Optimizing anaerobic digestion of agricultural substrates

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Environmental Technology

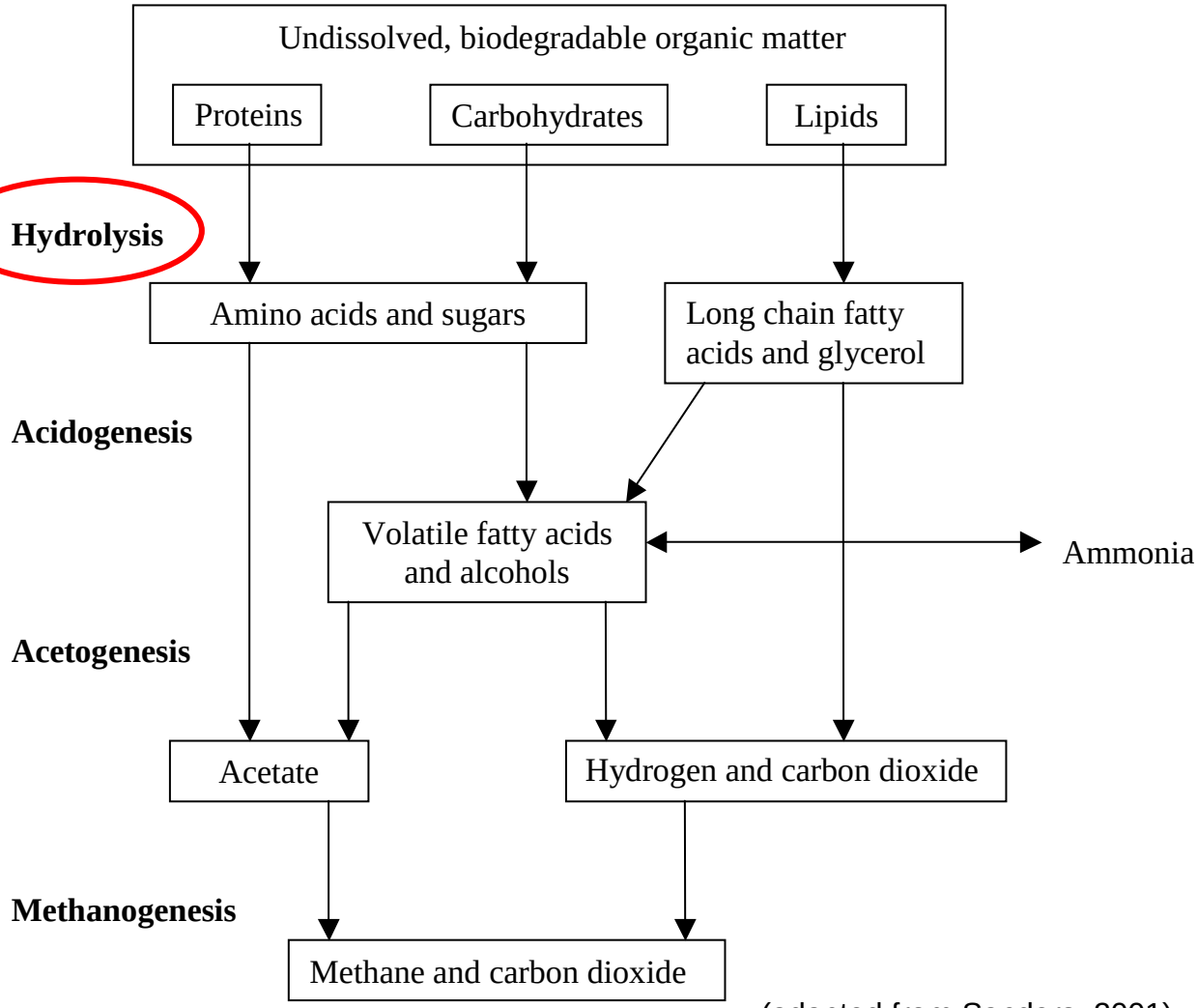
Anaerobic digestion process

Rate limiting step in anaerobic digestion of complex substrates

(Pavlostathis & Giraldo-Gomez, 1991)

Described by first order:

$$dX/dt = -khX$$



(adapted from Sanders, 2001)

Anaerobic potential of different substrates

Aerobic sludge

Industrial waste

OFMSW

Energy crops

Crop residues

Manure

Substrate	BMP (lCH_4/gVS)	Methane yield (m^3 CH_4/ton $_{ww}$
Slaughterhouse waste	0.57	150
OFMSW	0.5-0.6	100-150
Energy crops	0.30-0.50	30-100
Straws, sugar beet tops	0.2 - 0.4	36-145
Pig manure	0.29 - 0.37	17-22
Cow manure	0.11 - 0.24	7-14

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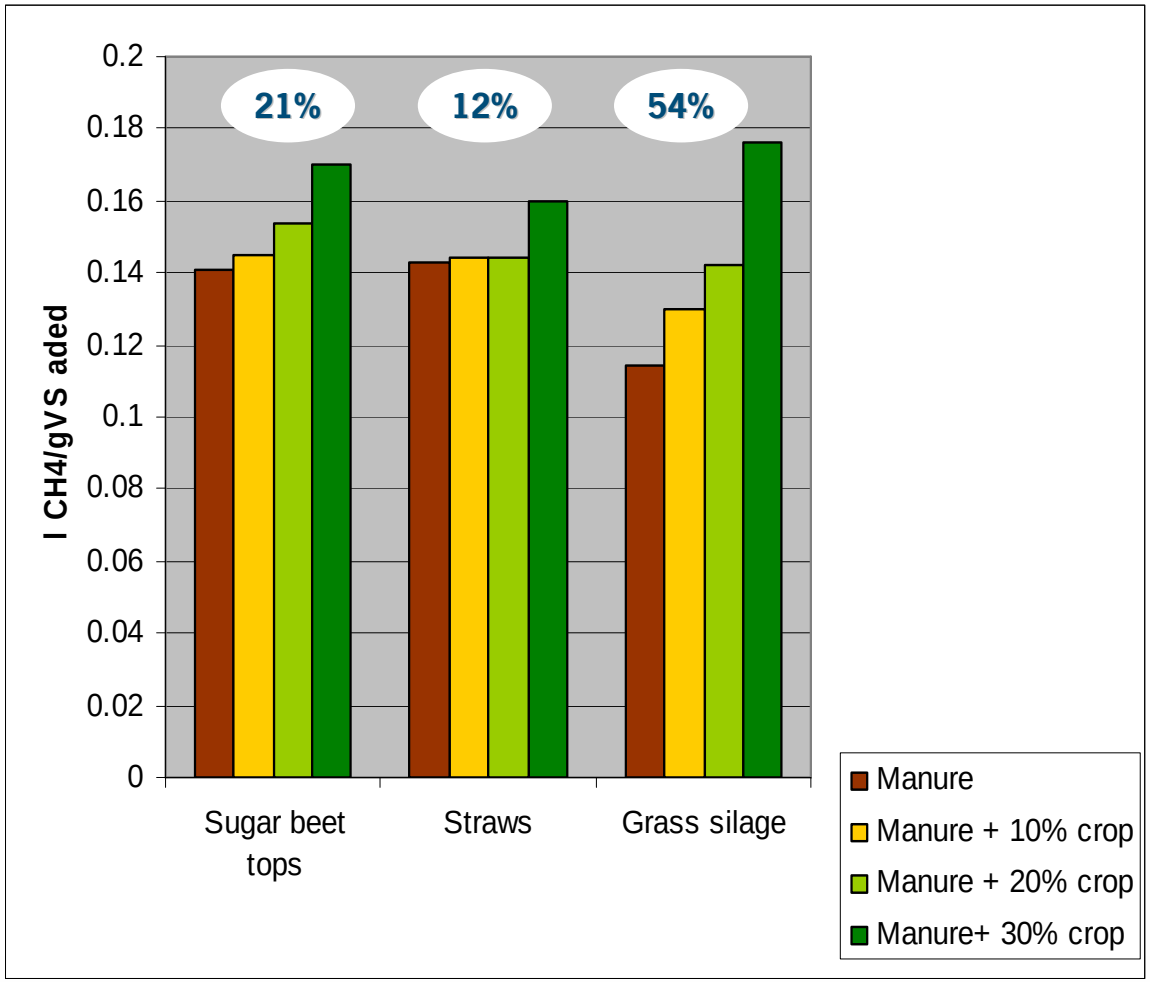
(Lehtomaki,2005)

Codigestion of crops and manure



Lehtomakki, 2005

Recent trends

- **Austria:** 139 plants + 50 u.c.; 200 GWh (2004). Preferential rates and guaranteed purchase.
- **Denmark:** 22 CAD +40 farm scale digesters. Investment grants, long terms loans with low interest rate, tax exemption. Slurry storage required.
- **Germany:** ~4000 plants and 950 MW in 2005. 1800 in 2002, and only 450 in 1997; Guaranteed priority purchase, preferential rates, bonus for energy crops, subsidies.
- **Sweden:** 10 CAD +5 farm scale digesters. Use of biogas as vehicle fuel.
- **Netherlands:** ~ 37 registered plants. **22** use the energy for themselves; 7 use the energy for themselves and sell it to third parties; 8 sell the produced energy to third parties.

(Rintala , 2005)(Weiland, 2003) (Wulf, 2005) (© CBS, data from 2003)

Recent trends

- All important agricultural crops can be used for biogas production.
- In Germany, in 94% of the cases manure is used as a base material for digestion.
- Few experiences are available from plants with mono-fermentation of energy crops.
- CSTRs are preferred. One or two stage processes.
- Long Hydraulic Retention Times (60-90 days) and low Organic Loading Rates (1-2 Kg/m3.d)

Weiland, 2005

Challenges remaining

- **Technical challenge**: For increasing the process efficiency and reliability the whole process chain has to be optimized.
- **Design challenge**: Accuracy and simplification is needed in the design of reactors

Design parameters of anaerobic digesters

- Composition of substrates (TS, VS, COD, others)
- Biodegradability (BMP) and hydrolysis constant (Kh) of substrates
- Presence of inhibiting compounds (NH_4^+, humic acids, and intermediary products as LCFA, VFA, H_2S & glucose)

The need for a simple method

250.000 species of higher plants in the world

1000 species comprise the species cultivated to provide, food, industrial and construction materials

Different **manures** show different composition, i.e. cow manure has lower nutrient content and higher C/N ratio than pig manure





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Biodegradability of different substrates

BMP range	**0.15 - 0.54** l CH_4/gVS
Standard deviation	**5-10%**

However among authors values can differ strongly for a single plant specie.

Grass: **0.27 - 0.41 l CH_4/gVS**

Clover: **0.14 - 0.55 l CH_4/gVS**

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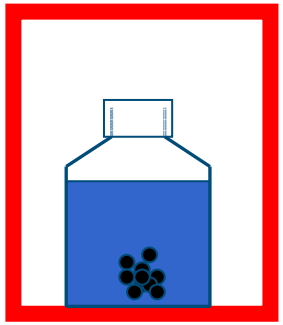
Why this variation?

From the substrate:

Ex. Different variety, growth conditions, harvest time. 30-60%.

(Pouech et al. 1998)(Lehtomaki 2006)



Or…from the test…

Anaerobic Biodegradability tests are not standardized

There is substantial uncertainty in the determination

(Hansen et al , 2004);(Rozzi and Remigi, 2004);
(Muller, 2004);(Colleran et al. 1992)

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Factors that may influence the assessment…

- **Substrate**: pretreatments (particle size, storage)
- **Inoculum** : Type (source, structure), age, concentration (S/I)
- **Buffer solution**
- **Macronutrients and trace elements**
- **Equipment**: type of bioassay (batch, continuous)
- **Operating conditions**: temperature, pH, sampling frequency.

(Hansen et al , 2004);(Rozzi and Remigi, 2004);
(Muller, 2004);(Colleran et al. 1992)

- So far differences of **25** - **50%** had been found when varying test conditions.
- The need for an standardized test is imminent
- Also the need for reporting findings in a complete way:
  - Characteristics of plant material digested
  - Characteristics of the test performed

What would be a good BMP and hydrolysis test?

Different objectives

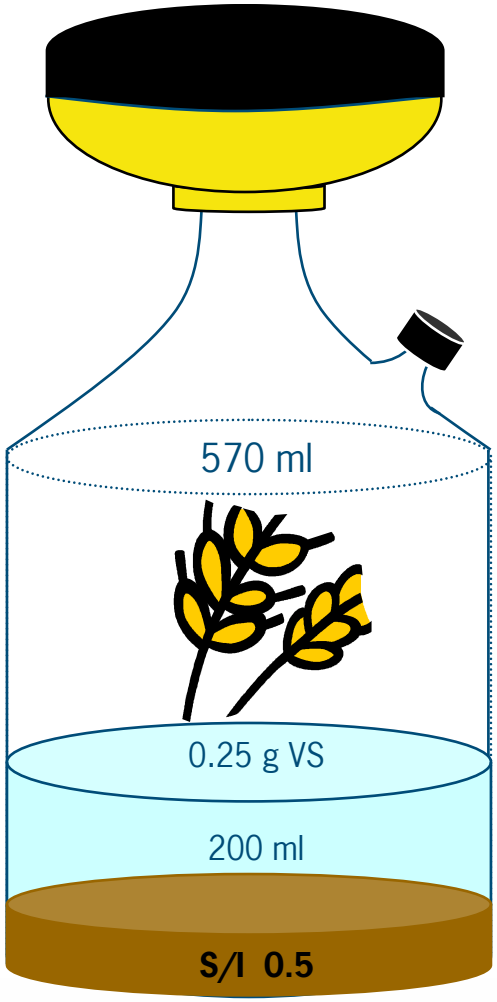
Find results close to reality?

or

To get the maximum amount of biogas and highest kh, and use it for screening purposes?

- Dry grinded substrates
- Sludge mixture
- Low S/I ratio
- Add buffer (low conc.) and nutrients

EXPERIMENTAL SET-UP



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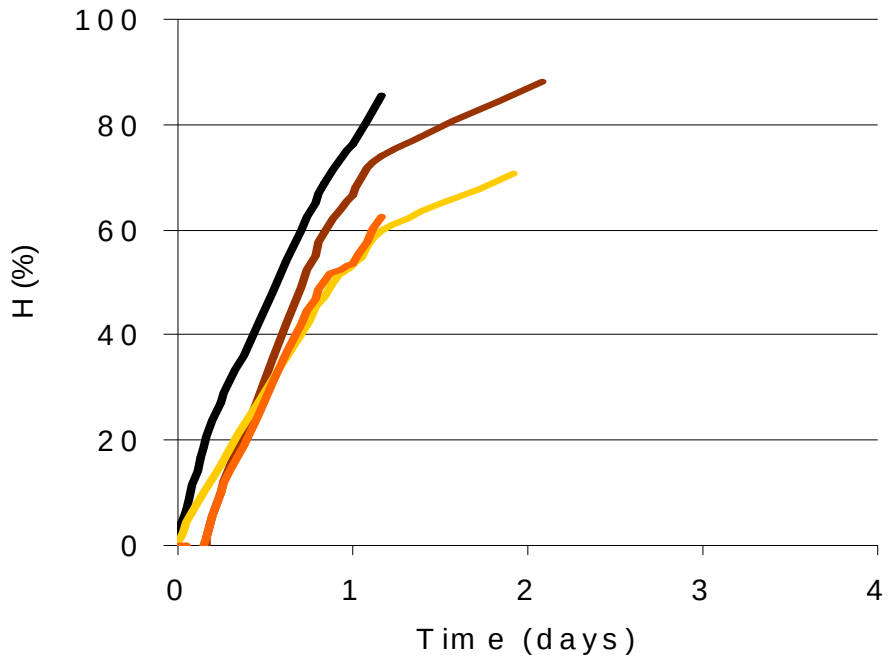
Inhibition of hydrolysis

Temperature	described by Arrhenius equation (kh) (Veeken and Hamelers 1999)
pH	max. enzyme activity at 6 – 8 (Sanders 2001) (Veeken et al. 2000)
Hydrolysis products	ex. production of cellulases inhibited by ↑ [glucose] (Angelidaki & Sanders 2004)
LCFA	at liquid-water interface inhibits lipases (ex. Surface tensions) (Verger 1980; Angelidaki & Ahring 1992)
Humic substances	Humic acids and fulvic acids may delay the hydrolysis (Brons et al. 1985; Fernandes in preparation)

SOME RESULTS

Hydrolysis rates in relation to NH_4^+



Digestion of Tributyrin at varying [NH_4^+]

Increase of [NH_4^+] did not decrease hydrolysis rate

2000 mg NH_4^+-N — 7000 mg NH_4^+-N

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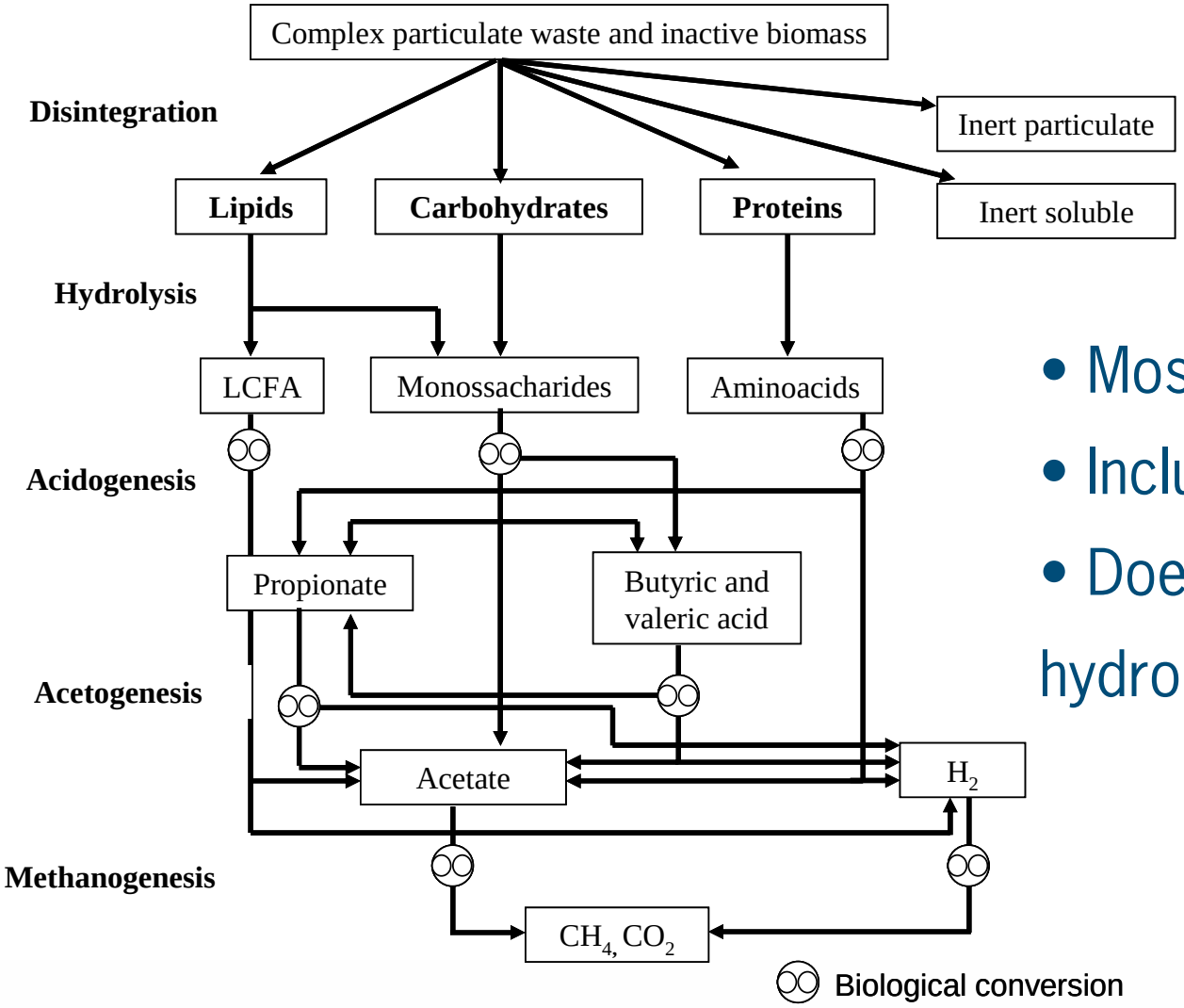
Anaerobic Digestion Model No.1

(Batstone et al., 2002)

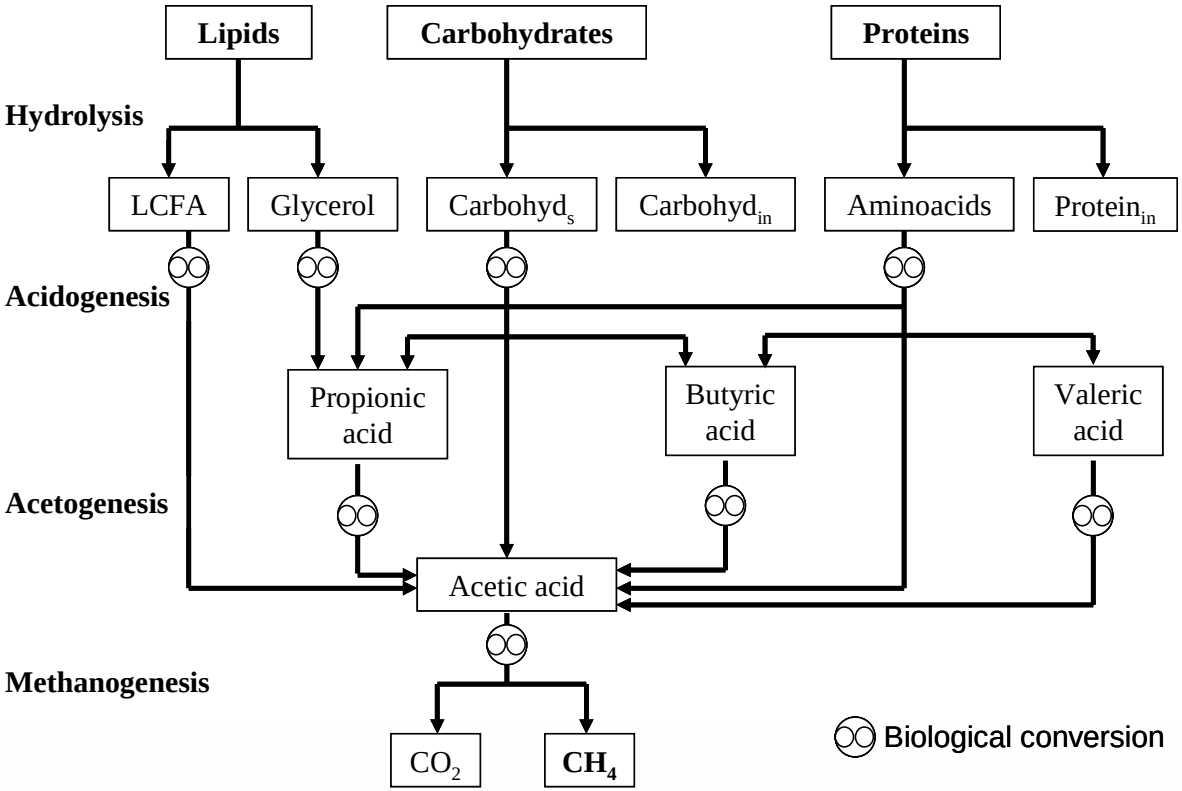


- Most used model in AD.
- Includes max. biod. & kh
- Does not include hydrolysis inhibition

(adapted from Batstone et al., 2002)

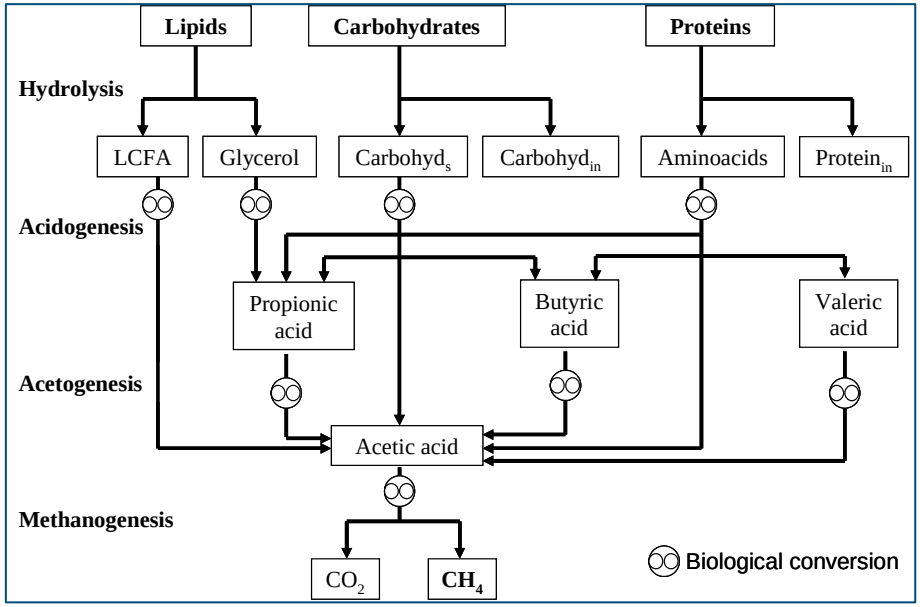
Anaerobic Bioconversion of Complex Substrates to Biogas Model (Angelidaki et al., 1999)

- Includes max. biod. & kh & VFA inhibit on hydrolysis
- Validated with co-digestion material (manure + org. ind. wastes)



(adapted from Angelidaki et al., 1999)

Modified model



Will include: Conversion processes

Maximum Biodegradability

kh

Hydrolysis inhibition

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THANK YOU FOR YOUR ATTENTION