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Basics of the Biogas Production Process

Stefan Junne, Kozani, 04.06.14

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Content

Materials and Methods for Biogas Production

- Background Biogas Process
- Applicable Substrates
- Substrate Pre-treatment
- Monitoring devices
- Summery and Outlook

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Basic terminology

Term	Description
Anaerobic	Without oxygen
Aerobic	With oxygen, e.g. in activated sludge plants or in aerobic ponds
Anaerobic digestion / degradation / treatment	These terms are all used interchangeably, and mean “breaking down of organic matter”
Digestate / digester residue / digested organic matter	The effluent from a digester; the liquid product of the anaerobic digestion process
Biogas	Gas produced by microorganisms in anaerobic process (typically 66% methane content)
Biogas digester / anaerobic digester	A covered vessel (or reactor) in which anaerobic digestion occurs

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Some facts about Methane

- Methane is the major component of “natural gas”, about 97% by volume
- At room temperature and standard pressure, methane is a colorless, odorless gas (the smell characteristic of natural gas is an artificial safety measure caused by the addition of an odorant)
- Methane has a boiling point of −162°C at a pressure of one atmosphere
- As a gas it is flammable only over a narrow range of concentrations (5–15%) in air

- Methane has a calorific value of 10 kWh/Nm^3 or 35,900 kJ/Nm^3
  - Hence, biogas with 65% methane has a calorific value 6.5 kWh/m^3 (23,300 kJ/m^3)

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Some facts about the microbiological process

- Under anaerobic conditions, organic substances are not aerated (oxidised), but are fermented (reduced)
  (Reduction = assimilation of electrons)
- Energy-rich end products, like organic acids or alcohols are electron acceptors
- It is quite a “slow” process (low growth rate of methanogens) compared to aerobic processes → relatively long sludge retention times are required
- Like all biological processes, it is temperature dependent (higher conversion rates at higher temperatures) → digesters are typically heated / insulated or below ground
- The process occurs as a four-step process (see next slide)

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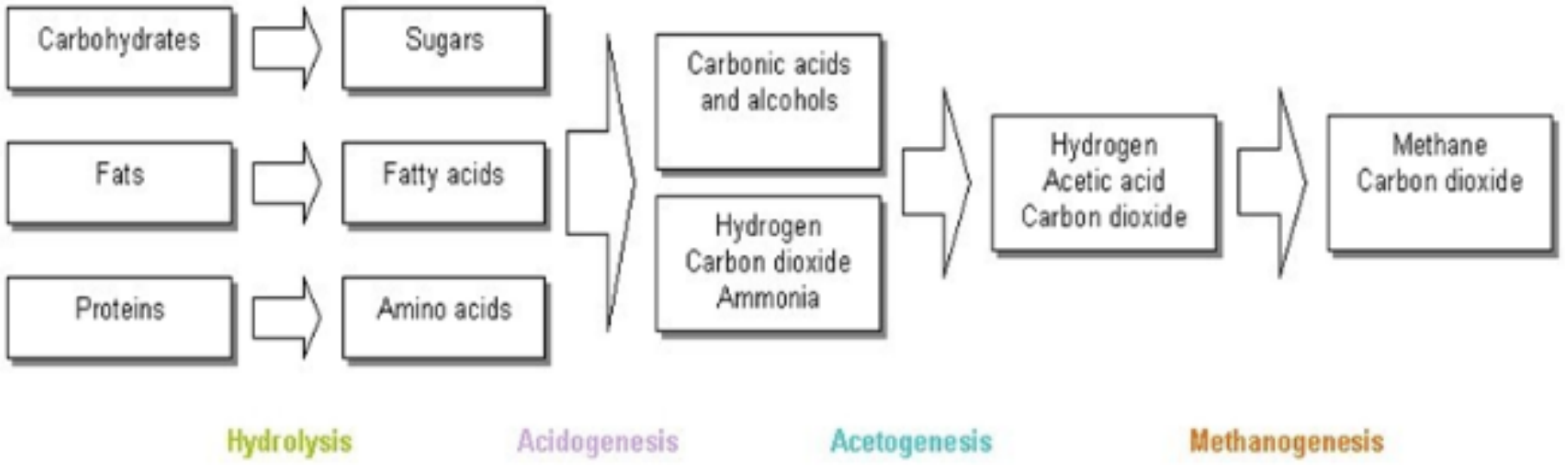
Four Stages of the Biogas Process



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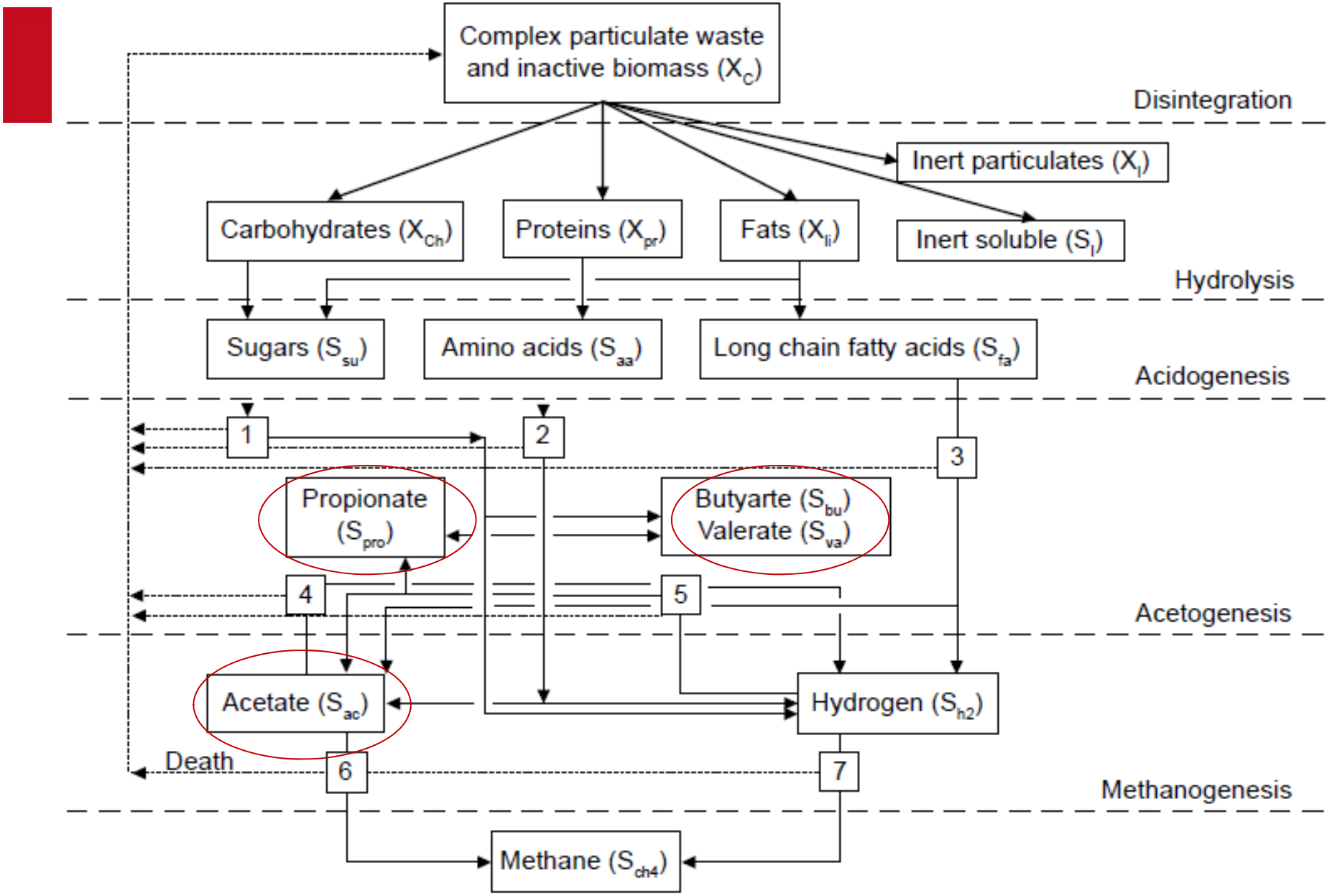
Complex particulate waste and inactive biomass (X_C)
Disintegration
Inert particulates (X_I)
Carbohydrates (X_{Ch})
Proteins (X_{pr})
Fats (X_{li})
Inert soluble (S_I)
Hydrolysis
Sugars (S_{su})
Amino acids (S_{aa})
Long chain fatty acids (S_{fa})
Acidogenesis
1
2
3
Propionate (S_{pro})
Butyarte (S_{bu})
Valerate (S_{va})
4
5
Acetogenesis
Acetate (S_{ac})
Hydrogen (S_{h2})
Death
6
7
Methanogenesis
Methane (S_{ch4})

Volatile Fatty Acids

Volatile fatty acids (VFAs) are an intermediate product:

- They should not accumulate under appropriate operation
- VFAs (e.g. acetic acid) accumulate if step 4 is inhibited
  - In that case, pH value will drop (e.g. to pH of 4.8) and the digestion process will stop (no more gas production)
  - This is also called a “sour” digester, and is usually very smelly (a well operating digester produces almost no odours)

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Biogas composition

The methane fraction produced in the biogas varies with the input material; as a rule of thumb:

- carbohydrates: approx. 50 vol.-% methane
- fats: approx. 70 vol.-% methane
- proteins: approx. 84 vol.-% methane

Compound	Vol %
Methane	50-75
Carbon dioxide	25-50
Nitrogen	< 7
Oxygen	< 2
Hydrogen sulfide	< 1
Ammonia	< 1

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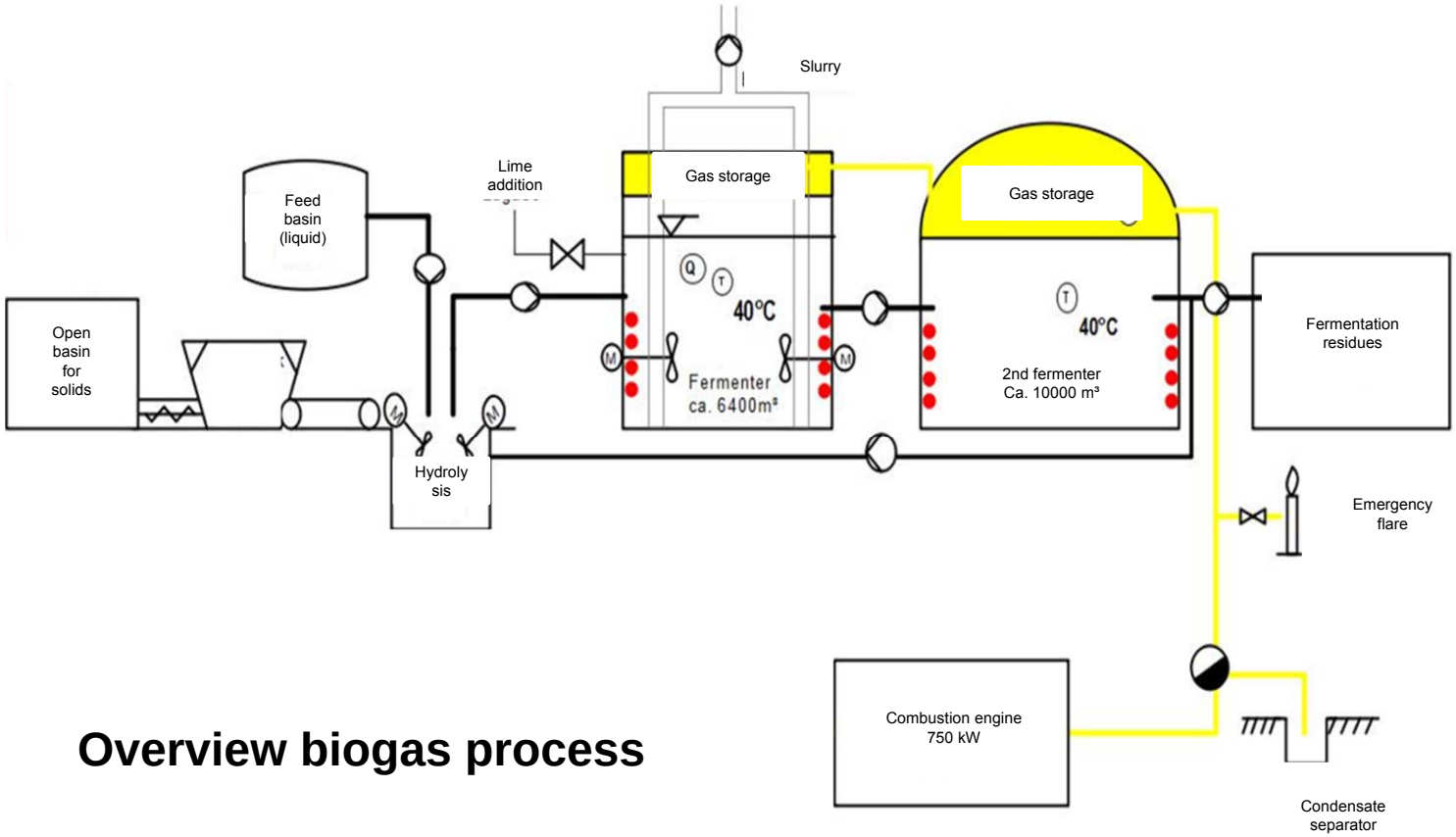
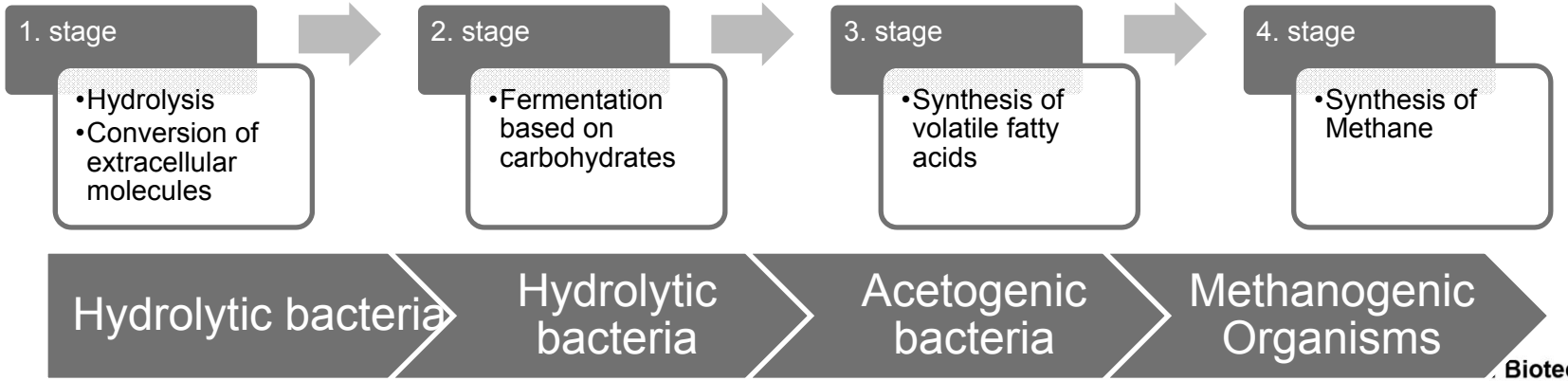
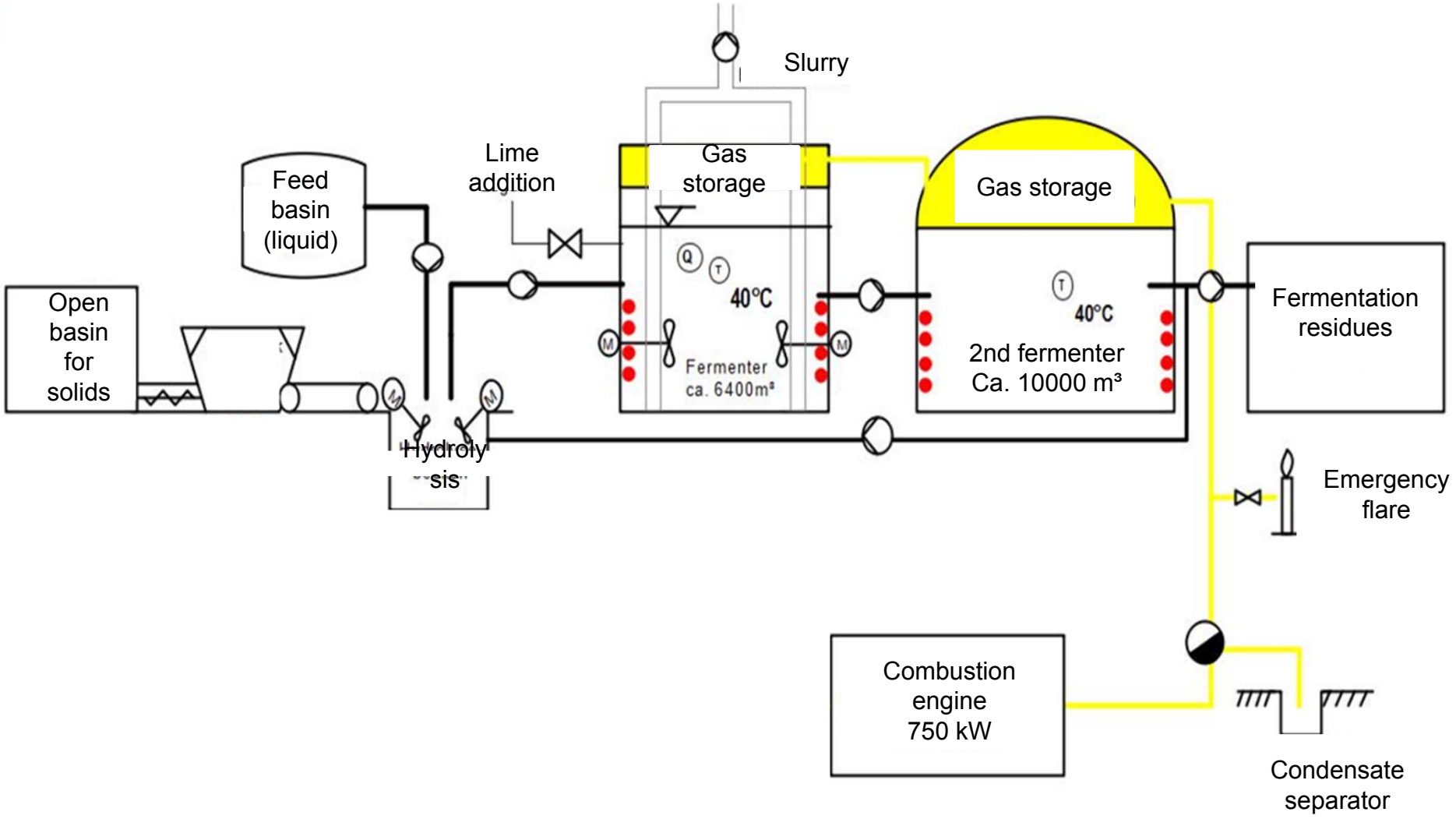


Overview biogas process





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Photos: ThyssenKrupp Stainless AG

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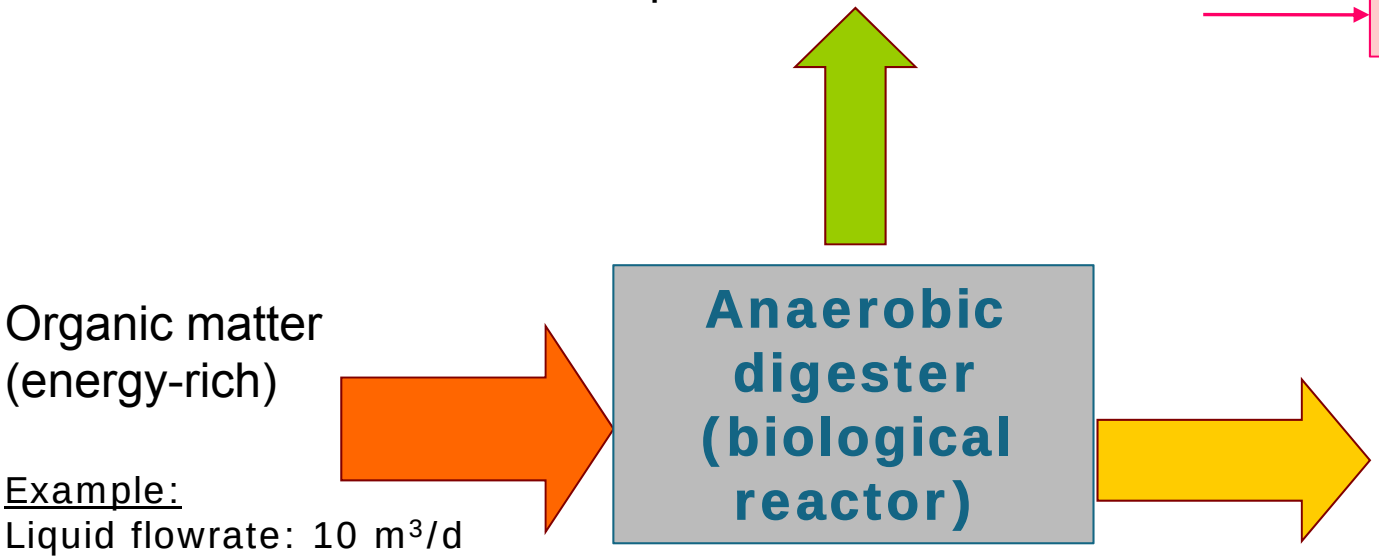
Biogas (methane): “Green energy”
Example: Gas flowrate: 665 Nm^3/d *

* Calculated at 0.95 Nm^3/kg VS



Nm^3 stands for normal cubic metre, meaning a measurement at STP or *standard temperature and pressure* (absolute pressure of 100 kPa (1 bar) and a temperature of 273.15 K (0 °C))

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Applicable substrates

- Anaerobic treatment works with organic input materials, such as:
  - liquid organic material
  - solid organic material (water content of ~ 50% or more), i.e.
    - slurries/sludges
    - organic kitchen waste
    - grops
  - greywater together with excreta

- The end product (digested material) is <u>not</u> pathogen-free, but often suitable for further applications

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Yield of biogas from different sources (1/2)

Materials and their main components	Yield of Biogas m^3/kg TS	Methane content (%)
Animal barnyard manure	0.260 ~ 0.280	50 ~ 60
Pig manure	0.561	
Horse droppings	0.200 ~ 0.300	
Green grass	0.630	70
Flax straw	0.359	
Wheat straw	0.432	59
Leaves	0.210 ~ 0.294	58
Sludge	0.640	50
Brewery liquid waste	0.300 ~ 0.600	58
Carbohydrate	0.750	49
Liquid	1.440	72
Protein	0.980	50

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Yield of biogas from different sources (2/2)

Material	YpCMDV (m^3/m^3d)	YpkgM (m3/kgTS)	Amount of biogas produced in a period of time (as a % of the total yield)			
			0 ~15 (d)	15 ~ 45 (d)	45 ~ 75(d)	75 ~ 13 (d)
Water Hyacinth	0.40	0.16	83	17	0	0
Alligator Weed	0.38	0.20	23	45	32	0
Water Lettuces	0.40	0.20	23	62	15	0
Cattle Dung	0.20	0.12	11	33.8	20.9	34.3
Pig Manure	0.30	0.22	19.6	31.8	25.5	23.1
Human Wastes	0.53	0.31	45	22	27.3	5.7
Dry Grass	0.20	0.21	13	11	43	33
Rice Straw	0.35	0.23	09	50	16	25

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Achievable Yields – biogenic waste

- Sewage sludge: 0.75 – 1.12 Nm^3 per kg of volatile solids destroyed (typical value: 0.95 Nm^3/kg)

- Organic solid waste:
  - 0.38 – 0.42 Nm^3 per kg of volatile solids added (at a retention time of 14 days) for single-stage processes
  - Up to 0.6 Nm^3 per kg of VS added for two-stage processes

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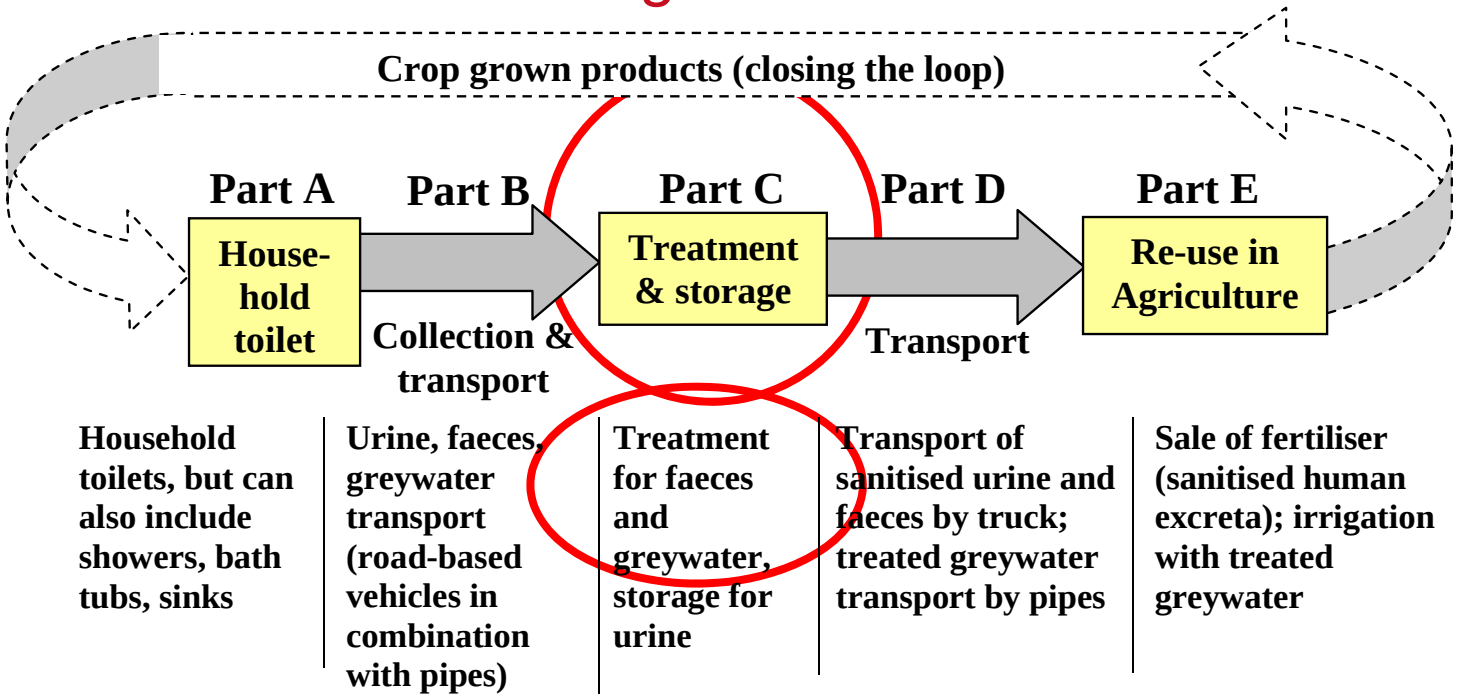
Applicable substrates: biogenic household wastes



→ Anaerobic digestion can be used to treat faeces, greywater and other organic waste with the aim to produce biogas and a fertiliser

→ A certain degree of pathogen kill can be achieved through raised temperatures and/or extended digestion times in the anaerobic digester

Different Pre-treatment technologies

- Hydrolysis (enzymatic degradation of polymer compounds, low dry matter content of 2%)
- Silage (enzymatic degradation, high dry matter content of 20% or more)
- Mechanical treatment (Hammer mill, shredder) for surface increase
- Ultrasound pre-treatement for increasing the solubility
- Chemical treatment (acid, base addition)
- Thermal treatment

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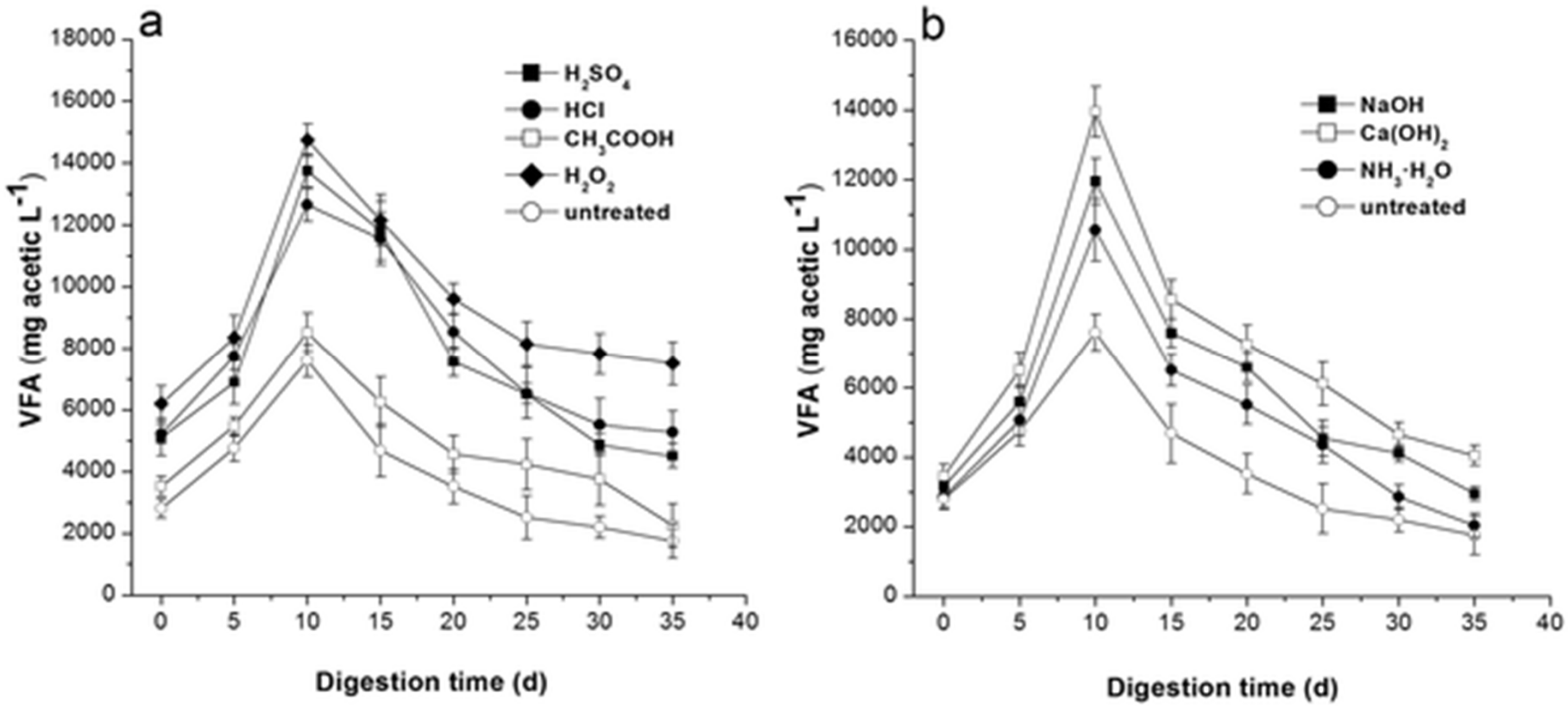
Figure 4. Change in the VFA of pretreated corn straw during digestion.



Song Z, GaiheYang , Liu X, Yan Z, et al. (2014) Comparison of Seven Chemical Pretreatments of Corn Straw for Improving Methane Yield by Anaerobic Digestion. PLoS ONE 9(4): e93801. doi:10.1371/journal.pone.0093801
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0093801

Table 3. Economic performance of the different pretreatments.

	Chemicals	Concentration	Price [a](CNY)	Cost [b](CNY)	Methane yield (mL CH_4 gVS^{-1})
Acid	H_2SO_4	2%	21	2.57	175.6
	HCl	2%	15	4.92	163.4
	CH_3COOH	4%	12.5	9.34	145.1
	H_2O_2	3%	6	3.6	216.7
Alkaline	NaOH	8%	9	4.2	163.5
	$Ca(OH)_2$	8%	9.5	4.58	206.6
	$NH_3{\cdot}H_2O$	10%	9	19.28	168.3

Song Z, GaiheYang , Liu X, Yan Z, et al. (2014) Comparison of Seven Chemical Pretreatments of Corn Straw for Improving Methane Yield by Anaerobic Digestion. PLoS ONE 9(4): e93801. doi:10.1371/journal.pone.0093801
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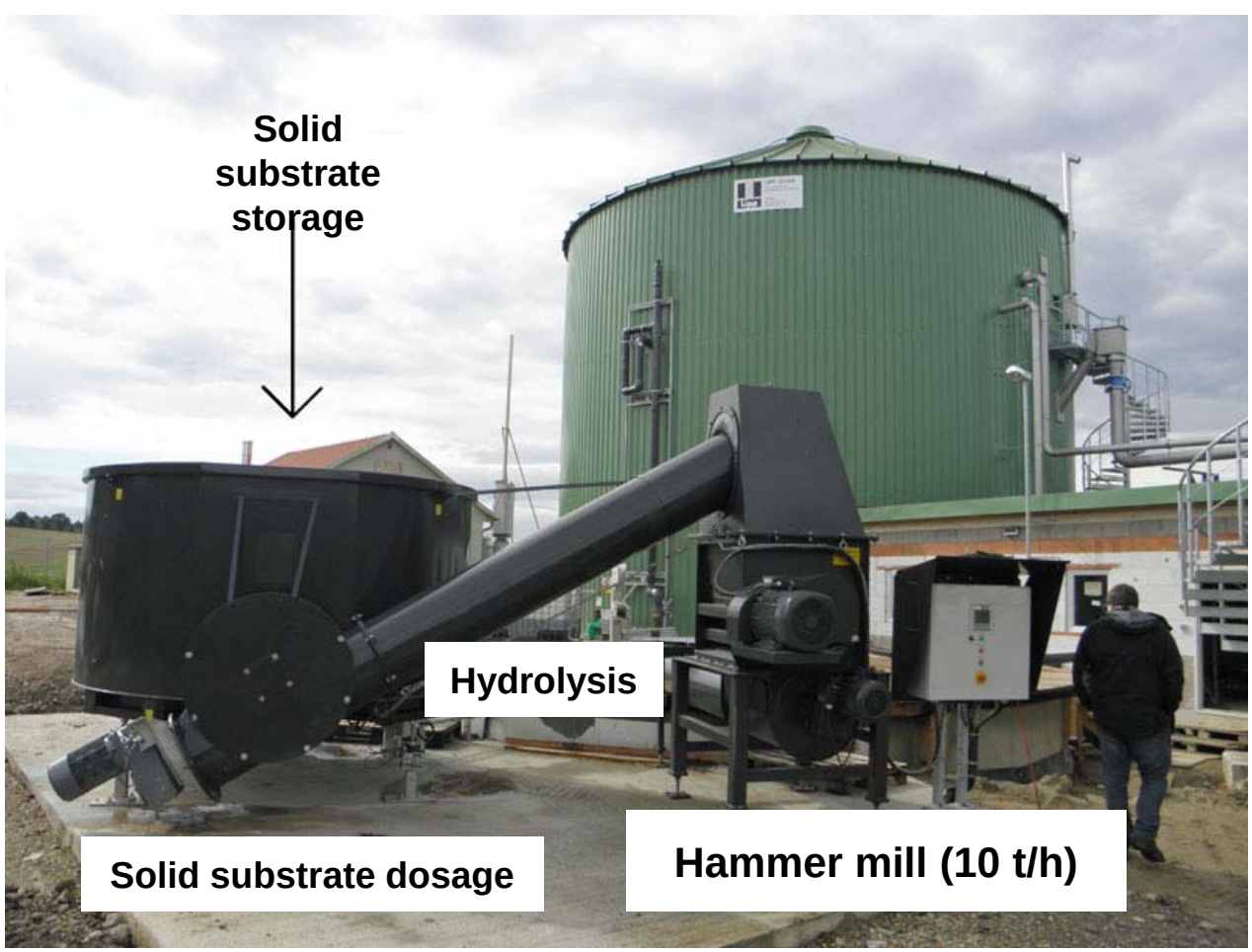
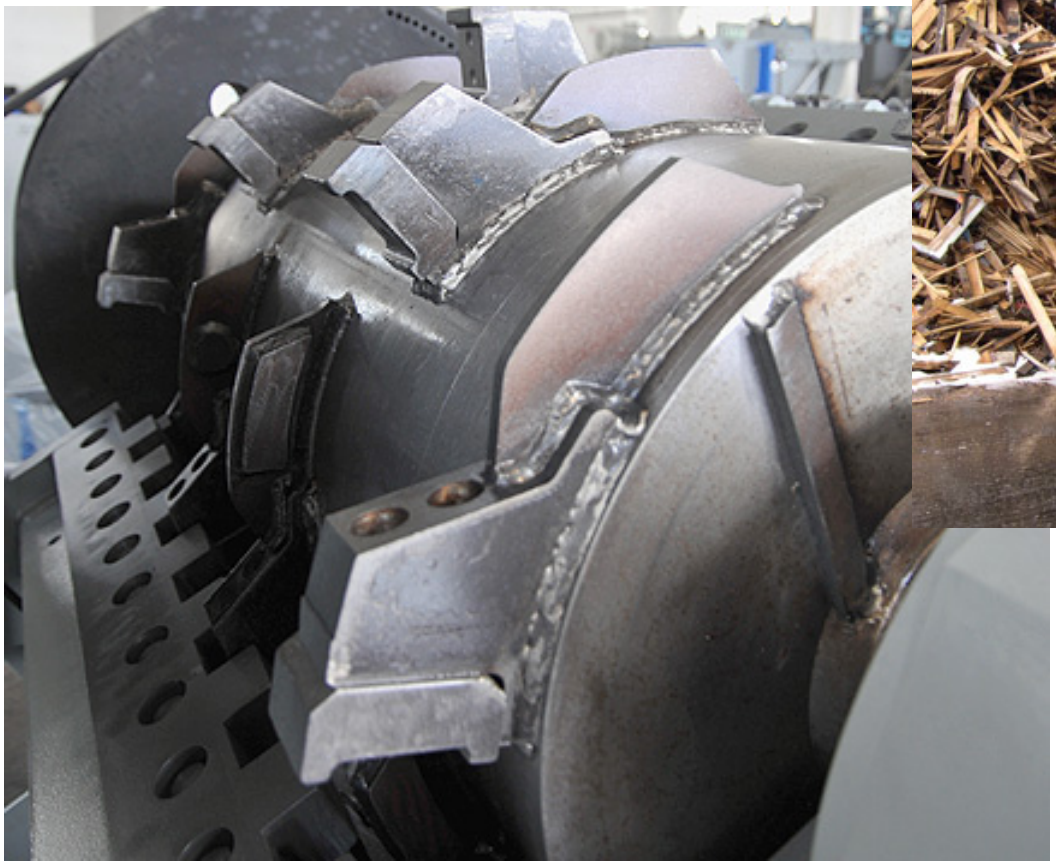

Solid substrate storage
Hydrolysis
Solid substrate dosage
Hammer mill (10 t/h)




HAAS

Pretreatment - Ultrasound

- Agglomerates are distroyed
- The surface of particles is increased

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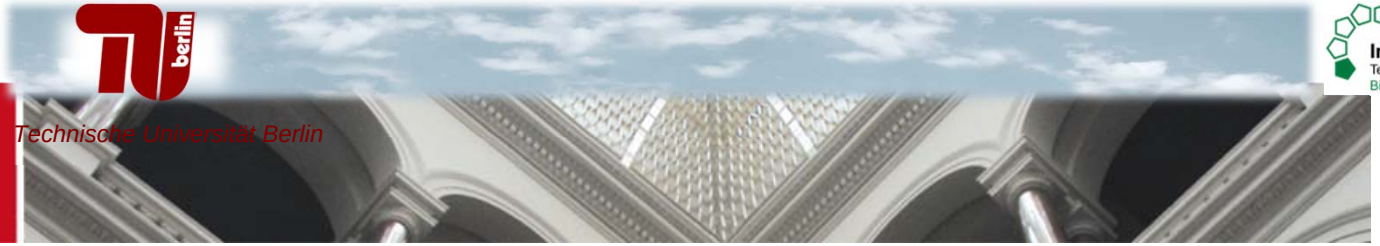
Monitoring devices

Analysis	Standard[a)]	Title
pH value	EN 12 176	Characterization of sludge – Determination of pH value
	APHA 4500-H^+ B	pH value "Electrometric method"
Total solids (TS) / Dry matter (DM)	EN 12 880	Characterization of sludges – Determination of dry residue and water content
	APHA 2540 B	Total solids dried at 103–105°C
Volatile solids (VS) / Organic dry matter (oDM)	EN 12 879	Characterization of sludges – Determination of the loss on ignition of dry mass
	APHA 2540 E	Fixed and volatile solids ignited at 550°C
Chemical oxygen demand (COD)	DIN 38 414 (S9)	German standard methods for the examination of water, wastewater and sludge – Sludge and sediments (group S) – Determination of the chemical oxygen demand (COD) (S9)
	APHA 5220 B	Chemical oxygen demand (COD) "Open reflux method"
Total Kjeldahl nitrogen (TKN)	ISO 5663	Water quality – Determination of Kjeldahl nitrogen – Method after mineralisation with selenium
	ISO 11261	Soil quality – Determination of total nitrogen – Modified Kjeldahl method
	APHA 4500-N_{org} B	Nitrogen (organic) "Macro-Kjeldahl method"
Biochemical methane potential / Biomethane potential (BMP)	EN 11734	Water Quality – Evaluation of the "ultimate" anaerobic degradability of organic compounds in digested sludge – Method by measurement of the biogas production
	DIN 38414 (S8)	German standard methods for the examination of water, wastewater and sludge – Sludge and sediments (group S) – Determination of the amenability to anaerobic digestion (S8)
	VDI 4630	Fermentation of organic materials – Characterisation of the substrate, sampling, collection of material data, fermentation tests



Questions so far?