Development of BIOGAS PLANTS

1 Harnessing Natural Energy from Waste

- The assumption that uranium will last for 30 more years, oil for 35 years, and natural gas for 50 years.
- Constant coal production of 140 million tons/year (without coal liquefaction).
- Global political stability without embargoes.
- Improving efficiency by 30%.
-

Even with these highly optimistic assumptions, alternative energy sources like hydroelectric power, solar energy, wind power, and biogas must cover one-third of the energy demand within a few decades. Each of these four alternatives is expected to contribute equally.

The value of an energy source like biogas is evident from the fact that a biogas plant can be paid off in about 8 to 10 years. Additionally, this reduces the agriculture sector's dependence on public energy supply.
The rapid increase in the number of biogas plants - doubling annually - indicates that farmers are recognizing the necessity of such plants. They realize that the increasing use of commercial fertilizers and pesticides is destroying the natural foundation of their profession, and surface and groundwater have reached their limits of tolerance. The increased economic viability of farms due to biogas plants will motivate many farmers to modernize their operations. Emerging economies like India and China are already far ahead in this aspect. However, their systems are not well suited to the climate of Central Europe.
This led to the development of distinct forms and fermenter types in Europe over the last 50 years. In early 1985, there were 105 biogas plants of various sizes in the Federal Republic. Just a year before, there were barely 60. Notably, automation is also increasing in this field.

While individual plants are built for various reasons, their primary objective is to replace expensive heating oil.

Given the substantial heat demand on a farm, biogas plays a significant role. Generally, more gas is produced than is consumed, creating additional utilization possibilities. The production of bio-fertilizer is often considered equally valuable to energy production. In pig farming, odor can be a major issue, making biogas plants almost mandatory in inhabited areas. A pig farm with a biogas plant is odourless. Cleanliness and odour-free conditions on the farm are particularly appreciated by farmwives.

Surveys conducted by the Board for Technology and Construction in Agriculture reveal that owners of biogas plants would readily build another one when needed, or after just two years, they can hardly imagine a farm without such a plant. This is due to reduced workload and the flexibility to store fertilizer without loss of value or inconvenience.

Research, often in collaboration with the industry, has significantly contributed to biogas plant development. Although this research often involves large installations like Ismaning in Bavaria or Liebenau in Upper Swabia with, for example, 820 cattle and 800 pigs, the insights benefit medium and smaller plants as well.

Within the context of biogas plants, plans include the combustion of straw and wood, using heat pumps to harness barn heat, and selling excess energy to power companies during peak demand using biogas-powered generators.

A recently tested method can produce briquettes with high heating value from household waste and sewage sludge through a biogas plant.

Today, individuals interested in biogas plants are not alone. Demonstrations and private biogas plants are already widespread. Consultation services are also available in each country, often associated with universities.

2. Biomass

Biomass encompasses a significant portion of organic materials, including plants, deceased animals, microorganisms, waste from all living beings, and all products made from plants and animals, such as paper, which, due to its substantial volume, holds considerable value as biomass. In the Federal Republic [of Germany], approximately 7 million tons of biomass are generated annually, and worldwide this figure rises to 150 million tons. In 1984, 53% of urban household waste consisted of paper.

However, for our current focus, the high energy value of paper is less relevant; instead, we are interested in the natural biomass produced in rural areas, primarily consisting of animal manure, straw, beet leaves, and any other organic waste.

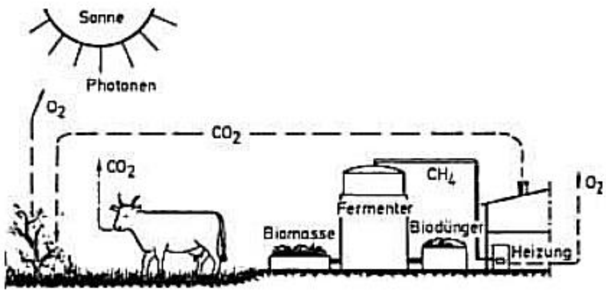


Figure 2.1: Natural Carbon and Oxygen Cycle: Plants-Food-Biogas

The existence of plants, which forms the basis for all lower and higher life forms, depends on the presence of minerals and sunlight. Sunlight, with its photons, builds our plant world through chlorophyll molecules, pigments, and enzymes.

The processes involved are too complex to be fully explained here. Figure 2.1 illustrates the essential connections: Everywhere, water (H2O), carbon dioxide (CO2), and minerals are present as chemical components. In addition, there are the elementary light particles, photons, which serve as an energy source for building large molecules from the chemical components. Through minerals and their material properties, plants find support and nourishment.

The cycle of chemical elements and molecules in nature looks as follows:

Living beings consume plant-based food, which consists of hydrogen, carbohydrates, and minerals. The water flows back into the soil directly through the bodies of animals. Carbon dioxide is released back into the air through respiration. The oxygen bound in CO2 is released by all higher plants. The minerals in the feces are naturally returned to the earth.

All components of the atmosphere and the earth's soil remain in equilibrium. As long as there is sufficient food for humans and animals, and nothing is added (e.g., chemicals) or removed (e.g., minerals) from the cycle, the cycle remains healthy indefinitely.

However, even a single change (e.g., excessive population, deforestation as oxygen producers, waste combustion along with its minerals, use of pesticides that kill bacteria, etc.) will inevitably disrupt the cycle.

This doesn't happen overnight. It worked relatively well for a long time until the rapidly growing technology and chemistry temporarily created conditions for an equally explosive population growth, leading to a surge in energy use, artificial fertilizers, pesticides, and other toxins.

To understand the processes in a Biogas plant, one must examine the chemical transformations involved. The energy from sunlight (photons) initiates the so-called photosynthesis, which builds carbohydrates from carbon dioxide (CO2), water (H2O), and oxygen, forming the basis of all plant substances.

During this process, **starch, cellulose, and sugar**, the main components of usable biomass, are created.

The energy liberated by bacteria, as shown in Figure 2.1, corresponds to the portion of solar energy that initiated the process of chemical transformation. This energy is released again in the form of a gas, mainly methane. The fermentation process involving bacteria will be discussed in the next chapter.

In the production of Biogas and bio-fertilizer in agriculture, it is essential to consider that the biomass generated on farms can vary significantly in composition:

- Unaltered materials such as **straw, leaves, spoiled fruits, roots, potato and beet tops, fruit pulp, kitchen waste, as well as shrubs, perennials, and wood waste**.
- **Faecal matter from all living beings**, for instance, cattle and pigs, found in rural areas.

The quantities are substantial.

For example,

1 cow	produces over **2 tons of manure annually**,
10 pigs	generate about **1.5 tons/a**, and
100 chickens	contribute **1 ton of dry matter each year**.

Typically, this "biological gold" is still disposed of on manure piles, with the **loss of valuable components**, which are irreplaceable in terms of plant compatibility, loss of manure cooling considered inevitable. The liquid portion of the manure, which contains nutrients beneficial to plants, often seeps into groundwater, becoming a **significant pollutant**.

Furthermore, the open storage of manure under the open sky results in a **considerable reduction in the quality of the fertilizer**. Oxygen from the air binds 25% of its valuable nitrogen, making it unavailable to plants. This loss must be **compensated** with commercial fertilizers.

In addition, households and farms generate waste composed of industrially produced basic materials. This includes newspaper, packaging materials, bags, partially biodegradable plastics, wood waste, and decaying cooked leftovers. These should not be disposed of in manure piles or biomass destined for Biogas plants since, apart from wood, it is uncertain whether they are free from toxins or heavy metals.

Herbicides and pesticides should not be introduced to manure piles or the biomass for Biogas plants either, as they not only kill pests but also the essential bacteria involved in the process.

Moreover, caution should be exercised concerning growth regulators like **estrogens**, which are not as harmless as they may appear. They remain among the unresolved issues faced by sewage treatment plants. Since estrogens are used in calf rearing, they enter the food chain and eventually reach humans. In any case, animal manure that might contain estrogens should be stored separately to prevent their inclusion in bio-fertilizer, which would then compromise its purity. The same applies, of course, to all waste materials containing toxins or heavy metals.
Conversely, all organic waste should be mixed together, as the composition of organic substances in feces varies depending on the animals' diet and species, resulting in a nutrient-rich fertilizer.

For the farmer, the **proportion of organic substances in grams per kilogram of feces dry matter is of interest,** as different plants have varying requirements for soil composition. Additionally, this information provides insight into which nutrients (potassium, nitrogen, calcium, or phosphate) are particularly essential.

Stoffe	Rind	Schwein	Huhn
Kalium (K_2O)	57,5	29	68
Stickstoff (N)	27,2	44	50
Calzium (Ca)	21,3	25,2	68
Chlor (Cl)	18,8	19	4,5
Natrium (Na)	8,2	12,6	1,8
Magnesium (Mg)	5,8	7,6	11,8
Schwefel (S)	3	6,4	3,2
Phosphat (P_2O_5)	1,7	40	27,3
Eisen (Fe)	1,7	2	1,3
Mangan (Mn)	0,25	0,38	0,37

Table 2.1: Daily Accumulation of Organic Substances in g/kg Dry Matter (DM) for **Cattle** and **Swine**, and in mg/kg DM for **Chickens**.

Can be translated in % of kg fresh manure

Table 2.1 clearly demonstrates the varying proportions of important fertilizer components such as potassium, calcium, nitrogen, and phosphorus in the dry matter of different animal species.
The **amount of manure** produced annually on an average farm with **20 cattle, 10 swine, and 50 chickens is surprisingly high.** See some calculation

	Kalium	Stickstoff	Calzium	Phosphat
20 Rinder	2 518	1 190	934	73
10 Schweine	106	166	92	146
50 Hühner	47	34	47	25
Summe (kg)	2 671	1 390	1 073	244

Table 2.2:
Annual Accumulation of Major **Organic Manure in kg** on an Average Mixed Farm with **20 Cattle**, **10 Swine**, and **50 Chickens.**

A model farm of this size typically has a cultivated area of **10 hectares,** and given the current intensive soil utilization, approximately half of the generated animal manure is sufficient for fertilization. This amount does not even include the additional organic substances such as fiber, fats, proteins, and others that are present in the biomass.

For instance, the daily dry matter content of manure is approximately:

- **Cattle: 6 kg** (annual total: approximately 2,400 kg)
- **Swine: 0.5 kg**
- **Chickens: 0.038 kg**

Adding the organic substances from Table **2.2, which amount to 5,376 tons**, to the **dry manure**:
(20 x 6 + 10 x 0.5 + 50 x 0.038) x 365 = 46,318 kg = **46.3 tons**

The annual manure quantity for such a farm is approximately 46 tons, of which **5 tons (around 10%) serve as active fertilizer,** while the majority is converted into **humus** when sufficient bacteria and microorganisms are present, as is the case with **organic fertilizers**.

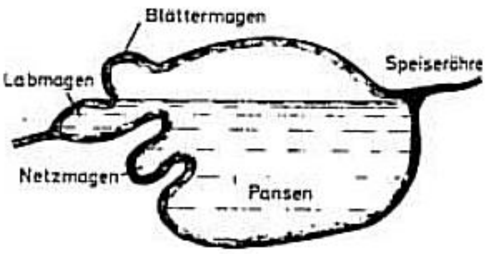
Without a biogas plant, half of the required fertilizer needs to be purchased. By employing a biogas plant, not only can the loss of 25% of plant-nourishing nitrogen, bound by oxygen in the air during storage on a manure heap, be avoided, but also rapidly assimilated nitrogen can be produced for the plants. Consequently, with a biogas plant, approximately **30% of the nitrogen** purchased from the market can be saved. As for phosphorus and calcium, the reduction is not as significant, as both elements do not degrade during storage on the manure heap. Nonetheless, the nitrogen gain achieved through the operation of a biogas plant is valuable and contributes to its economic viability.

In general, biomass is still perceived as a burdensome waste outside of agriculture, necessitating significant energy expenditure for disposal, rather than reclaiming the valuable components and utilizing the rest for energy generation. Yet, every waste, including biomass, possesses considerable energy content, the utilization of which saves fossil fuels and contributes to reducing pollutants that have pushed forests to the brink of their survival. **The most environmentally friendly method for recycling biomass is its fermentation in a biogas plant**.

3 Biogas Production

Even in the highly technological 20th century, nature had surpassed humans in biogas production. One doesn't need to venture into a marsh to observe the generation of gas from organic matter. A prime example can be found in one of humanity's domesticated animals: **the cow.**

Its **rumen** (Figure 3.1) serves as a **natural biogas plant**. It receives the shredded biomass and undergoes fermentation. This process is facilitated by anaerobic bacteria, which, unlike their aerobic counterparts, thrive and function without air (Latin: aer). Instead of "fermenting," the expert term for this process is "fermenting."
Hence, the fermentation or digestion chamber in a biogas plant is also known as a **fermenter**. The consistent temperature **of 36°C** in the rumen or stomach of cows provides an ideal working environment for anaerobic bacteria, which are sensitive to temperature fluctuations and digest at a much slower rate under lower temperatures.



The lying shape of the rumen is no coincidence. It aids in the continuous mixing of stomach contents and the expulsion of gases, making it a model for biogas plants. While vertical digestion towers were built in the past, the trend is now shifting towards horizontal digestion tanks, where local conditions permit.

There are three groups of anaerobic bacteria, also known as methanogens, distinguished based on their preferred temperature ranges:

1. **Psychrophilic** bacteria with operating temperatures between 4°C and 25°C.
2. **Mesophilic** bacteria with operating temperatures between 25°C and 40°C.
3. **Thermophilic** bacteria with operating temperatures between 40°C and 75°C.

The lower the operating temperature range, the lower the methane production per unit of time, as bacterial digestion becomes sluggish. Once the operating temperature is chosen, bacteria corresponding to that range establish themselves and require a relatively constant temperature to obtain the predicted biogas yield. The bacteria recover slowly after a "cold shock."

The operating temperatures for **psychrophilic** bacteria should fluctuate only between **14°C and 16°C,** while for **mesophilic** bacteria, they should be between **25°C and 33°C,**
and for **thermophilic** bacteria, between **50°C and 55°C.**

Due to the slow gas generation by psychrophilic bacteria, this temperature range is rarely chosen, except when the gas quantity is of secondary importance compared to the value of the biofertilizer, and when a higher operating temperature would result in excessive heating costs due to climate conditions.

The **mesophilic** range is currently preferred in general, as it provides a good compromise between high gas yield, moderate heating requirements, and sufficient mass throughput.
In the past, the **thermophilic** range was often favoured due to the high biogas output it provided.

However, maintaining a high temperature of 55°C required prolonged heating in our latitudes, consuming up to one-third of the generated biogas.
Today, there is a growing inclination towards the mesophilic range, with operating temperatures around 32°C to 35°C in the digester. In this case, approximately 10% of the gas produced, mainly during winter, is sufficient for the average yearly demand, and heating is typically unnecessary during summer months.

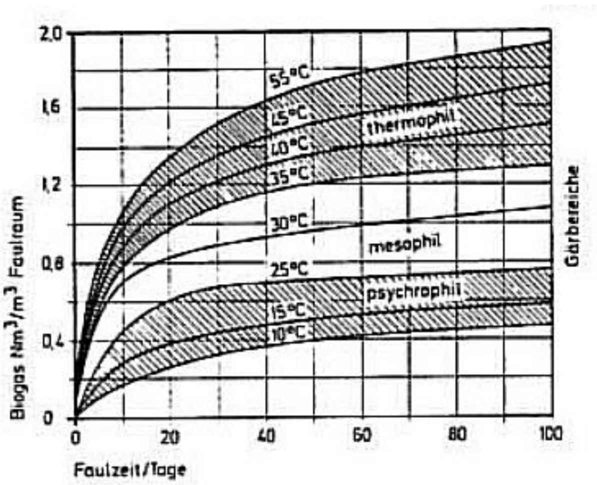


Figure 3.2: Biogas Production in the Three Domains of Methane Bacteria
as a Function of Retention Time and Fermentation Temperature

As depicted in Figure 3.2, a relatively high biogas yield in N m3/m3 digester is achieved after **approximately 30 days**. At this stage, the chemical digestion of biomass has reached a level where the fertilizer becomes biofertilizer. The duration of biomass retention in the digester depends on several factors, as the digester's size must be economically proportionate to the biomass. There are limits determined by the necessary retention time of three to four weeks.

In farms with predominantly cattle, the biomass generation is naturally relatively high, allowing for a minimum retention time of four weeks if the gas quantity is sufficient to accommodate a smaller digester. In cases of pigs or chickens, where manure production is considerably lower, a longer retention period can be chosen to favour higher biogas production.

It is essential to remember that **biogas production is not the only priority. High-quality fertilizer and transitioning to hygienic operations are also significant purposes of a biogas plant**.

Several factors influence the processes in the digester. We have already discussed the importance of **operating temperature**.
Additionally, the **ratio of dry matter to liquid content is crucial and should be around 1:10** (-5), typically achieved by incorporating urine and stable cleaning liquids.

Another rule suggests that the **carbon (C) to nitrogen (N) ratio should be around 15:1**. This ratio can be adjusted by the mixing ratio of organic substances, with 15:1 being a general guideline. Deviations from this ratio will only marginally affect the gas yield. It is **preferable to have a slightly higher carbon content than nitrogen**, as methanogenic bacteria digest carbon up to thirty times faster than nitrogen. If one of the two substances becomes depleted, methane production will cease.

Table 3.1 shows the carbon-to-nitrogen ratio (C/N) of various waste materials. The high C/N value of straw and sawdust is evident, as these materials consist of high-molecular-weight carbohydrate cellulose. With the addition of **small amounts of straw, the C/N ratio can be improved in favour of carbon**, which is often in higher demand, as bacteria process carbon more quickly.
The mixing of substances is determined based on their weights.

Table 3.1: Carbon-to-Nitrogen Ratio (C/N) of Various Substances

Substance	C/N Ratio
Pig Manure	6
Human Feces	8
Poultry Manure	15
Hay	12-18
Kitchen Waste	15
Cattle Manure	18
Horse Manure	25
Oat Straw	50
Grain Straw	150
Sawdust	200-500

One example will demonstrate the quantity of the regulating mass and its calculation.

Suppose we want to increase the C/N ratio of a biomass from **k1 = 12 to k2 = 20,** and the biomass has a volume of **M1 = 1200 kg**. The amount of straw to be added can be calculated using the following equation, where **k3 is the C/N ratio of saw dust, which is 200** (100 -500):

The addition amount of straw M2 =

$$\frac{(k2 - k1) \times M1}{k3 - k2} = \text{kg}$$

k1	12		
k2	20	kg =	53.33
k3	200		
M1	1200		

The amount of saw dust to be added,
M2 = <u>53.33 (kg)</u>

By plugging in the numbers for our example, the amount of straw, M2, would be **53.33 kg.**
For your own Numbers follow the LINK

In addition to the carbon/nitrogen ratio, the **pH value of the biomass also plays a significant role** in biogas development. The pH value should be between **6.5 and 7.5**.

Excessive acidity in the biomass can lead to an acidic fermentation process, damaging the methanogenic bacteria, which results in no further methane production. However, this occurrence is rare and can be prevented with proper attention to gas production. **A decrease in methane production usually indicates an incorrect C/N ratio or over-acidification**, which manifests as a reduction in gas production. This can be addressed by adding fresh biomass.

Of course, it is essential to prevent the entry of toxins such as pesticides and other chemical agents into the fermenter, as they would also kill the methanogenic bacteria. Ensuring an airtight system to prevent the entry of oxygen goes without saying. For the processing of algae, the salt content needs to be taken into consideration.[1]

Before delving further into anaerobic fermentation, let's discuss the value of nitrogen.

Nitrogen, a prevalent element on Earth, is mostly in a gaseous form and makes up approximately 75.5% by weight and 78.1% by volume of the air. The mass of nitrogen in the atmosphere is about 4,000 billion tons and can be considered virtually inexhaustible. Nitrogen is non-flammable, odorless, tasteless, and, most importantly, chemically inert. It also has moderate solubility in water.

Nitrogen is a building block for protein synthesis and is as vital to plants and animals as carbon. When plants are harvested for consumption, they continually remove nitrogen from the soil, which needs to be replenished. However, not all nitrogen compounds are suitable for plant growth. Calcium cyanamide (CaCN2), also known as lime nitrogen, is particularly favourable in this context.

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[1] The tolerated limit for salt in the biomass, in order to not significantly affect biogas production, can vary depending on the plant design and specific conditions. However, there are some general guidelines and recommendations:

1. **Total salt content:** The total salt content in the biomass is often measured as the total amount of dissolved solids (TDS) or as electrical conductivity (EC). A **limit of 3-4 grams per liter (g/L) of TDS or an electrical conductivity of about 4-6 millisiemens per centimeter (mS/cm)** is often considered acceptable.
2. Sodium content: Sodium content is particularly important as high concentrations of sodium can be detrimental to biogas production. A limit of 0.3-0.5 g/L of sodium is often recommended.

However, it is important to note that these values serve only as general guidelines and can vary from facility to facility. The specific tolerance limits depend on many factors, such as the type of biomass used, the specific biogas process, plant design, and operational parameters.

Für die Verarbeitung von Algen ist der Salzgehalt zu berücksichtigen.
Der tolerierte Grenzwert für Salz in der Biomasse, um die Biogasproduktion nicht signifikant zu beeinträchtigen, kann je nach Anlagenauslegung und den spezifischen Bedingungen variieren. Es gibt jedoch einige allgemeine Richtlinien und Empfehlungen:

1. **Gesamtsalzgehalt**: Der Gesamtsalzgehalt in der Biomasse wird oft als Gesamtgehalt an gelösten Feststoffen (TDS - Total Dissolved Solids) oder als elektrische Leitfähigkeit (EC - Electrical Conductivity) gemessen. **Ein Grenzwert von 3-4 Gramm pro Liter (g/L) TDS oder** eine elektrische **Leitfähigkeit von etwa 4-6 Millisiemens pro Zentimeter (mS/cm)** wird oft als akzeptabel angesehen.
2. Natriumgehalt: Der Natriumgehalt ist besonders wichtig, da Natrium in hoher Konzentration schädlich für die Biogasproduktion sein kann. Ein Grenzwert von 0,3-0,5 g/L Natrium wird oft empfohlen.

Es ist jedoch wichtig zu beachten, dass diese Werte nur als allgemeine Richtlinien dienen und von Anlage zu Anlage unterschiedlich sein können. Die spezifischen Toleranzgrenzen hängen von vielen Faktoren ab, wie z.B. der Art der verwendeten Biomasse, dem spezifischen Biogasprozess, der Anlagenauslegung und den betrieblichen Parametern.

The fermentation process in the fermenter is quite complex and occurs in three phases. The first condition for anaerobic fermentation is the absence of oxygen. This allows the first process stage to begin:

In **this first stage,** high-molecular compounds such as proteins, fats, and carbohydrates are biochemically transformed into low-molecular organic compounds.

In the **second phase**, anaerobic acid-forming bacteria further degrade the remnants from the first stage into organic acids like acetic acid (H2C02), salts, alcohol, carbon dioxide (C02), hydrogen, hydrogen sulfide (H2S), and ammonia (NH3). Additionally, the last traces of oxygen are bound to elements still capable of accepting oxygen, resulting in a nearly absolute anaerobic state in which methanogenic bacteria can thrive. During the second stage, other gases present in biogas, such as hydrogen and traces of hydrogen sulfide, begin to form.

In the **third process stage**, a portion of the compounds from the second stage is processed by the numerous methanogenic bacteria, resulting in larger quantities of methane (CH4), along with carbon dioxide, hydrogen gas, and some hydrogen sulfide.

The third stage is the most time-consuming because the metabolism of methanogenic bacteria is slower than that of acid-forming bacteria. This can lead to the over-acidification of biomass by the latter, causing the **pH value to drop below 6.5** and reducing the activity of methanogenic bacteria.

If methane production unexpectedly declines, **acid measurement is advised**. Raising the pH value can be achieved by adding fresh manure.

The size of the biomass particles, which influences their surface area for bacterial colonization (Stage 1), is directly related to the fermentation process. **The smaller the particles are broken down, the larger the surface area and gas yield.**

Fermentation leads to the reduction of particle weight through the separation of carbon and hydrogen, making it easier to convert to methane. Additionally, small gas bubbles adhere to the particles, causing them to float to the surface. This results in the formation of a floating layer on the liquid fermentation mass, which can reach a thickness of one meter or more. This floating layer increasingly impedes methane release from the biomass. If methane accumulates in the medium, methane production immediately decreases. Therefore, appropriate methods are used to continually prevent the formation of a floating layer.

The quantity and chemical composition of biogas are partially determined by the feedstock and the degree of fermentation. Biogas produced from mixed biomass after a fermentation period of four weeks has approximately the following composition:

Gas Type	Volume %	Density
Methane (CH4)	55 - 70	0.72 g/Liter
Carbon Dioxide (CO2)	25 - 40	1.98 "
Nitrogen (N2)	0.5 - 3	1.25
Hydrogen (H2)	1	0.09
Oxygen (O2)	0.1	1.43 "
Carbon Monoxide (CO)	0.1	1.25 "
Hydrogen Sulfide (H2S)	0.01	1.54 "

Table 3.2: Average Composition of Biogas

As we can see, biogas also contains **toxic** gases such as **carbon monoxide** and especially **hydrogen sulfide**, albeit in very small quantities. Therefore, biogas requires purification, but we will address this later. The methane content increases with fermentation time and can be raised to 90% through post-fermentation. However, often the rapid throughput of biomass takes precedence over increasing gas quantity.

Post-fermentation is especially crucial because carbohydrates are degraded more slowly than fats. For a fixed fermentation time, carbohydrates are broken down to 30%, proteins to 50%, and fats to 80%. Hence, even after complete fermentation of fats and proteins, there is still an active residue of carbohydrates, **which make up about 50% of agricultural biomass and contribute about one-third of biogas.**

Post-fermentation primarily occurs due to the outgassing of carbohydrates.

Table 3.2 provides the composition of biogas but not the properties of each gas component.

Pure **methane** has a calorific value of **8500 kcal/Nm3**, while **70% methane gas,** as commonly found, has a **calorific value of 5290 kcal/Nm^3 = 22,150 kJ**. It is not explosive without the presence of air or oxygen, and it is non-toxic. With its low density of 0.72, methane rises, preventing it from accumulating in open pits but allowing it to collect in gas bells. Since methane lacks oxygen, gas bells pose suffocation risks.

Carbon dioxide is a chemically neutral molecule, non-toxic, and non-flammable but somewhat environmentally damaging. It can be absorbed with lime water. Due to its high density of 1.89, it sinks and displaces air at the bottom. Open anaerobic pits must be ventilated with fans for an extended period; otherwise, there is a risk of suffocation (refer to operating instructions).

Nitrogen is both chemically and ecologically neutral, as it is already a part of our atmosphere. It can remain in biogas. With its specific weight of 1.25, the same as for carbon dioxide, it poses the same suffocation risk.

The small **hydrogen content of 1% contributes to the calorific value** of biogas unless it has already combined with oxygen remnants and condensed as water.

Carbon monoxide is toxic enough to be lethal within a few hours. With a density of 1.25, it leads to gas sinking. Therefore, intense ventilation is necessary in pits. Due to the CO content in biogas, all areas where biogas can be present or burned must be continually ventilated.

Even at its low proportion **of 0.01%, hydrogen sulfide** is still highly toxic. During combustion, it transforms into sulfuric acid, which is so aggressive that it can damage metals and machine oils. Hydrogen sulfide should always be removed from the gas, and suitable catalysts are available commercially.

Depending on the purity of biogas or the methane content, **2 to 3 Nm3 of biogas can replace 1 liter of heating oil.** The precise definition of a normal cubic meter (Nm3) corresponds to the gas density at "normal" atmospheric pressure of 1000 hPa at a temperature of 0°C (1000 hPa = 1 bar = 750 Torr).

To assess the economic viability of a biogas plant, it is necessary to know the time required for a specific outgassing of biomass.

Based on general experience, a biomass in the mesophilic range at a fermentation temperature of **33°C reaches full outgassing of 100% after approximately 100 days**.
With a fermentation period of
30 days, it reaches 80%,
65% after 20 days, and up to
40% after 10 days.
Setting the fermentation period to 100 days is rarely economical as it would require designing the fermentation space for 100 days' retention, which can be quite costly. With a fermentation period of 30

days, the mass throughput is three times larger, while gas loss is only 20%. Furthermore, biomass can be post-fermented outside the fermentation room.

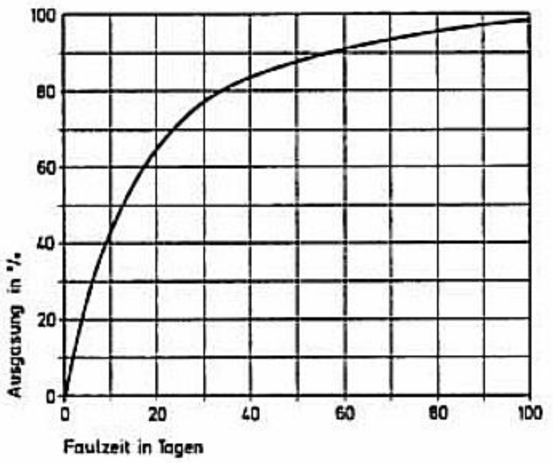


Figure 3.3: Outgassing factor in percentage of possible outgassing as a function of the fermentation period in the mesophilic range.

The absolute gas quantities depend on both the composition of the biomass and its consistency, which is the liquid content. The **methane gas yield, with proper dilution using manure or water, is approximately twice as large as that of undiluted biomass**.

An **optimal ratio of dry matter to liquid is about 1:8 to 1:10**.

Excessive dilution would result in a larger fermentation space, requiring more heating during winter for a greater mass. As a consequence, the potential gain in biogas might be lost due to increased heating energy, which is typically supplied by the biogas itself. However, it is **not advisable to go below a dilution of 1:8**, which is often achieved by using liquid manure and stall cleaning water. If a large gas quantity is not essential due to low demand, a dilution of 1:5 to 1:6 could be considered as a last resort.

The gas quantities in Table 3.3 are based on a **dilution of 1:9 and apply to 1 kg of dry matter dissolved in the fermentation mass**.

Fermentation Period	10 Days	20 Days	30 Days	100 Days
Cattle Manure	0.024	0.048	0.19	0.24
Swine Manure	0.040	0.068	0.21	0.26
Grass	0.087	0.099	0.39	0.49
Potato, Cabbage	0.085	0.092	0.42	0.53
Sugar Beet	0.099	0.100	0.35	0.46
3 cm Straw	0.029	0.045	0.27	0.36
2 mm Straw	0.051	0.077	0.31	0.39

Table 3.3: Specific gas production from various sources in Nm3/kg DS in 10, 20, 30, and 100 days.

These values in Table 3.3 are applicable to the mesophilic range.

To obtain the **actual biogas quantities, the amount of dry matter from the animals must be known. The dry matter amount is as follows**:

Cattle:	**6 kg/day**
Horses:	**2.7 kg/day**
Pigs:	**0.6 kg/day**
Sheep:	**0.2 kg/day**
Poultry:	**0.038 kg/day**
Human:	**0.12 kg/day**

See the excel calculation

Based on this information, we can now calculate the potential biogas production on a model farm with **20 cows, 10 pigs,** and **50 chickens** in the **mesophilic** range for a fermentation **period of 30 days.**. This calculation involves the **number of animals (z),** the **daily amount of feces (m) in kg** along with **60% bedding,** and the **daily biogas production (q) in Nm³** (see Table 3.3).

Since we want to determine the annual biogas production, the result is multiplied by 365. The formula for the annual biogas production (Q) is as follows:

Q = z • m • q • 365 (Nm3/a)

Number	ODS/Day	% Bedding	Gas m3	Period	Total/Year
20	6	0.6	0.19	360	13,133

Results:

For cattle: 20 x (6 + 3.6) • 0.19 x 365 = **13,133 Nm³/a**
For pigs: 10 x (0.6 + 0.36) • 0.21 x 365 **= 726 Nm³/a**
For poultry: 50 x (0.03 + 0.018) • 0.2 x 365 = **175 Nm³/a**

The total biogas production is 14,034 normal cubic meters per year.

The values within the parentheses represent the daily amount of feces plus 60% bedding.

One could also calculate the gas yield of the bedding (straw) separately, eliminating the second value within the parentheses. The daily feces amounts (q) are extracted from Table 3.3, the column for 30 days.

These **14,034 Nm³ replace approximately 5,200 liters of heating oil per year**, resulting in a yearly savings of 4,200 German marks (based on the 1982 oil price). Additionally, there are savings of 25% on commercial nitrogen fertilizer and the elimination of diesel fuel consumption if the tractor is converted to run on gas.

Practically any biomass that is low in **herbicides** and **antibiotics** can be fermented in the fermenter. The greener the plant, the faster the gas production occurs during anaerobic fermentation.

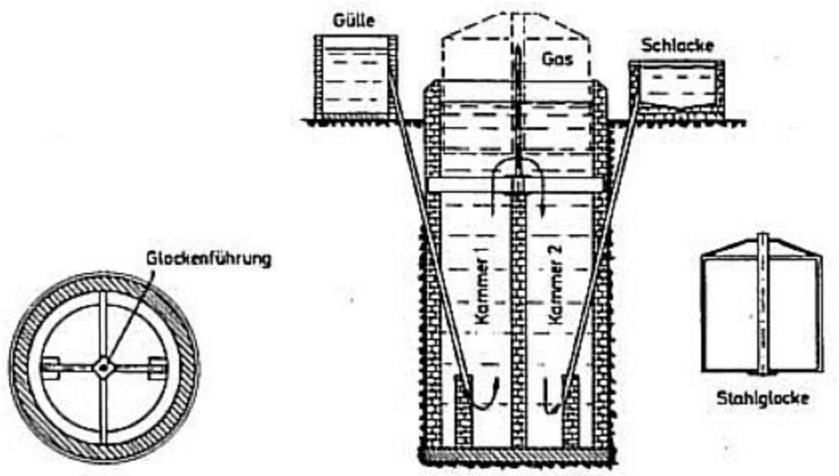
Since all **seed viability is lost during anaerobic fermentation**, straw can also be added without the concern of transporting seedlings into the soil with the biogas slurry. This applies to a **large extent to pest eggs and pathogens as well**.
The biogas slurry is less rich in pathogens but contains all the necessary nutrients that the soil and plants can readily absorb and process, such as active nitrogen, phosphorus, and humus-forming bacteria.

4 Biogas Plants Abroad

The extraction of methane from organic materials is not a new concept and has been successfully implemented in various countries for years. Especially in developing nations, there is always a demand for affordable and readily available sources of energy. It is no surprise that as early as 1939, India developed a biogas plant that utilized the dung of the revered cows as its raw material. The success of the cow dung or "Gobar" plant, established by **the Indian Agricultural Research Institute**, led to the creation of the **Gobar Gas Institute in the 1950s**. This institute specialized in the anaerobic digestion of cow dung on a small scale to produce methane gas and fertilizer.

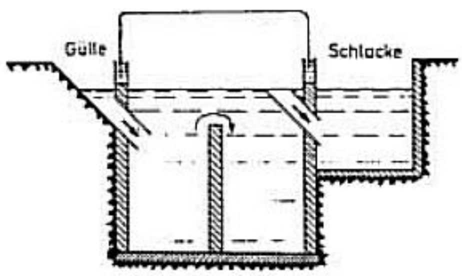
Today, the Gobar plant is a commonly found biogas facility in India. The Indian construction method (see Figure 4.1) is relatively easy to construct, except for the gas dome. The digester is placed underground, benefiting from the relatively warm temperature of the dry soil even during winter, eliminating the need for external heating. The biogas production is continuous due to the presence of two chambers. The liquid manure (slurry) is mixed in a mixing tank and then flows into chamber 1. Once chamber 1 is full, the biomass overflows the partition wall and fills chamber 2 during the digestion process. The design ensures that after three to four weeks, chamber 2 is also filled, and the fermented mass flows into the sludge pit. The replenishment of biomass in chamber 1 occurs continuously, as does the discharge of the biodigested slurry. The biogas is collected in a floating dome and supplied to the burner. The steel dome is rotationally mounted and equipped with stirrers. The dome is manually rotated daily to break the floating scum layer.

Figure 4.1: Indian Gobar plant, **20 m3 type with 7 Nm3 of biogas/day.**



The Philippine biogas plant is similar to the Indian design but has already undergone **significant improvements.**

Image 4.2: Philippine Biogas Plant



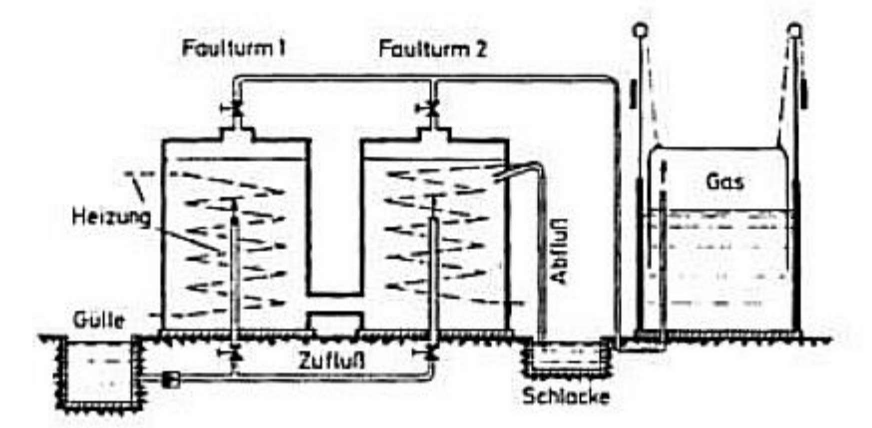
Originally, the gas dome floated directly in the digester slurry. However, the dome often got stuck due to coarse impurities, resulting in gas leakage and, worse, the entry of oxygen whenever the slurry level fluctuated. Consequently, the dome had to be removed from the slurry. To resolve this, a **separate water-filled ring channel** was created, and the dome was submerged in it. This Philippine design can also be found in India now. The submersion depth of the dome is relatively large, allowing it to move up and down accordingly with changes in gas volume. **The movable dome ensures a constant gas pressure within the system**, solely determined by the weight of the dome.

The digester tower itself, consisting of only a base plate and a constructed cylinder, needed improvement as there was no flushing system initially. Over time, **thicker materials accumulated in the corner near the base plate**, requiring the entire plant to be shut down and cleared at least once a year. Consequently, the gas supply was frequently disrupted, resulting in a discontinuous operation.

Due to the vital significance of biogas plants in India, research shifted towards the development of larger facilities to serve entire cooperatives. The breakthrough came in the form of solving a problem that previously made biogas plant construction significantly more complicated. The gas dome's weight had to match the desired operating pressure's gas buoyancy. To achieve this, every gas dome was individually manufactured to specific dimensions and weight, often costing more than the entire biogas plant itself. To overcome this issue, Indian engineers replaced the dome's mass with adjustable weights in their large-scale biogas plants. This allowed them to customize the gas pressure by increasing or decreasing the weights.

Additionally, the complex water ring surrounding the digester was replaced with a simple basin. The gas is supplied from the bottom of the dome. All large-scale biogas plants are equipped with a digester heating system to maintain a constant fermentation temperature and optimize gas production.

Image 4.3: Large Biogas Plant in India for Colder Climates



In this context, a solution was found for a problem that has significantly complicated the construction of biogas plants. The gas dome's weight must correspond to the gas buoyancy at the desired operating pressure. To achieve this, each gas dome was traditionally custom-made in terms of dimensions and weight, often costing more than the entire biogas plant. In their large-scale biogas plant, the Indians replaced the **dome's mass with weights**. This allowed them to individually adjust the gas pressure by increasing or decreasing the weights.

The mass of an expensive standard gas dome is replaced by inexpensive counterweights.

Furthermore, the elaborate water seal around the digester is replaced by a structurally simpler basin. The gas is supplied to the dome from below. All large-scale plants are equipped with a digester heating system to maintain a constant fermentation temperature and optimize gas production.

In China, biogas generation has already achieved significant importance in decentralized energy supply due to strong government support.
By **1983, there were already over 7 million biogas generators in operation**, providing energy for both individual families and rural cooperatives, **catering to 10% of the population.**

Figure 4.4 shows an underground plant without heating. The oval cross-section of the digester allows for easier and more complete circulation of biomass through a stirring device, enabling continuous operation. For small family-scale plants, the stirring device is operated manually once a day, while larger plants employ a motorized system. As there is no floating gas dome, the gas pressure changes with gas production and consumption.

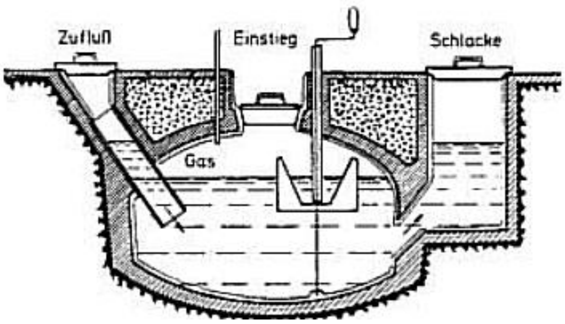


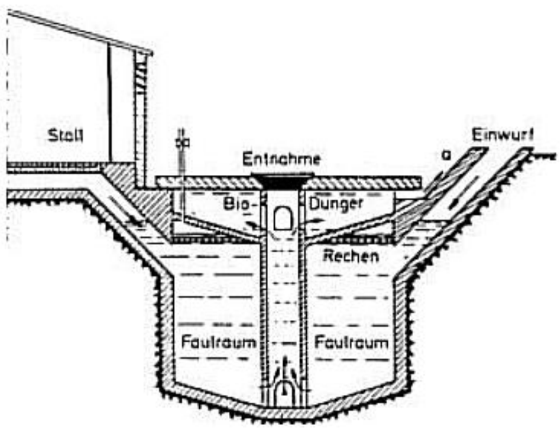
Figure 4.4
shows an underground plant without heating.

The digester is constructed large enough to accommodate approximately **50 days** worth of manure. When there is a surplus of manure, the biomass is pushed through the digester faster, accelerating the fermentation period. Conversely, during lower manure input, the biomass remains in the digester for a slightly longer time.

The digester needs to be periodically cleared to remove sediment, including non-degradable materials such as stones. For this purpose, an access point (Einstieg) is provided.

Some European countries also showcase interesting solutions. In **Tyrol**, there is a biogas plant following the **Berlin system**, which resembles the Chinese design in its layout but already includes a post-digestion chamber. Instead of mechanical stirring, it employs a hydraulic system, which is much simpler than it appears at first glance.

Image 4.5: Biogas plant in Tyrol according to the Berlin system



The plant can be filled automatically from the barn or manually by hand. The digester is divided into two chambers by a horizontal partition. The lower chamber serves as the primary digester, housing a central shaft. The upper funnel-shaped chamber contains the pre-digested biodigester with an outlet (on the right side). A horizontal rake is installed in the upper section of the digester, with the gas space above it.

The operational process within the facility unfolds as follows: The production volume of gas and the consumption volume typically do not occur simultaneously or at equivalent magnitudes. This dynamic gives rise to fluctuations in gas pressure. In instances where there is no withdrawal, the gas pressure increases, exerting downward force on the digested mass. Consequently, the mass ascends within the shaft, partially infiltrating the upper chamber. Conversely, during heightened gas consumption, gas pressure decreases, causing the level of digested mass to rise once again, thereby resulting in a portion of the biodigested material flowing back into the shaft. Throughout the fluctuation of levels within the digestion chamber, the biomass continually traverses the screen, inadvertently disrupting the scum layer.

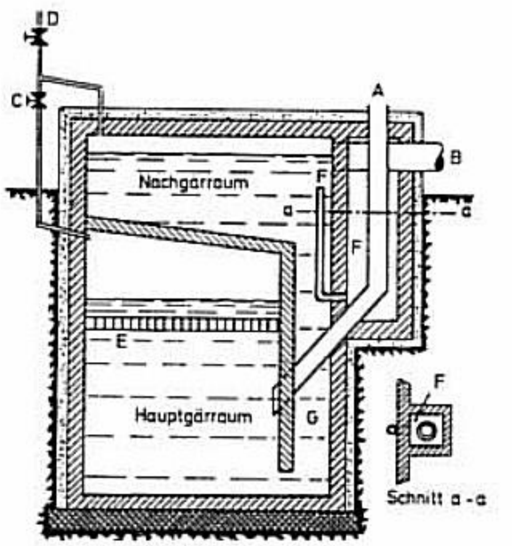
Due to the consistent inflow of fresh organic matter, the digested material progressively ascends through the shaft, ensuring that the final biodigested product departs the upper chamber at point 'a' in synchronization with the rhythm of gas pressure fluctuations, while maintaining the same degree of correlation.

Another biogas facility in **Austria**, based on the BIMA system, is particularly intriguing due to its notable feature of achieving substantial degassing of biomass through an integrated post-digestion chamber. This facility is designed for the treatment of manure from **60 livestock units** (LSU) (**1 LSU** generally corresponds to **500 kg** of animal weight), making it a compelling case study.

Upon introducing liquid manure at point A into the primary fermentation chamber, a progressively escalating generation of biogas occurs, leading to an increment in gas pressure. This elevated pressure initiates the displacement of the digested mass within the primary fermentation chamber, causing it to be partially transported through shaft G into the post-digestion chamber. Subsequently, upon opening gas valve C, the gas flows from the primary fermentation chamber to the gas storage facility (gasometer). This action results in a reduction of gas pressure within the primary fermentation chamber, leading to the re-elevation of the manure level therein. Consequently, a portion of the content from the post-digestion chamber returns to the primary fermentation chamber.

However, should the gas pressure within the primary fermentation chamber be intentionally elevated to a higher degree, due to the completion of a sufficient degree of anaerobic digestion, the uppermost fraction of biodigested material from the post-digestion chamber is discharged through conduit B.

Figure 4.6: Cross-section of a BIMA facility in Vorarlberg, Austria.

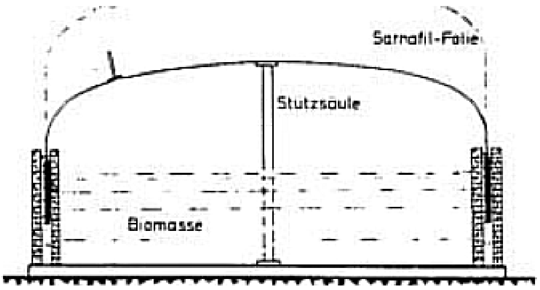


Fresh manure can be replenished at point A. The entire process operates continuously, with the movement of the biomass through gas pressure changes ensuring good and constant mixing. Simultaneously, the biomass has to pass through the rake E at each movement, destroying the floating scum layer as it forms.

The inflow of manure through pipe A occurs in a heat exchanger F, which is filled with warm digested material, warming up the incoming manure. Cold manure would shock the methane-producing bacteria and hinder gas production.
The daily gas production is approximately 90 Nm3.

For gas storage, a round open silo with double vertical walls is utilized, with a solution (water with antifreeze) in between. The gas dome floats in this solution and is composed of a solid ring and a plastic hood made of Sarnafil foil. A solution is not required if the submerged water is heated during winter. In the center of the storage, there is a column to prevent the foil from coming into contact with the manure in case of low gas pressure. To prevent the gas pressure from lifting the hood out of the water ring (cup), the concrete hood ring has a weight of 15 tons. The gasometer's liquid could also consist of water, in which case the external water ring would not be necessary. Alternatively, as shown in Figure 4.7, fermented manure can be stored in the gasometer, **using the entire gasometer as a post-digestion chamber.**

Figure 4.7: Gasometer for the BIMA plant (Figure 11) with a diameter of 12 meters.



The storage capacity is designed to accommodate the daily gas production, which is utilized for a five-hour hay drying process. Those with substantial gas requirements for drying purposes find it difficult to circumvent the post-digestion phase.

A biogas plant catering to 65 livestock units (LSU) has been operational in Langen near Lake Constance **since 1979**. This facility comprises a sizable primary fermentation chamber, directly receiving warm manure from the barn, followed by a subsequent post-digestion chamber system. Notably, it also includes an inoculum chamber—a rarity—which expedites the degassing of biomass by maintaining a consistently abundant supply of methane-producing bacteria. The outflow of liquid biodigested material matches the inflow rate of fresh manure. In this setup, the biodigested material container serves as the vessel for the gasometer, allowing the utilization of even the final stages of gas production. The gasometer has a capacity of 310 m³. The daily biogas production of 100 Nm³, coupled with gas storage in the gasometer, suffices for an 18-hour drying period. Hay drying constitutes the most energy-intensive process on the farm, rendering reliance on external energy sources economically unviable.

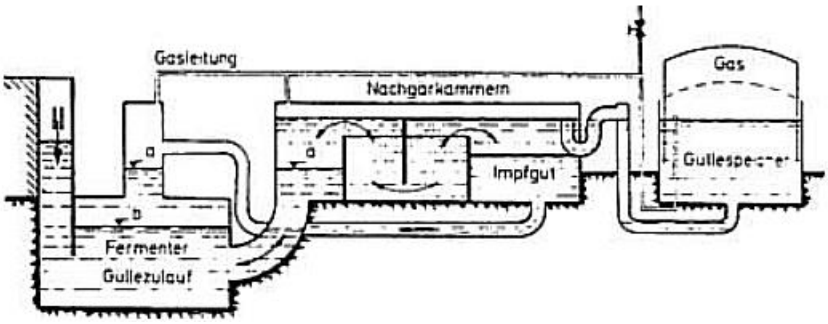


Figure 4.8: Schematic of the biogas plant in Langen near Bregenz featuring post-digestion and inoculum chambers for hay drying.

In the typical setup, the biogas utilized for the warm air furnace in hay drying is combusted without prior purification. However, to effectively dry the entirety of this farm's hay, at least ten times the current biogas production would be required.

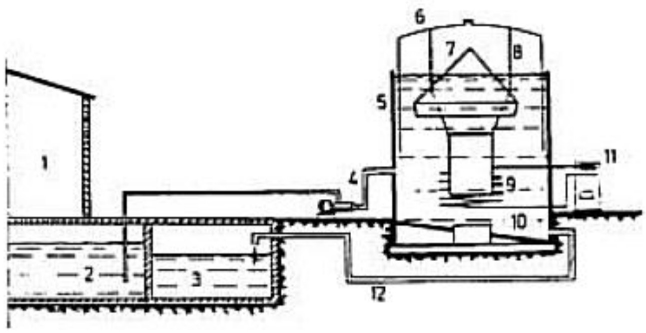
Switzerland places significant emphasis on the construction of biogas plants. Currently, five companies are already engaged in the development and construction of such facilities. In 1979, a mere two years after the commencement of development, 30 plants were already operational. These plants ranged in size from **25 to 150 livestock units (LSU),** featuring anaerobic digestion towers reaching heights of up to 11 meters and fermentation volumes of up to 300 m³, either in overground or underground configurations. The walls of the digestion chambers are constructed using either insulated concrete or a double-walled fiberglass design with a substantial core layer of polyurethane.

In instances where an excess of gas is produced, electricity is also generated and sold to the public power grid.
Noteworthy biogas installations in Switzerland are those established by **Inventa** for cheese dairies. By incorporating closed-loop systems, these installations result in energy self-sufficiency. Cheese dairies exhibit significant energy demands, ranging from 250 to 300 kWh per ton of processed milk, wherein approximately three-quarters are attributed to heat production and the remaining quarter for agitation purposes. Typically, biogas is employed to power a generator, ensuring a versatile energy source for all operational tasks.

In the biogas plant showcased in Figure 4.9, which serves a Swiss cheese dairy, the biomass originates from 160 pigs that are nourished with the byproduct of the manufacturing process, namely whey.

The subsequent biogas plant illustration highlights three notable design features.

Figure 4.9: Biogas plant at a Swiss cheese dairy



1. Barn	5. Digesters	9. Heating Element
2. Manure	6. Gas Dome	10. Floor Heating
3. Biodigested Material	7. Agitation Funnel	11. Boiler
4. Manure Pump	8. Guidance Structure for 7	12. Fertilizer Outlet

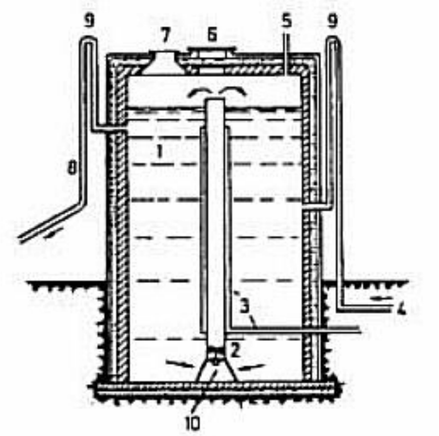
The 1st feature entails the **compact assembly of all plant components**, including the barn, pre-tank, digesters, and fertilizer storage, into a single integrated unit.

The 2nd feature introduces a novel **specialized pump for thick substances**, specifically an **eccentric screw pump.**

The 3rd feature comprises the **agitation mechanism** within the digesters, designed to disrupt the scum layer. By intermittently drawing varying amounts of biogas from the gas dome, the dome's position is manipulated to rise and fall. This movement is transmitted through a guiding structure to the agitator cone, which consistently breaks through the scum layer. A similar principle underlies the operation of Swiss biogas plants.

An alternative Swiss system, while not inherently representative of the country, introduces a new method developed by **Agrogas** for the **hydraulic dispersion of the scum layer.** This involves the insertion of a central vertical pipe into the digestion chamber. Within this pipe resides a circulation pump that draws in the manure and releases it at the upper end, creating a liquid circulation loop that prevents the formation of a scum layer. The system is both straightforward and effective.

Figure 4.10: Swiss biogas plant featuring a central pipe and circulation pump.



1. Fermentation Chamber	4. Slurry Feed	7. Observation Window	10. Circulation Pump
2. Central Pipe	5. Gas Extraction Pipe	8. Fertilizer Drainage	
3. Heating System	6. Inspection Opening	9. Siphon	

The upper opening of the pipe can be adjusted in its height, allowing for the adjustability of the slurry level. Fresh slurry is supplied through a tall siphon pipe that prevents uncontrolled discharge of processed slurry. The inflow is also regulated through a siphon (9), enabling controlled dosing of the inflow. The central pipe (2) is insulated. Warm water flows through the insulation to maintain the biomass temperature. This type of heating requires minimal effort and does not disrupt the circulation flow. Moreover, it remains resistant to contamination.

The use of a siphon becomes necessary whenever the automatic inflow or outflow of liquid needs to be controlled without valves. However, filling or emptying is accomplished using a pump.

The first biogas plants in **Denmark emerged in 1973**. They were predominantly constructed through collaborative self-build efforts and knowledge exchange.

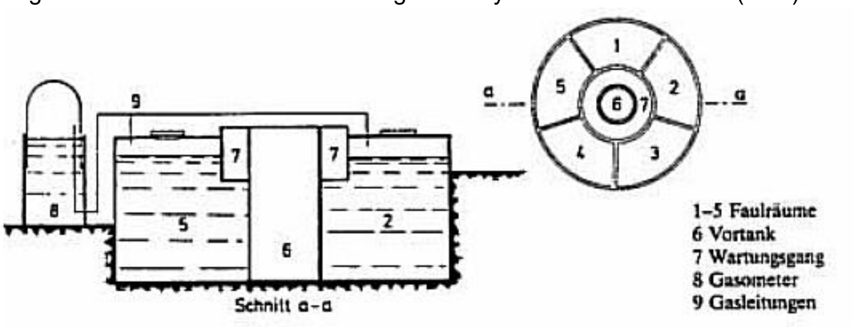
Following initial small-scale pilot plants, the focus shifted swiftly to the construction of larger facilities. The system adapts to the accumulation of manure waste. It operates continuously and features a primary tank for receiving and mixing fresh slurry, often supplemented with multiple fermentation tanks.

The depicted system (Image 4.11) even incorporates five anaerobic chambers arranged circularly around the primary tank (6). Designed for 60 livestock units (LSU), this facility's size is sufficient to accommodate a maintenance pathway (7) encircling the primary tank. A gas pipeline extends from each individual fermentation chamber (1 to 5) to the gasometer, and sometimes to a cushion storage system. The latter involves an excavated pit, typically partially filled with biodigested material for post-digestion, and covered with a membrane.

For the five anaerobic chambers, the operational continuity is hardly affected when one chamber is opened for biodigested material extraction.

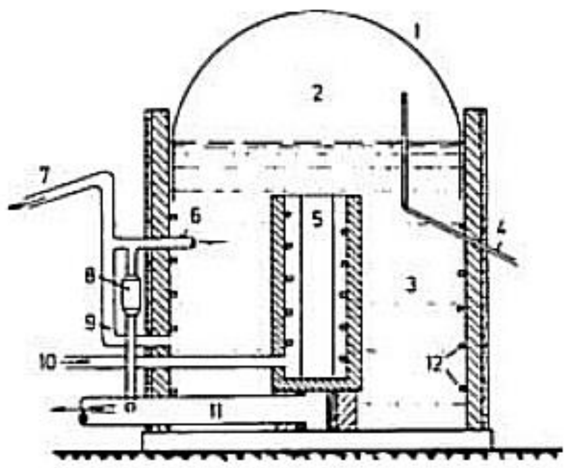
In the facility shown in Image 4.11, each fermentation chamber has a capacity of 90 m^3, filled to 75 m3. Annual gas production reaches 40,000 Nm^3. The yearly savings amount to 20,000 liters of heating oil and 1200 German Marks for commercial fertilizers (equivalent to 20 DM/LSU).

Image 4.11: Danish multi-chamber biogas facility for 60 livestock units (LSU)



Another intriguing Danish biogas facility designed for 200 livestock units integrates the primary tank, fermentation tank, and gas dome into a concentric structural unit. This approach significantly reduces costs, but it necessitates a thorough understanding of the operational workflow, particularly during the anaerobic digestion phase. It's imperative that the facility not be undersized. However, if an extended digestion period is required later to enhance gas production, the addition of another primary tank and a post-digestion pit with a cover can be implemented. The incorporation of an extra gasometer is also feasible.

Image 4.12: Danish Compact Biogas Facility with a Fermentation Chamber Volume of 680 m3



1. Gas Dome
2. Gas Chamber
3. Fermentation Chamber
4. Gas Outlet
5. Primary Tank
6. Circulation Pipe
7. Overflow Pipe
8. Multi-purpose Pump
9. Circulation Pipe
10. Slurry Inlet
11. Biogas Residue Extraction
12. Fermentation Heating System

In the preheated tank (5), a daily intake of 3 m^3 of fresh slurry is introduced while simultaneously extracting an equal amount of digested biomass at 11. The farm's layout allows the accumulating manure to fall through gaps into a collection channel. From there, the liquid manure flows through a sizable intermediary tank into the fermenter, where it is gradually transferred to the primary tank using a 7 kW pump.

In this well-designed establishment, manual transportation of manure is no longer necessary. Activating the respective pump stands as the only task alongside cleaning the stable areas, involving manure disposal and processing.

Of particular interest is the proprietor's motivation for constructing the biogas facility. Repeated outbreaks of worm-related diseases had plagued the barns before, proving difficult to eliminate over time. During the biomass digestion process, worm eggs are eradicated, rendering the dung hygienic. Since then, no further worm infestations have occurred. Alongside energy production, the benefits for the owner include saving 5,000 tons of heating oil annually and a substantial reduction in nitrogen-based commercial fertilizers. This doesn't even touch upon the farm's overall cleanliness and odorlessness. The daily output of biogas residue (3 m^3) is diluted with water and promptly applied to fields, ensuring that all the nitrogen benefits the plants.

With the manure generated here, twice the amount of biogas could easily be produced if the biomass remained in the fermenter for an extended period. However, this would reduce the throughput by about half or necessitate doubling the facility's size. Since extensive hay drying isn't planned, the gas quantity from the biomass of 200 livestock units (LSU) cannot be consumed. As a result, the fermentation period was set at only 14 days, thus optimizing the facility's economic viability.

The systematic development of biogas facilities began in the early 1930s. In Mediterranean countries, a modular system of three equally sized towers was soon adopted. Two of these served as fermenters while the third functioned as a gasometer. These facilities operated without mechanical aids. The anaerobic digestion process was left to proceed naturally for three months until complete degassing. Subsequently, the two digestion chambers were emptied sequentially using excavators. In the meantime, open manure piles with their well-known disadvantages continued to accumulate. Following World War II, when biogas was no longer utilized as a vehicle fuel, these technically undemanding systems fell out of use. Today, interest in biogas technology is resurging in the Mediterranean region, albeit for the purposes of modern agricultural enterprises.

In the **United States**, the development of biogas facilities dates back to 1933. The horizontal digesters introduced by Buswell and Boruff are once again being constructed, as they can be easily situated beneath the stable floor, allowing manure to be transferred to the fermentation chamber with minimal effort and while still warm. Notably, the United States prioritizes cost-effectiveness. Implementing labour-intensive systems there is a challenging endeavour.

5 Development of Biogas Plants in the Federal Republic of Germany

In the Federal Republic of Germany, there are approximately 450,000 agricultural farms cultivating more than 10 hectares of land, making them suitable for biogas plants.

In Central Europe, there were over 500 biogas plants operating in 1984, with over 100 of them located in the Federal Republic of Germany, each one being quite diverse. To gain practical insights, studying several typical plants is the quickest way.

One such plant design took inspiration from the horizontal position of a cow's rumen, even though the initial attempts used horizontal underground fermenters for easier integration into the existing barns. It was found that the larger liquid surface area resulted in a thinner scum layer on top of the digester's contents. Additionally, the mixing challenges were reduced, making the operation more manageable.

Here is the schematic of a horizontal biogas plant suitable for small-scale farms:

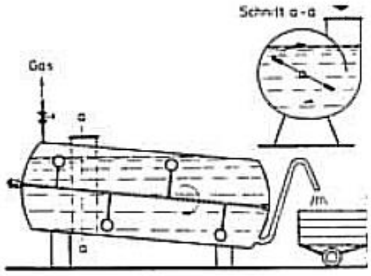


Figure 5.1: Schematic of a horizontal biogas plant with agitator

The fermenter is a large water or odelfass barrel, set at an angle to allow a corner for the accumulation of biogas. The agitator consists of a shaft with multiple paddles, rotated either manually or with the help of a motor with strong reduction. The discharge of the digestate can be through a siphon with a pump or without a siphon using a shut-off valve. The plant operates discontinuously.

This system can be easily expanded into a continuous large-scale plant, known as the Darmstadt System.

In the Swabian Alps, a similar plant has been reliably operating since 1959. It was built by the owner in a modern way, even by today's standards. The biogas plant is designed for 20 LSU (Gross Livestock Units), suitable for an average-sized farm. The material cost back then was only 6,000 DM. The stable, mixing pit, and fermenter are integrated into one unit. A non-stationary pump is used for mixing, which also grinds the incoming manure.
The agitator makes 2 revolutions every 1.5 hours, which is sufficient.
The daily energy requirement for mixing is 0.1 kWh, and for the mixer, it is 7 kWh. The energy is extracted from the biogas, with 15% used in the winter.
The daily amount of cattle manure is 36 kg TS (Total Solids), and straw is added as bedding. Together, they produce 14,000 Nm^3 of gas annually, sufficient for building heating, hot water, and even for a potato steamer. A gasometer with a **desulfurization** system serves as the gas storage.

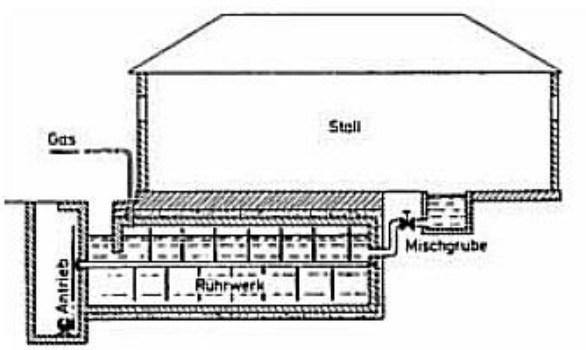
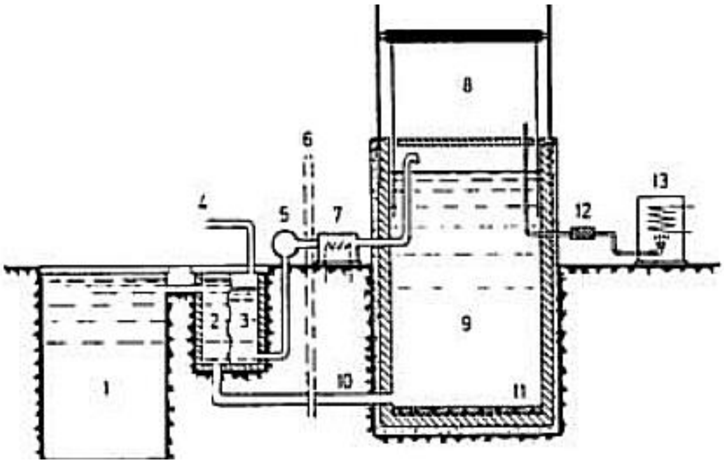


Image 5.2: Diagram of an Underground Biogas Plant for 20 Livestock Units in Bernloch

There are numerous reasons to establish a biogas facility, and each agricultural operation may prioritize different factors for construction. Situated in the heart of an Upper Bavarian community is a swine-fattening farm where, as is common with pig farming, odor pollution had been increasingly becoming unbearable. Consequently, in 1981, the farm owner made the decision to construct a biogas plant. Since then, the locality has been devoid of odors, the farm's cleanliness has improved, labor has been reduced, and the farmer is thoroughly content. The "Landtechnik Weihenstephan" research institute provided assistance during the planning phase, resulting in the creation of a demonstration facility.



1. Biofertilizer Storage Tank (300 m3)
2. Thermal Storage for 3
3. Primary Tank for Fresh Slurry
4. Inflow of Fresh Slurry
5. Central Pump
6. Siphon between 2 and 9
7. Heat Exchanger for Fresh Slurry
8. Gas Dome
9. Fermentation Chamber 80 m3
10. Outflow for Biofertilizer
11. Floor Heating for 9
12. Gas Cleaner
13. Gas Heating Boiler

Image 5.3: Biogas plant for 20 livestock units (500 pigs) in Gilching/Obb

The facility incurred a cost of approximately 100,000 German Marks, encompassing all constructions and gas-supplied installations. The upright anaerobic digester tower is constructed with 20 cm of concrete, 12 cm of thermal insulation, and an aluminum cladding, which is technically unnecessary. The floor heating (11) operates only during the winter months. The fermentation temperature is maintained at 32°C. The steel dome weighs 4 tons to withstand a gas pressure of 0.04 bar. The immersion depth of the dome fluctuates between 0.4 and 1 meter. The daily operational effort amounts to 10 minutes.

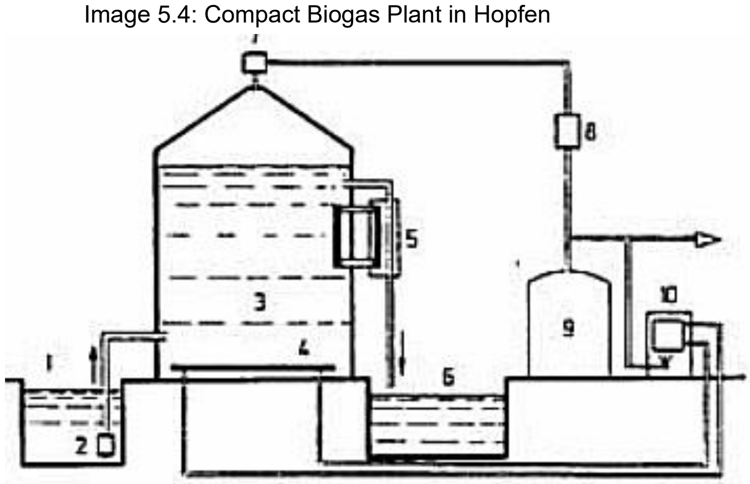
Although the mesophilic digestion range of 32 to 35°C is generally chosen due to low heat losses, the temperature range of thermophilic bacteria from 50 to 55°C is justified when aiming for high methane production or shorter digestion periods (see Figure 3.2).

A prototype for the industrial production of compact biogas systems has been operational since the 1970s in Hopfen near Weiler im Allgäu. It can rapidly digest the manure from up to 35 livestock units, making it suitable for 350,000 agricultural operations with individual adaptations. The investment costs are estimated at 1,200 to 1,500 German Marks per livestock unit (LSU) without storage.

The maximum daily gas yield reaches 50 Nm^3, equivalent to a heating oil saving of 10,000 tons per year.

The diluted manure is automatically fed to the digestion chamber every few hours.

Image 5.4: Compact Biogas Plant in Hopfen



1. Fresh Slurry
2. Homogenization Pump
3. Digester Tower 50 m3
4. Heating for 3
5. Heat Exchanger
6. Biofertilizer
7. Gas Dryer
8. Condensate Separator
9. Gas Holder
10. Gas Heating Boiler

To mitigate the heating demand using biogas, the heat from the outgoing biofertilizer is reintroduced into the digester chamber through a heat exchanger. Additionally, combined heat and power generation (CHP) and a heat pump are employed. Excess gas is compressed into steel cylinders using a compressor (300 bar).

Heating and insulating the fermenter often pose challenges and expenses. When heating coils within the fermentation chamber are not concealed, they frequently become clogged or obstruct the flow, complicating the disruption of the scum layer. Even with external insulation and heating, temperature fluctuations persist, prompting a somewhat reduced gas production by the delicate methane-producing bacteria.

This can be circumvented by immersing the entire digestion vessel, whether constructed from steel or glass-fiber-reinforced plastic (GRP), in a warm water bath. Naturally, this “bathtub” must be externally insulated, a task easily accomplished with the straight walls. Even the more cost-effective option of Styrofoam can be utilized. With proper insulation, the process energy requirement for heating the water bath is exceedingly low. Another advantage of this design is that the gas-fired boiler is free in its supply temperature and can be elevated for space heating during winter, a scenario not feasible when the heating coil is placed directly within the fermentation mass.

Experience with such systems is limited, as previously, facilities primarily comprised of digester towers accessible from the exterior were constructed, enabling better maintenance. The inlet and outlet of the digestion chamber, as well as potential cleaning processes, are simpler with such designs. This type is likely to be reserved for specific scenarios. It is implicit that the water basin is kept as compact as possible. A gap of 15 to 20 cm between the digester chamber and the interior wall of the bath should suffice.

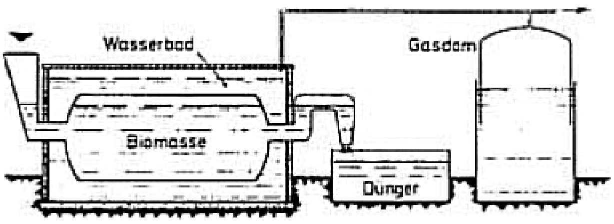


Image 5.5: Digestion Chamber Container in a Water Bath

As depicted in Image 5.5, the drainage of the fertilizer is regulated by a siphon, the overflow edge of which aligns with the biomass level.
The importance attributed to thermal management in a biogas plant, for both biological and economic reasons, is demonstrated by the following construction, which stems from the realization that the circle possesses the smallest surface area, measured against the cross-sectional area, and consequently, the least cooling surface. Only the sphere surpasses it in this regard.

A sophisticated yet simple system for increasing the gas quantity until complete fermentation, with the lowest possible use of external energy for the process, has been designed and constructed multiple times by the **company Lipp**.

In this system, all containers—the primary fermenter (1), the fresh manure tank (3), the secondary fermentation chamber (2), and the water basin (4) for holding the gas bell (5)—are arranged in concentric rings. This setup minimizes heat loss, as the heat from one ring warms the mass of the adjacent ring container. Only the innermost container (1), the main fermentation chamber, is insulated, along with the outer shell of the entire system.

The process in the fermenter works as follows:

Periodically, a certain amount of fresh manure is pumped into Ring 3, from where it flows through a pipeline into the innermost chamber (1). The biomass is then heated and anaerobically fermented there. By introducing fresh manure into Chamber 1, an equal amount of digested material is pushed into Chamber 2 for secondary fermentation. As a result, an equivalent amount of fermented material is conveyed from the secondary chamber (2) to the storage pit (7) for biodigester.

On the gas bell (5), gear racks (6) are attached. When the bell is raised and lowered due to gas pressure changes during gas extraction, a chain drive moves steel plates up and down, continuously breaking the forming scum layer.

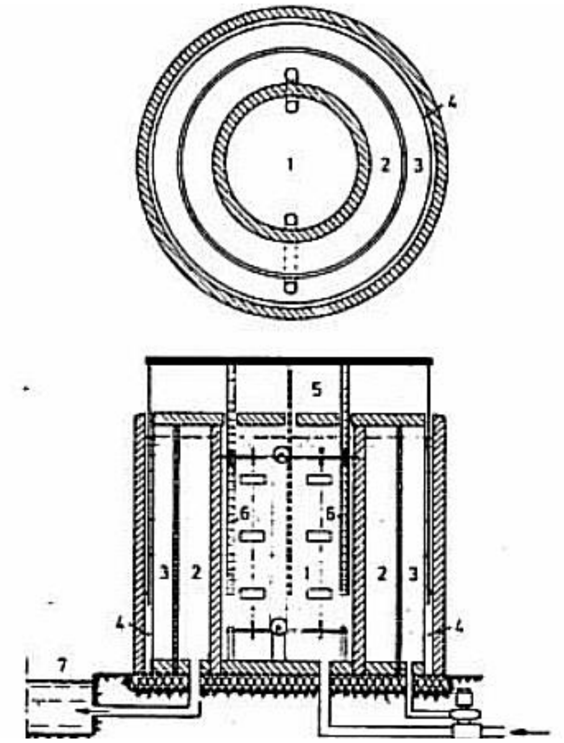


Image 5.6: Concentric Biogas Plant according to Lipp

1. Main fermentation chamber
2. Secondary fermentation chamber
3. Slurry room
4. Water basin
5. Gas bell
6. Gear rack for agitator/stirrer
7. Pit for biofertilizer

A plant like this cannot be self-built, except for the foundations, external pipelines, pump installation, and power generators. The fermenter itself consists of standard sizes used in steel silo construction, making the cost of the plant lower than expected from its intricate design. The minimal heat losses allow for thermophilic operation at 55°C, at least for larger recommended plants.

For large-scale plants designed for 100 livestock units, prices of approximately 1400 DM per livestock unit (LSU) are mentioned, and for sizes of 200 LSU, the price is around 1000 DM per LSU. Therefore, a cooperative consortium of biogas stakeholders would be beneficial. In such a case, however, the fresh manure must be preheated before introduction into the fermenter since cold liquid in the compact heating system would be a disruptive factor.

For small-scale plants serving about 20 LSU, the mesophilic methane range of about 32°C is usually applied. In this case, the ratio of the fermenter's surface area to its mass is less favourable, and higher temperatures would result in excessive heat radiation, necessitating a heating system. This system operates without any additional process energy, making the entire biogas output available for use.

Even long-established knowledge is now being systematically examined by research, as there is always room for improvement. For instance, a joint biogas production project was launched in Quickborn in the Lüchow-Dannenberg district in 1983. It involved the construction of five biogas plants for decentralized manure fermentation on five farms. Only two neighboring farms delivered additional fermentable material to the five biogas plants.

The produced biogas is not directly utilized on the farms but is sent to a central gas depot. From there, it is introduced into the village's gas network at a favourable pressure for consumers. This gas network not only offers higher gas reserve capacity but also allows greater flexibility in individual consumption.

During the summer, when gas demand for households and the process heat for the fermentation chambers are low, larger amounts of gas are available for energy-intensive tasks, such as hay drying.

This system allows for other farms to connect to the central gas storage at any time, provided they only need to build a fermenter. Each new connection improves the overall gas supply of the consortium.

As individual farms and the environment improve, regional gas supply networks are created, which can eventually be combined, leading to significant savings in expensive diesel fuel and heating oil. Since not every agricultural enterprise needs to build its gas storage, the decentralized biogas plants pay for themselves even more quickly.

The main advantage of this consortium system is that each participating farmer can tailor their biogas plant to local conditions and have the freedom to prioritize gas production and the quantity of biodigester.

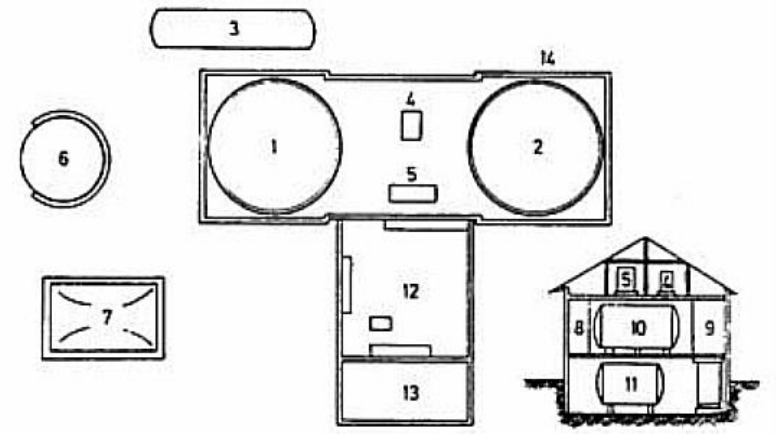
The Quickborn consortium system initially emerged from the development of a central fermenter. The planning and execution of the Ismaning/Obb. facility were carried out by Messerschnitt-Bölkow-Blohm. The design departed from previous practices and incorporated new fermentation technologies. The size of the biogas plant would not be feasible with private funds, but it turned out that even this investment paid off.

The Ismaning large-scale biogas plant is designed to digest 50 m^3 of biomass daily, an amount that a single farm alone cannot provide. It also serves as a test to determine if a community-based plant is accepted by neighbouring farmers. Fresh manure needs to be delivered in odour-free closed tanks following a common transport plan to ensure uniform filling. The success of this delivery system has proven the anaerobic manure digestion as a valuable option within a short time.

Initially, some farmers in Ismaning were hesitant, but as more and more farmers began supplying their stable manure, the plant's utilization increased. The benefits included reduced farm labor, improved quality of fertilizers, and overall better farm hygiene. By 1983, the plant was mostly operating at full capacity, producing 1,000 to 1,500 Nm^3 of biogas daily. Switching to thermophilic operation increased the gas production to about 3,000 Nm^3/day with secondary fermentation.

The large biogas plant comprises two insulated fermenters, each with a capacity of 500 m3. They have a diameter of 10 m and can handle the manure from 1,000 livestock units. The two fermenters are located in a closed building with external insulation, made possible and permitted due to the presence of gas detectors. The manure storage pit (6) is located outside the building and is heatable. It serves as a temporary intermediate storage into which the suppliers pour their manure. A pump with a capacity of 3.6 kW periodically pumps around 70 m^3 per hour from this storage into one of the two fermenters after mixing and homogenizing (shredding) the manure in a mixing tank and passing it through a heat exchanger to bring it to a temperature of about 22°C. The manure is introduced at the bottom of the fermenter, where the existing digested material is already partially fermented, preventing over-acidification in the absence of new fresh material. The fermenter is divided into two phases by a larger movable flap (see Figure 5.8), with the lower section maintaining the optimal acidity of about pH = 7 and being anaerobic.

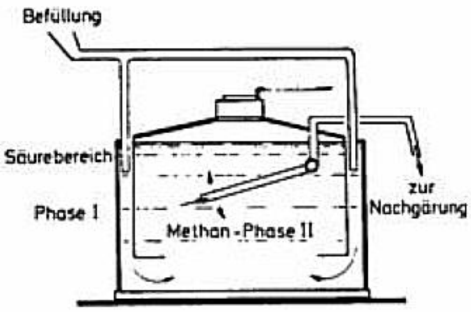
Image 5.7: Structure of the large-scale biogas plant in Ismaning



1. Anaerobic Digester 1
2. Anaerobic Digester 2
3. Gas Storage
4. Compressor
5. Power Generator
6. Manure Pit with Heat Exchanger
7. Secondary Fermentation Pit
8. Desulfurizer
9. Manure Preheater
10. Hot Water Storage 95°C
11. Hot Water Storage
12. Control Room
13. Office
14. Insulated House

The biochemical conversion process (fermentation) takes place in the lower section at a rate approximately 3 to 5 times faster, resulting in an increased throughput. The two-phase separation is protected by patent law. This protection, as per Section 11 of patent regulations, does not extend to the personal construction undertaken by private individuals on their own property and for their own purposes.

Bild 5.8: Prinzip der Zweiphasentrennung nach MBB



The Ismaning plant operates in the fermentation range of 33 to 37°C, achieved by warm water pipes in the base of the digesters. In summer, about 10% of the produced gas is required for heating, **while in winter, it increases to 25%.** The usable gas is compressed to **a pressure of 11** bar using a compressor and stored in an external container with a capacity of 140 m3. Since the large amount of gas produced - during the trial run, **3,500 Nm3 of gas were generated daily** - cannot be fully utilized on the agricultural estate, **a gas engine** was installed to drive an **80 kW generator**. This setup generates around **700,000 kWh of electricity annually,** which is either fed into the **public utility grid** or sold.

It has been calculated that the value of the biogas produced annually, combined with the savings on heating oil and commercial fertilizer, amounts to **480,000 DM,** resulting in a theoretical payback period of seven years. However, in reality, it may take a bit longer as the plant is not yet fully utilized, and ongoing research programs are still running.

Now, let's move on to the operation of this large-scale facility. **Before the initial filling, the oxygen in the new towers was burned off**. Alternatively, it could have been displaced with carbon dioxide (CO_2). Then, the digester was preheated and seeded with digested sludge, which must not come into contact with oxygen during transport and filling. The digester was gradually charged with warm fresh manure, with the initial **dry matter content being as low as 5% (instead of 10%**). The **charging** rates could soon be increased from **5 to 25 m3 per day**.

At full operation, about **40%** of the produced biodigester can be directly **applied to the fields,** while 60% must be temporarily stored. This is done in an open earthen basin, known as the **lagoon**, with a capacity of **1,400 m3**. As the biomass in the digester is **not fully degassed** due to the retention time, the lagoon is **covered with a plastic foil**, resulting in secondary fermentation with a daily gas emission of 100 Nm3.

Continuous hot water at 95°C and 60°C is kept available through a heating boiler.

With such a large facility, having its own control room is affordable. **Gas cleaning and, most importantly, desulfurization are of high importance**. Ensuring the safety of the plant against toxic gases or explosives requires special monitoring and adequate automatic ventilation.

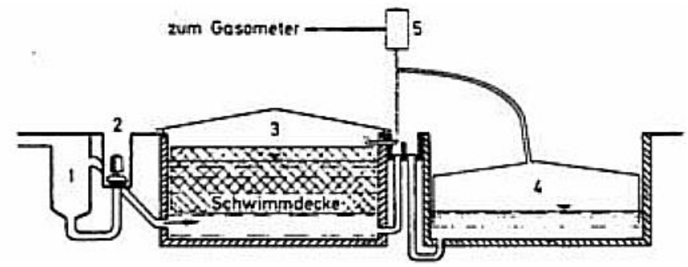
In the Ismaning facility, the phase separation in Areas 1 and 2 prevents scum formation, eliminating the need for specific measures.

In individual biogas plants, the expenditure on mechanical or other systems can often be quite extensive. For example, beneath the scum layer, the gas pressure increases to a level where methane production by the bacteria decreases, apparently due to the stress caused by this overpressure.

Additionally, without intervention, the scum layer would continuously grow, leading to smaller refill amounts and reducing the plant's efficiency. Moreover, the increased scum layer could cause blockage of pipes or gas outlets, necessitating a shutdown and cleaning of the facility, resulting in further losses. Subsequently, the fermentation would need to be restarted biologically with all necessary precautions, not to mention the intermittent aerobic digestion of the accumulating stable manure. Hence, phase separation is advantageous both chemically and mechanically.

Is all this effort always necessary, or can the scum layer be utilized for methane fermentation and converted into high-quality biodigester? This question was posed by Fritz Weber, an agriculturally experienced farmer from Georgenau, who has dedicated himself to this specialized field of fermentation processes since 1952 by constructing several biogas plants based on his principles. He realized that a **greater yield of gas and active nitrogen and phosphorus occurred precisely in the scum layer with a higher straw content**. This inspired him to develop a completely new gasification method. He, so to speak, deliberately cultivated the scum layer, which he had previously attempted to suppress. The objective now was to achieve a high nutrient value of the biodigester for the plants, as well as ensuring good gas output and operation without external energy, requiring the use of psychrophilic methane bacteria with a digestion range of 4 to 25°C. He knew that this would result in a longer digestion period since these bacteria are slower. For an 80% degassing, he estimated about 55 days instead of 30 days. However, the higher fertilizer value was worth the longer fermentation time.

Since the psychrophilic range does not necessarily sterilize most pathogens and pest eggs, the fermentation temperature is finally raised to 55°C using a heater.



1. Mixing pit
2. Multiple pump
3. Main fermentation chamber
4. Post-fermentation chamber
5. Gas filter

Figure 5.9: Biogas plant in Georgenau according to F. Weber

The main fermentation chamber (3) has dimensions of **11 x 9 x 4 m (depth), equivalent to 396 m³.** The digestion chamber is not round, which is not necessary as there is no need for agitation. The space accommodates biomass from **60 animal units** (LSU). Manure is directly fed into the fermentation chamber floor in a quantity that allows the floating scum layer to freely float, with 4/5 of the scum layer located below the liquid level for weight reasons. **Daily, 60 liters of mixed slurry containing 37 kg of fresh manure and 3 kg of chopped straw** are added here. The average fermentation temperature is 20°C, and the retention time in the fermentation chamber is up to 100 days.

When the main fermentation chamber (3) is full, the slurry flows into the larger post-fermentation chamber (4). The scum layer in chamber 3 builds up from below to a thickness of 3 m and releases approximately 50 Nm3 of biogas daily. However, the most **valuable aspect is the exceptionally high-quality fertilizer with 3.6 times the active nitrogen content and 2.3 times the active phosphorus content compared to the common composting method on the manure pile**. The potassium content is approximately the same for all composting methods. The extended fermentation time requires larger digestion chambers and, therefore, higher construction costs. However, the increased gas production and savings in commercial fertilizers, which amount to up to 100 DM/LSU (in this case 6,000 DM per year), allow for more investments. Georgenau saves 10,000 DM in heating oil annually.

The main disadvantage of this fermentation method is the slightly higher workload. The scum layer, which can weigh up to 200 tons, needs to be dredged and stored quarterly. However, fermented biomass does not lose any of its nutrients in the air and can be stored for a long time without causing any odorous emissions. **When fresh manure is stored for an extended period, up to 70% of the nitrogen and up to 50% of the phosphorus transform into a molecular form that the plants can no longer utilize**.

To succeed with this method, one must familiarize oneself with the process of scum layer cultivation. The high nutrient content of the biodigester can only be achieved when, after anaerobic digestion, the biomass is at a stage where the entry of small amounts of oxygen does not harm the methane bacteria nor lead to aerobic decomposition. The permissible air quantity must be precisely dosed. While the partial aerobic operation is not fully understood scientifically, it has been proven that when initiated at the right time and carefully dosed, it significantly enhances the fertilizer's nutrient value for the plants.

Weber calls this method "controlled composting". During the daily replenishment of 50 liters of fresh slurry with the pump, 500 Ncm3 of air is introduced, rising immediately into the scum layer, where it distributes and leads to the partial aerobic fermentation of solids, especially straw. This process increases the local temperature within the scum layer by a few degrees through controlled putrefaction. Temperature differences of 8°C were measured between the slurry and the scum layer.

Certainly, variations of partial aerobic fermentation are conceivable, such as conducting the main fermentation anaerobically in the mesophilic range and allowing partial aerobic fermentation to take place in the post-fermentation chamber, or draining the scum layer from time to time and continuing partial aerobic treatment in a post-digestion basin according to the aforementioned pattern.

A new biogas plant with a two-phase fermenter was developed by Messerschmitt-Bölkow-Blohm and presented to the public for the first time at IFAT 84. It is suitable for both industrial operation, functioning reliably even on a larger scale and producing high and consistent quality biogas, and for agricultural use, for which the company intends to offer series-produced standard plants. The new plant has already gained valuable experience in digesting distillation residues from distilleries, making them more energy-independent with biogas technology.

The fact that biogas technology can also be combined with other alternative energies on a farm was demonstrated by Vilshofen farmer Adam Reinhardt. After building a 33 m^2 solar collector on the roof for only 2,400 DM in material costs and assembling a stall air-heat exchanger for 1,500 DM, he installed a biogas plant for 65,000 DM after an initial failure (the digestion container rusted through within a year). The biogas plant now functions flawlessly and saves him 18,000 liters of heating oil per year. At current heating oil prices, the plant, which utilizes gas for cooking and heating, is expected to pay for itself in six to seven years.

The presented biogas plants are just a selection, demonstrating the potential diversity and design possibilities. Pioneering plants in the Federal Republic, such as those in Eggersglüß, Schmidt, Schulz, Perwanger, and others, are not shown here due to space constraints, but their developments are encompassed in the presented biogas plants. It can be observed that it is possible to function without process energy, but it is generally worthwhile to equip at least the digestion chambers with heating.

As the size of a plant increases, more auxiliary units can be employed, making it more appropriate to fully automate the entire plant. This automation can start from the inflow of slurry from the barn with automatic barn cleaning, mixing, and possibly heating and shredding of manure, automatic dosing and charging of the digestion chamber, temperature control inside the digestion chamber, and all the way to the removal of the biodigester. Simultaneously, monitoring of the acidity value, gas pressure, and gas purification should be conducted.

The degree of automation of the biogas plant is undoubtedly related to the modernization of the entire operation. Conversely, when modernizing the farm, practical considerations for a future biogas plant should be taken into account, even if it is not currently planned. For example, in the barn, the drainage channels for liquid manure should be laid in a way that allows for connection to a mixing tank that can serve as an interim storage in the meantime. Similar considerations should be made regarding the sprinkler system for barn cleaning, especially regarding water consumption. One should aim to have a ratio of about 6:1 (water to dry matter of manure). Every construction measure on the farm should consider the potential for a future biogas plant. This incurs no additional cost at the moment but will pay off in the future.

One does not need to be a prophet to predict that within the next 10 years, biogas plants will become standard installations on many agricultural enterprises, not only for energy generation but also for the sake of odorless fermentation residues that can be used as high-quality natural fertilizers. Moreover, the hygienic fermentation substrates are a protein-rich feed supplement.

6 Auxiliary Machinery and Equipment

6.1 In the Mixing Pit

For those who do not want to ferment at low psychrophilic temperatures (around 20°C), using some technical aids for the feeding of the biogas plant is advisable. These aids are already developed and available in specialized stores.

If the barn has not been modernized yet, the **barn manure should be placed in a mixing pit** instead of a free manure heap. The mixing pit should be built as close to the barn as possible. It is recommended to make the pit large enough to hold the slurry (manure and liquid) **for one week** to avoid time pressure if the fermenter's progress is slow. It is best to cover the mixing pit to be able to connect it to a heating system later without changes. It's even beneficial to incorporate some pipes into the concrete floor during construction. The costs for this are low at this stage, and later it will be easy to maintain the slurry temperature in the mixing pit at around 20°C to preserve the fermentation process during each refill.

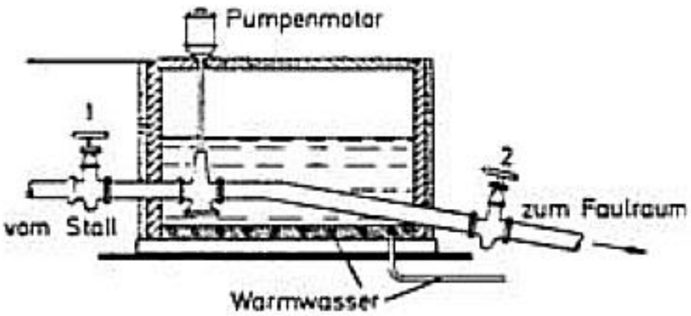
The **supply** of slurry from the mixing pit to the digestion chamber typically occurs **at least once a day**, depending on the performance of the mixing or transfer pump. Ideally, these three operations in the mixing pit (**mixing, shredding, and further conveying**) should be carried out by a single **multipurpose pump** for economic reasons, as the bedding material, usually straw, is often not pre-shredded small enough. The size of this pump determines whether the daily manure output can be processed and pumped into the digester in less than an hour. The actual pumping process to the digestion chamber only takes a few minutes.

The pump in the mixing pit must be positioned deep enough to prevent it from sucking in air, as this would introduce oxygen into the slurry and, consequently, into the fermentation chamber, causing the death of anaerobic bacteria.

To **prevent the entry of air** into the pump, a **simple float switch** can be used to shut off the motor at a specific liquid level in the mixing pit.

The required multipurpose pumps are manufactured by companies such as Feluwa, Glygt, Mortensen, Ritz, and Schweizer. They are specialized **thick slurry pumps.**

The slurry lines from the barn to the mixing pit and from there to the fermentation chamber typically have an inner diameter of 100 to 200 mm. The lines are equipped with shut-off valves before and after the mixing tank. This serves both for controlled inflow and outflow of liquid manure and to prevent gases from the mixing pit from entering the barn. This must be avoided, as during the mixing process, hydrogen sulfide may be released, which, even at a concentration of only 6 parts per thousand in the air, can be lethal. Therefore, the mixing pump should be stopped while the liquid manure is being transferred from the barn to the mixing pit. Relying solely on a siphon between the barn and pit should also be avoided because if the liquid level in the siphon drops for any reason (e.g., leakage), the necessary gas barrier will be compromised.



1. Shut-off valve before the mixing pit
2. Shut-off valve after the pit

Figure 6.1: Mixing pit with shut-off valves, pump, and heating pipes

Regarding the pump itself, it must be a thick slurry pump in any case. These are also known as free-flow pumps since the flow path within the pump is free of construction elements, and the impeller does not obstruct the flow. **The motor power of the pump** is about **2 to 3 kW** for smaller farms and **5 kW for larger operations**. Since the pumping periods are relatively short, the daily electricity consumption is quite low, usually no more than 10% of the heating requirement for the digestion chamber. Therefore, an overhead covering for the pump is not required. Today, most of the pumps are designed for outdoor installation. It is advantageous to place the pump under the floor in a lateral niche of the mixing pit. This keeps paths and work areas free from obstructions.

For the mixing pit's tank, concrete is recommended as the building material. Masonry pits often lead to sealing issues.

If the slurry remains in the mixing pit for an extended period, it cools down and needs to be reheated. This might be the case with non-automated biogas plants or can occur more frequently. However, cold slurry disrupts the fermentation process. Since the pit releases a lot of heat through its concrete walls, insulation is recommended in our latitudes, especially during winter. **The insulation material should be at least 10 cm thick**. However, glass fiber mats and Styrofoam are not suitable here as they absorb moisture and become thermal conductors again. Additionally, their mechanical strength is insufficient.

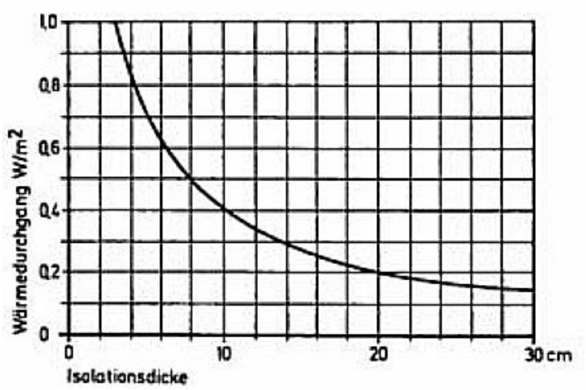


Image 6.2: Heat transfer in W/m2 as a function of insulation thickness for rigid foam

Polyurethane, often preferred as plates or foam in biogas plants, is useful only if it is protected from moisture. This applies to above-ground installations. In the underground area, **polystyrene** boards are currently the preferred choice.

The design of the **heating system** in the mixing pit depends on the **amount of slurry, the retention time, temperature differences, and the wall material**. The temperature of the heating medium (usually warm water or warm water pipes) is limited by two factors. First, **the sensitivity of the bacteria, which can withstand about 55°C without damage**.

The second factor is determined by the behaviour of cellulose, which tends to stick or become cemented to hot pipes, leading to deteriorated heat transfer to the slurry and potential contamination. In practice, the warm **water temperature should not exceed 50°C**. If this is not sufficient, a larger heat exchange area (longer pipes) should be chosen.

It is particularly recommended to embed the **heating coil under plaster.** This not only protects it from corrosion but also does not impede the flow in the slurry. It also facilitates the occasional cleaning of the fermentation chamber.

Gas pipes (threaded pipes) according to DIN 2440 with a nominal size of 11/2 to 2 inches (40 to 50 mm internal diameter) are sufficient as heating pipes.

For **biological reasons**, the slurry in the mixing pit should **not be heated above 35°C, nor should it be kept significantly below 25°C** if fermenting in the typical mesophilic range.

The heating demand for the mixing pit is not significant due to its relatively small size and the low maximum temperature of **25 to 30°C**. The heat requirement is hardly more than 10% of the demand for the digestion chamber. Therefore, the waste heat from the biodigester is sufficient to bring the incoming slurry close to the operating temperature using a heat exchanger. The most cost-effective approach is to immediately dilute and homogenize the barn manure and introduce it into the fermenter with its natural warmth, which is done in automatically controlled systems.

The height difference between the mixing pit and the digestion chamber plays a minor role. It is hardly possible to place it high enough for the slurry to flow into the digestion chamber through natural gradient alone. The slurry level would have to be higher than the digestion chamber level for that. Therefore, the pit's location should be determined based on the barn's position, allowing at least the liquid manure from the barn to flow into the mixing pit naturally.

For economic reasons, **the mixing pump is sometimes provisionally anchored** in the mixing pit, so it can be removed and used elsewhere.

It is advantageous for the **mixing pit to have a sloping floor and a pump sump**. This facilitates the cleaning of the mixing pit significantly.

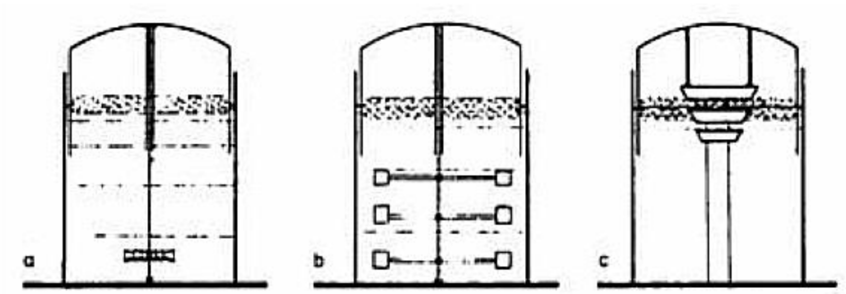
In large plants, the mixing pit is often replaced by a "**pre-tank**," which is sometimes sized to the same capacity as the main digestion chamber and is already operating under anaerobic conditions. This **provides an additional fermenter or the possibility of expanding to double capacity**.

6.2. Dissolution of Floating Layers

In the discussed biogas plants, we have learned about several methods to prevent or destroy the unwanted floating layer in the digestion chamber. To make the problem clearer, let's extract and compare the fundamental solutions. The various systems can then be modified by the client to suit their specific needs and preferences. Five main systems are available:

6.2.1 Mechanical Agitators

Image 6.3: Examples of Mechanical Agitators



a. Externally driven propeller with **high speed**
b. Stirring paddles with **low speed**
c. Disrupting elements moved up and down by the **gas bell**

The energy required in all cases is insignificant.

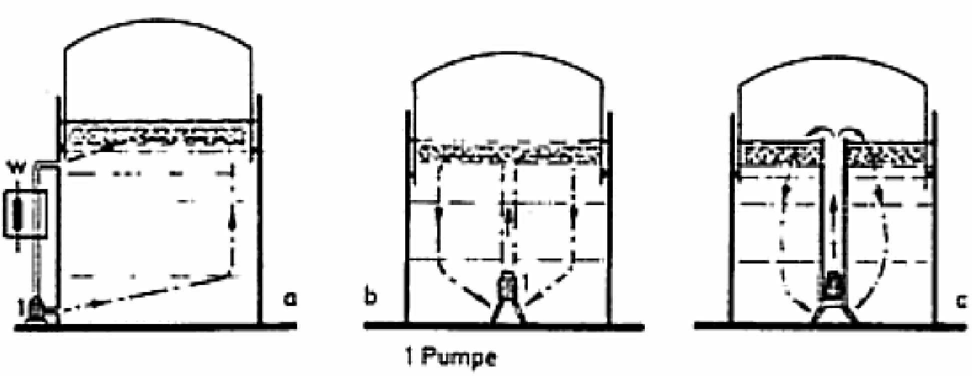
The agitation times per day are very short. For instance, in a large fermenter with a **biomass of 150 LSU**, the daily agitation time was around **5 minutes**, with an electricity consumption of **0.1 kWh/day.** Mechanical agitators are often oversized, run at too high a speed, and operate for excessive durations. The **rotational speeds should be extremely low to minimize energy consumption**, which decreases roughly with the cube of the agitator's speed.

6.2.2 Hydraulic Mixing Systems

Hydraulic systems typically make use of pressure changes in the biogas caused by periodic variations in gas consumption while gas production remains constant.

Another method for hydraulic destruction of floating layers **involves circulation pumps**. The constant movement of the fermentation mass in circulation prevents the formation of floating layers, as the straw particles have to follow the circulation. Here, too, the pumps only need to be in operation for a short period.

Image 6.4: Examples of Hydraulic Floating Cover Disintegration

Figure 

6.4(a) shows an **externally** located circulation pump (a). It has the **advantage of easy accessibility and interchangeability**. However, the **mixing may not be as efficient** as in (b), which could result in longer operation times and higher energy consumption. Nevertheless, the externally located pump **can be an ideal solution if connected to a heat exchanger** (w), replacing the entire internal heating of the fermenter.

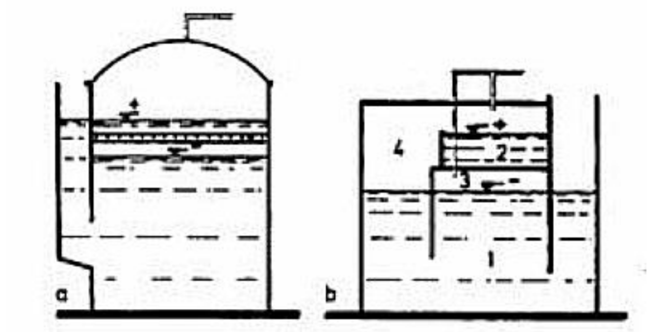
Figure 6.4(b) illustrates a **symmetrical circulation of the slurry**, which, with its thorough flushing action, **achieves high efficienc**y with low energy consumption. This design ensures that the digestion chamber walls remain intact, making it advantageous.

While the solution in Figure 6.4(c) may be **slightly more complex in terms of construction**, it combines the benefits of (a) and (b), as the pipe not only provides **symmetrical circulation but can also be designed as a heat exchanger**.

6.2.3 Pneumatic Systems

The destruction of floating layers using gas pressure changes in the fermenter has led to inventive methods.

Image 6.5: Examples of Floating Cover Dissolution through Gas Pressure Variation



a. With screen in the level change area
b. With larger pressure changes and post-digestion area

In the case of construction (a) in Figure 6.5:

When gas is extracted, the gas pressure in the gas bell decreases, causing the level of the digestion material, which is under atmospheric pressure at the inlet channel, to rise. It must pass through the rake, leading to the destruction of the floating layer. With the gas valve closed, the gas pressure in the fermenter increases, pushing the fermentation mass level back down, and again forcing it through the rake. The downside of this system is that a significant amount of gas must be extracted daily, which can potentially lead to gas losses.

In construction 6.5(b), the fermenter is divided into the main digestion chamber (1) and the post-digestion chamber (2). Gas can be extracted from either the gas space (3) of the main digestion chamber (1) or the gas space (4) of the post-digestion chamber (2), providing a continuous gas extraction during changes in slurry levels in both chambers.

For example, if biogas is extracted from gas space 3, the pressure in chamber 1 decreases, causing the slurry level to rise. This can even result in some of the mass flowing into the post-digestion chamber 2. Conversely, extracting gas from gas space 4 creates a vacuum, causing some of the biomass from chamber 2 to flow back into the main chamber. The agitation in the digestion chambers makes it difficult for floating layers to form. The advantages are a continuous gas flow and slightly improved degassing. However, the intricate dual-chamber construction is challenging to construct in a do-it-yourself manner and requires iron reinforcement for the inner structure.

6.2.4 Thermal Methods

Most substances and gases expand when heated, reducing their density and causing them to rise within their medium.

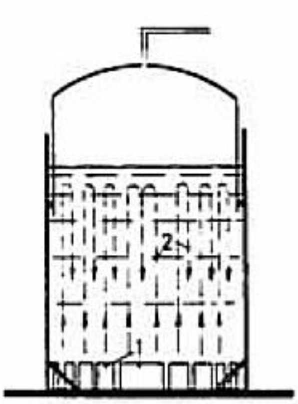


Image 6.6: Arrangement of Radiators with the Side Effect of Flow Around

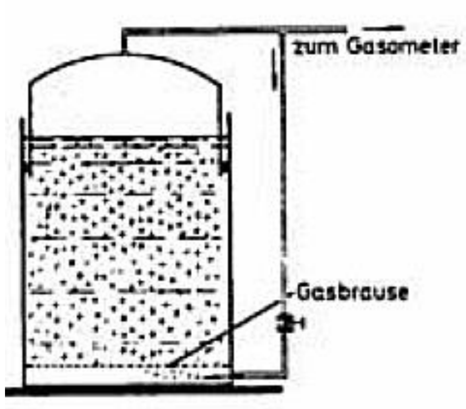
1 Radiator
2 Thermosyphon Flow

In this system (Figure 6.6), the digestion heating elements are not in the form of heating coils but flat radiators, which are arranged diagonally around the digestion chamber. The heated slurry rises, cools down, and then sinks back to the radiators, repeating the cycle. This thermosyphon method was common for automobile radiators until the 1920s but was eventually replaced due to high engine output. However, it may not be sufficient for the dissolution of floating layers in the fermenter in all cases, particularly if the straw content is high. However, it might be suitable for thin slurry with few solids. Cleaning the digestion chamber in the radiator area might pose some challenges.

6.2.5 Introduction of Gas into the Digester

Biogas is approximately 800 to 900 times lighter than slurry. When it is blown from below into the liquid manure, the gas bubbles rise rapidly and have the capability to prevent the agglomeration of solids, usually straw, at the surface of the slurry in the fermenter. The gas itself is not consumed during this process.

Introduction of Biogas into the digesting Material



A portion of the biogas is diverted from the biogas pipeline and introduced into the fermenter below a perforated plate known as the "shower." The gas bubbles rise everywhere to the level of the slurry and then re-enter the gas bell. It is essential that the gas lines are **completely sealed to prevent** any air containing oxygen from entering the biomass. Oxygen entering the biomass would quickly poison the methane bacteria, requiring the system to be shut down, refilled, and reseeded. Furthermore, this method should be applied with consideration for the **relatively low mixing efficiency, which is effective only when the straw is finely chopped**.

6.3 The Gas Storage

6.3.1 The Gas Dome

It is rare for biogas to be consumed immediately in the same amount as it is produced. To avoid flaring this valuable gas, the use of a gas storage system becomes necessary. In most cases, the initial gas storage is directly built on top of the fermenter and generates a gas pressure within the gas bell above the slurry level, depending on the gas production and consumption. If this is not achieved, the system might be leaky, or the bell might not immerse deeply enough into the sealing liquid. If more gas is produced than consumed, the surplus gas must be continuously pumped out and directed to a second gas vessel. In many cases, the gas dome can be designed large enough to serve as a gas reserve, **capable of accommodating about twice the daily gas consumption**. A dome is defined as the gas space above the fermenter that remains unchanging in shape and tapers dome-like towards the top. Otherwise, it is referred to as a gas bell.

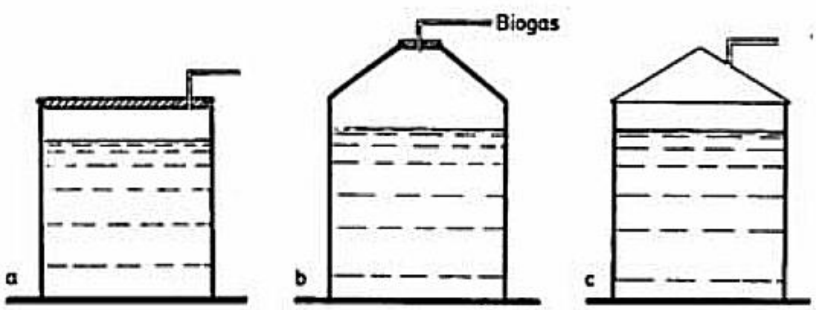


Image 6.8: Various Gas Dome Designs

The flat cover of the fermenter in Image 6.8a has the advantage of easy manufacturing, simple assembly, sealing, and dismantling. Sighting holes and access openings can be easily incorporated into the cover. To prevent the cover from being lifted by gas pressure, it must have a certain weight, which will be discussed later**. Adjusting the weight** for this simple disc is relatively straightforward.

In the case of the upwardly conical brick dome, the small cover (Figure 6.8b) is **exposed to a much lower gas pressure**. Moreover, the **risk of sludge accumulation** in the gas outlet is significantly **reduced**. The rarely used sheet metal hood as a gas dome (Figure 6.8c) is cheap but poses sealing difficulties.

For solutions **a and c**, a **recalculation** of the necessary dome **weight** is required to prevent the cover from being lifted by gas pressure, leading to ventilation of the fermentation chamber.

The common **gas pressure** in biogas plants today is approximately **50 mbar**, equivalent to a mechanical pressure of **0.05 kg/cm² or 0.5 N/cm².**

The overall area refers to the horizontal top surface of the gas hood.

For Figure 6.8a and c, the area is identical to the internal cross-sectional area of the digester tower, while for b, it is only the small top cover surface. Let's briefly calculate the pressure on the cover of a and b:

The clear **diameter** of the digester tower is **5 m** (500 cm). The maximum gas pressure is **0.05 bar**. The active cross-sectional area of the cover is then:

$A = r^2 * \pi$ $= 2.5^2 * 3.14 = 19.625\ m^2 = 196{,}250\ cm^2$ **$* 0.05$** = **9,812 kg = 9.812 tons.**

So, the gas bell must weigh at least this much to prevent it from being lifted by gas pressure.

An **overpressure valve** should be used to ensure that the gas pressure does not exceed 0.05 bar.

If we calculate the pressure on the cover of Figure 6.8b, assuming a diameter of **50 cm** (manhole), we obtain a pressure of:

$p = 25^2 * 3.14 * 0.05$ = **98.1 kg.**

The calculation also shows that a sheet metal funnel is hardly suitable for a digester diameter of 5 m. With a steel price of 3 DM per kilogram (1984), a hood weighing 10 tons would cost 30,000 DM. Thus, type b is the most economical design.

The cost of gas hoods in biogas plants is often the largest item. However, this need not be the case. Operationally, a bell weighing 10 tons is hardly manageable, as it can only be lifted with a crane.

Regardless of the weight, it should be emphasized again that a fixed gas dome connected to the digester leads to a variable gas pressure.
LINK to calculation table for your own numbers

6.3.2 The Gas Bell

The requirement for a constant gas pressure with varying gas production and consumption can only be met through an adjustable gas space expansion or reduction. This can be achieved in two ways.

The first method involves placing a film above the digester or the pit, which is not only tightly sealed at the transition from the digesting material to the plastic film but also large enough to form a sufficiently large bubble for the desired gas reserve. Multiple heavy boards are placed over the bubble, and their weight keeps the gas pressure constant as long as the bubble is not fully inflated. This method is mostly chosen for downstream gas storage.

In general, a floating steel or plastic bell is built directly above the digesting material, which immerses more or less deeply into the liquid depending on the amount of gas present.

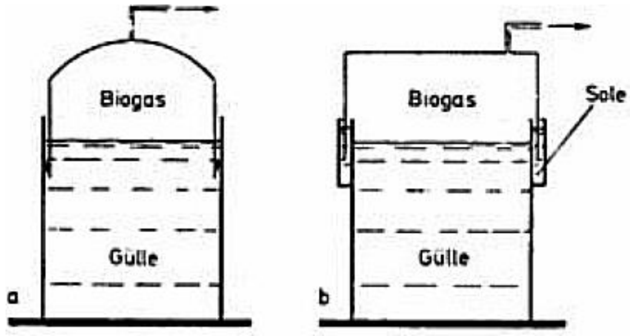


Image 6.9: Connection of Gas Bells to the Digesting Material

The bell in a can only be industrially manufactured in this dome form. It is not cheap but relocates the gas outlet pipe further away from the fermentation mass. The gas vessel b in the pot form, on the other hand, can be built in any workshop. It has the advantage that the gas pressure can be increased by adding weights.

For the **lifting movements** of the bells, heights of approximately **1 m** are usually planned, ensuring a **submergence depth of at least 10 to 15 cm** in the liquid to ensure a gas outlet or air entry is securely excluded.

For case a in 6.9, the bell floats directly in the slurry. Since the bell performs vertical movements up to 1 m, one can easily imagine the **contamination of the bell walls**, which can repeatedly hinder movement. For this reason, the design in **6.9b is preferred, where a water ring**, the so-called cup, is built around the digester, which can have a depth of 1 to 2 m, depending on the desired gas reserve in the bell. As frost is expected in our latitudes in winter, the water in the cup is treated with an antifreeze agent for -20°C.

The cup and the bell should **have a stopper** (see Image 6.9b) that prevents the bell from being lifted out of the cup when there is too much gas. Naturally, the gas pressure increases when the bell reaches the top.

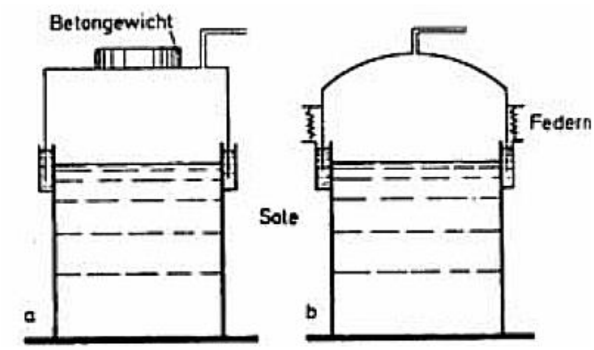
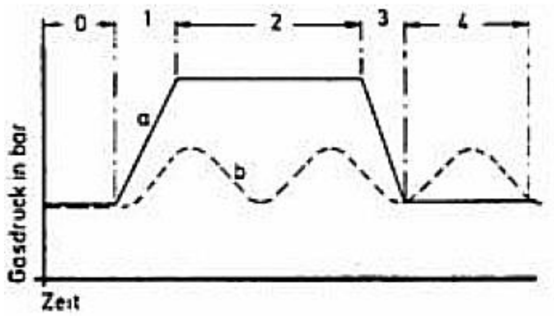


Image 6.10: Gas Pressure Regulation of Movable Bells

The weight of the bell was already discussed. However, it is not necessary for the bell itself to have the calculated weight. It can be **externally weighted in a much cheaper way,** or the gas pressure can be adjusted within certain limits **using a spring system** (Image 6.10b).

The additional weight of concrete on the pot hood in 6.10a is obtained by subtracting the gas pressure from the weight of the hood. The force of the springs in Image 6.10b is calculated similarly. The required individual spring force is $F_{Fed} = (F_{Gas} - F_{Bell}) / z$, where F_{Gas} is the **gas pressure** on the normal surface of the hood, F_{Bell} is the **weight of the bell in kg**, and **z** is the **number of springs**.

With a spring suspension of the bell, it is inherent that the gas pressure can only be kept constant within certain limits, which is often sufficient. The spring force increases linearly with the compression distance or the length of the extension. Its force is zero in the unloaded state. In our case, when no gas pressure is present, the springs must bear only the weight of a bell, which can be built quite light, as its weight need not balance the gas pressure, which the springs are supposed to do. As the gas pressure begins to rise, the bell rises initially due to the relaxation of the springs bearing the bell's weight. With further increase in gas quantity, the bell's load is lifted, and the springs begin to expand in the opposite direction, gradually causing the gas pressure to rise. However, by this time, the gas volume has significantly increased without a corresponding increase in pressure. When gas consumption begins, the gas pressure fluctuates only insignificantly. Only when the bell reaches its upper stopper does the pressure rise as if no springs were present. As the bell size and consumption are matched from the start, this case rarely occurs.



a Gas pressure behavior without springs,
b Gas pressure behavior with springs
0 Normal pressure,
1 no gas decrease,
2 too low decrease, flaring,
3 high gas consumption,
4 Normal pressure with balanced consumption

Image 6.11: Pressure behavior in the fermenter,
a with free-floating bell,
b with spring suspension, during irregular gas consumption.

If there is a downstream gas pressure storage vessel, the bell suspended by springs will be more economical due to its lower weight. Additionally, the bell suspended on springs has simultaneous guidance, preventing the bell from hanging crookedly or becoming stuck.

There have been instances of gas bells that cost more than the entire other biogas plant. In such cases, the spring suspension significantly reduces costs. **Coil springs from passenger cars, shock absorbers, etc.,** available at scrap yards for little money, can be used as springs. The cost savings for gas bells, on the other hand, can be in the four-digit range.

6.3.3 The Downstream Gas Storage

In most cases, the storage capacity of the gas bell or dome is insufficient to serve as an energy reserve for consumption purposes.

In some cases, it is sufficient to place the previously mentioned foil storage between the biogas plant and the consumption point. This depends on the required buffer quantity and available space. If the consumption unit sporadically demands large quantities of gas or is not fixed in location, high-pressure storage vessels are often preferred, in which large amounts of energy can be accommodated in relatively small spaces. At normal pressure (atmospheric pressure at sea level and a temperature of 0°C), **the calorific value of biogas of standard purity and composition is approximately 5,000 kcal per cubic meter**. Normal atmospheric pressure is about 1,000 mbar.

By compressing the biogas to 10 bar, which is usually common, **a 10 m³ vessel can store 100 Nm³ of biogas, which corresponds to the daily quantity of around 70 LSU.** In the case of compression, a constant pressure is no longer required in the gas bell above the digesting material. The bell no longer needs to be movable and can be built lighter. The costs for the compressor and the medium-pressure storage vessel are approximately offset by the elimination of a floating bell. Larger storage vessels are subject to TÜV inspections. The color for the vessels and pipes is red.

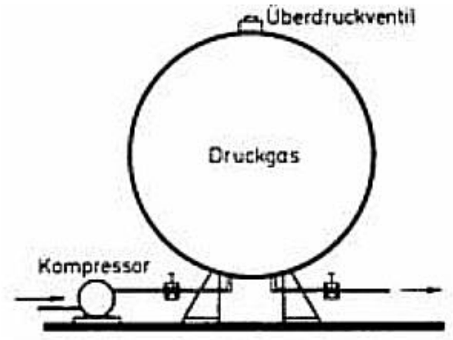


Image 6.12: Larger High-Pressure Gas Storage Sphere

6.4 Heating of Biogas Plants

The answer to the question of heating biogas plants depends on various factors. Not only is the temperature variation throughout the year of decisive importance, but also the choice of fermentation temperature. Other factors include the interaction between the barn and biogas plant and the applied fermentation system. Importantly, it should be determined what the main purpose of the plant is, **whether it is for maximum gas production** or **rapid biomass throughput** with **high biogas slurry production**. Lastly, economic considerations should be taken into account.

With the exception of the specific digestion of the floating layer, as practiced in Georgenau, the **psychrophilic digestion** at approximately **20°C is not suitable** in most cases.
With the currently **preferred mesophilic fermentation temperature of approximately 33°C**, the heating operation can be limited to the winter season if the plant is well insulated in all parts. In this case, the fermenter heating system is usually sufficient, requiring around 10% of the produced biogas on average, assuming high gas slurry production is not the primary goal. In such cases, it is also advantageous to heat the mixing pit or pre-tank. The energy demand can then reach up to 20% of the produced biogas.

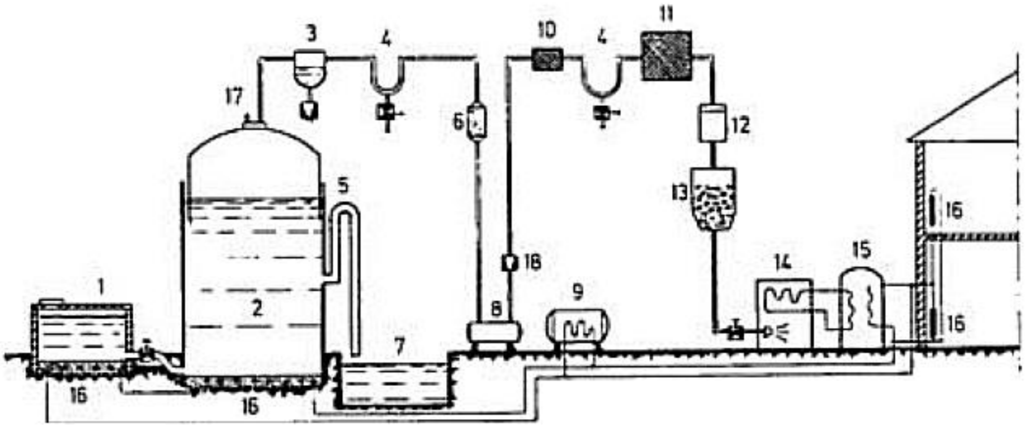
In the **thermophilic** operation with the highest throughput and gas production, almost every tank needs to be heated more or less throughout the year. The energy demand can reach 25 to 30%. However, the results in all aspects are optimal.

Biogas is used for all heating circuits, including for the biogas plant, heating living spaces and the kitchen, as well as providing hot water for the agricultural operation.

There are no fixed regulations for the size of the heating elements in the fermenters; only practical experience exists. Since heat transfer in liquids is significantly higher than in air, smaller heating elements are sufficient in the fermenter. About half the heating surface area of a traditional heating system can be used. Using a mixing valve, **the supply temperature, which should never exceed 50°C, can be reduced to maintain the fermentation temperature. The mixing valve is controlled, in** our case, by a remote thermometer placed in the fermentation mass. This ensures that the supply temperature of the heating boiler is always at the required level for heating and hot water.

The following heating and gas scheme clearly shows that all lines, of course, well-insulated, can be laid in the ground.

Image 6.13: Heating and Gas Scheme of a Medium-Sized Biogas Plant



1 Pre-tank	12 Gas meter
2 Fermenter	13 Gravel filter
3 Condensate separator	14 Heating boiler
4 Pipe drainage	15 Boiler
5 Siphon	16 Radiator
6 Gas cleaner	17 Overpressure valve
7 Biofertilizer	18 Relief valve
8 Gas pressure vessel	
9 Hot water tank	
10 CO2 absorber	
11 Desulfurizer	

6.5 Equipment

The anaerobic fermentation process, once initiated through inoculation, is inherently self-sustaining. When appropriately composed biomass, considering the **C/N ratio** and **correct liquid content**, is introduced daily, it requires minimal monitoring. This holds especially true for fermentation in the lower temperature range, known as the psychrophilic range. A seasoned practitioner can identify reasons for insufficient biogas generation using simple means. By the gas's odor, he can deduce its quality, such as the **presence of sulfur.** Using a thin pipe inserted into the interior of the digestate tower, he can measure the fermentation **temperature** or assess the **biomass's acidity level using litmus paper**. However, these measures only need to be taken when biogas production decreases, which can be observed through the lowering of the gas bell.

Nonetheless, the installation of a thermometer and a pH meter from the outset is cost-effective and helpful. For **pH measurement**, a small electrical **power source in the form of a battery** is necessary. A **sight glass** with an **internal lamp** in a moisture-resistant design aids in monitoring floating layers' dissolution. All of these entail minor expenses.

For medium and larger biogas plants, investing in additional equipment is worthwhile. A small **monitoring center** saves time and provides early indications when the system deviates from optimal values in terms of **temperature, acidity, gas quantities, or gas composition**. One can adjust the **heating** or **add straw or fresh biomass** to restore the most favourable process.

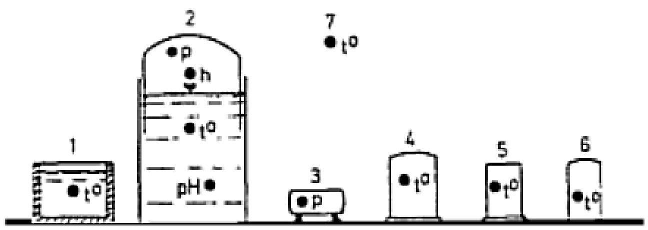
In the case of larger facilities, automation becomes essential. Deviations from the optimum will trigger appropriate actions automatically or at least raise an alarm to summon the facility operator. As a comprehensive study of almost all biogas plants has shown, the **average daily time spent on**

managing a biogas plant is half an hour. This is less time compared to what is required for manure disposal in non-biogas equipped operations.

A fully automatic programming of biomass flow from the barn to the expulsion of biofertilizer is not strictly necessary. However, for the initial years, personal monitoring is recommended to gain better control over the system.

After these general considerations, an overview of the possibilities of an **extensive monitoring and control system** for a large bio plant will be presented.

Figure 6.14: Monitoring Scheme for a Larger Biogas Plant



1 (t) Pre-tank temperature (° C)

2 (p) Gas pressure in the fermenter (bar)

2 (t) Fermentation temperature (° C)

2 (pH) Acidity level of biomass (pH)

2 (h) Slurry level in the fermenter

3 (p) Pressure in the gas storage (bar)

4 (t) Temperature in the hot water tank

5 (t) Hot water temperature in the boiler

6 (t) Hot water temperature in the heater (° C)

7 (t) Outside temperature (° C)

Especially vital for optimal biogas production are observations of **2 (t) and 2 (pH).** When the guideline values for the fermenter's temperature, approximately **32°C in the mesophilic range and about 52°C in the thermophilic range**, and the **acidity level of 6.7 to 7.5** are maintained, the system functions well. The other measured values indicate the proper functioning of auxiliary units that secure the primary values.

Whether the opening or closing positions on the control panel should be remotely displayed is a matter of personal judgment. It may also be of interest to know the temperatures in the gas lines to identify the risk of pipe freezing and frozen wastewater taps. If the display instrument is already available, monitoring stall temperature can also be achieved at minimal cost.

Finally, it is important to note that **all pipes, including gas pipes, must have a gradient to allow condensate water to flow towards designated drainage taps**. Biogas not only comes from a humid environment but also carries hydrogen with it. However, cleaning devices will not work if frozen water is present in the gravel or catalyst. Effective insulation of all gas lines is therefore necessary.

7 Guidelines for Self-Construction of Biogas Plants

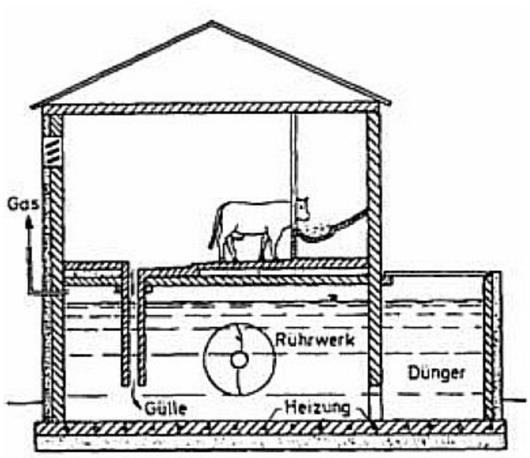
As the increasing number of biogas plants indicates, farmers are finding it progressively easier to decide on modernizing their farms with such facilities. They sense that they are falling behind the times.

In the following chapter, one of the many possibilities for constructing a properly sized biogas plant on their own will be presented. This is based on a specific farm size, an average agricultural operation. The conversion to a larger or smaller farm can be easily carried out by anyone using the provided information.

The "model farm" is assumed to have **20 livestock units**, and the biogas plant is intended to be added to the existing farm buildings.

First, a solution is presented for Case 2, which involves complete modernization.

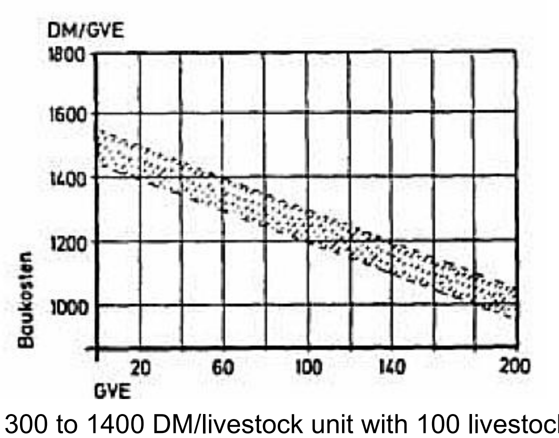
Image 7.1: Example of a Biogas Plant with Barn



In this compact system, the manure diluted by flushing is directed through a drain channel into the fermentation chamber. The **flushing liquid is preheated**.

The vertical concrete walls from the barn to the digestion chamber and between the digestion chamber and the biofertilizer storage extend deeply to prevent oxygen from entering the slurry. The fully digested biomass is already relatively insensitive to oxygen, so a wooden plank closure is sufficient for collecting the biofertilizer. The gas storage container is located outside the barn next to the wall. Since the fermentation chamber occupies the entire length of the barn, a clear height of about 2 meters is sufficient to allow for easy access for potential maintenance.

Image 7.2: Construction Costs of Biogas Plants without Self-Engagement



Now, turning to Case 1, the retroactive installation of a biogas plant. Before planning, the anticipated cost of the facility is of course of interest. While this cost depends on a series of assumptions, an average cost has crystallized from the many well-known biogas plants, and generally holds as long as everything is kept within a reasonable framework. Construction costs in DM/livestock unit decrease with the size of the plant. For instance, the costs for an agricultural operation with 200 livestock units range from 950 to 1050 DM/livestock unit, rising to about 1300 to 1400 DM/livestock unit with 100 livestock units, and reaching a height of 1450 to 1550 DM/livestock unit for 20 livestock units (our model farm).

This pricing pattern suggests the feasibility of a community plant for multiple farms. On the other hand, the proportion of self-contribution in a small plant is much higher, potentially keeping the price from being significantly higher. Depending on the level of self-contribution, up to 700 DM per livestock unit can be saved in our case.

This could reduce the cost of the biogas plant from 20 * 1500 = 30,000 DM perhaps down to 20 * 800 = 16,000 DM, with the possibility of deducting government subsidies (all prices are based on the year 1984). The plant would amortize itself in about 10 to 12 years solely through energy gain.

In any case, it poses no risk.

After determining the fermentation temperature – here in the mesophilic range of around 33°C – planning for the size of the digestion chamber can commence.

This size is roughly calculated based on the **daily manure yield + dilution times the retention time in the fermenter** (fermentation period).

A single cow produces about 40 kg of feces per day, along **with approximately 5 kg of bedding material (10%)**.
The feces also already contain a certain level of dilution, resulting in a desired **dry matter/dilution ratio of 1/9**. Therefore, the **liquid manure per cow** amounts to **45 kg/day.**

For 20 cows, this totals to 900 kg/day.

Assuming a **fermentation period of 30 days**, the active digestion chamber size is **0.9 * 30 = 27 m³** (per tonne = 1 m³ * days).

Since the density of liquid manure is approximately **1 kg/dm³ = 1 t/m³,** the calculation can equate one tonne to one cubic meter.

For the **gas space above the manure level in the digestion chamber, we need to allocate 20% of the active fermentation space to gas**. Thus, the total volume of the digestion chamber is **27 + 0.2 * 27 = 32.4 m³.**

However, to provide a margin, a digestion chamber size of **40 m³ is chosen.**

The dimensions could, for example, be determined as follows:
The diameter of the **digestion tower** should be **3 meters**.

This results in a cross-sectional area of **π * r² = 1.52 * 3.14 = 7.065 m².**

Dividing the digestion chamber volume of **40 m³** by the cross-sectional area gives a digestion chamber height of **h = 40 / 7.065 = 5.66 m,** rounded up to **5.7 m**. This includes 20% gas space.

The manure level is assumed to be at a height of **0.8 * 5.7 = 4.56 m**, rounded up to 4.6 m. Naturally, a larger or smaller diameter can be chosen, resulting in different heights.

Thus, the dimensions of the digestion chamber are established, and attention can now be directed toward the gas dome.

Since a gas bell with a pressure of **0.05 bar** requires significant weight, the **minimum weight** of the **gas bell** for this system is **70,650 cm² * 0.05 = 3,532 kg = 3.5 t**, which would likely cost over 10,000 DM. By tapering the upper part of the digestion tower to a clear width of 1.2 meters, a bell weight of 0.56 t can be achieved. If this is still too heavy, the bell diameter can be reduced. However, that leads to excessive movement of the bell during changes in gas volume. Therefore, a diameter of 1.2 meters with a spring suspension is recommended.

Before starting construction, the suitability of different building materials should be evaluated. In Table 7.1, the numbers indicate suitability as follows: 1 = very good, 2 = conditionally suitable, 3 = unsuitable. **LINK to calculation table for your own numbers**

Table 7.1: Suitability of Building Materials

Material	Pre-tank	Fermentation Chamber	Fertilizer Chamber	Gas Chamber
Wood	2	3	3	3
GRP (Glass-Reinforced Plastic)	2	1	1	1
Films	3	2	2	2
Plastic Mesh	3	2	2	1
Hard Foam	1	1	-	3
Concrete	2	3	2	3
Reinforced Concrete	1	1	1	2
Masonry	1	2	1	2
Steel Sheet	3	1	2	1

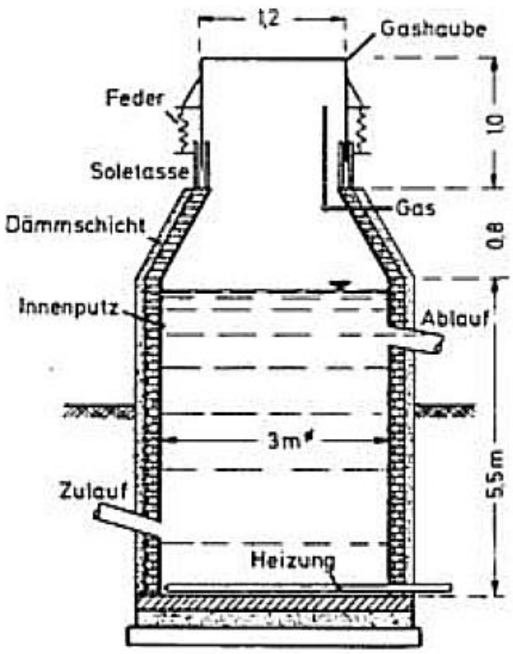
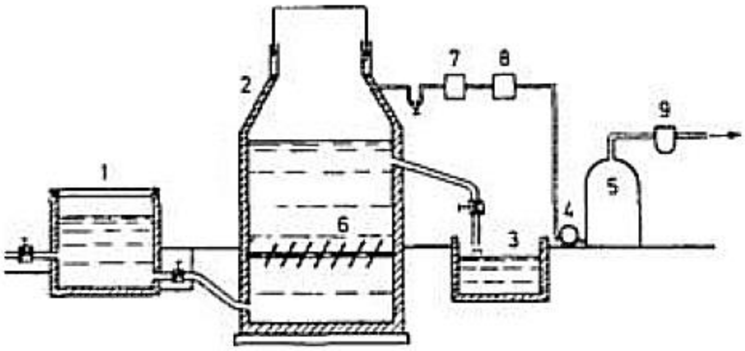


Image 7.3: Design of a Digester Tower with Gas Bell for 20 Livestock Units

Before construction begins, thermal insulation planning is essential. It is advisable, in any case, to place **a layer of rigid foam on the concrete base plate and cover it with a reinforced concrete plate** that already contains **embedded heating coils**. The construction of the circular tower must be densely mortared, both inside and outside, with an **additional tar-epoxy coating on the interior plaster**.

The upper masonry cone must be carefully measured to accommodate the steel cup, approximately 70 cm high. A 5 cm gap is sufficient between the inner and outer rings of the cup. The stainless steel gas hood should be 0.9 to 1 m in height. A steel ring is welded onto both the cup and the hood, between which a spiral spring of at least 60 cm in length can be mounted. If building without the spring suspension, the necessary bell weight of 0.65 t can be achieved by placing a round concrete disk of 10 to 15 cm thickness, depending on the weight of the steel hood.

Naturally, all installations must be defined and ideally procured before construction begins to ensure proper compatibility. The preliminary work cannot be too precise, with the **dissolution of floating covers** ideally carried out using **low-speed agitators** to save energy and **prevent foaming**.



1. Mixing Pit
2. Fermenter
3. Manure Pit
4. Compressor
5. Pressure Gas Tank
6. Agitator
7. CO2 Absorber
8. Desulfurizer
9. Gravel Filter

Image 7.3: Design of a Digester Tower with Gas Bell for 20 Livestock Units

The necessary **shut-off valves, drainage taps, gas and manure pipes** should be determined based on the local conditions.
All devices like 7, 8, and 9 should be situated **between two closure mechanisms**, enabling replacement during operation without introducing oxygen into the lines.

The size of the pre-tank or mixing container should be tailored to the conditions of the individual farm. For instance, if the liquid manure is used immediately every day, the pre-tank could be constructed to hold only the volume of liquid manure generated in a single day. However, this is unlikely to be the approach chosen. Some systems have pre-tanks capable of holding manure for 30 days. The size determination depends on various factors, such as the operational flow of the property, the temporal focus of gas demand, the size of the digestion chamber, fermentation temperature and period, varying livestock numbers, and available space. Taking the average from many biogas plants suggests a pre-tank capacity of 6 to 8 times the daily liquid manure.

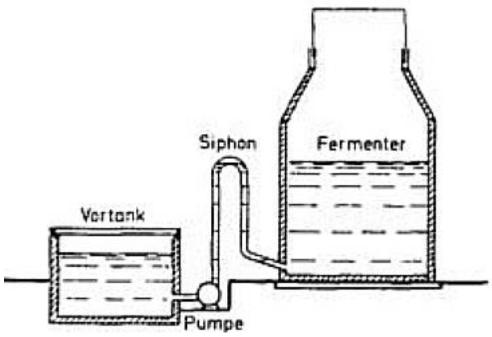


Image 7.5: Inlet from Pre-tank to Fermenter with a Siphon

If the **pre-tank**, as proposed, is intended not only as a mixing space but **also as an interim storage**, efficient **thermal insulation** and moderate heating are essential to bring the refill amount at least close to the fermentation temperature. The effort for this is not significant. Furthermore, warm water is already available.

The supply of liquid manure from the barn to the pre-tank is usually straightforward. A **simple slide valve** is sufficient as a barrier. The high manure level in the fermenter requires preventing the flow of fermenter contents into the pre-tank when the shut-off valve between both tanks is opened. With the help of a pump, the **flow direction should only be from the pre-tank to the fermenter**, not the reverse. Theoretically, of course, the pre-tank could be raised to the height of the manure level in the digestion chamber, but this is rarely feasible. Additionally, the **siphon** also acts as an **airlock**. For example, if the pump sucks air due to a low liquid level in the pre-tank, the manure level in the siphon prevents the entry of air into the fermenter. However, the pump must be vented before being put back into operation in such a scenario. If the pre-tank contains more biomass than the amount generated in a day or refill, and if manual switching is not practical, the filling amount must be controlled via a time relay, which only activates the pump during the necessary filling time.

For an undisturbed fermentation process in the fermenter, it is sufficient for **the refill amount** to be heated to approximately **5°C below** the fermentation temperature.

Since the fully digested slurry no longer poses an odour issue and is hardly affected by oxygen exposure, there are no restrictive factors influencing the size of the biofertilizer container or pit. It's also advantageous that biofertilizer can be applied to the fields when it's convenient or suitable. It's not an ecological burden and retains its nutrient value for plants.

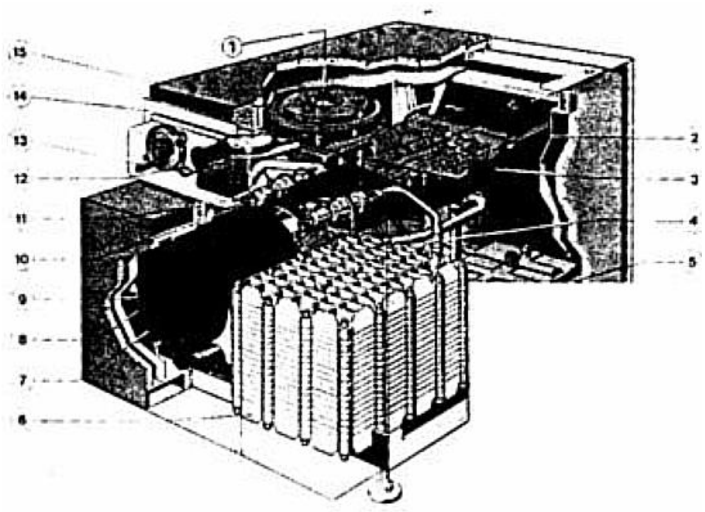
The size of the slurry lagoon can be freely chosen. The discharge of the fully digested mass from the digestion chamber should be at least 1 meter above the floor of the fermenter and about 1 meter below the manure level. The lower discharge height is determined by the retention of seeding material in the digestion chamber. The upper value for the location of the discharge pipe is related to the potential presence of a floating cover that could obstruct the pipe during drainage. Additionally, there's a risk that if the manure level is too low, oxygen could enter the fermentation mass through the pipe. To prevent this with certainty, **a siphon is often provided** on the discharge side in addition to the shut-off valve.

Naturally, no more biofertilizer should be removed than liquid manure added on the other side. Therefore, it's worth emphasizing the installation of a viewing window again, as the floating cover prevents accurate level measurement. Without a **viewing window** in the conical part of the tower, one could easily lose sight of their biogas plant.

8 Additional Energies

The efficiency of all combustion processes is notoriously low, averaging around 50% in heating boilers and 25% in gas engines over the course of a year. Seventy-five percent of this energy is lost as heat. Therefore, the industry has developed so-called TOTEM systems (TOTAL ENERGY MODULE), which involve combined heat and power generation. Within a compact space, a gas engine, generator, heat exchanger, hot water tank, and electrical control devices are integrated into a sound-insulated container. Through the utilization of waste heat, the efficiency of gas utilization increases to 95%.

The cost of such systems is (as of 1984) between 15,000 and 20,000 German Marks for a 15 kW unit. Some of this cost can be recovered due to having access to a more versatile form of energy, namely electric power, and potentially selecting a shorter period of inactivity in the summer. This is the time of highest biomass availability. Consequently, the biogas plant can be designed somewhat smaller. Asynchronous generators, which require external excitation, are often used in these systems. Synchronous generators enable independence from the power grid.



1 = Engine
2 = Water tank
3 = Exhaust water heat exchanger
4 = Oil-water heat exchanger
5 = Oil tank
6 = Water-water heat exchanger
7 = Hot water outlet
8 = Exhaust gas outlet
9 = 15 kW generator
10 = Cold water inlet
11 = Power grid
12 = Air inlet
13 = Biogas supply
14 = Profile frame construction
15 = Noise-reducing panels

Figure 8.1: TOTEM System, 15 kW by FIAT

An **additional energy source** for biogas is of great advantage, especially for small agricultural operations. Through it, one can often achieve nearly complete self-sufficiency in energy, with biogas ideally taking on the role of an energy storage medium, while solar and wind energy provide the required energy during their favourable hours and days. To what extent this can be achieved with minimal effort, some indications will clarify.

If a few **solar collectors are** oriented towards the southwest to southeast, then one square meter of collector area on sunny days between 10 AM and 4 PM in our latitudes yields about 2 kWh/day. Over 120 sunny days per year, this results in 240 kWh/year per square meter. With only 10 square meters of total collector area, this amounts to 2,400 kWh/year. The DIY production of solar collectors is relatively straightforward.

Using **wind energy** isn't much different. An average wind at 2,500 hours per year with a speed of 5 m/s produces a power of 35 W per square meter of wind turbine area. If we build a wind turbine with a 6-meter diameter, this corresponds to an area of 28.26 square meters, which at 35 W/m2 offers around 990 W = 0.99 kW and generates about 2,475 kWh/year during the 2,500 hours of wind per year.

The **biogas facility** of an agricultural subsidiary with **5 cattle produces approximately 2,500 cubic meters of gas per year** with a **calorific value of 13,750,000 kcal** (calories multiplied by 5,500). With a conversion efficiency of 50%, this calorific value translates to an annual output of **8,000 kWh.**

So, all three types of energy together yield the subsidiary farmer:

2,400 + 2,475 + 8,000 = 12,875 kWh per year, which they do not have to buy from an energy supply company.

Larger agricultural operations will naturally use much more than 10 square meters of collector area. A collector area of 5 x 10 square meters is quite common and already yields a heat output of 12,000 kWh/year. However, self-built wind turbines are hardly larger than 8 meters in diameter. Furthermore, industrial installations are necessary for turbines with a diameter of 10 meters and a power output of 10 kW, costing between 30,000 and 50,000 German Marks.

Medium to larger agricultural operations, where significant amounts of heat are generated in the barn, have the option of **using heat pumps**, especially if they generate their own electricity. This significantly increases the economic viability of the heat pump when the compressor's electricity does not need to be purchased. From a barn, about 5,000 kcal per livestock unit (GVE) can be gained daily.

9: Operation of Biogas Plants

9.1 Commissioning

Initiating the operation of a biogas plant involves introducing anaerobic bacteria into the biomass stored in the fermenter. This process is referred to as "**seeding**" the biomass.

As anaerobic bacteria are intolerant to oxygen, during the setup of a new facility, measures must be taken to **remove air from the fermenter**. For this purpose, the digester must be hermetically sealed. All lids, shut-off valves, inlet and outlet pipes, as well as gas lines, need to be closed.

Various methods exist for ventilating the fermentation chamber:

- Filling the **fermenter with water**, attaching a **steel cylinder containing compressed methane gas** to a gas pipe, and then gradually draining the water. This fills the digester with methane gas in proportion to the decreasing water level. This is the safest method as there is no explosive gas present in the chamber at any moment, and a favourable environment is created for the subsequent methane bacteria.
- Oxygen can be depleted through **combustion processes within the fermenter,** using wood, gas, or liquid fuels.
- Removal of air from the digester can also be accomplished by **suction with a vacuum pump**, followed by the **introduction of carbon dioxide**. However, introducing biogas would lead to the accumulation of a highly explosive gas mixture over time, which must be avoided.

Once the fermentation chamber is free of oxygen, the filling of the chamber with biomass can commence. **Initially**, the digester is loaded with **approximately 15% of its volume with fresh liquid manure**, consisting of half unfermented material and half anaerobically fermented material as the seeding material. The **ratio of manure to liquid** should be initially mixed at **1:10** during the initial filling to prevent premature acid formation and bind any remaining oxygen. After a few days, daily portions of manure and slurry can be added, preferably from an existing mixing pit **with the correct temperature**.

Regarding initial seeding, it is worth noting that cultivating methane bacteria is too time-consuming to be practical. It is simpler and more effective to obtain the corresponding biomass from sewage treatment plants, provided assurance is given that they do not contain heavy metals, toxins, or estrogens. If another nearby biogas plant is available, its material should be preferred. Naturally, the seeding material must be hermetically packaged for transport.

Maintaining the fermentation temperature, in our case **33°C, is essential from the outset**. It is advantageous to **heat the entire digester for a week prior to the initial filling**. Instances arise where the fermentation process does not initiate in new installations. Often, this is due to inadequate temperature or too rapid filling of the fermentation chamber. **Filling should ideally commence only after the initial filling has released some methane**. Additionally, excessive acidity often hinders anaerobic fermentation. **Ensuring all valves are closed is crucia**l; a single leak reintroduces air to the digester, necessitating a repeat of the oxygen displacement process.

With adherence to all fermentation guidelines, the biogas plant should generate nearly full methane gas **production within three weeks**, which is not immediately utilized.

Initially, **all lines and gas containers are flushed with the first gas by introducing gas for hours through open drain valves until it can be assured that no residual air remains in any gas chamber, which could form an explosive mixture with methane**.

Supply lines to **consumption devices** such as stoves and boilers must also be briefly flushed with methane gas through open windows to expel air from these lines. Afterward, consumption devices can be turned off and, following ventilation of the rooms, are ready for use. Operating no longer differs between natural gas, town gas, and methane. If burners are already equipped for town gas, no replacement of burners will be necessary for methane operation. As methane gas burns virtually odourless, it is recommended to use newer stoves and appliances that automatically shut off the gas supply when the flame goes out.

9.2 Operational Procedures

The presence of a biogas plant significantly alters the tasks on a agricultural property, streamlining them. However, in the absence of an automated stall cleaning system, manure still needs to be manually removed as before. The distinction now lies in the fact that manure is no longer dumped outside the house but is immediately transported to the mixing pit. There, it **is homogenized, mixed, and pumped into the digester using a multipurpose pump.** A daily inspection around the plant may involve one or two rounds to ensure everything is properly sealed. Over time, even this will reduce to a weekly check. Only the **fermentation temperature and gas meter readings** need to be recorded daily.

After the daily feedstock addition to the digester, an equivalent amount of fermented biodigester residue will generally flow out, which, if sufficient in quantity, can be directly applied to the fields. This concludes the stall and manure-related tasks for the entire day. The application of **biodigester residue offers flexible timing as it is odourless, non-putrescent, and retains its nutrient value**.

Other farm tasks are also transformed to some extent. Methane gas simplifies certain chores. If the tractor is adapted for methane use, it will be employed even more, as the energy comes at no additional cost. Manual labour is gradually reduced. Excess gas can be used to dry hay.

9.3 Operating Regulations

Managing explosive and toxic substances and gases necessitates adhering to specific safety regulations to avoid endangering individuals, animals, oneself, and the property. Pertinent guidelines can be obtained through agricultural authorities. These encompass universally applicable fact sheets regarding the handling of methane, carbon dioxide, carbon monoxide, hydrogen sulfide, and sulfur dioxide, as well as the specialized accident prevention regulations for biogas plants. All of these should be displayed in a visible location, preferably behind glass. This is also a stipulation. Everyone involved with the biogas plant must be familiar with and abide by them. Employed personnel should be educated every quarter about these regulations. It's highly advisable to obtain written confirmation of these educational sessions.

In addition to legal safety requirements, operational instructions for the biogas facility and regulations from the Technical Inspection Association (TÜV) are also applicable. It's recommended to establish contact with the nearest TÜV during the construction phase. They often offer free valuable advice that enhances the plant's safety. Currently, biogas plants are not required to undergo TÜV inspections and approvals. However, if pressure vessels, such as those used for methane gas storage, are employed within the facility, they must undergo TÜV examination once they exceed a certain pressure and size threshold. The exact regulations in effect can be obtained from the TÜV.

9.4 Accident Prevention Regulations

Preliminary Note

During the decomposition of organic matter (manure, humus, leftover feed) within cesspits, channels, etc., a combustible gas forms in the absence of oxygen. This gas, largely composed of methane (CH_4) and carbon dioxide (CO_2), is known as marsh gas, sewage gas, manure gas, digester gas, and biogas. This gas can be utilized for heating and as fuel for internal combustion engines, making it a byproduct of specialized facilities known as biogas plants. Biogas does not contain carbon monoxide

(CO), making it non-toxic. However, it can lead to asphyxiation due to its lack of oxygen. **When mixed with air (oxygen), biogas becomes explosive**. Prior to entering fermentation chambers for cleaning, repairs, or similar tasks, the containers must be ventilated using appropriate equipment such as blowers until the flame of a safety lamp remains steady, indicating that an adequate amount of breathable air is present for human occupation. Carrying out a flame test in the presence of open flames is prohibited due to explosion risk. Gas masks do not provide protection, as they can only be used in environments with breathable air. An individual entering must always be held by two individuals on a rope and observed, allowing them to be quickly pulled out in case of danger, such as the safety lamp going out, without requiring another person to enter. Correct roping procedures are demonstrated in the illustrations in Section 3.

Regulations

§ 1:

The following accident prevention regulations apply to biogas plants with a container capacity of up to **100 cubic meters**. For larger facilities, the accident prevention regulations of the trade associations for gas and water utilities apply.

Facility

§ 2:
Biogas plants must be constructed in accordance with recognized technical standards.

§ 3:
The entrepreneur must entrust the construction of the biogas plant to an experienced company specializing in such construction, under the condition that the facility adheres to the provisions of Section 2 and the subsequent accident prevention regulations. A comprehensive operating manual must also be provided.

§ 4:
(1) The fermentation and pumping rooms must be equipped with **ventilation systems** that allow thorough ventilation within a short time.

(2) A sign with the following inscription must be posted at the fermentation chamber:

Risk of Suffocation and Explosion!

Entry only after thorough ventilation and a flame test using a safety lamp. The person entering must be roped and observed by two individuals."

(3) A safety lamp and ropes for roping (safety harness) must be kept available at a suitable location.

(4) Gas containers must be situated at a sufficient distance from residential buildings, stables, storage areas, and public roads. Minimum distances for soft roofs are 10 meters, for hard roofs 5 meters, and for public roads 5 meters, unless otherwise specified by the permitting authority. If container installations are not located within the yard, they must be secured against unauthorized access by enclosing them.

(5) Smoking and open flames near gas containers are strictly prohibited and must be communicated through permanent notices.

§ 5:
Electrical systems in explosion-prone areas must comply with the regulations of the Association of German Electrical Engineers for the installation of electrical systems in hazardous workplaces (VDE 0165) and for explosion-protected electrical equipment (VDE 0717).**

Operation

§ 6:
The independent operation and maintenance of biogas plants may only be assigned to reliable individuals with expertise in this field.

§ 7:
Maintenance instructions (operating manuals) must be observed. They must be displayed in operational rooms or at the facility itself.

§ 8:
The water level in the bell-shaped gas containers and the mobility of the containers must be regularly checked. Ice formation must be prevented during winter.

§ 9:(1)
Before entering the fermentation tanks for repairs, painting, or removal of sediment, any accumulated biogases in the room must be removed through thorough ventilation using the designated equipment. The room may only be entered after determining, through a safety lamp, that sufficient breathable air is present. Entry is permitted only while carrying a burning safety lamp in the presence of two individuals holding the person entering on a rope (safety harness), continuously observing the burning of the safety lamp and the person entering.

(2) In case of accidents, § 3, Paragraph 3, must be observed.

§ 10:
Repairs to containers and pipelines may only be carried out by an expert (manufacturer of the biogas plant). This applies especially to all welding and soldering work on the gas container and pipelines.

§ 11:
Smoking, use of open flames, and fire within a radius of 10 meters from gas containers are prohibited.

§ 12:
When renewing protective coatings in the containers, Section 3, Paragraph 2, applies accordingly.

Section 9.5 - Operating Instructions

For handling biogas plants, regulations issued by agricultural trade associations apply, especially sections 4 to 26 for biogas plants and manure tanks from the time of initial filling, even if the plant is still or again open.

Maintenance and operation must only be carried out by knowledgeable personnel. Existing support staff must be familiarized with relevant regulations.

Within a radius of 15 meters, smoking, open flames, or fire must not be maintained. Access to biogas plants, including gasometers, must always be kept clear and ice-free in winter. The same applies to escape routes.

If gas-carrying parts, equipment, and lines, or the entire biogas plant, are housed in enclosed spaces, intensive ventilation must be provided. Closing ventilation facilities, such as windows, must be technically prevented; otherwise, sensitive gas measuring devices must be installed, which give an alarm when the gas content in the air reaches 4%. It is best to plan two independent measuring and ventilation systems.

Fire extinguishers of the ABCE type P 50 are suitable. The prescribed fire extinguishers must be installed so that they are within reach of the potential fire site. They must be protected from weather influences. A small roof is usually sufficient. Above all, they must never be obstructed. They should be checked for removability every quarter, which also ensures that they can be found in case of emergency. Fire extinguishers must be inspected, refilled, or replaced with new ones at the prescribed intervals by a monitoring service. It is advantageous for the owner to be present during inspections. Personnel must be familiarized with the use of fire extinguishers annually.

Electrical installations in all rooms that may contain gas must comply with regulations VDE 0165 and regulations for explosion-hazardous workplaces. They must generally be installed by approved electrical installers and inspected by the relevant energy supply company.

The same applies to modifications to electrical installations. Existing electric motors, generators, contactors, handheld lamps, etc., must comply with the protection class of VDE regulation 0171.

The use of so-called isolation transformers when using electrical machine tools, including handheld lamps, is recommended for each device separately in biogas plants. This is necessary to prevent fatal accidents in case of insulation faults in cables. The voltage of 220 volts is often underestimated. The accident prevention regulations also allow a tool voltage of 40 volts. In that case, isolation transformers are not required. However, converting everything to 40 volts is not only cumbersome but also expensive.

When working in the digester, even after an extended opening time of the container, it must be considered that gas is still present. After each work interruption, a test for gas-free conditions must be performed before entry, and the area must be ventilated. Gases can continue to escape from the bottom sludge and concrete pores for an extended period.

Two components of biogas have a density less than 1 and therefore naturally rise. These are methane and hydrogen. All other components such as the toxic carbon monoxide and hydrogen sulfide are heavier than air and settle downwards, as does carbon **dioxide (25 to 40%). As it contains no oxygen, it leads to suffocation. These** gases must be vented upwards using a fan before commencing work in the fermenter. Ventilation of the room must be carried out for several hours until it is deemed safe to enter with all precautions in place. This includes using a safety lamp to avoid igniting any remaining explosive gas. Even after hours of ventilation, the heavier gases at the bottom of the pit remain dangerous, some being toxic and others suffocating. Once it's certain that no explosive gas is present, a candle can be lowered. If it goes out, carbon dioxide is still present, and the area must not be entered. However, if it's necessary to enter for the rescue of another person, **an oxygen mask is required.**

During periods of downtime, such as nighttime or Sundays, the pit must not be covered, as sulfur hydrogen may still be present in pores or crevices. However, the opening must be secured with a railing around the clock, whether work is being performed or not. It's even mandated that a note is affixed to the railing, indicating who is authorized to remove the railing or turn off the fan.

Section 9.6 - Maintenance Work

When repairing or revising fermenters in winter, it's important to remember to drain all pipes and keep the valves open. After completing the work, the pipes must not only be closed again but also tested for leaks. To do this, the lines are pressurized (2 or 3 bar) and a pressure gauge is observed to check if the pressure remains the same over a day. **Leaking points** can often be quickly **identified using soap foam** at all connection points.

A second person must always be present nearby during work in pits.

When working from platforms, railings must be installed. Additionally, the person must be secured with a rope, which is advantageous in pits to enable lifting if the individual becomes unable to do so themselves.

Section 9.7 - Maintenance Work

Every system operates reliably only when regularly maintained. This is essential to prevent costly repairs or production interruptions. Moreover, the effort required for maintenance is usually minimal.

This holds true for biogas plants as well, where maintenance tasks are limited to a few simple steps each day. These include:

Daily:

- Recording temperatures, pressures, gas meters, which should be documented in a logbook to identify long-term changes.

Weekly:

- Checking all system components for leaks. This requires no specific work; a visual and olfactory inspection is sufficient. All movable parts, units, pumps, and stirring equipment should be manually activated briefly, with attention to any unusual noises. In winter, it's advisable to verify the operability of shut-off valves and, if necessary, defrost them—however, not with hot water, but with warm air or sandbags.

Monthly:

- Lubricating shut-off valves, performing lubrication service, draining pipelines, checking the antifreeze level in the gas hood cup, measuring acidity, detecting gas odor.

Semi-annually:

- Inspecting the system for cracks and leaks, taking and analyzing water samples in the operational area to ensure they are free of slurry, cleaning open pits, renewing or replenishing filters with new filtering material, conducting oil changes if the operating times have been sufficiently long. In any case, all oils should be changed annually due to natural aging.

Annually:

- Comprehensive inspection, and if possible, cleaning; perform necessary overhauls if required, renew coatings, remove rust, inspect and repair insulation, maintain fire extinguishers, check all cables, and replace them if necessary.

Figure 9.2: Large Biogas Plant in Liebenau - 850 m3/d Gas, 1983

Section 10 - Cost-effectiveness

The cost-effectiveness of a commodity or installation is generally determined by the following factors:

- Utility value
- Production costs
- Operating costs
- Utilization
- Follow-up costs

If we set aside all ecological benefits associated with a biogas plant and create a cost-benefit analysis, the **price for one cubic meter of biogas (P_{Gas})** can be calculated as follows:

$$P_{Gas} = \frac{A + Z + B - H - D}{E1 - E2}$$

Where:

A = Annual depreciation sum
Z = Annual interest
B = Annual operating costs
H = Heating oil savings
D = Savings on commercial fertilizers
E1 = Annual energy generation in Nm^3
E2 = Annual consumed process energy

Taking the example of the Gilching biogas plant, where individual values are known:

The total construction cost of the entire plant was 96,261 German Marks (DM), without any self-performed work.

The average annual gas production is 32,850 Nm^3

Around 10,000 Nm^3 of process energy is consumed per year. (1/3)

The annual heating oil savings amount to 5,000 liters (equivalent to approximately 3,700 DM based on 1984 heating oil prices).

Annual operating costs are estimated at 500 DM. The electricity requirement is self-generated. Working hours are not factored into the calculation.

Precise information on savings from commercial fertilizers is not available, but they are estimated at 800 DM per year.

With a **depreciation rate of 10%** per year, this yields the following gas price:

$$\frac{9{,}626 + 4{,}000 + 500 - 3{,}700 - 800}{32{,}850 - 10{,}000} = \underline{0.42\ DM/\ Nm^3}$$

Here is a **LINK to a calculation table** for your **own numbers:**