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The biological fermentation process for hydrogen and methane production from food waste and microbial community analysis

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Content

- Hydrogen-production from food waste by anaerobic digesters.
- two-stage anaerobic process for hydrogen and methane production from food waste
- High-solid anaerobic digestion of food waste

Production and distribution of food waste in China

Food waste produced

Annual output	**30 million tonnes / year**
Daily output from cities	**0.15 kg /day / person**
Annual growth rate	**10% - 20%**

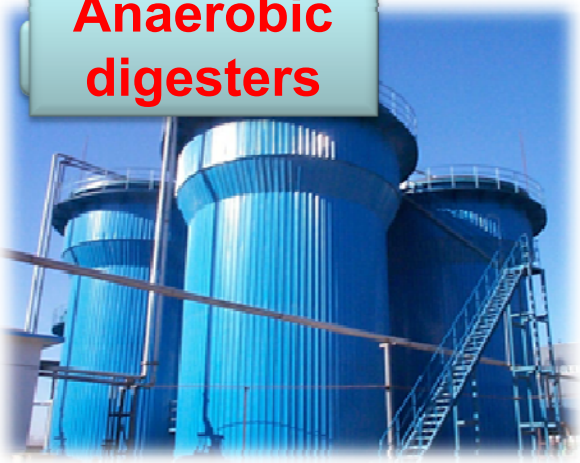
Treatment method of organic waste

Combustion

Landfill

Compost

Anaerobic digesters



Hydrogen production of anaerobic digesters

Hydrogen production rate and fermentative type

Acetate Fermentation：

$C_6H_{12}O_6 + 2H_2O \rightarrow 4H_2 + 2CH_3COOH + 2CO_2$

Butyrate Fermentation ：

$C_6H_{12}O_6 + 2H_2O \rightarrow 2H_2 + 2CH_3(CH_2)_2COOH + 2CO_2$

Propionate Fermentation ：

$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2CO_2$

Hydrogen consumption

Sulfate-reducing bacteria

$4H_2 + SO_4^{2-} + H^+ \rightarrow HS^- + 4H_2O$

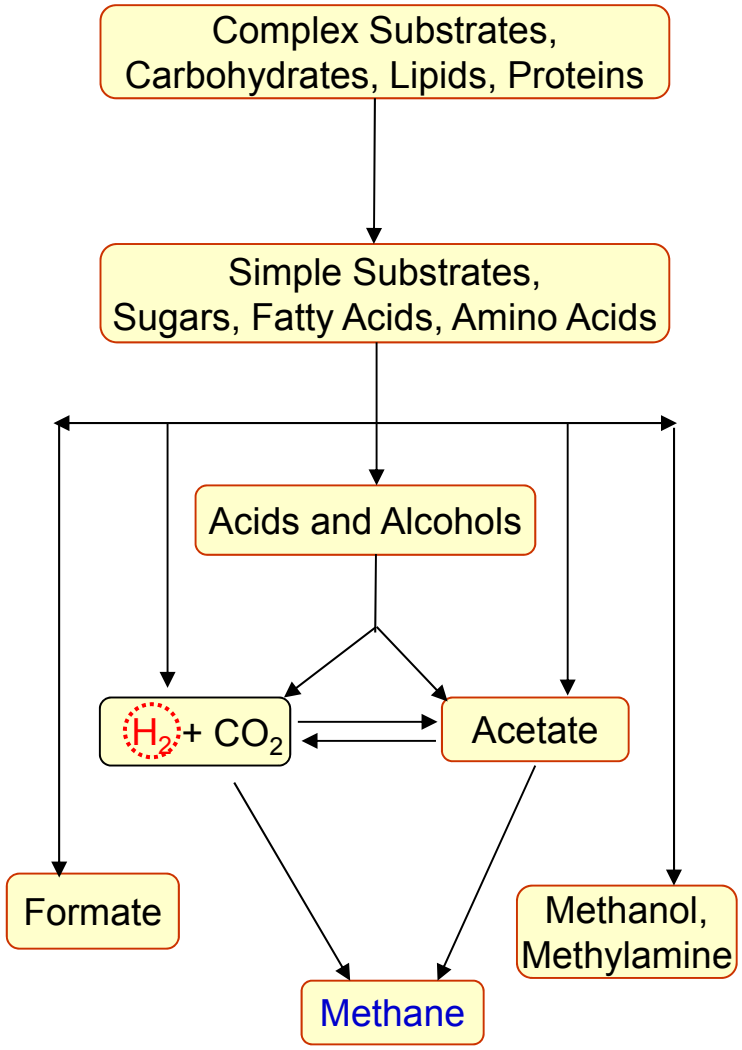
Hydrogenotrophic methanogens

$H_2 + HCO_3^- + H^+ \rightarrow CH_4 + 3H_2O$

Syntrophic acetogenic bacteria / Homoacetogenic bacteria

$4H_2 + HCO_3^- + H^+ \rightarrow CH_3COO^- + 4H_2O$

The anaerobic food chain



Key point to promote hydrogen-production

- **The pH control for effective hydrogen-production.**

  Hydrogen-producing bacteria optimum pH: 5.5～6.5

  Methane-producing bacteria optimum pH: 6.8 ～7.2

- **Short hydraulic retention time (HRT) for hydrogen-producing bacteria and wash out methane-producing bacteria.**

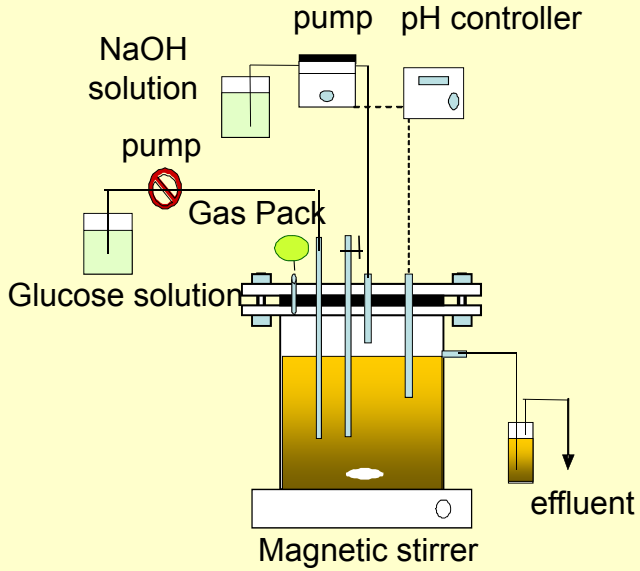
  Hydrogen-producing bacteria HRT: 1 ～3d

  Methane-producing bacteria HRT: 5 ～15d

- **Heat-shock pretreatment of the inocula, used for induction of hydrogen production and kills methanogens.**

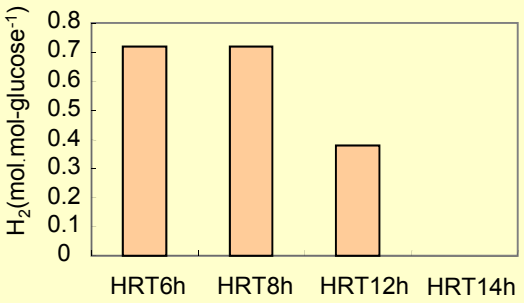
Effect of hydraulic retention time on the hydrogen yield

Continuous enrichment

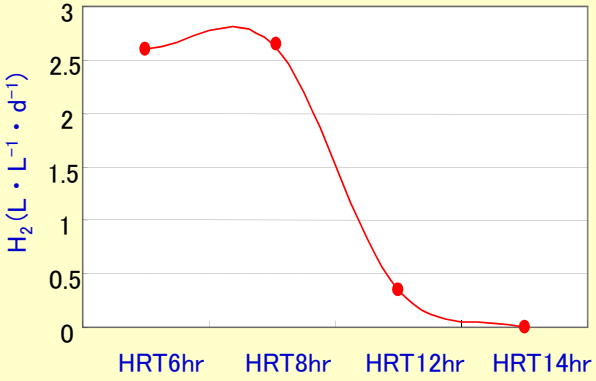


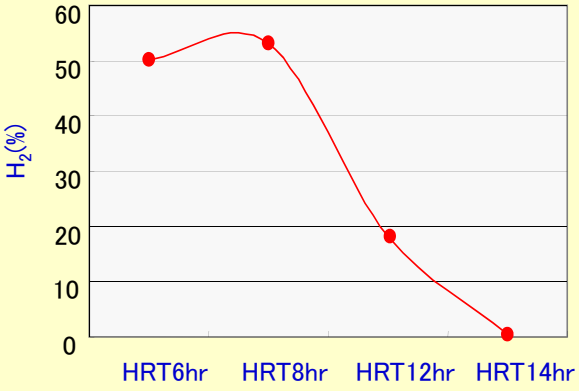
Operation condition

Reactor volume	**0.5 L**
Feed	**Glucose minimal medium**
Seed sludge	**Heated digested sludge**
HRT	**6, 8, 12, 14 h**
Temp.	**30℃**
pH	**Adjusted to 5.5**



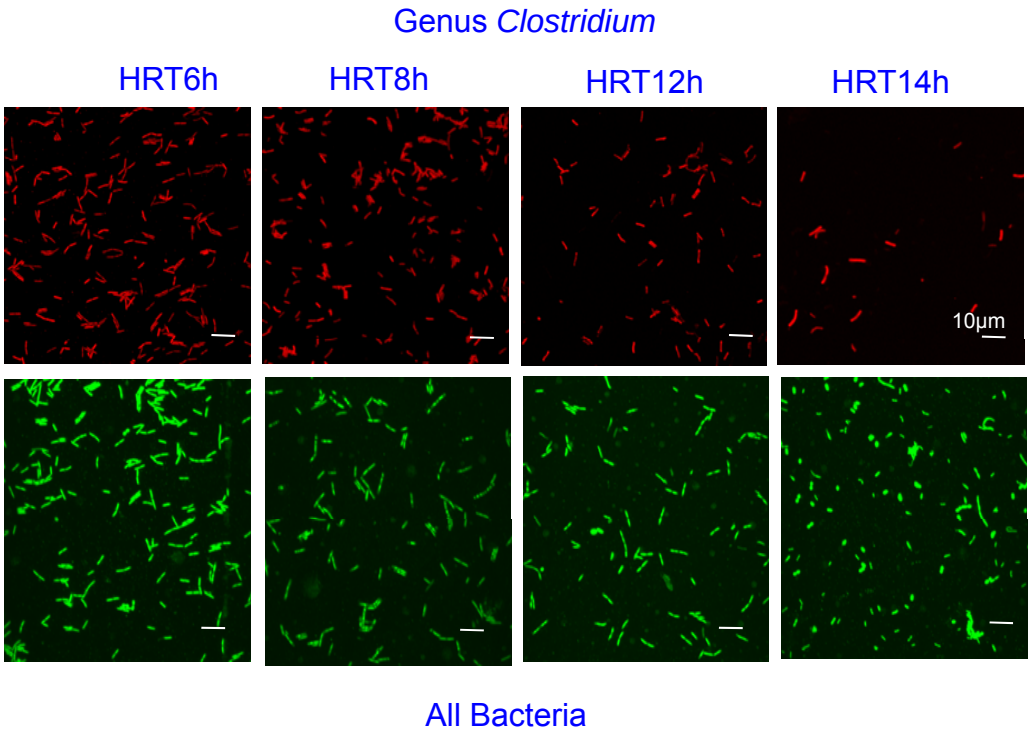
Effect of HRT on hydrogen productivity



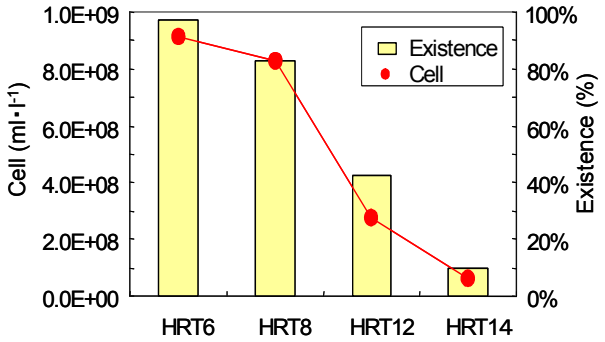


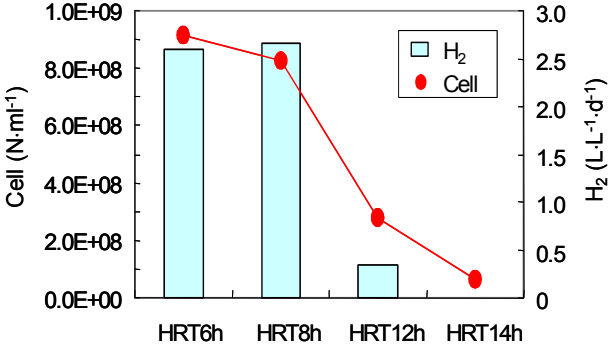
Hydrogen productivity rate decreased as HRT increased.

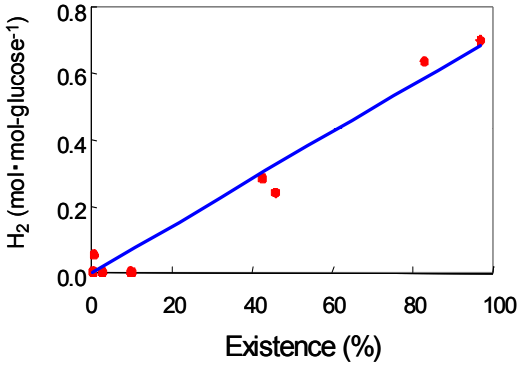
Quantification by FISH in Continuous reactors



CLSM images of sludge samples from continuous fermentative reactors after FISH with CY3-labelled probe Clost IV (in red) and SYBR Green I stained cells (green).

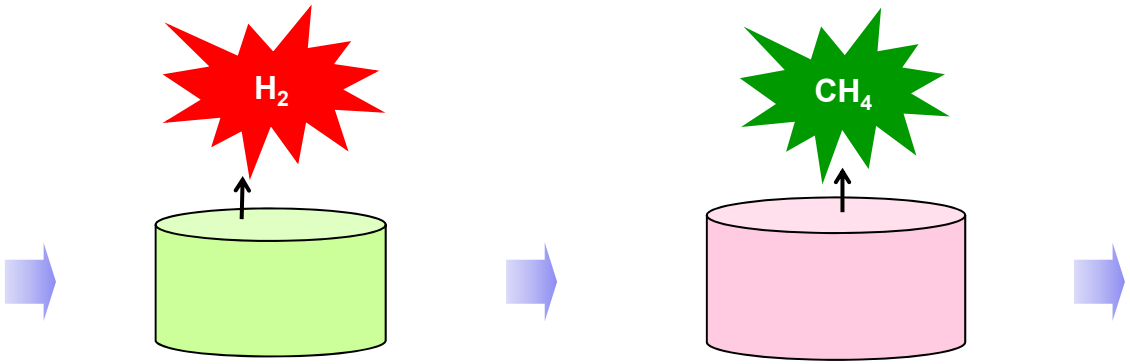






J Environ Sci 2009, 21: 424–428

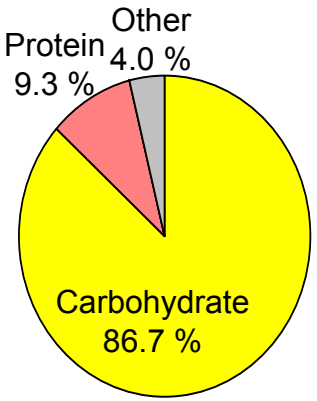
Two-stage process for hydrogen and methane production from food waste



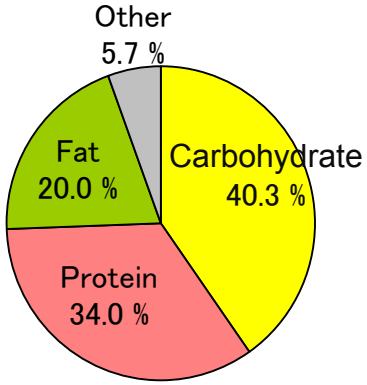
Hydrogen and methane potential based on the nature of food waste materials in a two-stage thermophilic fermentation process

Characteristics of food waste as feedstock

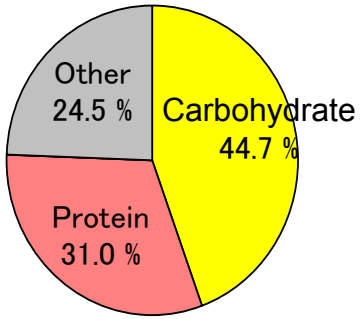
Parameter		Potato	Garbage	Okara
TS	g / l	38.9	40.3	45.5
VS	g / l	35.8	38.1	43.6
T-COD_{Cr}	g / l	52.1	52.2	52.0
Carbohydrate	g / l	41.2	21.0	23.2
Protein	g / l	4.8	17.7	16.2
T-N	g / l	1.4	1.3	1.7
NH_4-N	mg / l	6.5	7.6	3.8



Potato

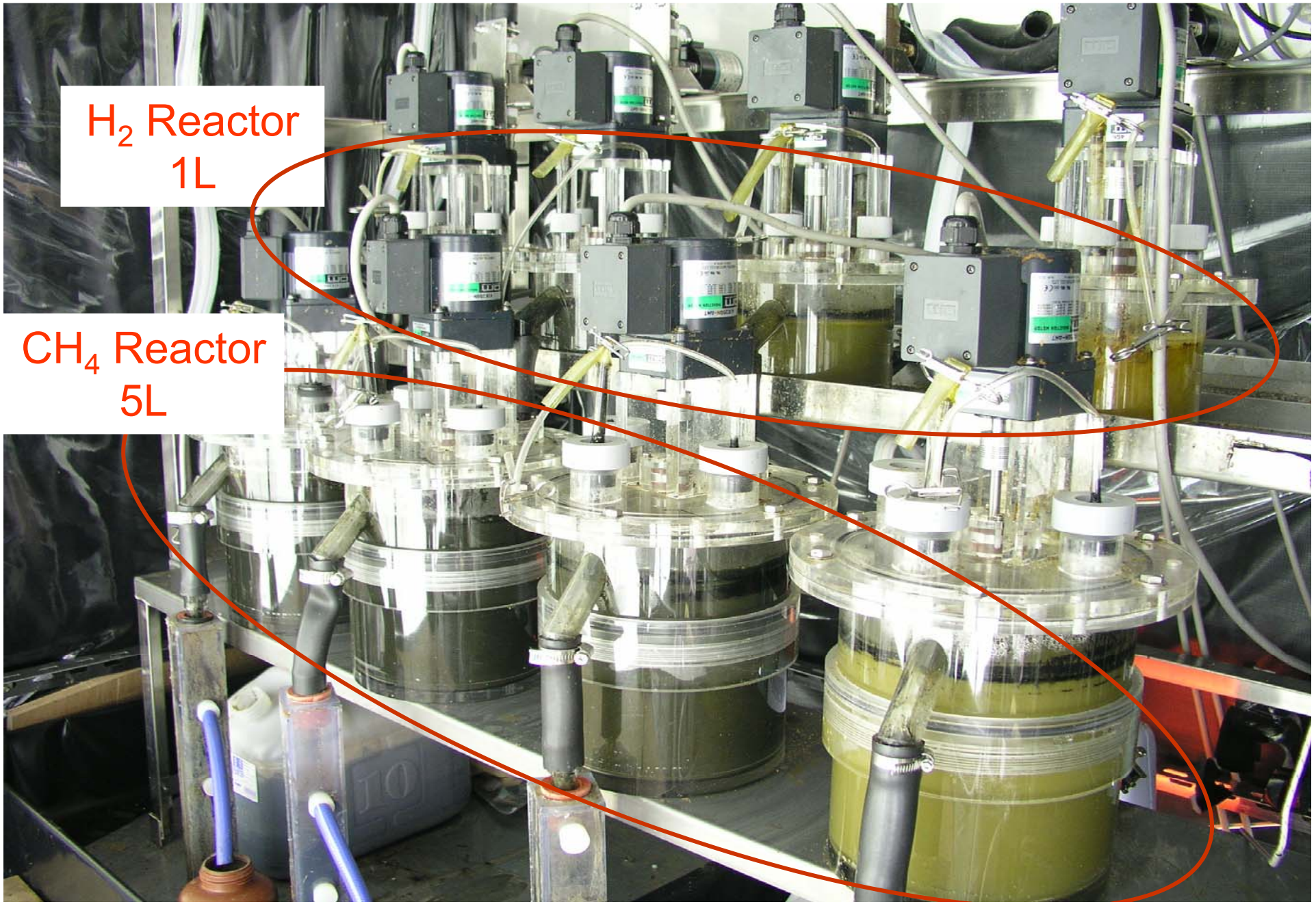


Garbage

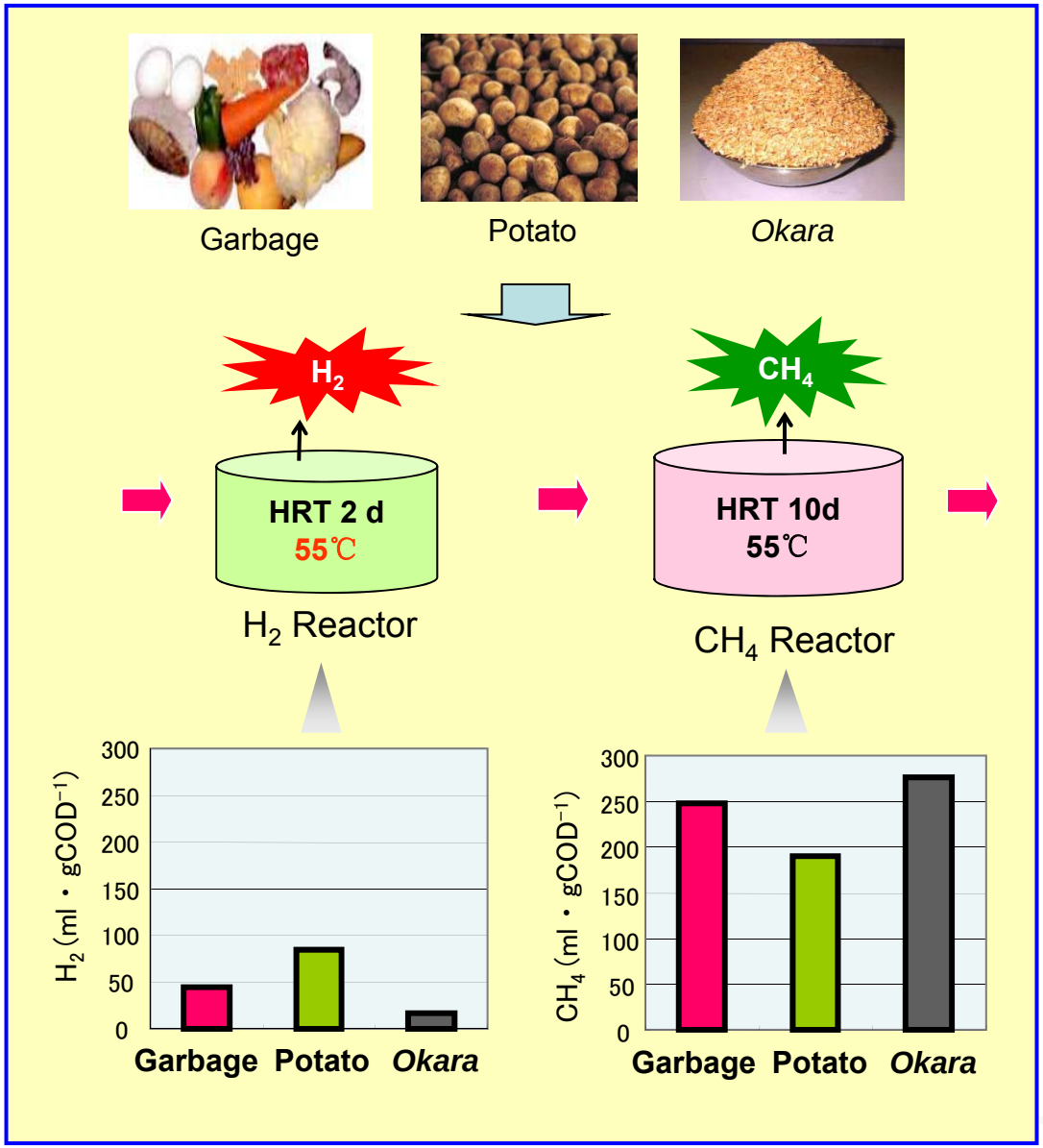


Okara

A two-stage fermentation experiment **apparatus**



Effect of materials characteristic on hydrogen and methane yields



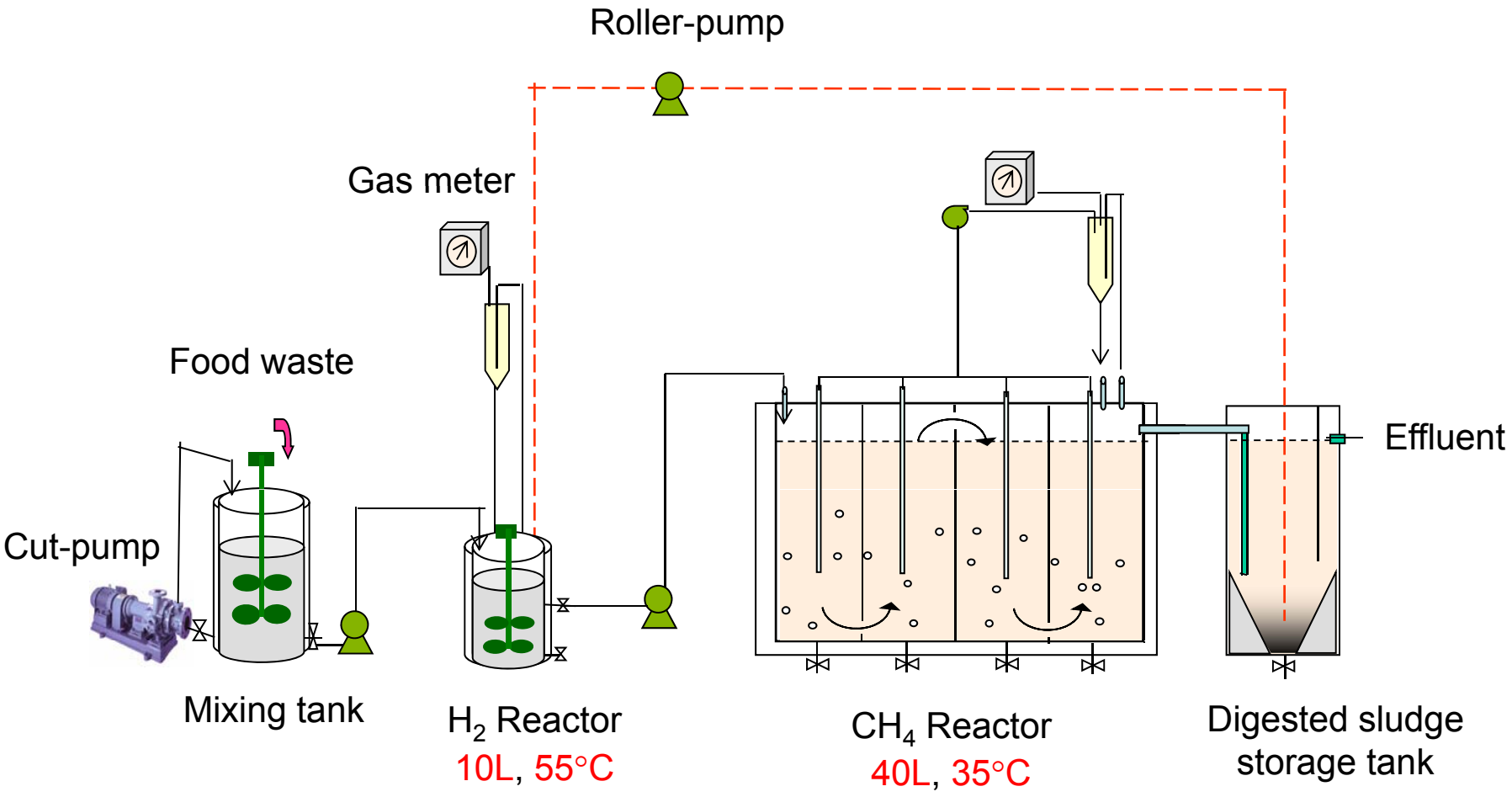
Int J Hydrogen Energy. 2012, 37: 10611-10618

The biohydrogen potential not only depends on the carbohydrate content but also on the hydrolysis pH of waste, which is affected by the nature of the waste materials.

The H_2 yield increased and the CH_4 yield decreased in the order of potato, kitchen garbage and okara.

Okara food waste might be suitable for CH_4 production process without any pre-treatment.

A pH- and temperature-phased two-stage process for hydrogen and methane production with recirculation of the digested sludge

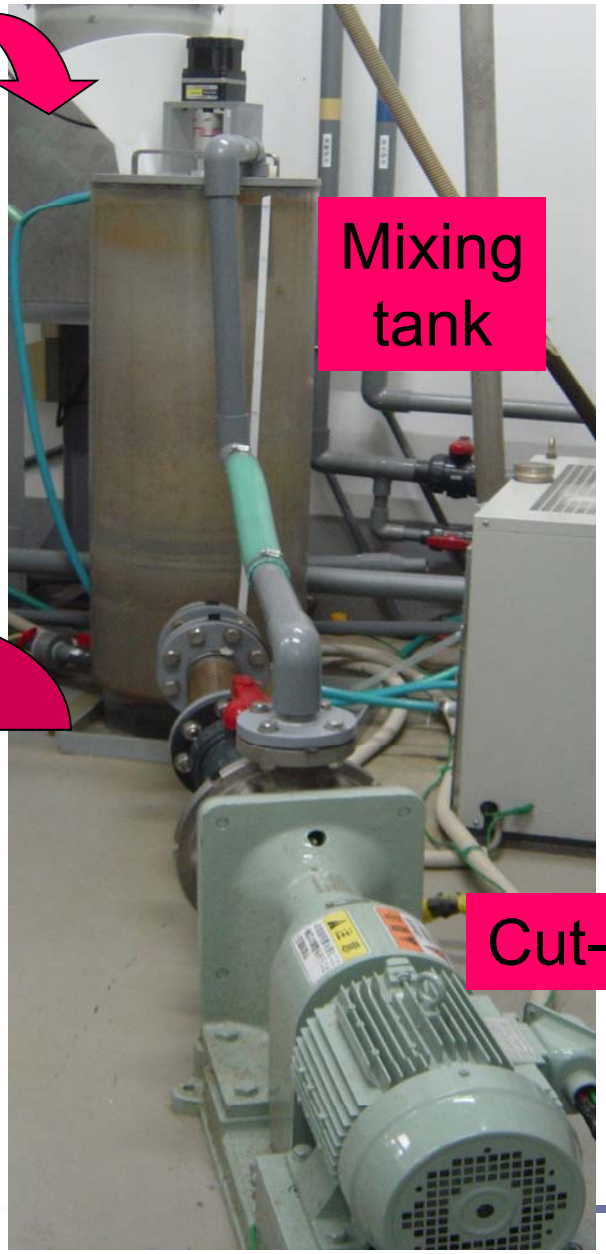


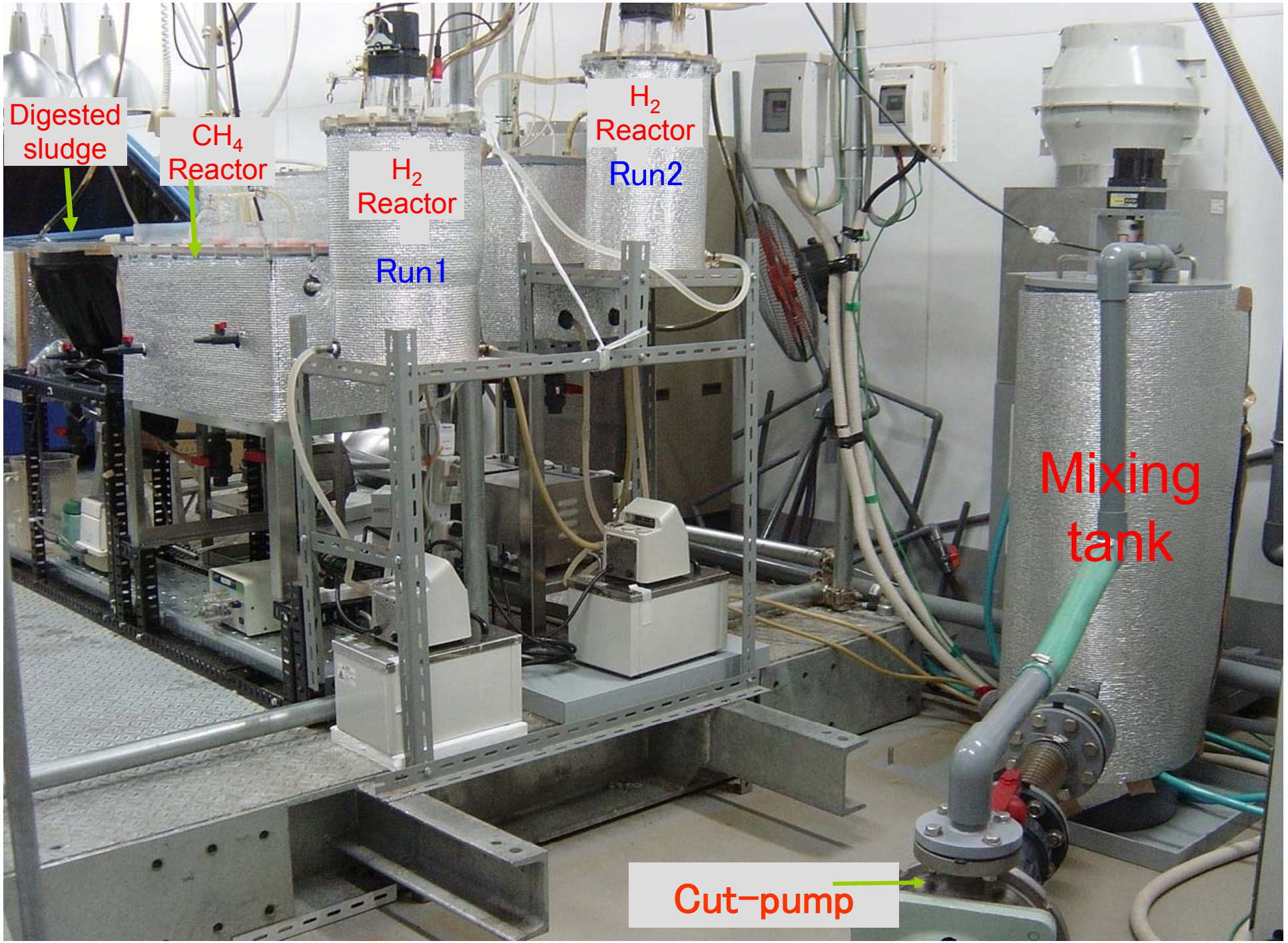
Feedstock

Food waste :
water = 1 : 1.4
(w/w)

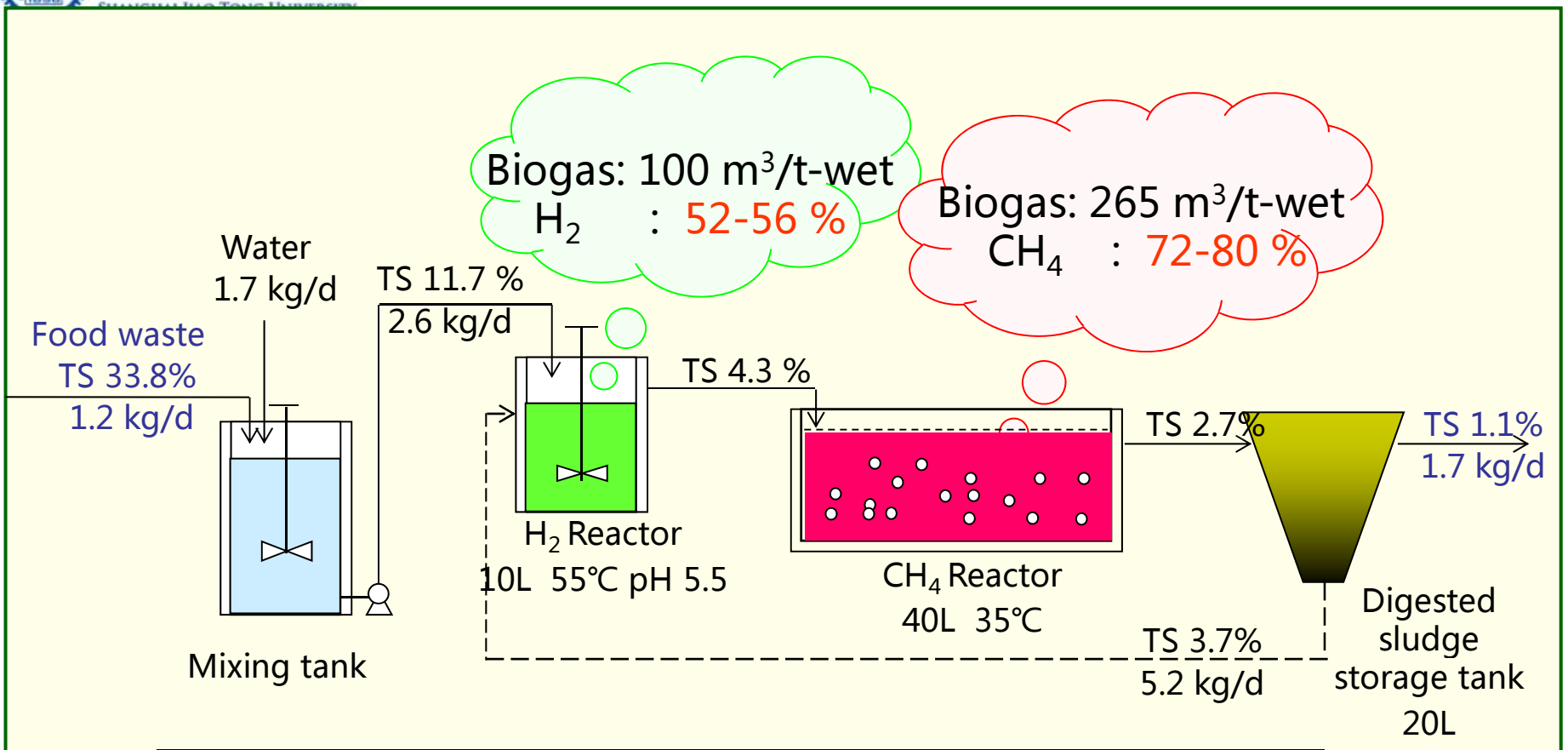
raw food waste
（TS 33.8%）

diluted food waste
（TS 11.7%）




Digested sludge
CH_4 Reactor
H_2 Reactor
Run1
H_2 Reactor
Run2
Mixing tank
Cut-pump

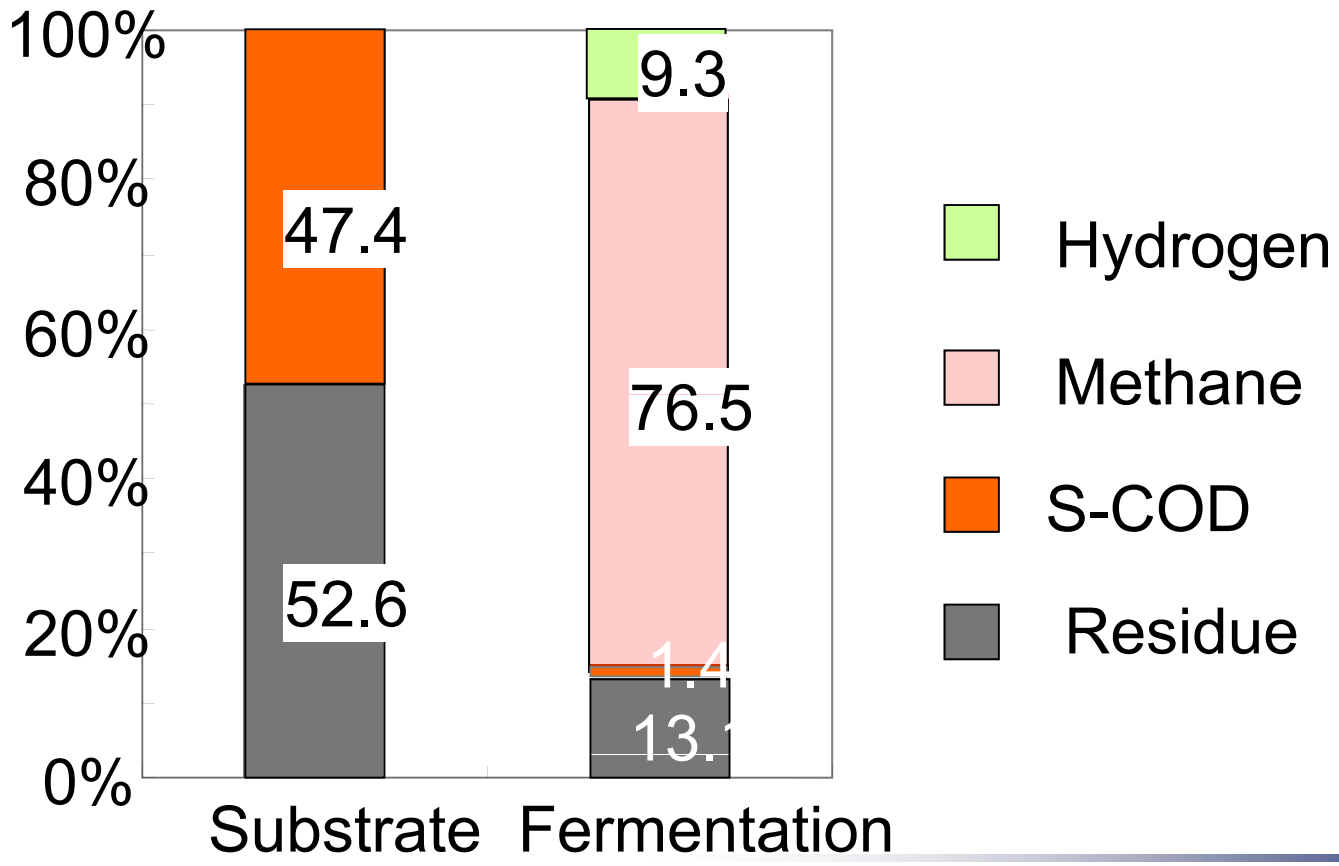
Mass balance in the process



H_2 yield	**2.5-2.8 mol/mol-hexose** **205 ml/gVS added**
CH_4 yield	**464 ml/gVS added**

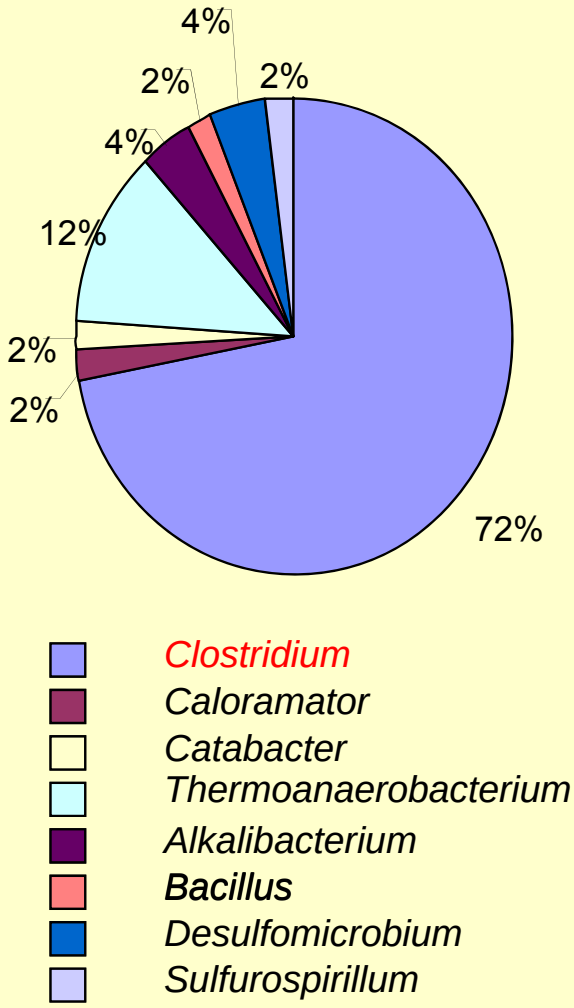
Int J Hydrogen Energy. 2008, 33: 4739-4746

COD mass balances after two-stage fermentation

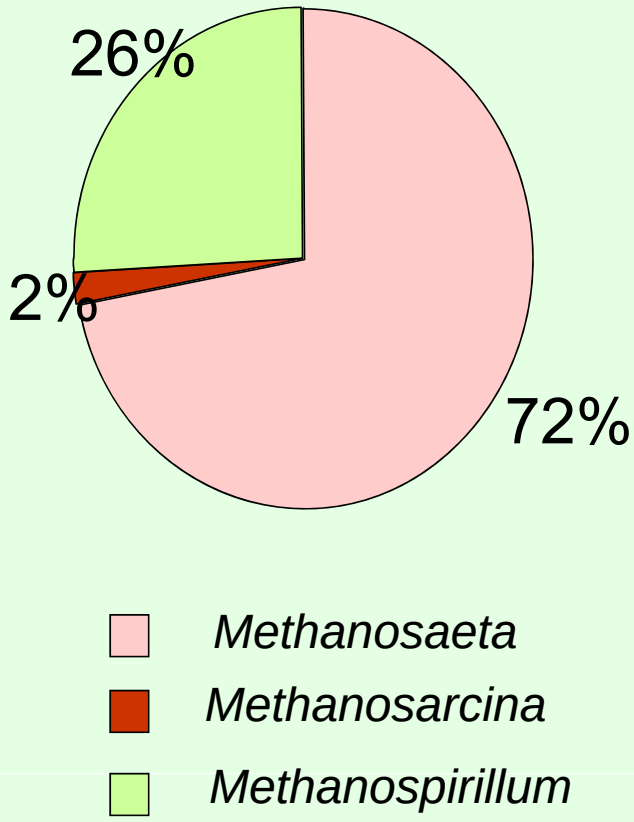


Microbial Community in two-stage process for hydrogen and methane production

Hydrogen production reactor



Methane production reactor



Int J Hydrogen Energy. 2010, 35:8253 – 8261

High-solid anaerobic digestion of food waste

Feedstock :TS > 15% (w/w)

Advantageous

- **smaller reactor volume,**
- **lower energy requirements for heating,**
- **less material handling.**

Question

- **High nitrogen content**
- **VFA accumulation**

Aim:

- **Using fluorescent in situ hybridisation (FISH) techniques, to elucidate changes in the microbial population and linked to changes in ammonia and VFA concentration.**

High-solid anaerobic digestion of food waste

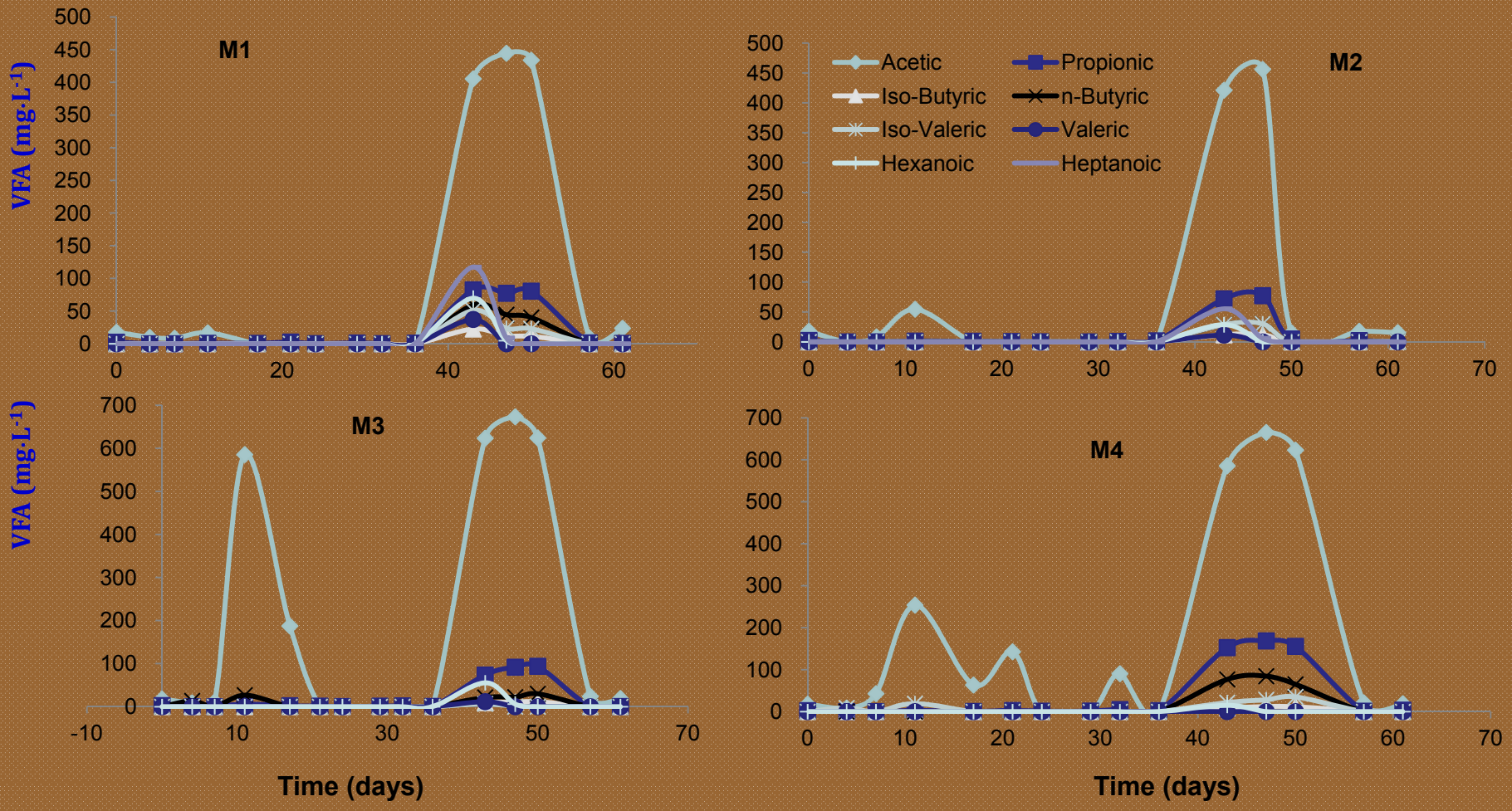
ECOFUEL project

ECOFUEL: EU-China Cooperation for Liquid Fuels from Biomass Pyrolysis

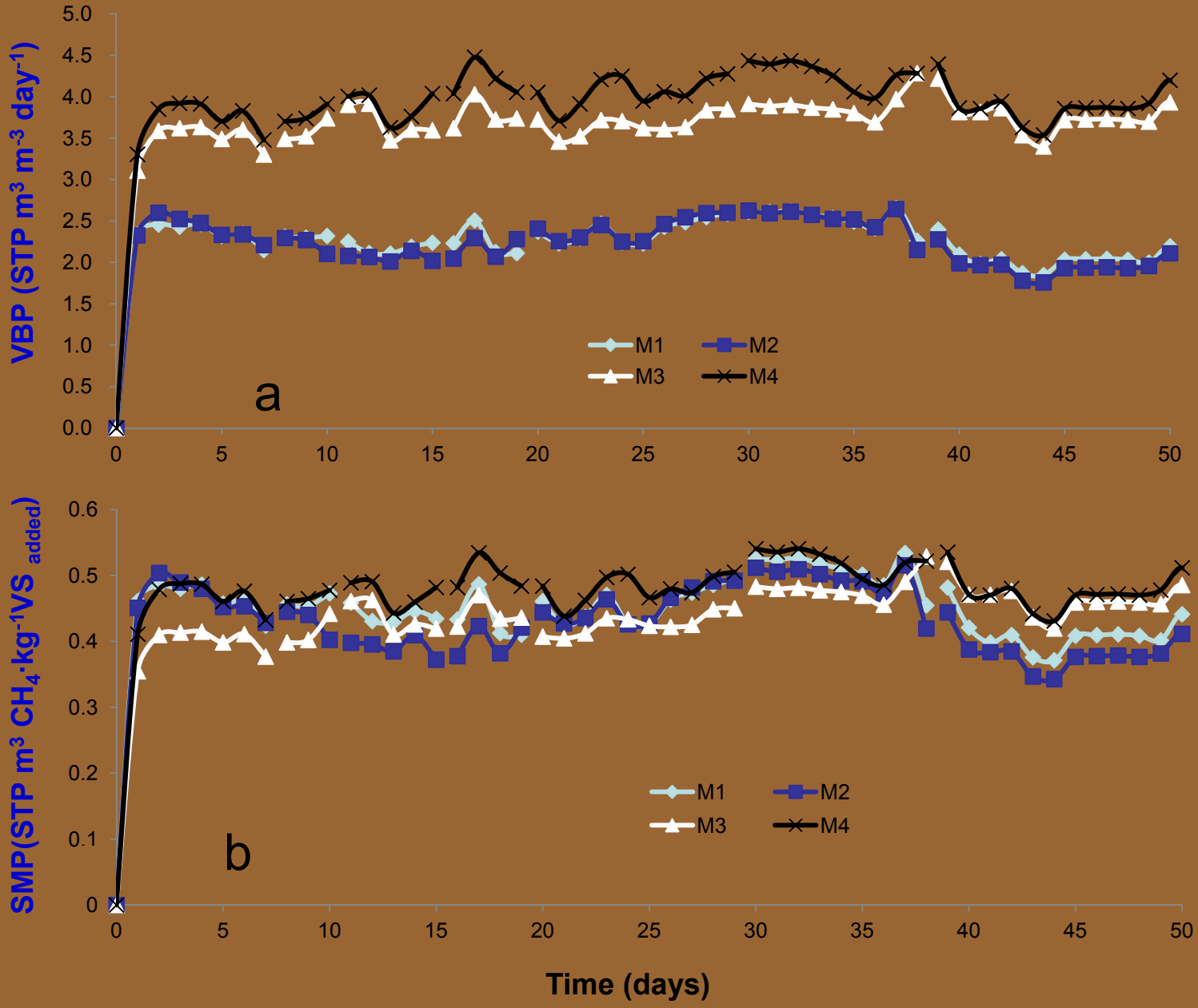
FP7-PEOPLE-2009-IRSES Grant 246772

Feedstock （TS 24.6 %)

M1,M2: OLR 3 gVS·L^{-1}·d^{-1}
M3,M4: OLR 5 gVS·L^{-1}·d^{-1}



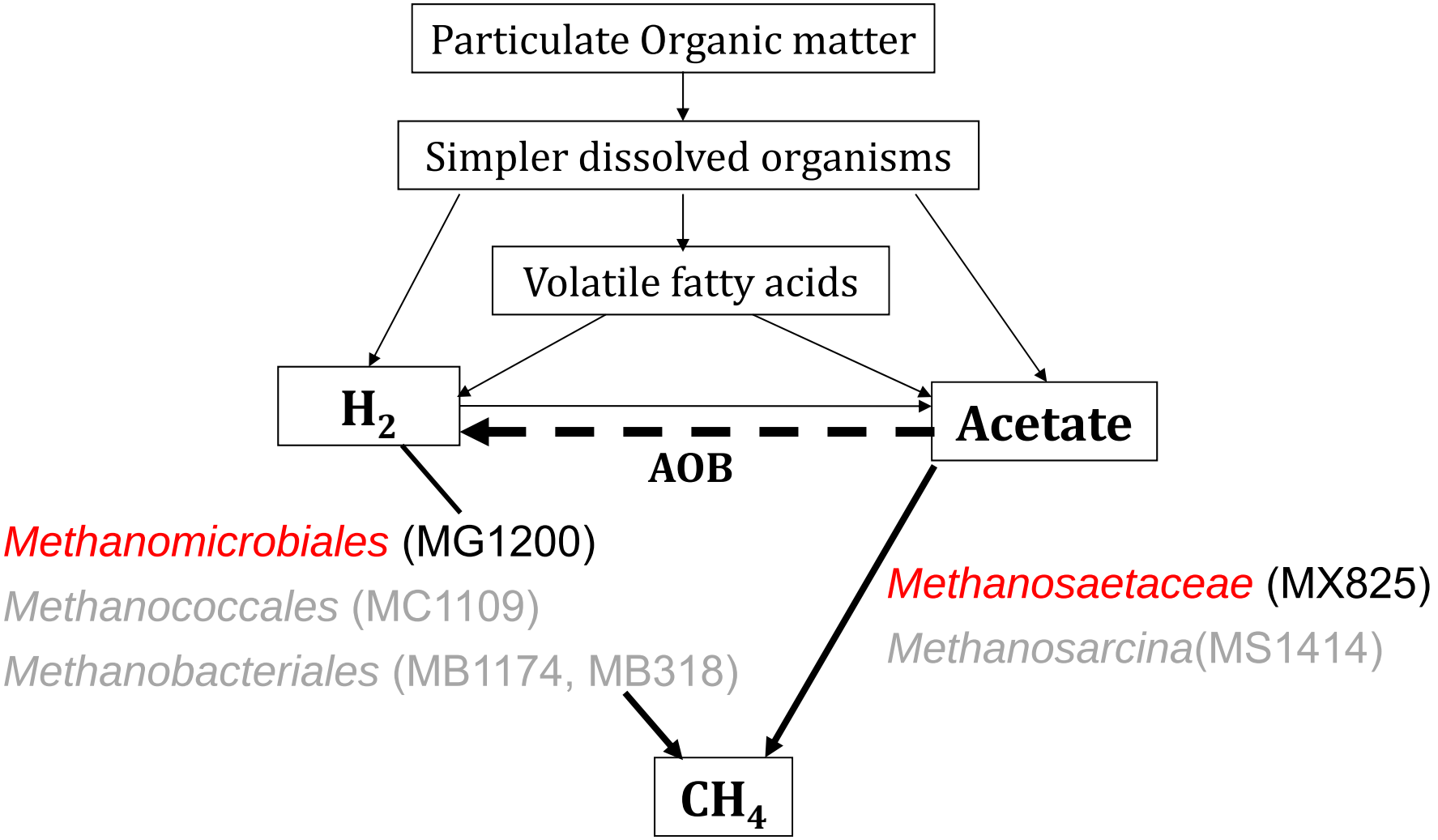
VFA concentration profile in digestate



Volumetric biogas production(a) and specific methane production (b) during the experimental period.

16S rRNA oligonucleotide probes used FISH

Probe/Dye	Target group	Fluorochrome	Formamide	Temperature(℃)
DAPI	Total cell			
Eub 338	*Eubacteria* (most)	**Cy3**	5%	46/48
Eub 338+	*Eubacteria* (remaining)	-		
ARC915	*Archaea*	**6-Fam**	35%	46/48
MS1414	*Methanosarcinaceae*	**Cy3**	35%	46/48
hMS1480	MS1414-helper	-		
hMS1395	MS1414-helper	-		
MX825	*Methanosaetaceae*	**Cy3**	20%	46/48
MG1200	*Methanomicrobiales*	**Cy3**	20%	46/48
MC1109	*Methanococcales*	**Cy3**	20%	46/48
MB318	*Methanobacteriaceae*	**Cy3**	22%	40/42
MB310	*Methanobacteriaceae*	**Cy3**	20%	46/48
MB1174	*Methanobacteriaceae*	**Cy3**	35%	46/48


Particulate Organic matter
Simpler dissolved organisms
Volatile fatty acids
H_2
Acetate
AOB
Methanomicrobiales (MG1200)
Methanococcales (MC1109)
Methanobacteriales (MB1174, MB318)
Methanosaetaceae (MX825)
Methanosarcina(MS1414)
CH_4

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Conclusions

- Although relatively high concentrations of ammonia 2600mg l^{-1}, can be significant inhibitory to *Archaeas* and *Eubacterias* of both groups, but will resume soon under mesophilic conditions, the results indicate that inhibition may be "self-correcting" at ammonia concentrations range of 1500-3300 mg/L.

Conclusions

- *Methanosaetaceae* was the dominant acetoclastic methanogens at ammonia concentrations range of 1500-3300 mg/L .

- *Methanomicrobiales* was the dominant hydrogenotrophic methanogens at ammonia concentrations range of 1500-3300 mg/L, the results prove *Methanomicrobiales* to be extremely ammonia tolerant under mesophilic conditions.

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Thanking your attention !