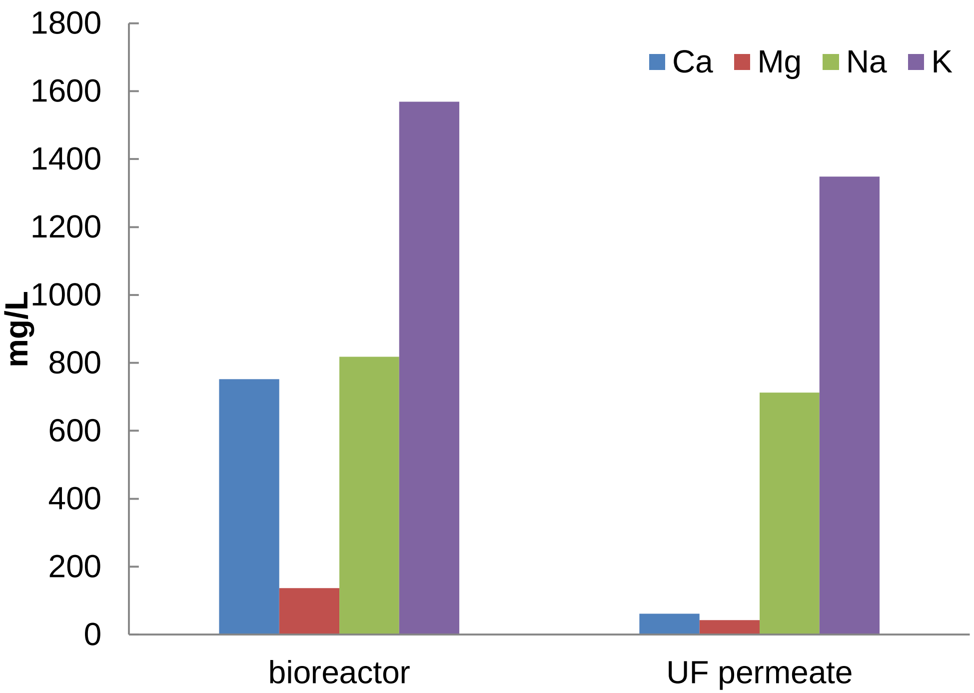
rate?



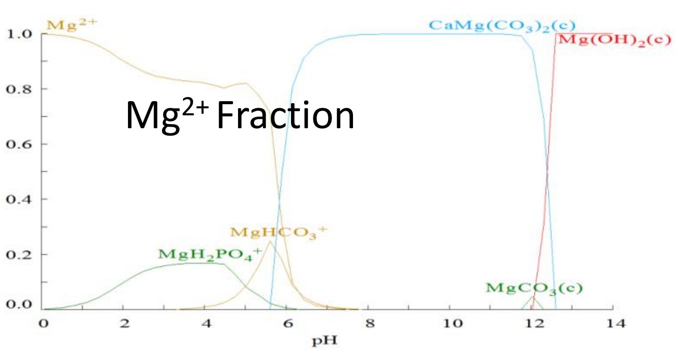
after citric acid chemical cleaning

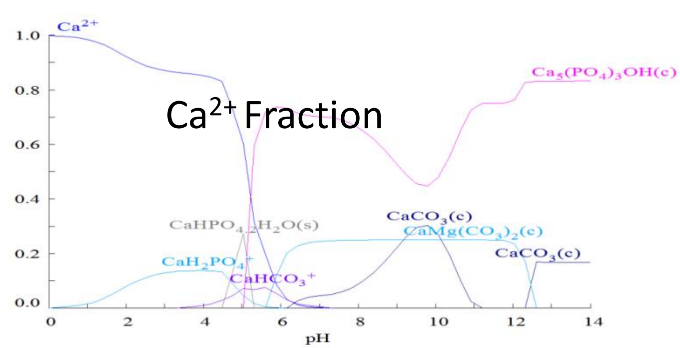
Cross-flow velocity = 3 m/s
TMP= 0.8 bar

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



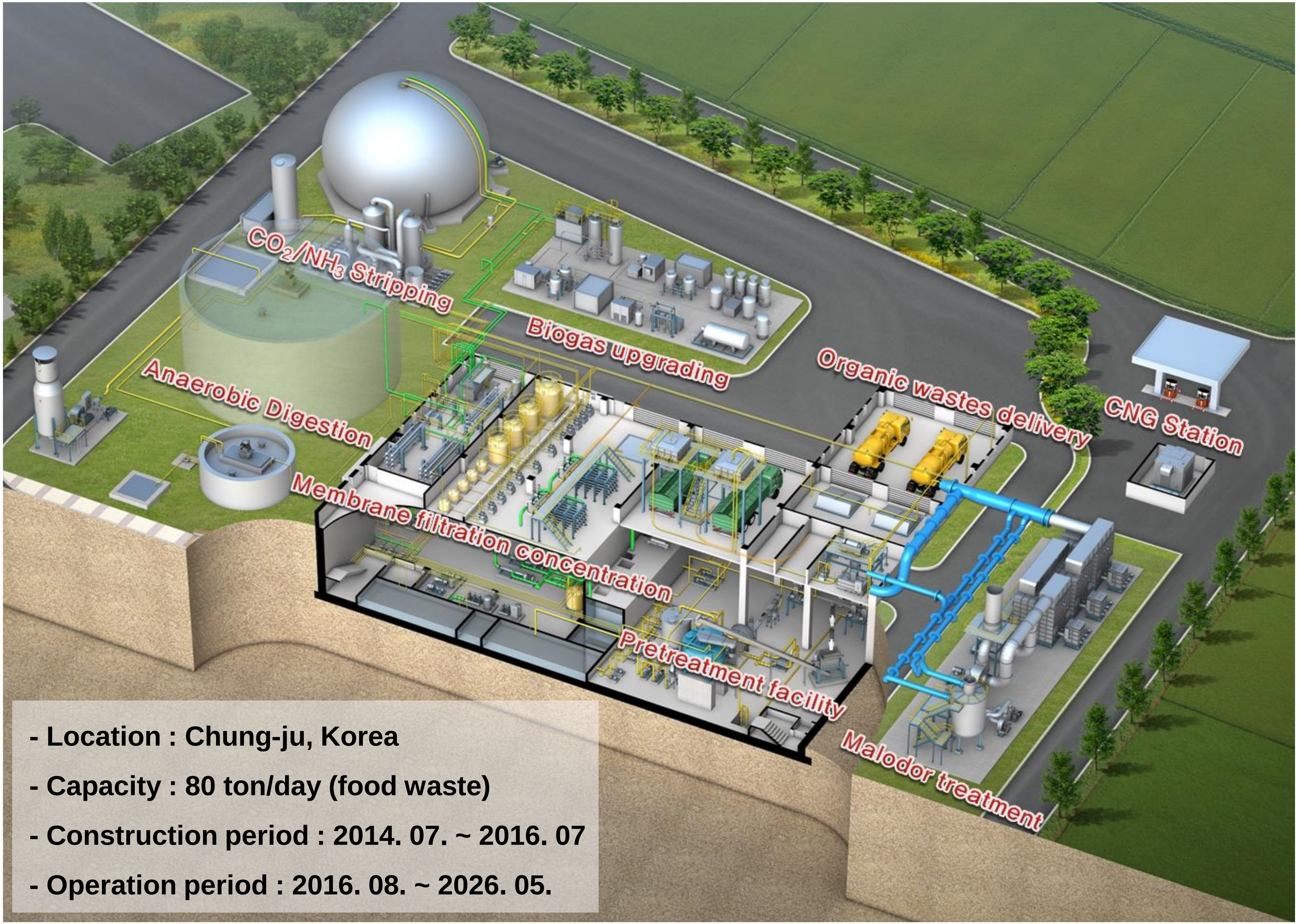


$[Ca^{2+}]_{tot}$=20 mM,
$[NH_3]_{tot}$=200 mM
$[CO_3^{2-}]_{tot}$=200 mM
$[PO_4^{3-}]$=10mM
$[Mg^{2-}]_{tot}$=5 mM,
$[K^+]_{tot}$=40 mM

Food wastes to Energy : Full scale

- Biogas energy plant (80 ton/day), Chung-ju, Korea

Food wastes to Energy : Full scale

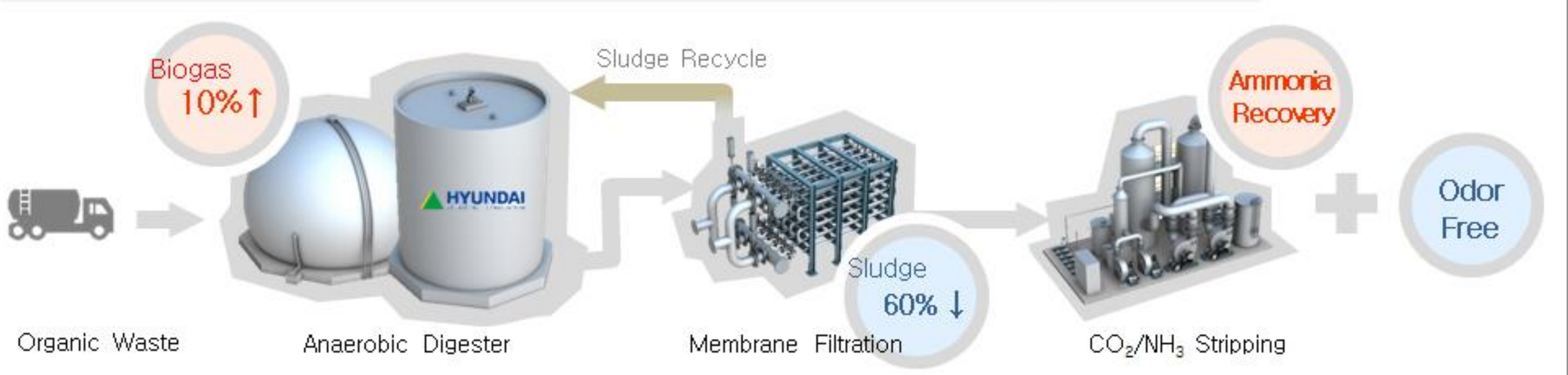


- Location : Chung-ju, Korea
- Capacity : 80 ton/day (food waste)
- Construction period : 2014. 07. ~ 2016. 07
- Operation period : 2016. 08. ~ 2026. 05.

Food wastes to Energy : Full scale

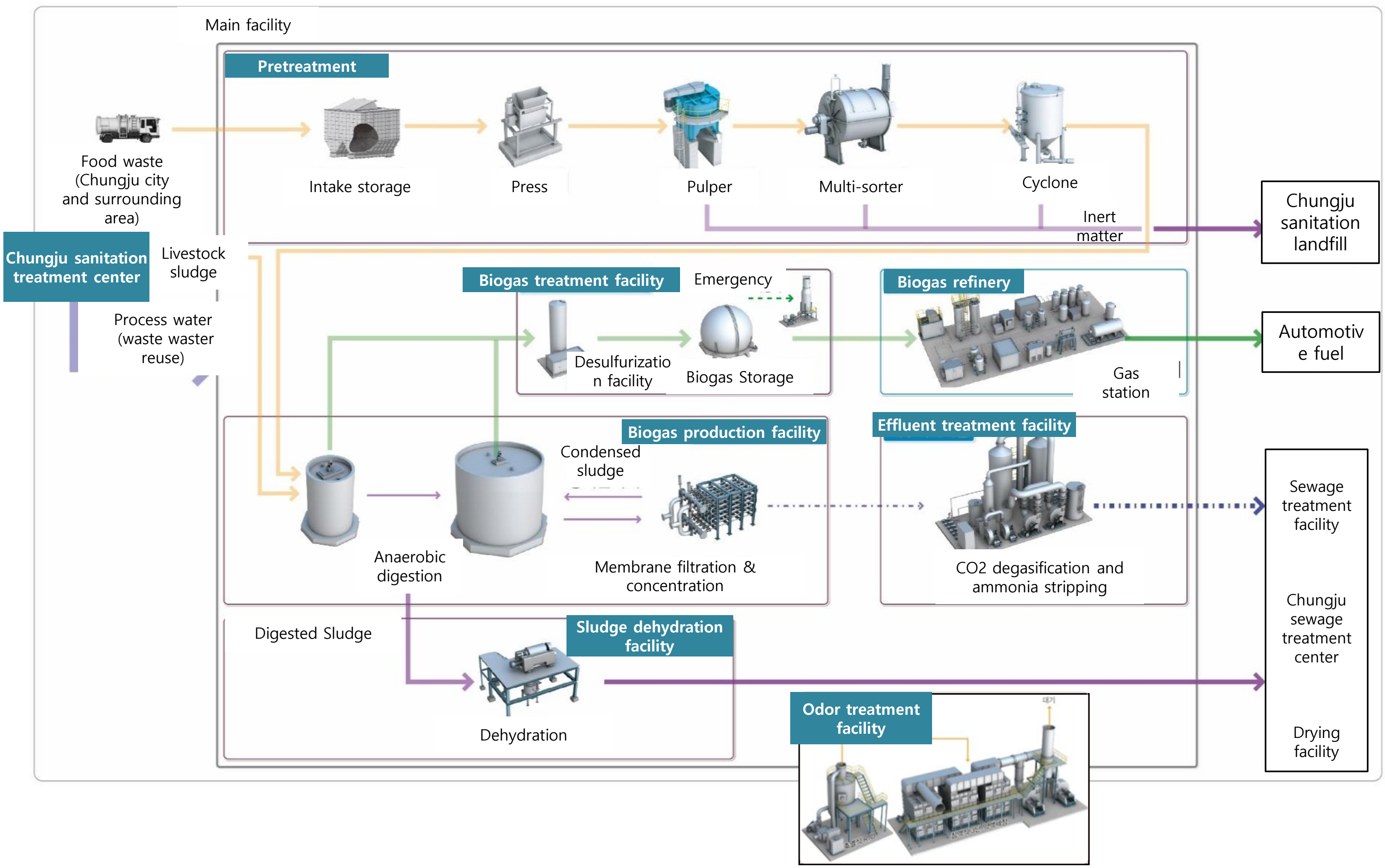
Characteristics of Process

HAnDs® is an Anaerobic Membrane Bio-Reactor which maximizes biogas production from organic waste



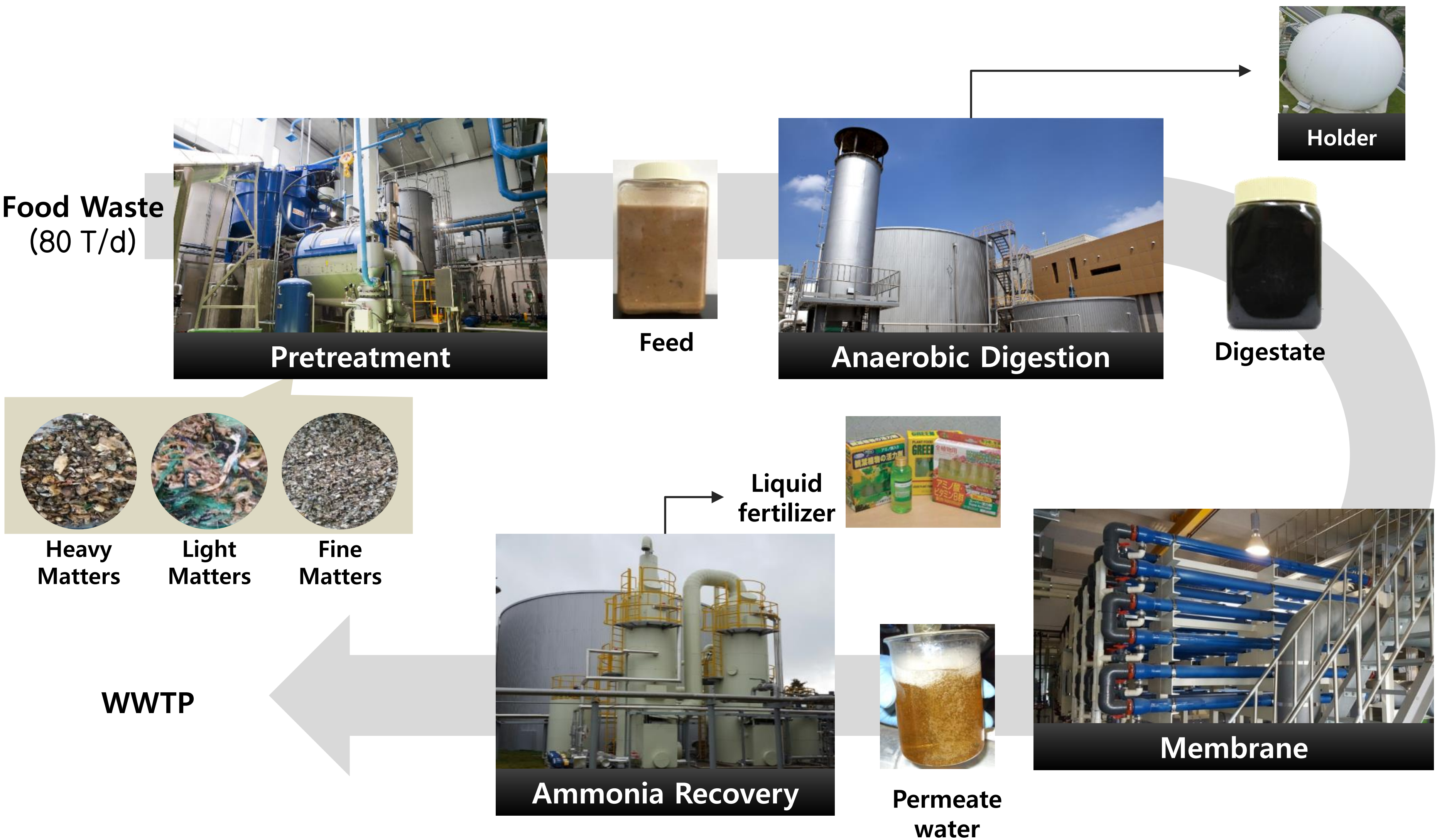
Food wastes to Energy : Full scale

Process Flow



Food wastes to Energy : Full scale

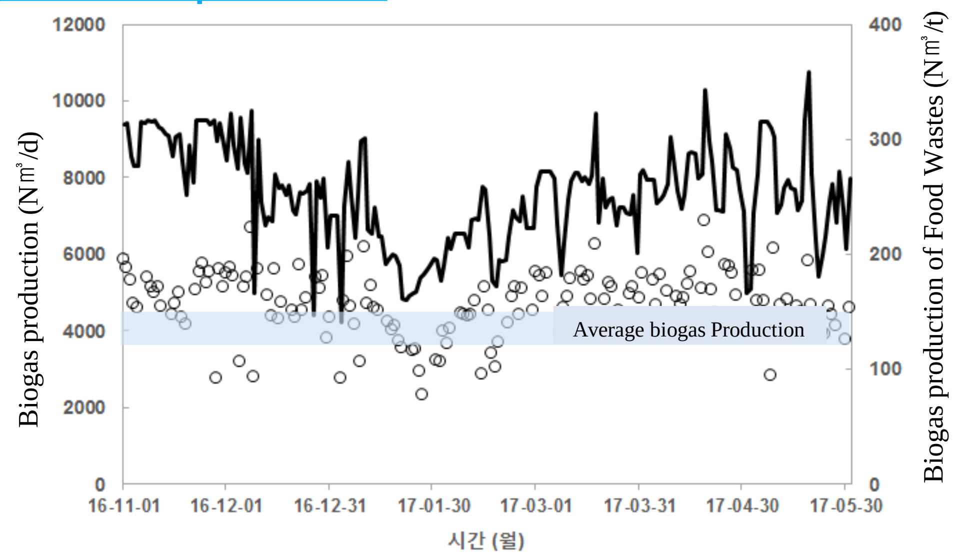
Process Flow of Biogas Production & Water Treatment

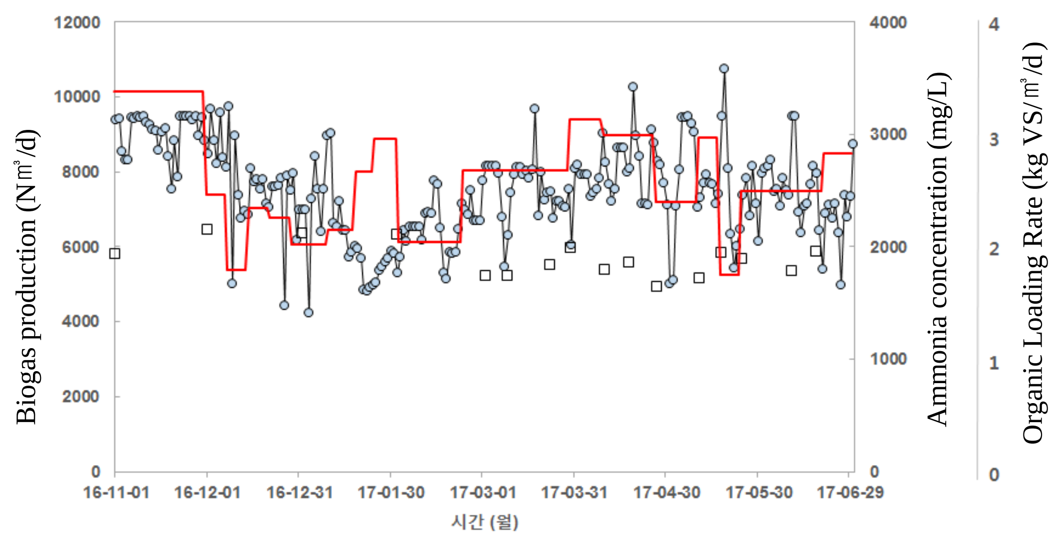


Food wastes to Energy : Full scale

Results of Anaerobic digestion operation

- OLR : 2.4~3.2 kg/ m³/d
- Biogas Prodcution :
  7,760 Nm³/d (110 ~ 135 Nm³/t)
- Biogas Composition :
  CH_4 60~64%, CO_2 36%, H_2S 1,300 ppm

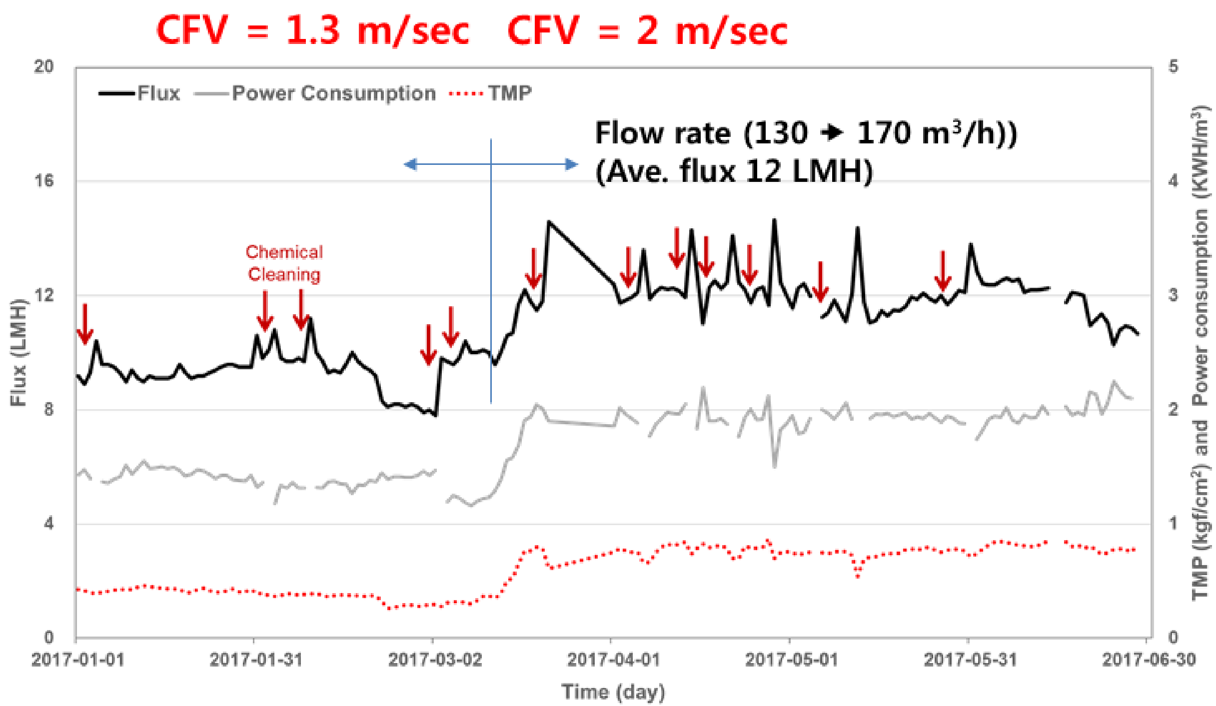




Food wastes to Energy : Full scale

Membrane System Conditions & Performance

Item	Conditions	Note
Input SS	1.5%	
FLUX	11~13 LMH	
Time	18 h	▪ Stop to discharge from center to WWTP in night time
Cleaning	Water : 2 time/d Chemical : 1 time/10d	▪ Chemical : Citric acid (0.1M)



Food wastes to Energy : Full scale

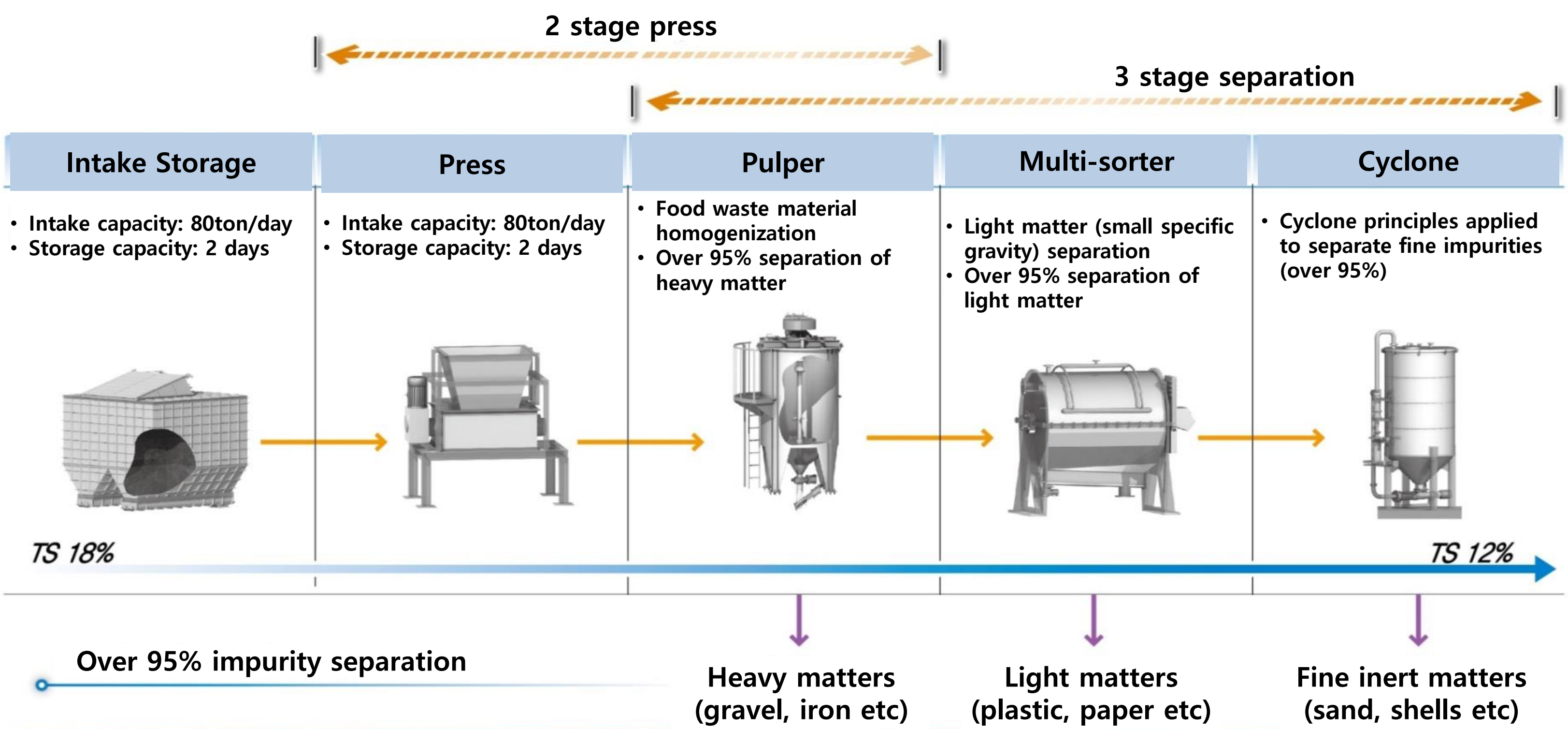
Water Quality

	Food Waste	Digestate	After Membrane	After NH_3 Stripping
BOD (mg/L)	145,000	2,630	-	-
COD_{Cr} (mg/L)	252,000	22,797	6,000	750
TS (mg/L)	177,000	33,912	3,300	3,000
VS (mg/L)	156,000	25,682	607	-
SS (mg/L)	-	13,600	< 100	< 100
T-N (mg/L)	6,300	4,634	2,015	3,090
T-P (mg/L)	2,200	441	< 100	< 100

본 연구는 환경부의 폐자원에너지화 기술개발사업(유기성폐자원 에너지화 사업단)에서 지원받았습니다.(과제번호:**2013001580002**)

How to apply ?

Pretreatment facility



2 stage press, 3 stage separation system introduction:

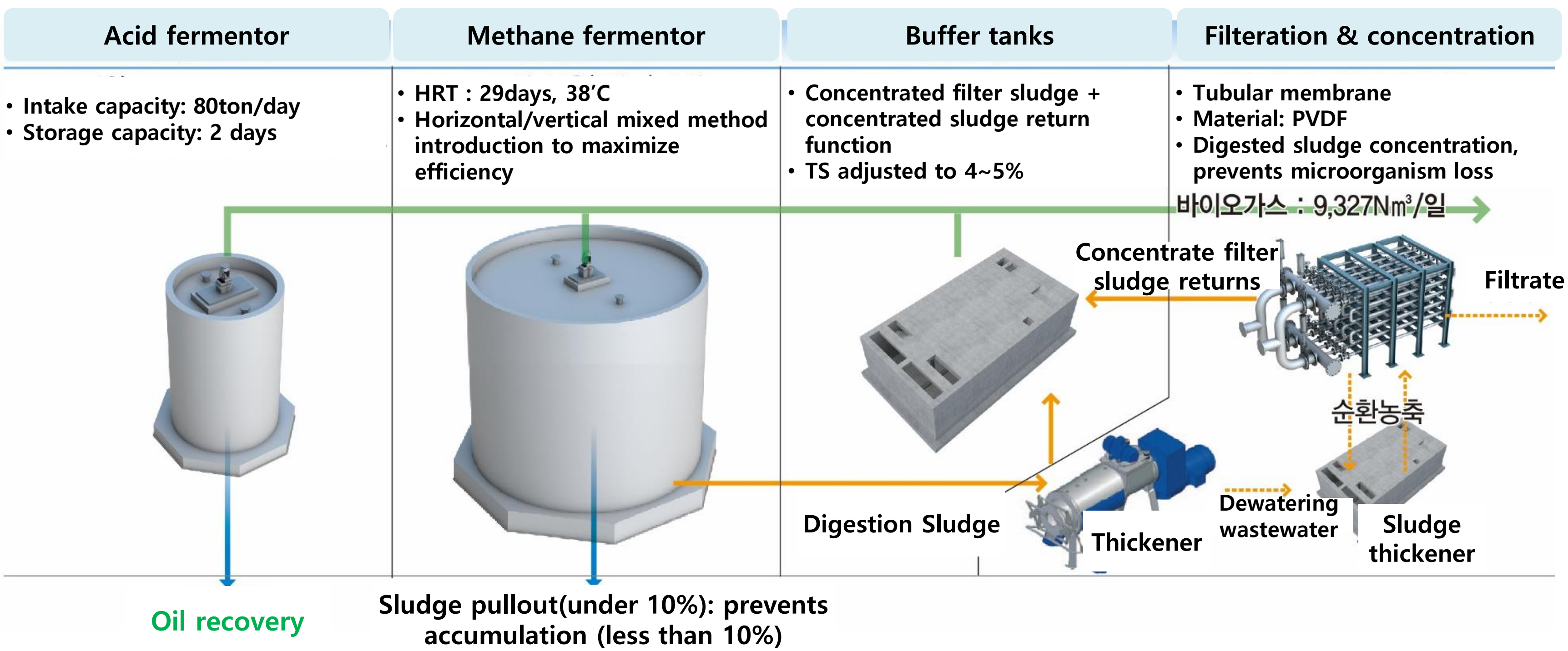
- Improvement of material homogenization and impurity separation ability (over95%)
- Construction of TS content adjustment function suitable to the applied anaerobic digestion

Improvement of food waste digestion efficiency

How to apply ?

Biogas Production

- Sludge recycle → Providing long SRT needed while operating
  Biogas more production, reduce sludge discharge



How to apply ?

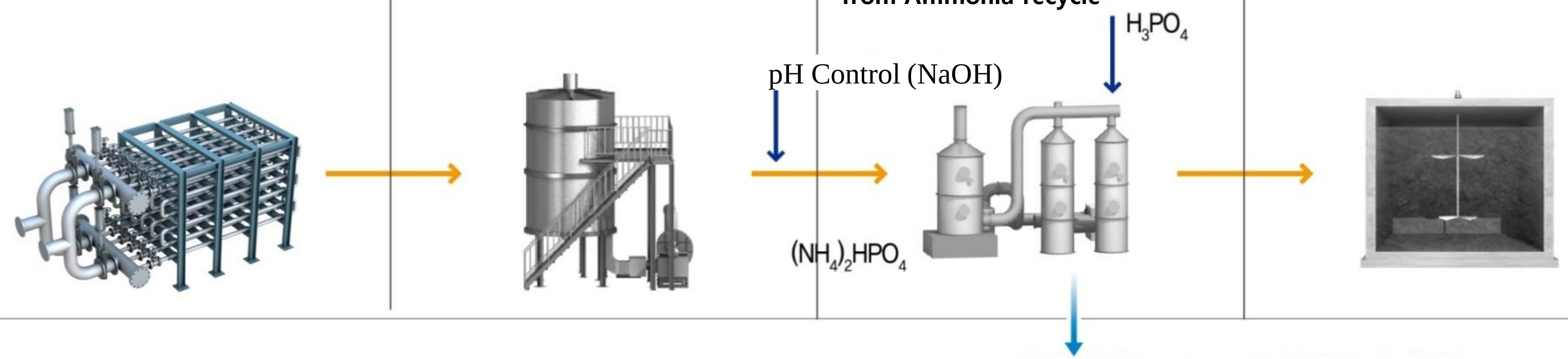
Wastewater treatment facility

- Planning of connecting wastewater to STP and recovery of valuable resources

Reduce Nitrogen loading rate by collection ammonia

Planning of connecting wastewater to STP, cost saving

Filteration & Concentration	CO2 stripping	Ammonia Stripping	Storage tank
• SS removal through membrane filter in advance -> allows easier treatment in the latter unit	• pKa increase from High temperature(45′C) stripping -> pH altering chemical reduction	• C/N ratio increase from ammonia removal -> linked disposal and self disposal • Liquefied fertilizer production from Ammonia recycle	• Consider wastewater connection : HRT 1 day • Changeable by the operating conditions (time, flowrate)



Liquid fertilizer ($(NH_4)H_2PO_4$), Supply to farm