Institute for Bio-Energy and Innovative Waste Management at BTU Cottbus-Senftenberg

Brandenburg University of Technology Cottbus - Senftenberg

IV Baltic Biogas Forum

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Biogas from municipal, agricultural and industrial waste via dry and other innovative fermentation technologies

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Waste management and Biogas

Biogas Technologies may contribute to

- Reduction of diffuse greenhouse-gas emissions from dumping sites and landfills
- Generation of eco-friendly energy (heat, electricity) and bio-fuel (methane)
- Humus re-production, production of fertilizers, and other chemicals, recovery of valuables

Typical input material ("substrate", "feedstock")

Biogas Crops	Corn, sunflower, wheat, rye, etc.	→	"out" due to competition with food production
Biowaste	Commercial , agricultural and municipal biowaste	→	Highly accepted
Mixed waste	Municipal waste, landscaping waste	→	Promising but challenging
CO_2, H_2	Inorganic Gases	→	Under development

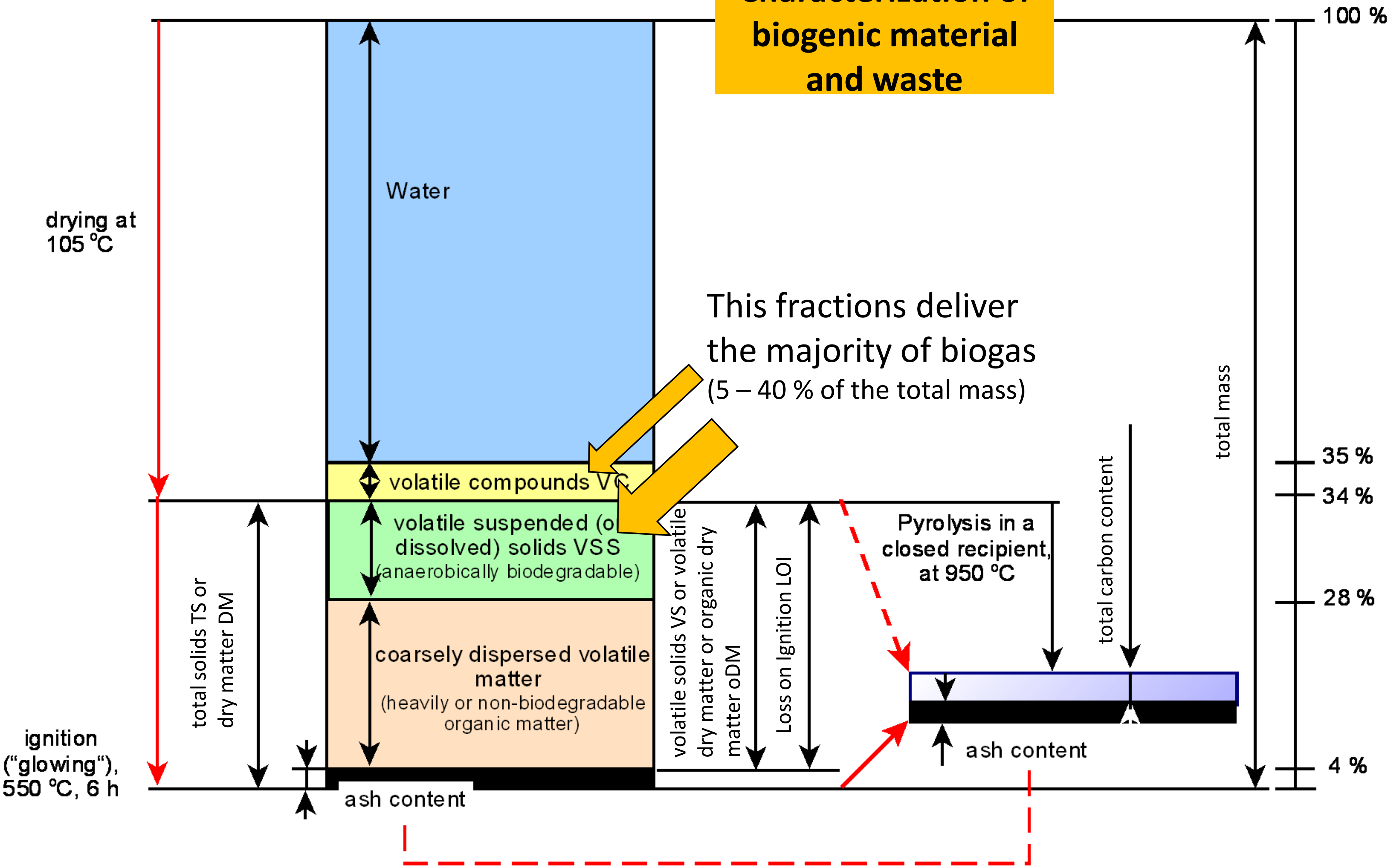
Methane yield of different waste fractions
(the same amount of methane is produced either in landfills or in fermenters!)

Type of waste	Methane yield, in m³ / Mg VS	CO_2- equivalent, in Mg / Mg VS	energy-equivalent, in kWh / t VS
Municipal Solid Waste, 60 % Biowaste	150 - 280	2.2 – 4.1	1,500 – 2,800
Market waste	275 - 420	4.1 – 6.2	2,750 – 4,200
Food waste	250 - 580	3.7 – 8.5	2,500 – 5,800
Waste from oil and fat separators	520 – 1,100	7.6 – 16.2	5,200 – 11,000
Slaughter waste	400 – 1,200	5.9 – 17.6	4,000 – 12,000

Consider:

The concentration of Volatile Substance (=organic dry mass) amounts often from 8–33 %

Characterization of biogenic material and waste



Characterization of common biowaste

Market waste, logistic waste

- Mostly "fresh" material: High water content, low VS (=oDM)!
- High to medium biodegradability
- **Low biogas yield due to high water content (!)**
- Large particle size, shredding is necessary
- Separate Collection is possible
- Medium concentration of impurities

Food production, food processing

- Waste water (washing, cleaning) with very low VS
- May contain non-biodegradable dirt, sand etc.
- **Solid residues from processing with medium to high VS(with inhibitors?) and high (very high) biogas yield**

Food preparation waste

Post-consumer waste

- Mostly solid, pasty waste with medium VS
- With some impurities (sand, dirt, packaging materials)
- **Medium to high biogas yield due do higher concentrations of oil/fat, hydrocarbons, proteins**
- Often mixed with other MSW (!), separate collection is strongly recommended
- May contain preservatives and other food additives

Expired food

- Removal of packing materials (plastic, paper, carton, aluminium) necessary
- **Medium to high VS, but may contain preservatives and additives**
- **High biogas yield**

Biodegradability	Substrate, organic waste constituent		
Non biodegradable	Plastic, glass, metals, ceramics etc.	Lignine	Proteins (Keratins)
Poor biodegradability	Cellulose		
Medium biodegradability	Fat, Oil	Hemi-Cellulose	
Good / very good biodegradability			
Excellent biodegradability	Sugar, starch, alcohols		Proteins (Mucins)

The biodegradability determines the process intensity (e.g. degradation rate) but not the biogas yield. In other words: The higher the biodegradability, the faster the degradation of the substance. Oil and fat are high-yielding!

Problems arising from	Technological and other consequences
High biodegradability of biowaste constituents	➢ aerobic or anaerobic biodegration of biowaste starts immediately after waste ge[illegible] and cannot be stopped ➢ Biodegradation run[illegible] at higher temperatures ➢ Easily biodegradable constitu[illegible]ears within a few days completely ➢ Thus, immediate collection, transportation an[illegible]igestion without intermediate storage is necessary to obtain a high biogas yield
High moisture content of biowaste	➢ Self-running biodegradation produ[illegible] water as result of hydrolysis. This water m[illegible] substances and organic acids, [illegible]igh. ➢ Therefore, [illegible] (containers, trucks) must be tight to avoid po[illegible] water needs treatment (digester!) .
Residues of the biogas process	➢ Liquid residues may contain high concentration of nitrogen and contaminants ➢ Solid residues [illegible] as well as recyclables (metals, plast[illegible] ➢ Utilization as compost or fertilize[illegible]east after-treatment (drying, separation, rotting etc.), or is impossible ➢ Drying and separation before landfilling or incineration is recommended

Logistic determines efficiency

Regulations and costs for waste water disposal?

Aftertreatment and recovery/disposal costs?

High solid fermentation for "biogas from waste"
Examples of technologies

Wording

What is a „stage“, what is a „phase“ in biogas technology?

Stage:
Individual and separate reactor (fermenter) for the conversion of feedstock or intermediate Products of the fermentation.
Single stage biogas plants:
All biochemical conversions take place in parallel with respe[illegible] ace.
Multi-stage biogas plants :
The individual steps of bioconversions ta[illegible] actors in a defined sequence. Most com[illegible] a "hydrolysis" stage and a "methanation" sta[illegible]

Hence:
Double-phase systems are usually two- or multiple stage systems;
single-phase systems can be single- oder multiple-stage systems.

Phase:
It character[illegible] (preferably) hydraulic properties of the feedstock and intermediate products. Pumpable material is called "liquid phase", non-pumpable materials or bulk solids belong to the "solid phase".

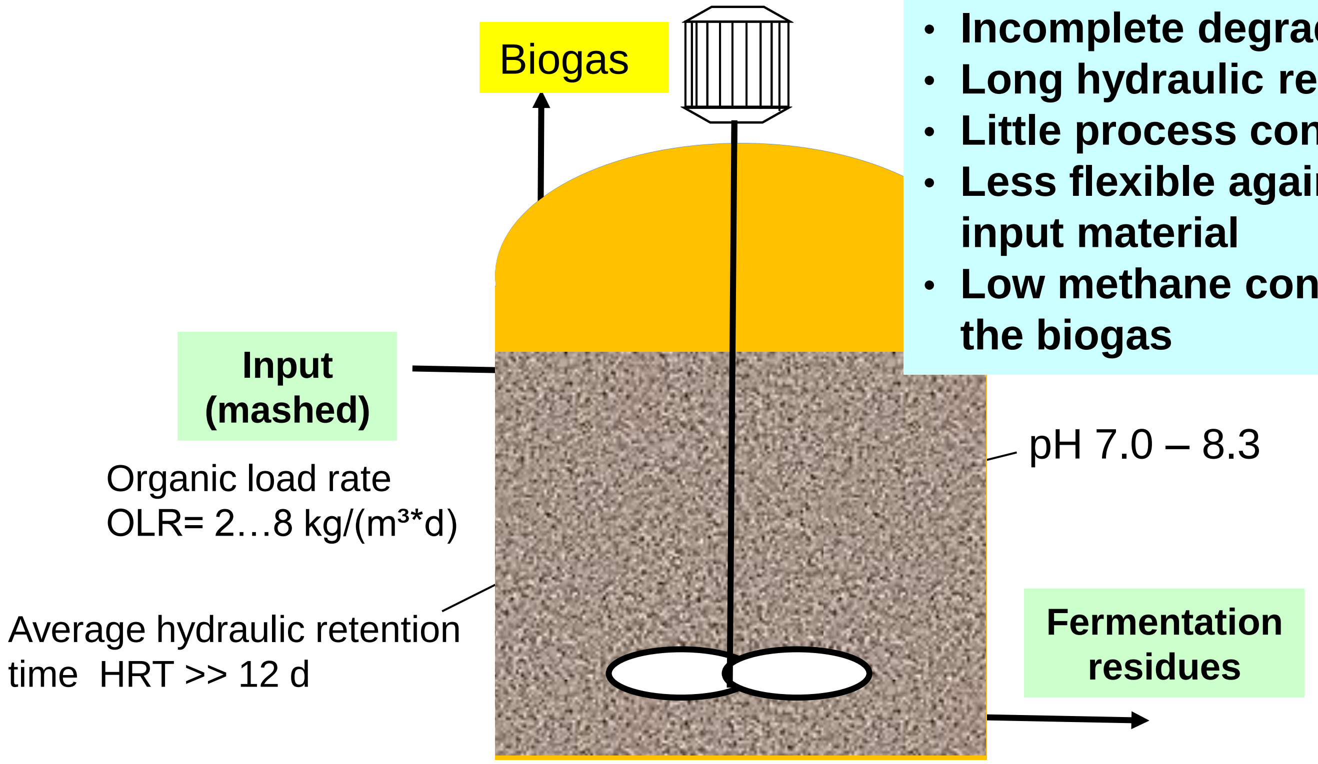
Classification of biogas technologies

Type	Phases and stages	Representative technologies
Fully homogenized fermenter	Single phase, single- or double stage	BTA, AAT, Strabag, AAB, Arrowbio, Entec, Envirotec, Envitec, Schubio, AMB Haase, Biostab, Preseco etc.
Perkolation technology	Double phase; single- oder double stage	BEKON, Bioferm, Loock TNS, Biocel, Biopercolat, GICON, Kompoferm, etc
Plug flow technology	Single phase; single stage	Axpo Kompogas, Archea, Dranco (vertikal), Valorga, Strabag, ATB Aufstrom, ATB Schwimmbett, etc.

Single-stage and double-stage

General layout:
Conventional single stage process

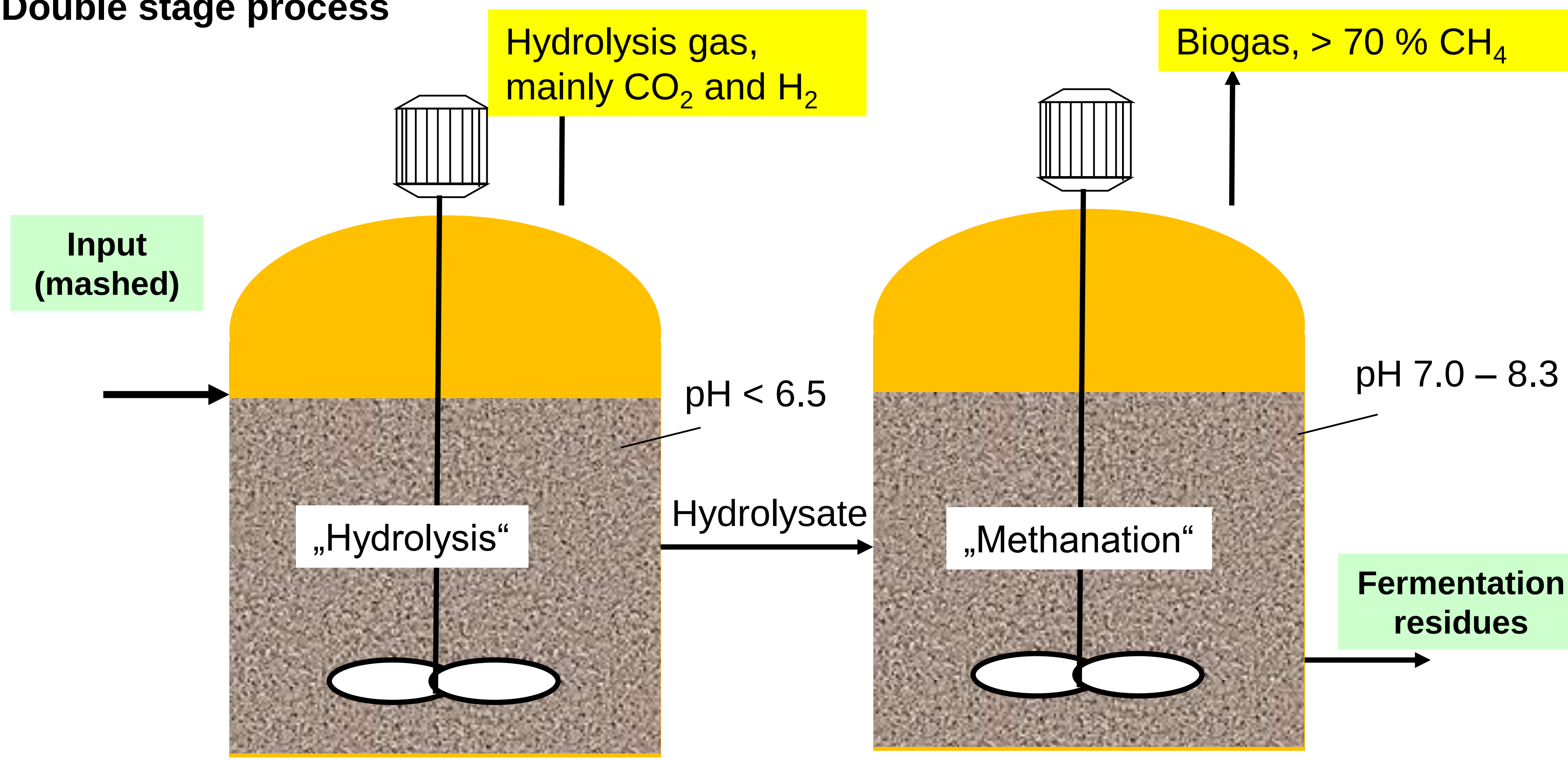
Risks and disadvantages:
- **Overfeeding is possible**
- **Low pH-value or exceeding the buffer capacity**
- **Self-inhibition**
- **Incomplete degradation**
- **Long hydraulic retention time**
- **Little process control only**
- **Less flexible against change of input material**
- **Low methane concentration of the biogas**



Single-stage and double-stage

General layout:
Double stage process

„gas splitting“



OLR = 10…50 kg oDM/(m³*d),
HRT = 2…5 d

OLR = 5…30 kg COD/(m³*d),
HRT = 1…7 d (in case of immobilized methanogens)

When do *double-stage processes* disclose their benefits?

Single-phase systems (liquid systems):

- When the composition of the substrate changes often.
- For rapidly acidifying substrates that lower the pH and/consume the buffer capacity quickly.
- At high rates of litter.
- For controlling the biogas generation ("biogas on demand").
- For improvement of methane concentration.

No or negligible advantages for slow hydrolysating and/or well-defined, constant substrates.

Double-phase systems (solid-liquid-fermentation):

- For removal of impurities, non-biodegradable waste and valuables after the 1st. stage, reduction of process disturbances.
- For the use of heavily contaminated substrates because of the selective degradation of biogenic materials.
- For substrates with high concentration of organic, but non-biodegradable materials, like landscaping waste (e.g. hedge trimmings).
- For consumer-oriented biogas production ("biogas on demand").
- For increasing the methane concentration.

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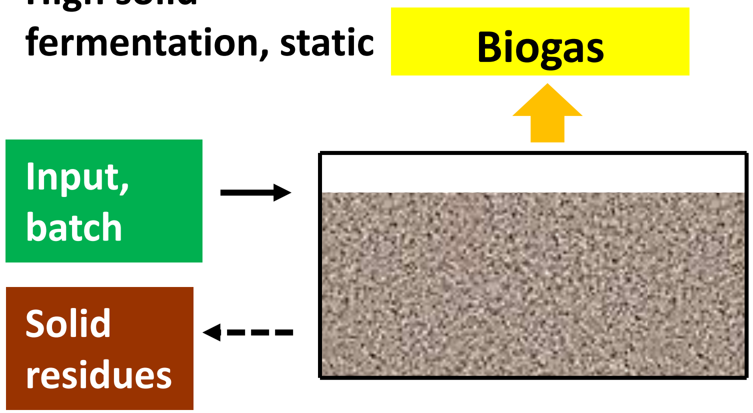
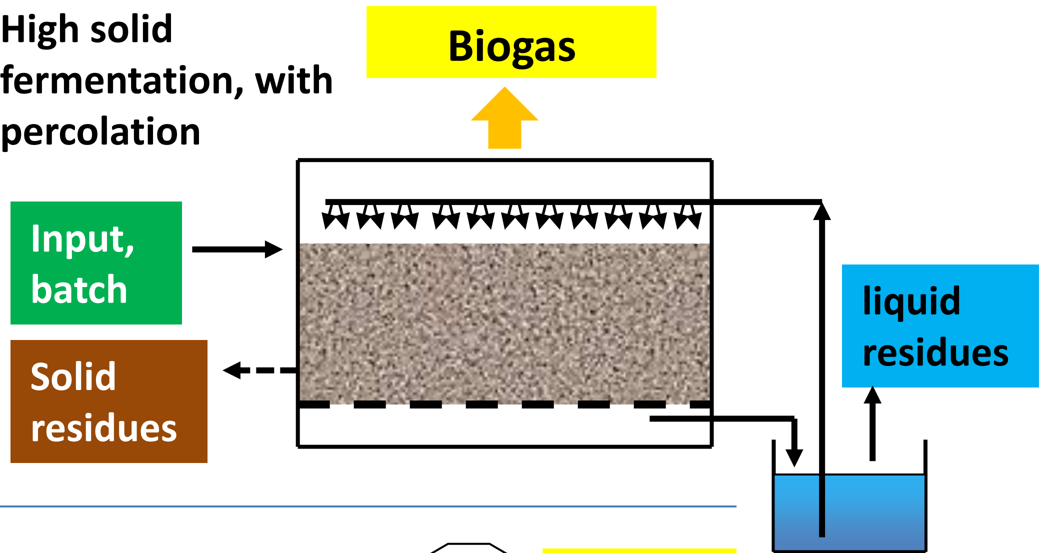
High solid (dry) fermentation (c_{H2O} < 75 ... 85%)

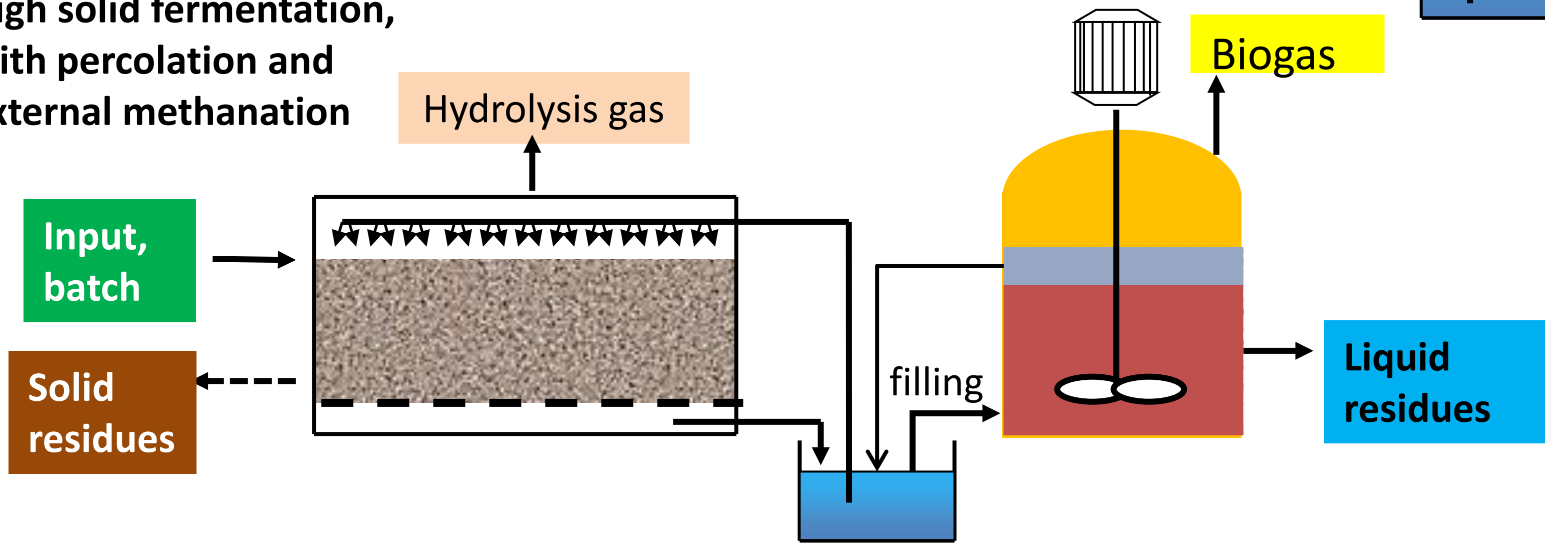
High solid fermentation, static



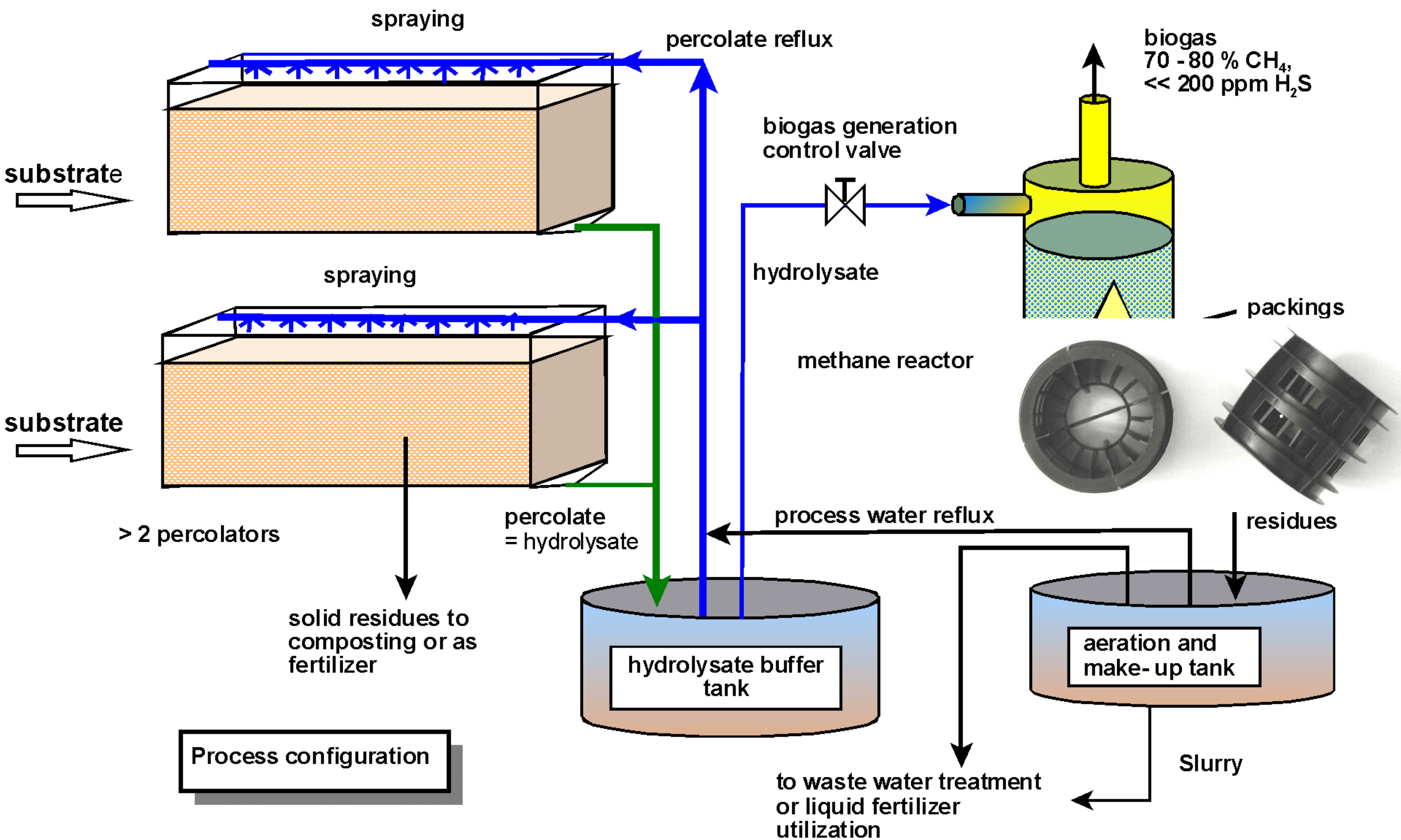
High solid fermentation, with percolation



High solid fermentation, with percolation and external methanation



The GICON© Process, developed by BTU Cottbus



Process configuration

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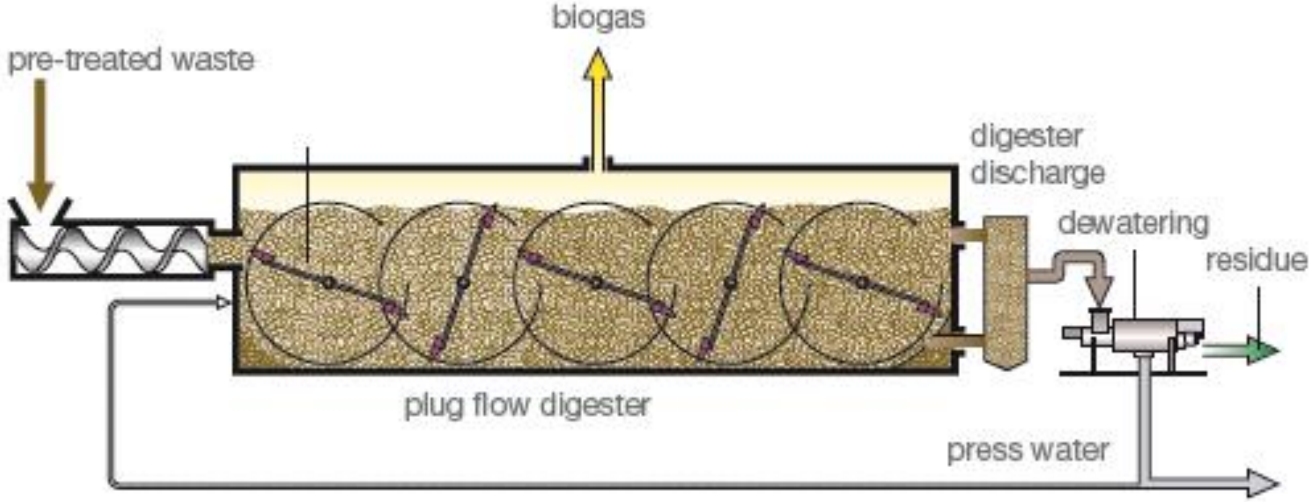
GICON Biogas Plant in Richmond, Canada, for processing of biowaste

Strabag LARAN® Plug-flow-fermenter

waste → preprocessing → "dry fermentation" → Separation

- waste: ***Biowaste, landscaping waste etc.***
- preprocessing: ***Separation, size reduction, blending, water***
- "dry fermentation" → Biogas → Make-up for feeding into grid, use as fuel
- Separation → **Recycling, recovery** / **Disposal**

Aerobic stabilization



Very robust, continuous process, ambitious design, high energy consumption, no control of biogas generation. Aftertreatment of residues is necessary

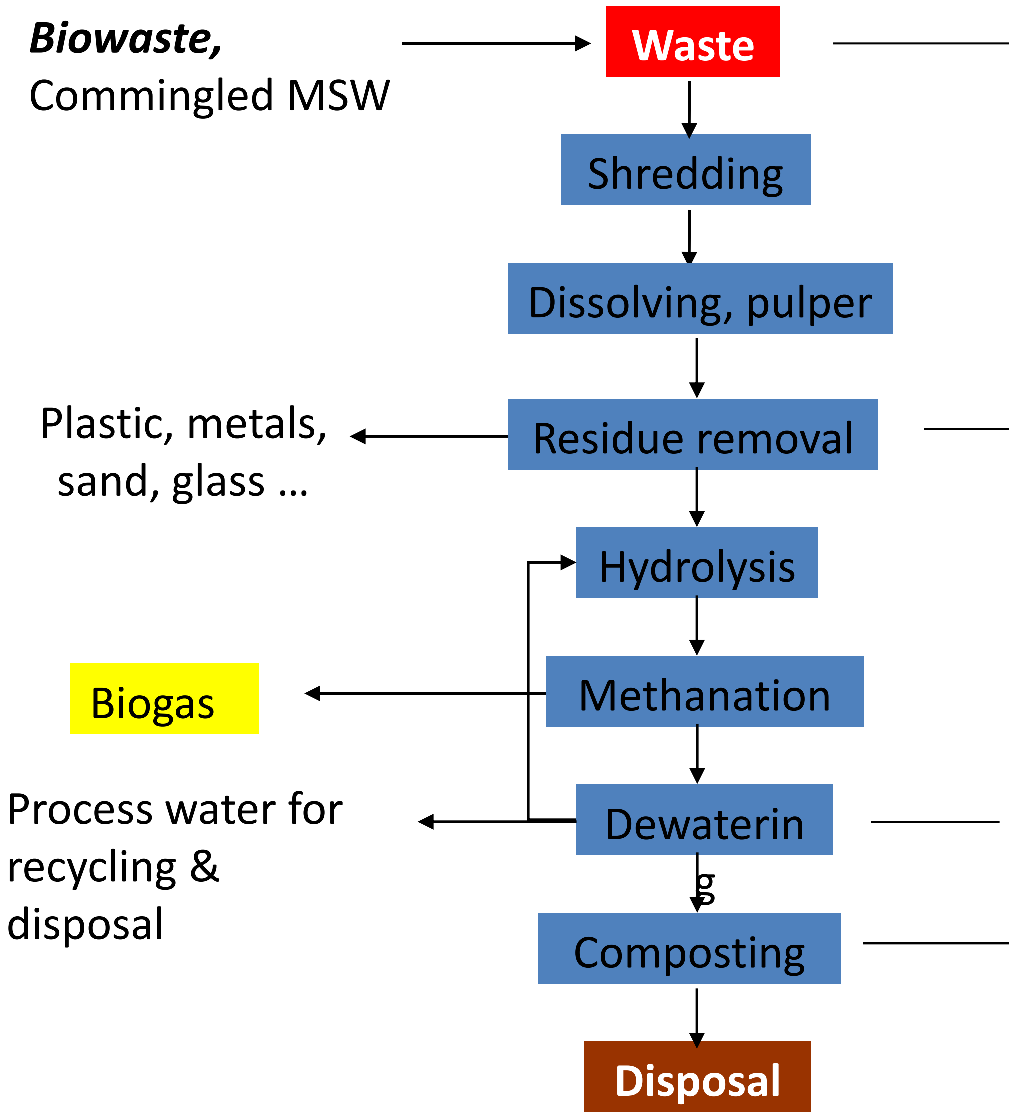
www.strabag-umweltanlagen.com, found on Sept. 1st., 2014

Feeding pump

Biogas plant BSR, Berlin-Ruhleben

Liquid fermentation for "biowaste to biogas"
- Examples of technologies -

The pulper system



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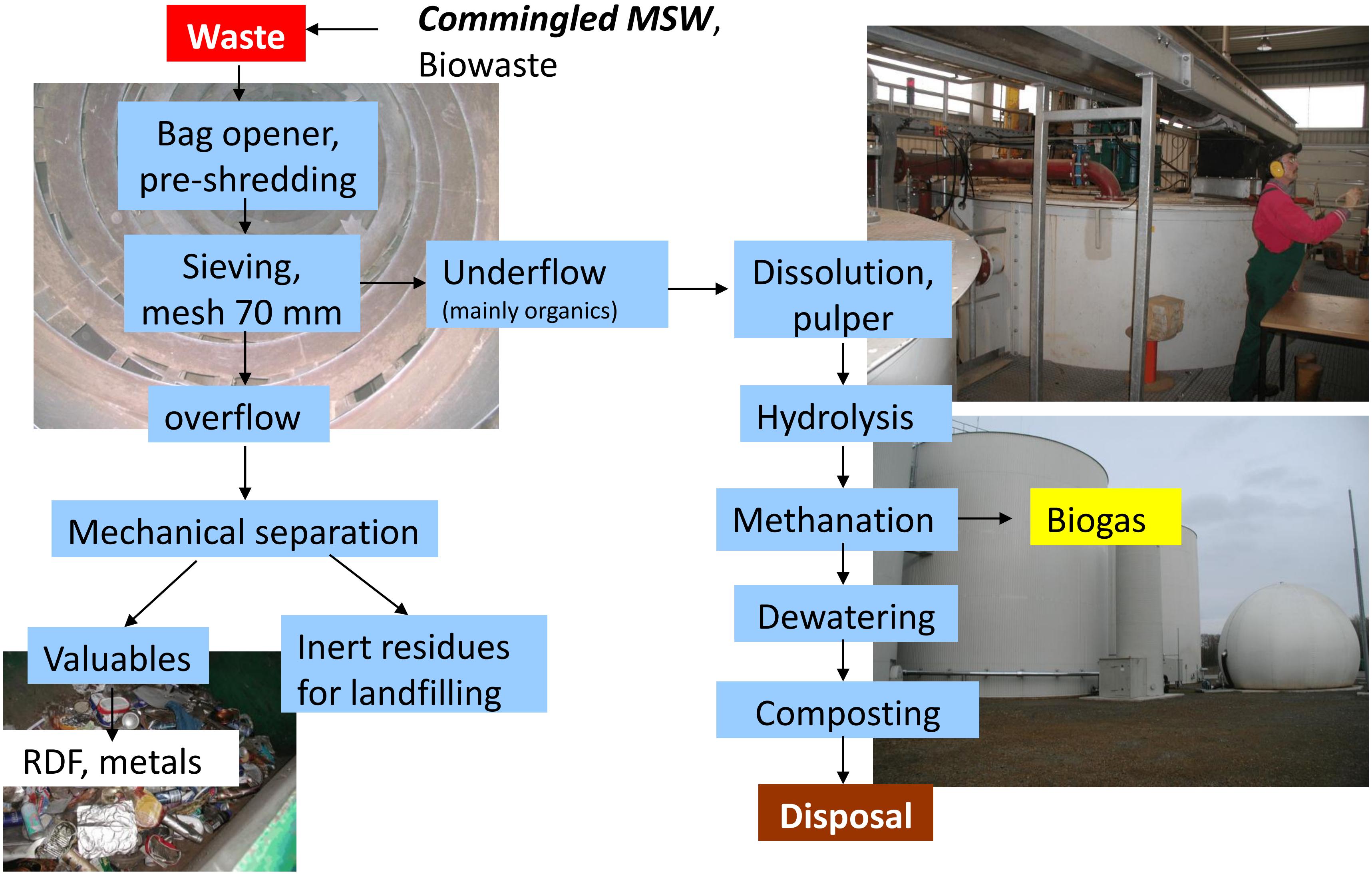
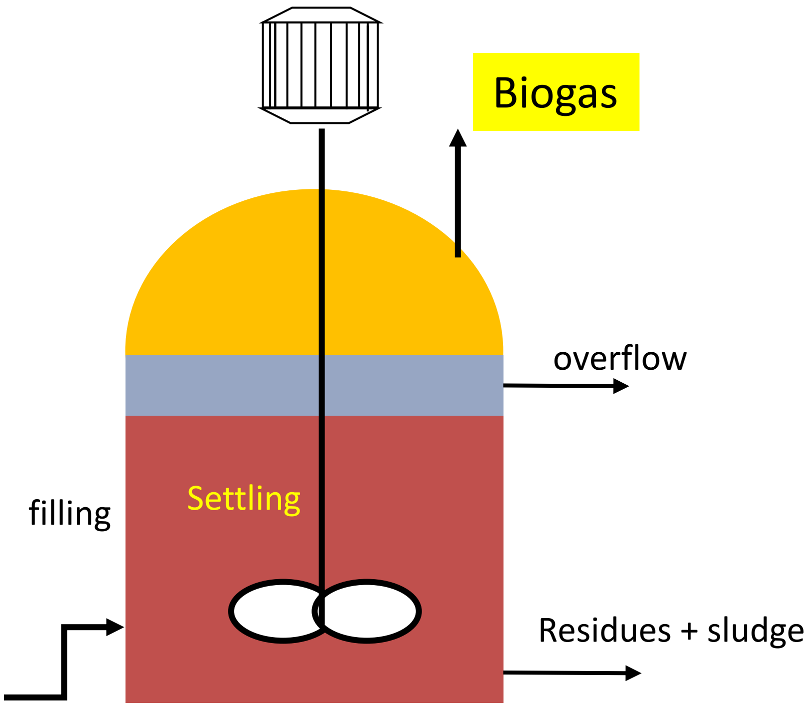
Liquid fermenter with dry pre-treatment system



Anaerobic Sequencing Batch Reactor ASBR



Avantages:

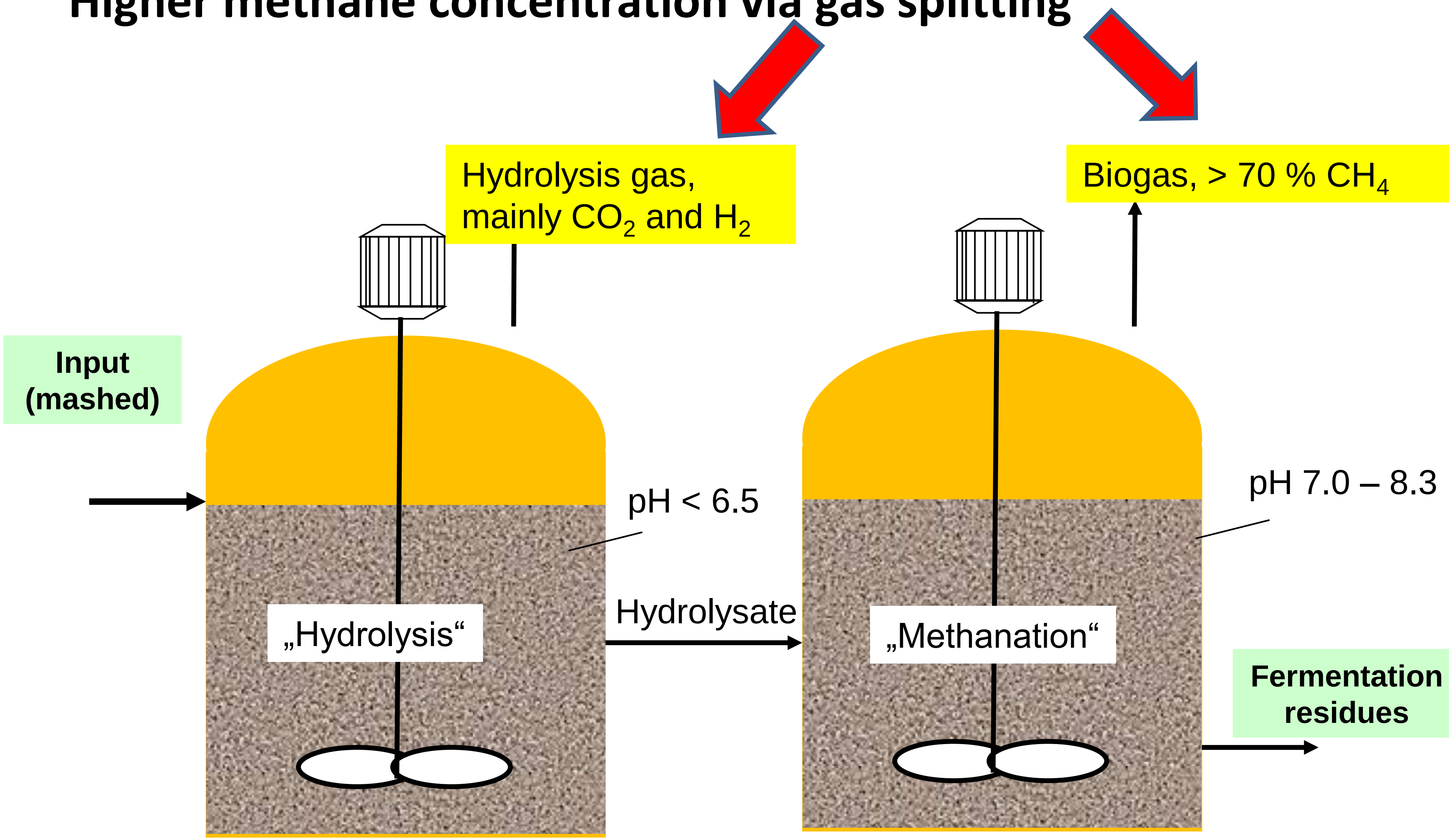
- **High performance, high stability, short retention time**
- **De-coupling of hydraulic retention time and biomas/solid retention time**
- **Less sensitivity against solids**
- **Low energy consumption (mixing time 10 – 30 min per cycle!)**
- **Suitable for single- and multistage processes**

One Cycle (total cycle time: 4 – 6 hrs) consists of:

- **feeding**
- **mixing**
- **settling**
- **discharge of clear liquid (overflow)**

Getting higher methane concentration

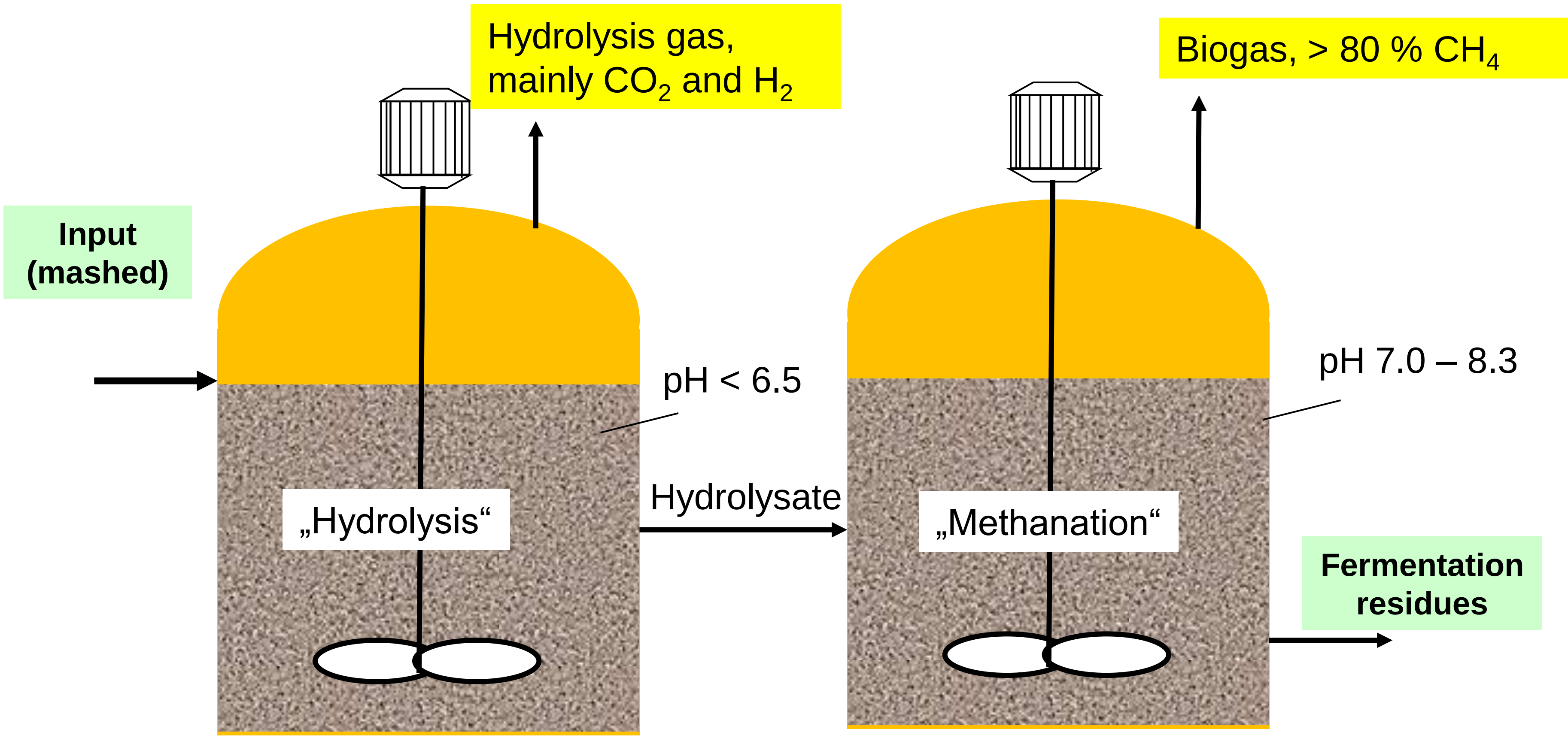
Higher methane concentration via gas splitting



OLR = 10…50 kg oDM/(m³*d),
HRT = 2…5 d

OLR = 5…30 kg COD/(m³*d),
HRT = 2…7 d

Higher methane concentration (and higher yield) through temperature control



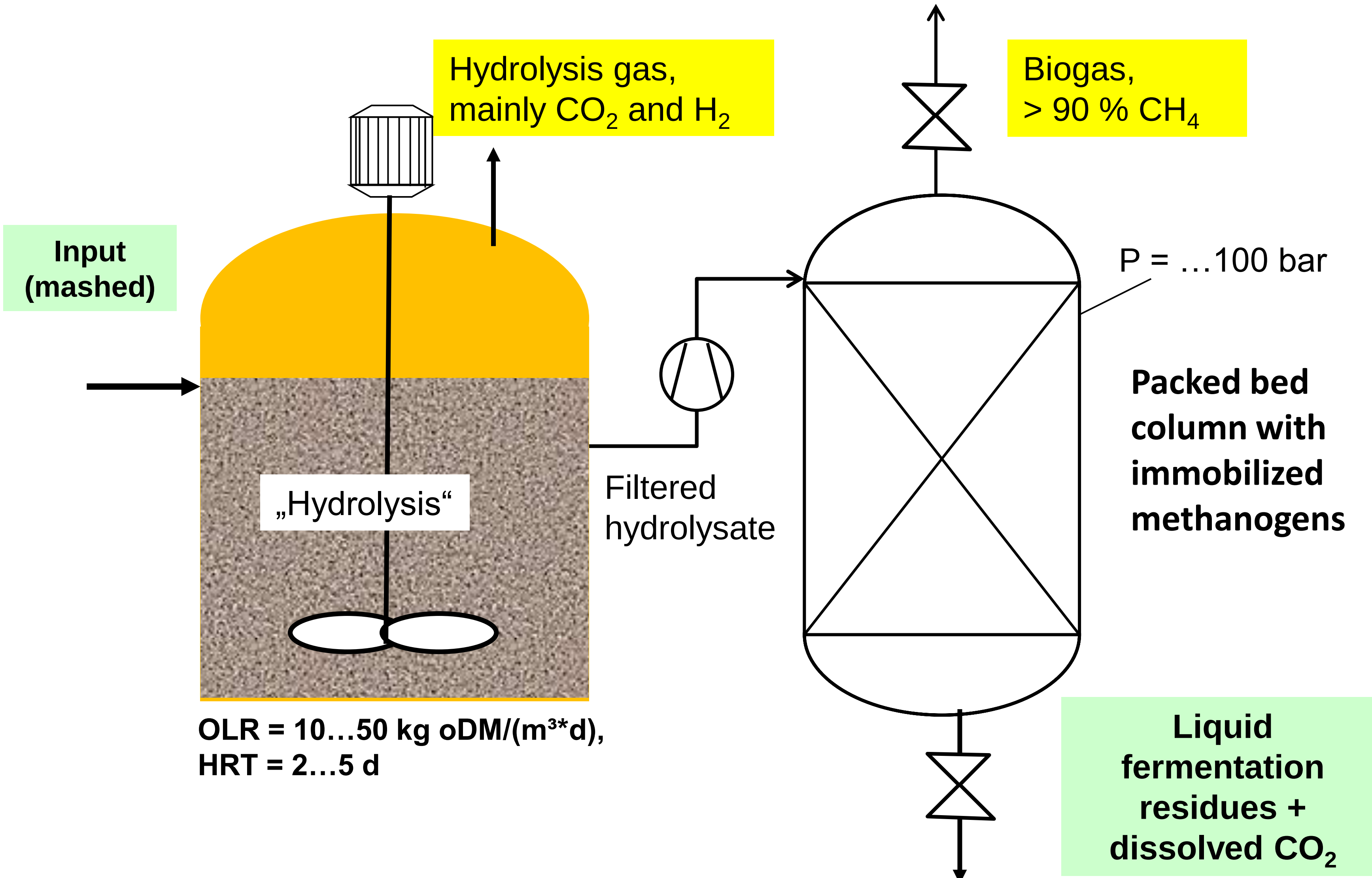
OLR = 10…50 kg oDM/(m³*d), HRT = 2…5 d

OLR = 5…30 kg COD/(m³*d), HRT = 2…7 d

Hydrolysis: thermophylic or hyper-thermophilic

Methanation: mesophilic

Higher methane concentration through pressurized methanation

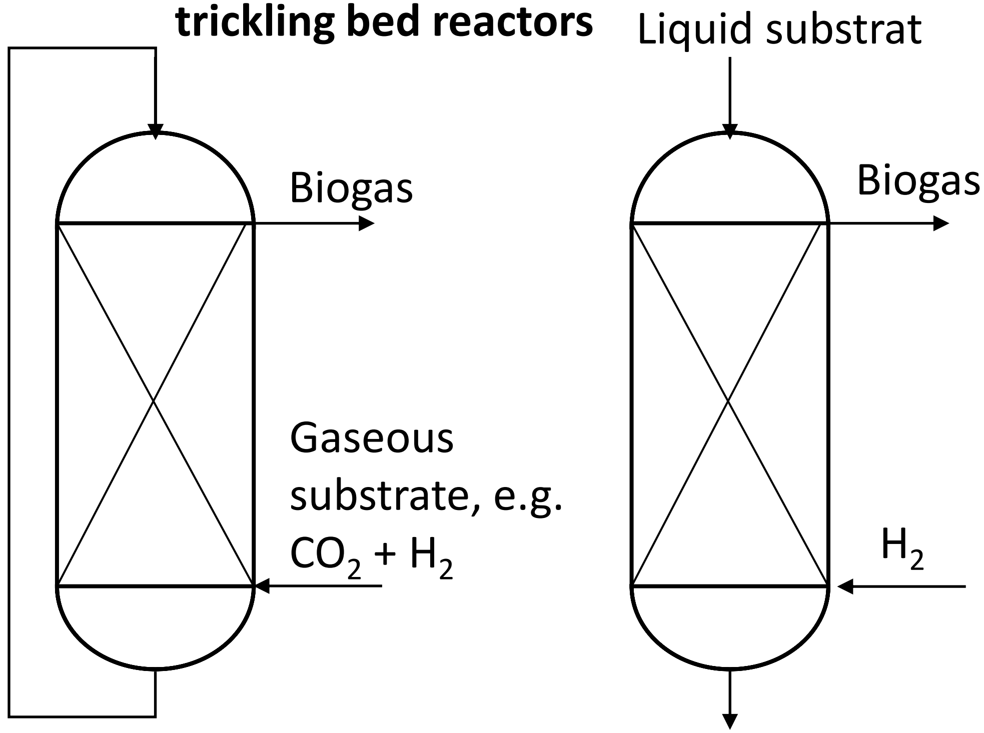


Basic Idea: Use of Carbondioxid as source für the hydrogenotrophic Methanation with Hydrogen

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O \quad \Delta G_0^{'} = -135{,}6 kJ$$

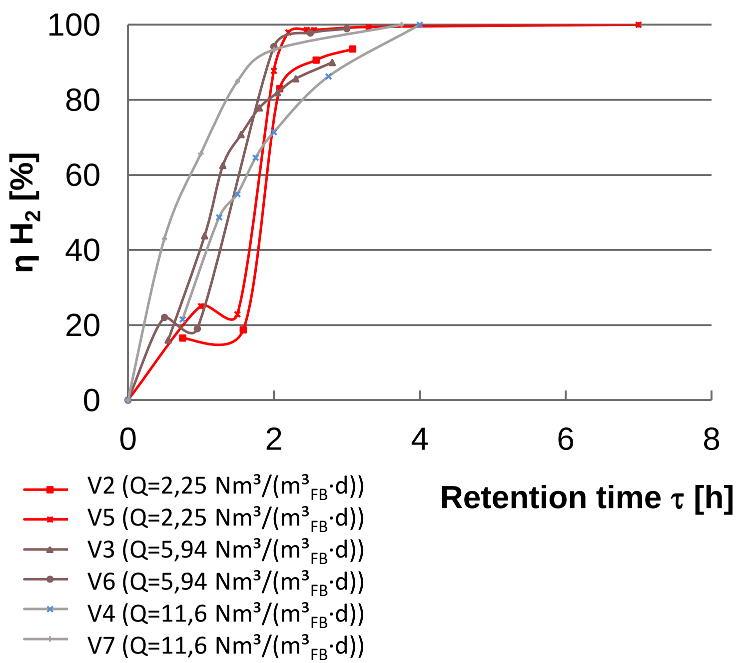
The Idea
Electrical energy from Windmills and PV-panels cannot be stored.
Water electrolysis delivers hydrogen.
With carbon dioxide, it can be converted into methane on a biological way. The trickling bed reactor has a high performance and efficiency!
Conversion rate for hydrogen: 100%!
Methane concentration: > 98 %

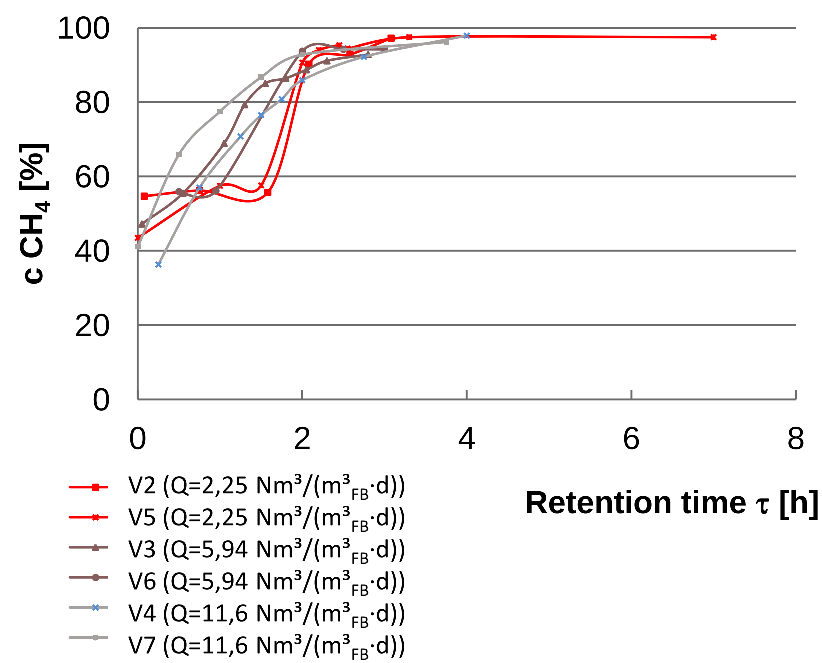
trickling bed reactors



Low gaseous pressure drop versus lenght

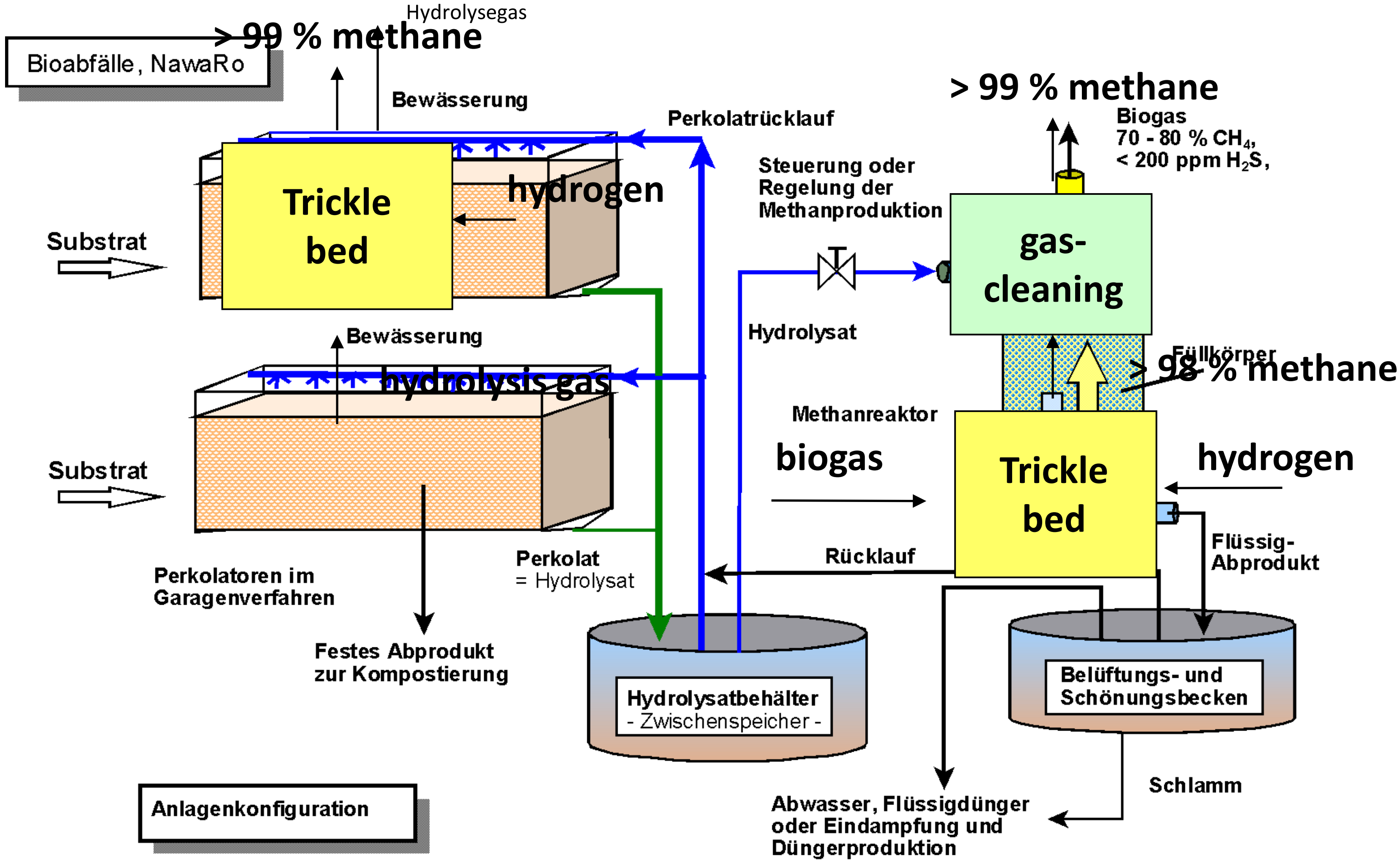
Methanation via batch operation, conversion rate η_{H2} and methane concentration c_{CH4}





η_{H2}	= 99-100%	
$c_{CH4,Ende}$	= 94-99 Vol%	
Y_{CH4}	= 0.25-0.26 Nm^3CH_4/m^3H_2	
P_{CH4}	= 1.17 $Nm^3CH_4/(m^3_{FB}\cdot d)$	(2012)
P_{CH4}	= 6.5 $Nm^3CH_4/(m^3_{FB}\cdot d)$	(2014)
P_{CH4}	= 0.15 $Nm^3CH_4/(m^3\cdot d)$	other processes, 2013

Methane enrichment via additional methanation as add-on-technology



How to start with the industrial introduction of waste fermentation?

Problems:

- **High investment costs**
- **Price for electricity made from biogas is too high compared to other sources**
- **Needs subsidies from government or "eco-tax"**
- **But: Saving of disposal costs, replacement of natural gas or fuel pay!**

The bad example: Biogas plant in La Habana, Cuba: Nice, but not working because of ignorance of waste logistic.

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Appropriate simplification of the process layout

Layout of most biogas plants:

substrate

Biogas plant

bi

Main problem:
- **High investment cost**
- **Cost for produced electricity is too high**
- **Who needs heat?**

Combined heat & Power Plant

Heat

Organic residues

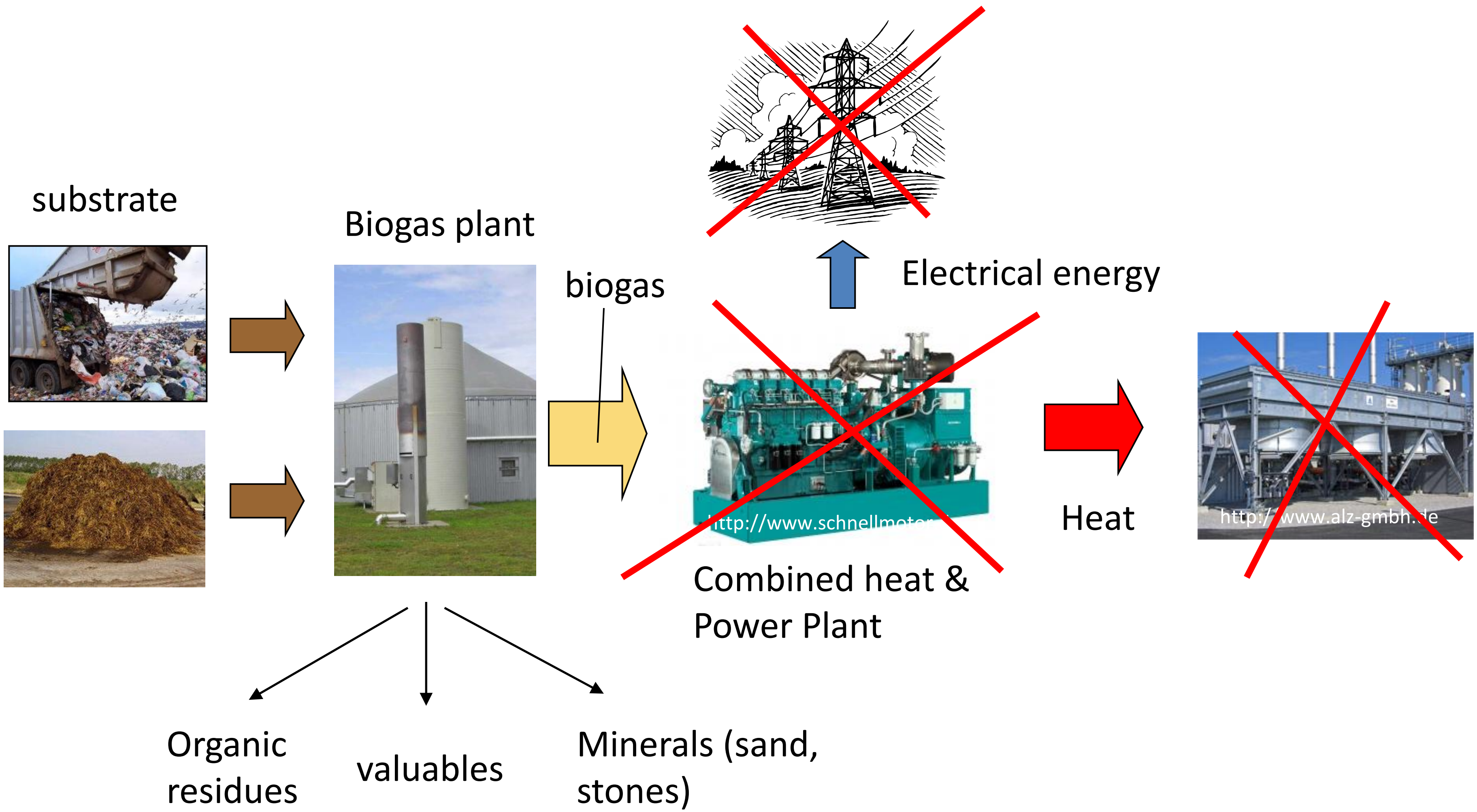
valuables

Minerals (sand, stones)

100 % chemical energy of biogas

40% electrical energy

60 % (waste) heat


substrate
Biogas plant
biogas
Electrical energy
Combined heat & Power Plant
Heat
Organic residues
valuables
Minerals (sand, stones)

Layout of simplified plant:

substrate

Biogas plant

biogas

Boiler (less costive than CHP, existing?)

Heat

e.g. food processing industries, paper mills, dairies etc.

Process industries

Organic residues

valuables

Minerals (sand, stones)

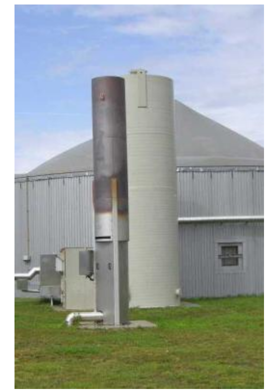
100 % chemical energy of biogas

100 % heat (e.g. steam, hot water etc.)

The positive example: The producer of waste, the investor and the beneficiary are the same person (or company). Simplifies everything!

Waste processing, blending

Substrate



Biogas plant

Biogas

The company benefits from its own waste!

Organic waste from Process industries

disposal

Heat demanding Process industries

e.g. food processing industries, paper mills, dairies etc.

(existing) Boiler

Fossil fuel

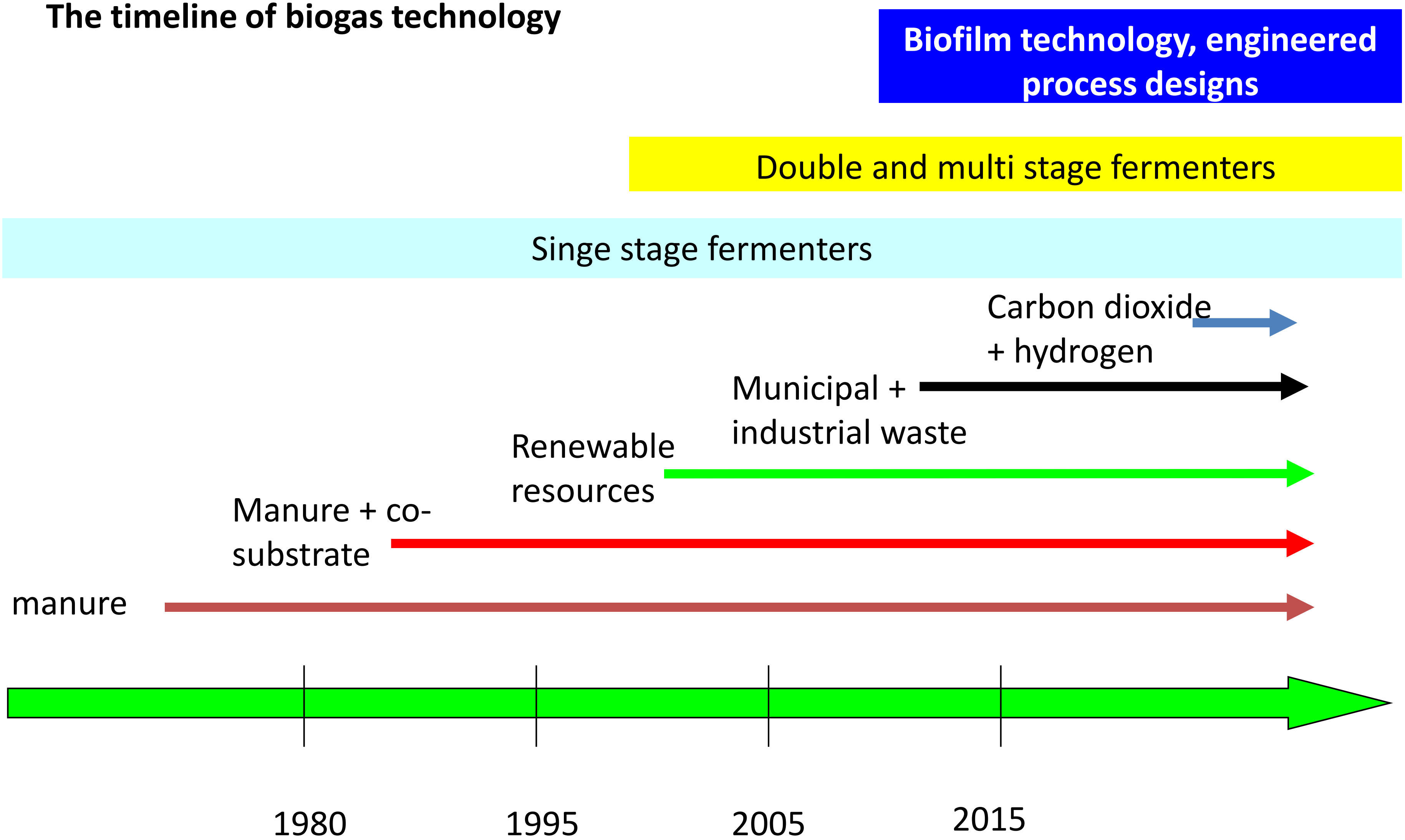
Replacement of natural gas or oil by biogas

Example: Pilgrim's Pride Ltd.

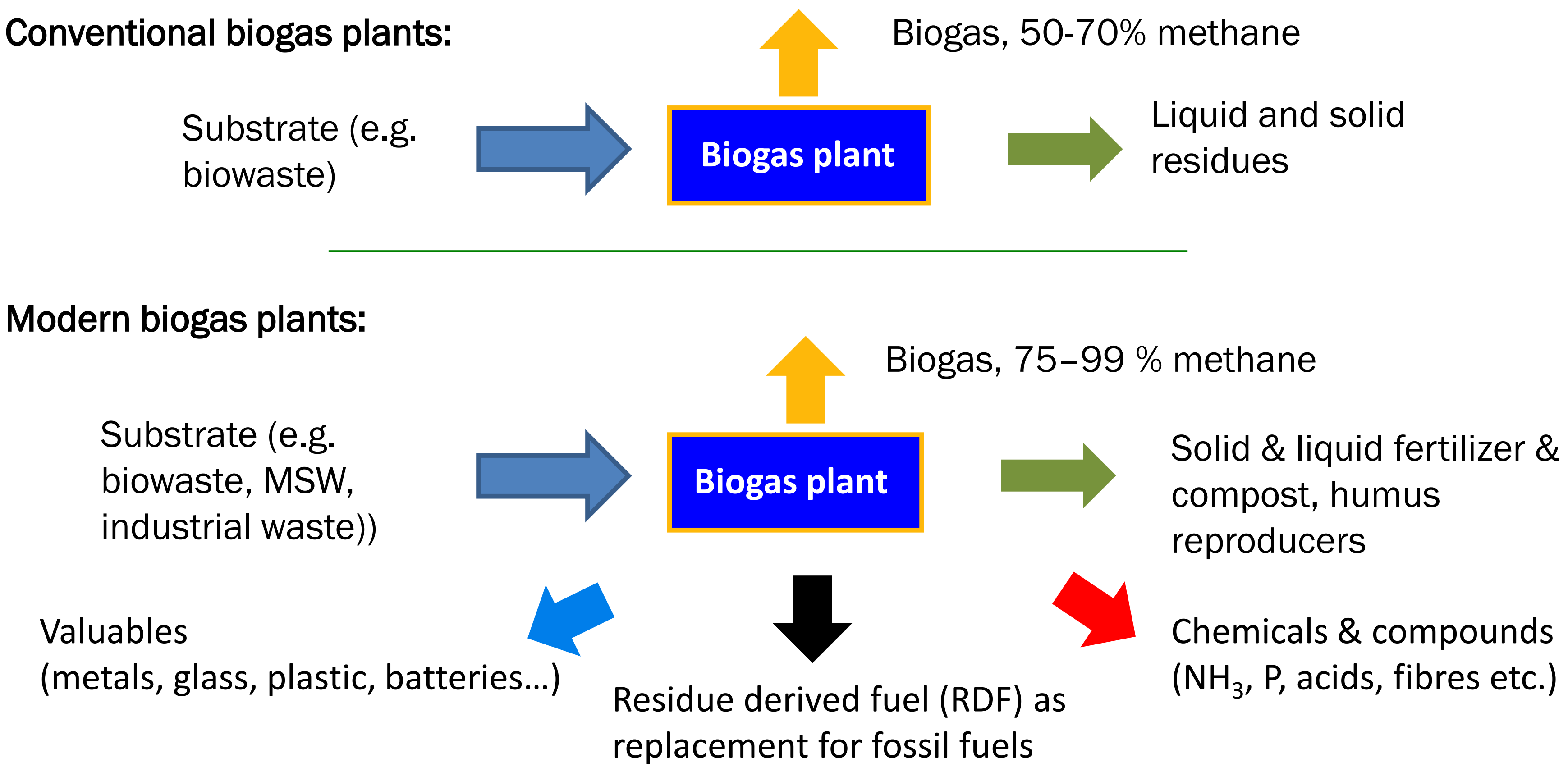
Smiley: http://www.gbsun.de

Biogas technology in progress

The timeline of biogas technology



Biogas plants: From single-purpose to multi-product technologies



Thank you for your attention!

Dziękuję za uwagę!