Biogas Plants

Basics – Function – Building Types

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What is Biogas?

Biogas is a combustible gas mixture of mainly methane (CH_4) and carbon dioxide (CO_2), with up to 2% hydrogen sulfide (H_2S) and trace gases such as ammonia (NH_3), hydrogen (H_2), nitrogen (N_2) and carbon monoxide (CO).

Biogas is generated as the metabolite of bacteria and microorganisms during fermentation of organic material and compounds under air absence.

Biogas is also known as sewage gas, fermentation gas, marsh gas or landfill gas.

From what Biogas can be produced?

Biogas can be produced from nearly all organic materials containing water, which are consisting of the basic components fat, protein and carbohydrates.

In agriculture, from animal excrement, from food residues and plant parts, from nearly all grasses and from energy crops.

In the food industry, from production residuals like distiller's wash, spent grain, whey, fruit and vegetable scraps, Products not placed on the market (incorrect batches), overstored goods, grease trap contents, etc., but also organically highly polluted wastewater like fruit juice or cellular water, blanching water, etc.

In municipal areas, from the organic waste and food waste disposal, from primary and secondary sludge of sewage treatment plants, but also from green parks and sports fields maintenance Biogas could be generated.

Fundamentals of Biogas Technology

The Biogas generation basically takes place in four successive phases by decomposition of organic substances to water and Biogas.

It needs an aqueous ambient for the involved mixed bacteria culture of facultative anaerobic (living in both with and without oxygen) and strictly anaerobic (living only without oxygen) micro-organisms like bacteria, molds and protozoa.

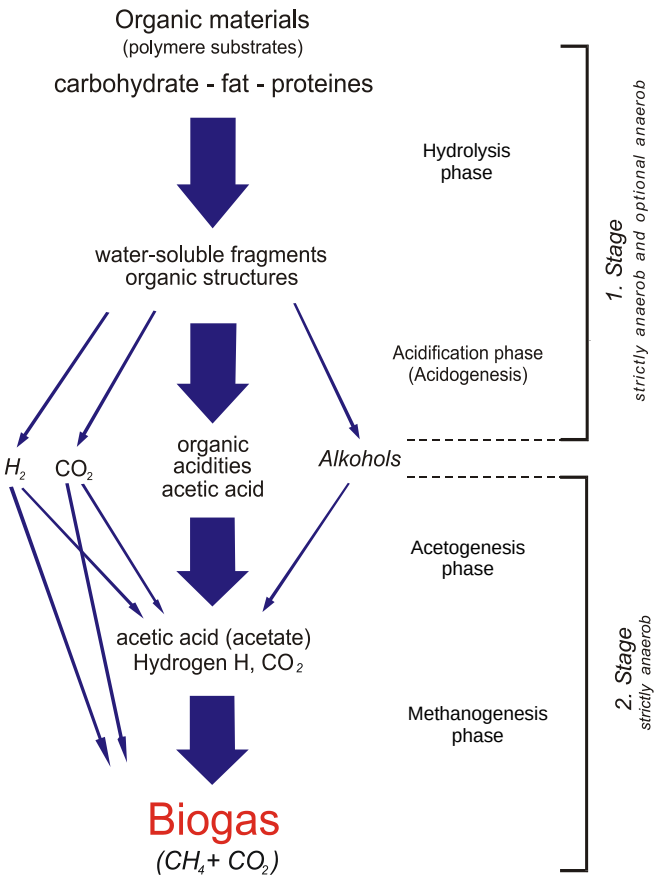
For each step of degradation different micro-organisms are involved. The respective group of microbes can only utilize the intermediate goods which are produced from the microbes in the phase before.

In the first two steps, called as Hydrolysis and Acidification phase, the complex polymers are disaggregated into their monomers. All involved microbes are living in symbiosis.

Because at this procedure the material becomes more liquid this step is named as Hydrolysis Step.

The well acidificated substrate could be now continuing degradated in the next following steps, the Acetogenesis and the Methanogenesis Phase".

Also this bacteria are in a closed symbiotic living. The methano bacteria now metabolite acetic acid and hydrogen into biogas.



If however the two main phases are spatial separated (we call it then as two-stage fermentation), each phase now could run in its ideal condition and the Biogas plant achieves the highest capacity at shorter retention time.

The methane producing bacteria are among the oldest creatures of our earth (Archaea species) and have a very specialized metabolism.

This bacteria are growing very slow but are extremely sensitive to changes in environmental conditions such as temperature and pH value. The optimal conditions and process parameters are:

Temperature	Mesophile Thermophile	35 - 40 °C 52 - 55 °C
pH - Value	Hydrolysis / Acidification Acetogenesis / Methanogenesis	4 (5) - 6 6,8 - 7,5
Nutrient Proportion C:N:P:S: = 2000:15:5:3		
preferably high Substrate stability		
preferably high Substrate homogeneity		
laminar flow conditions		
No wash-out of microorganism		

The optimum pH-value of the methanization is from 6.8 - 7.6 but at pH-values above 8 the process should be examined.

Because this could be caused by an increased accumulation of ammonia and these can make toxic effects on the process.

Also the Temperature is a significant parameter. It should be very stabile +/- 2 °C.

The methanization phase could work in mesophilic range, means between 35 and 40 °C but also in thermophilic range, between 52 and 55 °C. <u>But:</u> Either…or.

The thermophilic range is a little bit faster than the mesophilic range but the mesophilic population is much more stabile and insensible.

The Biogas generation and the Biogas quality, means the content of methane (CH_4) depends stringently to the material composition.

If the composition is known, it is possible to calculate the theoretical achievable amount of Biogas and its content of CH_4 and CO_2 by using the Buswell-formula. To simplify matter the possible Biogas yield and methane generation is shown in following table.

Ingredients / basic substances	stoichiometrical Biogas yield (Liter Biogas / kg ODM decomposed)	ca. Methan content of Biogas (% of Biogas)
Fat (Lipids)	1.400 l/kg (1,4 m³/kg)	80 .. 90 %
Proteins	600 .. 900 l/kg (0,6 .. 0,9 m³/kg)	75 .. 80 %
Carbohydrates	700 .. 800 l/kg (0,7 .. 0,8 m³/kg)	50 .. 60 %

Basically for the Biogas generation the group of content like raw-fat (lipids), protein and carbohydrates are suitable whereas Lignin is not anaerobic degradable. Therefore it won't be possible to generate Biogas from raw fiber if the lignin wrapping is stabile enough.

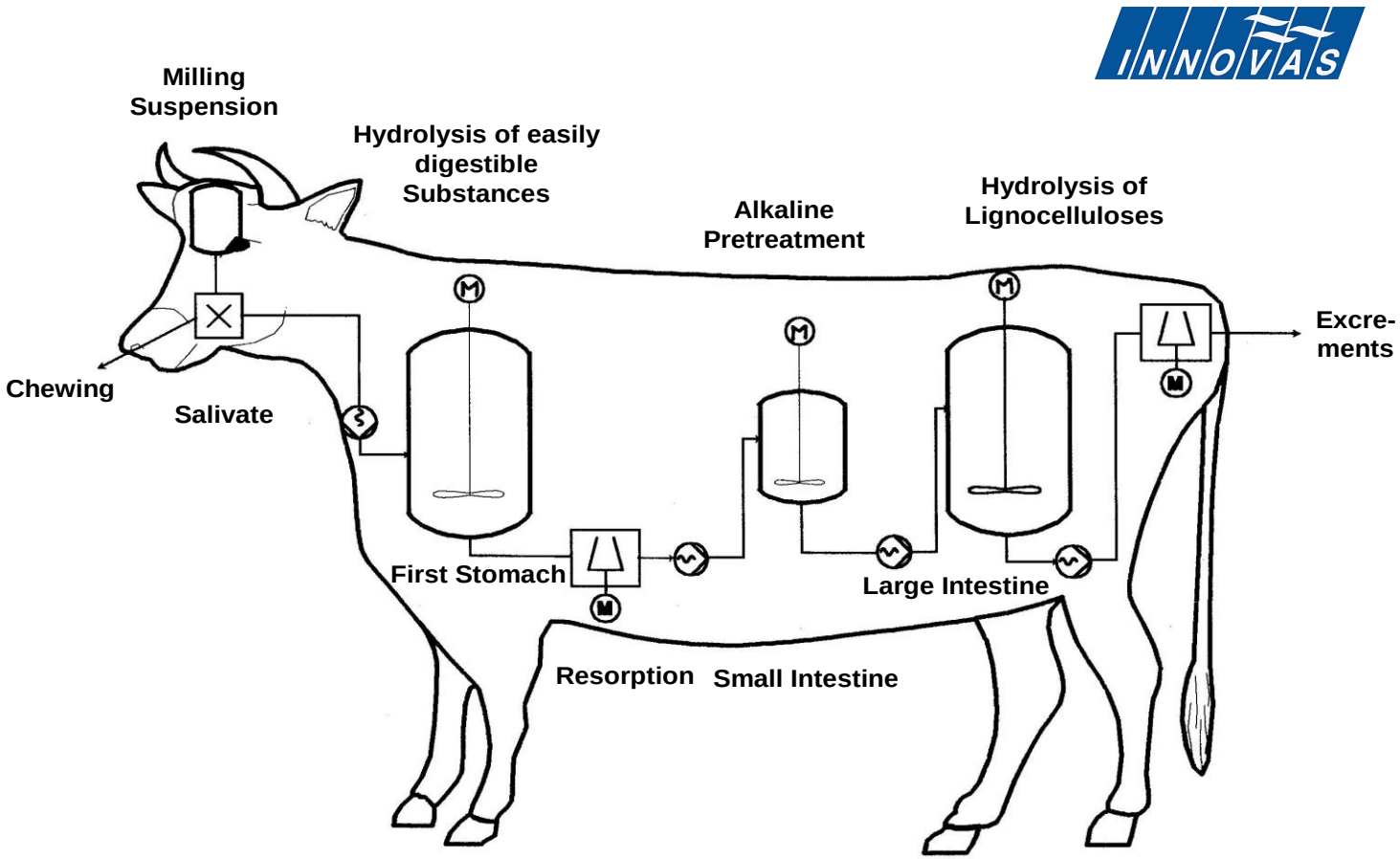
The procedure in a Biogas plant is comparable with the digestive principle of ruminant animals. If the Biogas plant shall work in the same perfect way we have to have a well knowledge of the most important process steps and we have to design the plants according to it.

This is an essential basic for a high efficient, well degradation and Biogas capacity and therefore an indispensable part of our Biogas plants.

By the way, let us work according the natural rules and not try to change it. The biogas technology is subject to immutable natural law. They are the natural measure that sets the limits in use of this technology.

As better as we understand really the natural needs as less problematically would be the operation of a biogas plant.

The most perfect anaerobic system in the World



The Hydrolysis analog to Ruminant Digestive

Requirements for the well function of a Biogas plant

- **Lignin, wood and woody raw fiber is not fermentable; Cellulose and hemicellulose can be decomposed only with more efforts for making it anaerobically degradable; and such is only possible with Two-Phase Biogas Plants (means hydrolysis phase is separate from methanization phase).**

  Such kind of Material needs a well pre-preparation.

- **For the input material is the best possible cell disruption shall be made. As finer the substrate but as bigger their surface as better will be the degradation and as more is the biogas yield,**
  The cell disruption could be made mechanically by milling, enzymatical or chemically.

- **The fermentation substrate must be mashed homogeneous and readily flowable.**

- **The Temperature into the fermenter shall be stable within ± 2°C. Avoide temperature shock; fill no cold substrate into warm fermenter.**

- **Take care on right pH-Values for fermentation and hydrolysis.**

- **Compared to simple one-phase biogas plants a two-phase biogas plant has always a better degradation of the organic substrates, thereby bringing a significantly better biogas yield and higher methane content, at the same time.**
  The separate, upstream hydrolysis is a true Turbo for each biogas plant.

- **Not at least the plant must be well calculated and designed. The retention time must be long enough and adapted to the characteristic of the input material. The usual load factor in the fermenter tank shall be not more than 3..4 kg ODM/m³*d. Higher load factors (and thereby very short retention times) are only possible with special systems.**

Possible Inhibitions and Interruptions

⇒ **Inhibition of the Biogas process could be caused by noncompliance of the process temperature, e.g. 35–40 °C on the mesophilic range. Also the process could be inhibited by strong temperature fluctuations, if for example very cold substrate is filled into the warm fermenter. Such is certainly one of the common causes of malfunctions.**

Corrective actions:

- **The fermenter shall be constructed with a sufficient insulation.**
- **Take care of stabile and constant temperature**
- **Warm up the substrates before filled in.**

⇒ **Disturbance of the biological balance by acidification.**
Critical values could be less than 6.8 pH and more than 8.0 pH

Corrective actions:

- **When feeding take care that only as much fresh material is dosed as the system could assimilate. Control the pH-value.**
- **When changing the material of after longer periods of non-operation increase the feeding slowly and gently.**

With an "Two-Phase Fermenter System" a overacidification is nearly impossible! Even if it comes to a overacidification, stop feeding and give the system time to adjust.

⇒ **Inhibition by higher salt and heavy metal concentrations.**
Salt concentrations could inhibit already at 10 g/l but adapted populations could allow up to 50 g/l.
With heavy metal concentrations it is difficult because some of this metals are necessary trace elements.

Corrective actions:

- **On critical material it's essential to make a substrate analysis before use.**
- **On critical input material it is recommended to check the conductance frequently**

⇒ **Disturbance of the biology by a <u>high ammonia level.</u>**
An ammonia concentration of more than 0,15 g/l could be critical. This could be caused by too much recirculation (with Nitrogen rich substrates) and thereby shifts the solution equilibrium of ammonium to ammonia. This is normally seen at the increasing of pH value > 8.0

<u>Corrective actions</u>:

- Frequently check of pH value.
- Reduction of the recycling or dilution with liquids low in nitrogen
- Possibly even any post-treatment of the effluent is necessary for use as recycling

⇒ **Disturbance of the biology <u>by Hydrogen Sulfide</u>**
The relevant literature sources indicates a possible inhibition of the biogas process on a H_2S concentration more than 50 mg/l but it's well known that adapted populations allows up to 1.000 mg/ H_2S.

Beside the inhibition of the biology by too much H_2S, there could be also another reaction disturbing the Biogas process.

In the anaerobic population are methanogenic bacteria and sulfur-reducing bacteria (SRB) living in symbiosis. Both are Achaea bacteria, the oldest live in our world.
When elemental sulfur is increased and the SRB reduce it to hydrogen sulfide, it comes to an competition situation.
Both bacteria groups compete with the available hydrogen dissolved in liquid.
In this situation the SRB are stronger (but are the older one…) and metabolize more H2 and this would disturb the metabolism of the methanogenic.
Not at least, such high concentration of H_2S is balanced dissolved in the liquid and part of the Biogas. This needs a more extensive desulfurization before the Biogas could be used.

<u>Corrective actions</u>:

- The dilution of sulfur rich substrates with sulfur less material.
- The precipitation of H_2S by using of ferrous based agents.

We have developed the Biogas system in a way that it could work also with higher sulfur levels – certainly within its naturally limits.

With the operational experience of many years we have also developed the de-sulfuring system for Biogas with extremely high H_2S concentration.

Otherwise the Biogas process is very unassuming and good-natured, but also very slow. A Biogas plant is very safe and easy to operate if some (logical) rules are observed.

- **The Biogas plant shall only be fed with this material for which it is designed and constructed.**
- **And the Biogas plant must be designed for the available and expected material and its conditions.**
- **The Plant should be operated in a normal and safe way according to the plant specification considering all specified operating parameters.**
- **All operational parameter and operating conditions must be recorded without gap.**

Such controlling enables the operator to see any disturbance right in time and allows the right countermeasures.

Overview of different Biogas Systems

As already mentioned before the biogas process is predestinated for any aqueous biomass. Biogas plants are different and in special application since many years state of the art (…and we are often not aware that this are biogas plants…)
For each specific application we should operate the right plant technology – than we would get the best result.

Now I will show some of the essential and principal differences in Biogas systems

- **Digester Tower in Waste Water Treatment Plants**
- **High Performance Systems for the anaerobic Pre-Treatment of Industrial Waste Water**
- **Single-Step Biogas Plants used in Agriculture**
- **High-Performance Two-Step Biogas Plants for Digestion of Organically Waste**
- **The so-called Dry-Fermentation**
- **Lagoon Biogas Plants**
- **Small-scale Fermenters**

The utilization of Biogas is manifold. After de-sulfuring and de-hydration Biogas can be fired like Natural Gas into a hot water or steam boiler. Biogas could be used as fuel for CHP engines for producing heat and power with electric efficiency of > 40 %, (this is the common way today). But biogas could be also processed into natural gas quality and feed into the grid or compressed (with 20-25 MPa) to Bio-CNG as car fuel.

What the most profitable utilization is depends on the local and market conditions.

Digester Tower in Waste Water treatment Plants

The anaerobic stabilization of sewage sludge is the oldest industrial application for biogas technology. The first applications was made already in the early 1920s in the Ruhr-area in Germany. The Biogas was used in the local gas network.

Today the most of larger Waste Water Treatment plants in Germany but also in the industrial world have digester towers as part of the treatment plants.

<u>Advantages</u>

Such systems are egg-shaped designed for easily removal of the sand rich sludge.

The generated Biogas is mostly complete used in the Waste Water Treatment Plant (WWT) for process heat and power.

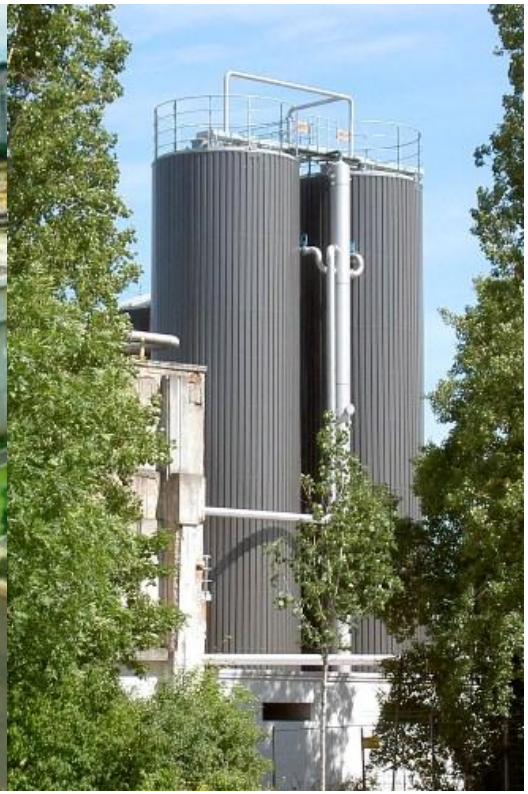
The sewage sludge is stabilized for the utilization as fertilizer.

<u>Disadvantages</u>

Very expensive construction.

Biogas Fermenter for organically polluted Industrial Waste Water

The utilization of anaerobic systems in front of industrial Waste Water Treatment is state of the art since many years. UASB (Up-flow Anaerobic Sludge Blanked) systems or Fixed-bed Fermenters are well used all over the world. Such special applications are used for effective waste disposal but not for production of energy as main goal.



Advantages

Very high degradation rates of organic purification.
An reduction of 95 % COD (98 % BOD) is possible. This makes significant cost reduction in the subsequent aerobic waste water treatment.
Very short retention times are possible because of an intensive bacteria immobilization.

Disadvantages

- **Only dissolved organics without any solids can be processed.**
- **All solids must be removed carefully before digestion.**

Single-Step Biogas Plants for Agriculture

The essential feature of such kind of Biogas plants is the complete degradation process, from Hydrolysis up to the Methanogenesis takes place in one common room. The degradation rate is accordingly average. This kind of plant technology is mostly used in agriculture and for energy crops in Germany.

Advantages

Cheap construction
Simple in use

Disadvantages

Lower degradation rate, therefore limited Biogas yield.

Much longer retention time compared with Two-Step Systems. Poorly process stability for mono-substrates (mostly manure is necessary).

Higher power consumption for agitators.

Insufficient insulation and therefore more self-energy demand.

Higher risk on storm loss of the foil roof .

Two-Phase High Performance Biogas Plants

For industrial applications the availability of a plant must be very high. Due to the need of final processing of the digested substrate a very high degradation rate is required. The convenient side effect is more and a better Biogas.
Such kind of plant must be standard for the digestion of urban and industrial waste.

Advantages

Degradation rates up to 85 % are possible.

Up to 25 % more Biogas compared to single-phase fermenter systems within the same time.

Better Biogas quality in regard of CH_4
Very high process stability.

Mono-fermentation of organic residues from food processing without difficulty.

More than 98 % plant availability.

Disadvantages

More complex technique required

Higher Investment cost compared to single-phase fermenter systems.

Dry-Fermentation

The more correct description for such Garage systems is “Percolation Process”. Because only the dissolved cellular water and therein dissolved organic could be digested.

Don’t forget: Any fermentation is naturally an aqueous process!

<u>Advantages</u>

Simple plant concept.

Low power consumption for the process.

Stackable and not flowing solid rich biomass could be digested (aqueous part only) without pre-processing.

Relatively good Biogas quality in regard to hydrosulfide (H_2S).

<u>Disadvantages</u>

Lower Biogas production compared to wet processes.

50 % of the box content is required as inoculum for the next fresh charge.

Longer retention time.

Batch process only.

Lagoon Biogas Plants

In warm countries in Asia, Central- and South-America are such simple solution found. Only covered with a foil. No insulation and no heating installed.
The demands on such simple solutions shall be not to high.

<u>Advantages</u>

Very cheap construction

<u>Disadvantages</u>

A very low Biogas production.

The Biogas quality is poor with less than 50 % CH_4.

H_2S concentration in Biogas sometimes up to 30,000 ppm (!)

No process stability.

Very bad in maintenance.

Small-Scale Biogas Fermenter

Especially in India and China there is a long tradition for very small biogas fermenter. With this home-made systems people can produce with handful cow dung or plant material enough Biogas for cooking the daily food. In the meantime such simple systems are widely-used also in Africa.

<u>Advantages</u>

Absolutely easy and cheap self-made construction with simple resources

<u>Disadvantages</u>

As good as no safety.

Only purely manual operation

If someone wants to built such small fermenter according to our safety standards and wants to have an more or less automatically and continuously process such small units comes to relatively high costs in relation to its performance.

Thereof in developed countries with their high-density areas small-scale fermenter are seen and used only in laboratories and for special purposes on which the economically plays no role.

Laboratory Biogas Plants

In our technical center in Munich, we have the most important facilities to carry out biogas experiments.

Eudiometer

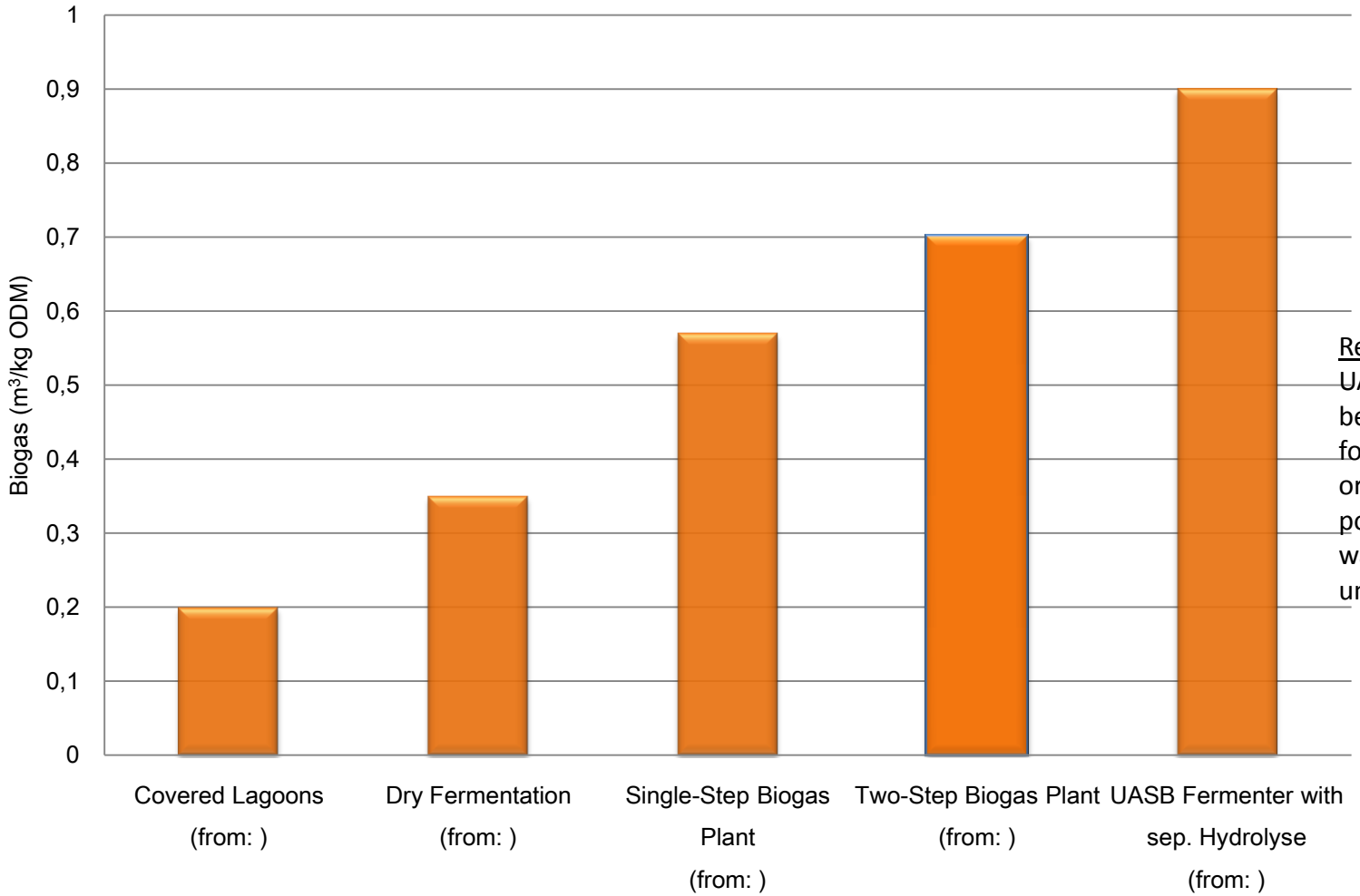
We have 2 Eudiometer experimental rigs with 6 fermentation glasses each for making fermentation tests in accordance to VDI RL 4630, or DIN 38414 standard.
The apparatus is simply consists of a glass vessel construction, in which the fermentation substrate is filled and an attached glass tube with scale to measure the recovered biogas.
With this test, the principle fermentability of a substrate can be determined and a statement about the possible formation of gas are derived.

Experimental Facility

We have also a test plant available with 600 liter scale, including two separate hydrolysis bins.
With this plant we can make digestion test over longer periods for finding out the fermentation behavior of substrates or sub-strate mixtures. With this test arrangement we can simulate exactly the later plant operation.
The identification of the realistic biogas yield, biogas quality and the grade of decomposition could be made reliable.

Not at least we can produce original digested substrate which enables us to make following test trials and designs for the specification of subsequent processes if required.

Comparison of the efficiency from different Biogas Production Systems



Remark:
UASB fermenters has been designed just for processing of organically high polluted (waste) water, without any undissolved solids

Conclusion

The Biogas technology is already very old and sophisticated. There are specialized and suitable techniques for different applications known and developed.

Each biogas plant must be individually tailored to the existing or planned substrates and to the intended use.

Therefore, a thorough pre-planning is essential in order to identify already in advance in what circumstances the desired project will be economically viable.

But, however one thing is not possible. The legendary "all-in-one device suitable for every purpose“ on which nothing remains, which works for alone, for very low budget but maximal profit.

The design of a biogas plant should be carried out by a manufacturer independent expert. A plant construction company pretended to make any planning for "free", but the only interest of equipment supplier is selling his own goods.
This is comprehensible but is surely not always the same interest the plant owner has(!)

A badly planned and designed Biogas plant, located at the wrong place, which earns not enough or has to high operational costs, never can be so "easy" and cheap that does not result in a financial fiasco.

Accommodativeness can be expensive (!)

Don‘t hesitate to talk with us....

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