Project no. **513949**

Project acronym: **EU-AGRO-BIOGAS**

Project title: **European Biogas Initiative to improve the yield of agricultural biogas plants**

Instrument: **Specific targeted research or innovation project**

Thematic Priority: **Priority 6, Sustainable Energy Systems**

Deliverable 08: Benchmarking Report on Critical Points and Influential Factors at Agricultural Biogas Plants

Due date of deliverable: **2007-06-30**
Actual submission date: **2008-02-04**

Start date of project: **2007-01-15**

Duration: **36 months (2005-2008)**

Organisation name of lead contractor for this deliverable:
Partner N° 2, IGER

Abstract

To assess and improve the production from European biogas plants a specific targeted research or innovation project (Project no. 513949) entitled ‘European Biogas Initiative to improve the yield of agricultural biogas plants’ involved collating data from 13 biogas plants across Europe. Data was collected by four means; the use of periodic data from the biogas plant, weak-point analysis from each of the biogas plant operators; a questionnaire and a schematic of each plant. The information revealed that although the biogas plants were performing relatively well, with an average specific biogas yield 0.44 m^3.methane.kg^{-1} VS and an average methane productivity of 1.25 m^3.m^3, there was considerable capacity to improve the performance of each of the biogas plants by a range of different means.

Economic comparison of these biogas plants across Europe was difficult. However, about 90% of the revenue was realised from electricity sold. The average specific capital expenditure for the 13 biogas plants was about 4,400 € per installed electric capacity (kW) or at 5% discount rate and 15 years economic life, 5.3 €-Cent per kWh of electricity. The average costs of feedstock was 5.6 €-Cent per kWh electricity produced. Also the average cost was 67 €-Cent per Nm^3 of methane produced. The average total costs were 19.5 €-Cent per kWh electricity produced which was slightly above the price paid in most of the countries involved.

Development of improved means of both introducing and treating the feedstock was important for improved biogas yields. The hydrolysis of crops and crop residues could significantly reduce the HRT of some digesters to below 100 days. The type and mixture of feedstock also influenced the biogas yield and optimisation of the inputs would be of benefit. However each feedstock may ferment at different rate and/or require different conditions so process control could produce more biogas. High levels of manure required up to 4 times as much volume as other feedstocks to produce the same amount of biogas.

There was up to 3 times the methane output per kg VS from different biogas plants. Some biogas plants had a variability (on standard deviation) of the specific methane yield as low as 7% others could be considered unstable with values over 100% of their mean values. Feedstocks were considered responsible for this variability, however such a range suggests that process monitoring and control would provide more stable biogas production and improved biogas yields. Monitoring fermentation parameters was limited to pH and volume of the various vessels for all biogas plants. Sensors did include means of measuring VFAs (36% of the total) and conductivity (18%) and redox potential (9%) for the 13 biogas plants.

The outcome of this study will be used to identify demonstration projects at different biogas plants and research facilities.

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1. Document Description

This report was produced as a requirement of Task 2.1 of work package 2 in the EU-AGRO-BIOGAS project entitled European Biogas Initiative to improve the yield of agricultural biogas plants Proposal/Contract no.:019884. Task 2.1 is defined as “Benchmarking of European biogas technologies and plants” (Months 2 – 6). Project partner 2 (IGER) acts as work package leader.
This deliverable provides information by benchmarking performance and technical parameters of existing agricultural biogas plants based on existing data. All project partners except for Partner 14 (RTDs) were involved as shown in Table 1.

Table 1. Project partners

Participant id:	1	2	3	4	5	6	7	8	9	10	11	12	13
Person-months per participant:	2.5	14.0	2.5	2.5	4.5	2.5	2.5	2.5	2.5	2.5	1.0	1.0	2.0

2. Introduction

This study will be based on the selected biogas plants from each of the partners. Information on the selected individual biogas plants can be seen in **Appendix I** which shows the output and input capacities of the biogas plants involved in the benchmarking process**. Appendix 2** describes their basic fermentation parameters. The average maximum and standard deviation for feedstock inputs are in **Appendix 3** and are arranged in order of fresh matter volume used. The most influential parameters that have an impact on the biogas yield and economy will be identified by the partners and benchmarked.

2.1 Objectives of benchmarking biogas production

⇒ To quantitatively assess biogas production processes primarily as inputs, fermentation and outputs
⇒ A means to improve biogas production/efficiency and potentially reduce environmental impact.
⇒ The objective of this work will be achieved based on both collected operational data and partners’ experience. The relevant targeted operational and fermentation parameters were identified following an initial science meeting of the partners. The agreed standard parameters for each biogas plant were collated in datasets from biogas plants across the EU through the science partners’ efforts.
⇒ The resulting data were analysed as well as critical (weak points) points identified by the operators at the selected biogas plants. This was necessary for planning and setting up demonstration activities, but also for planning automatic monitoring, management and development of an early-warning system. Some of the data from task 1.3 will be used in task 2.1 to benchmark the quality of the raw materials.

2.2 Overview of the function of a biogas plant

The function of the biogas plant is the production of biogas as a fuel from the fermentation of organic wastes and crop or crop residues. Primary interests of reduced environmental impact of energy production have motivated the resurgence in biogas production. Therefore the most efficient biogas plant will have undoubted benefits for the environment by reducing methane from wastes sources and providing non-fossil fuel energy. Biogas is about 70% methane and 30% CO_2. Methane producers are microbes, known as ‘methanogens’, and belong to some of the oldest groups of organisms, known as the *Archaea*. These are common in wetlands, where they are responsible for producing marsh gas, and in the gut of ruminants such as cattle and their faeces.

In terms of biochemistry, there are four stages to the production of biogas by the anaerobic digestion of degradable organic materials. The early stages of breakdown require an acidic environment, whereas in the later stages, when the methane is actually produced, a neutral pH environment is advantageous. To enable biogas production at the commercial level, there are a range of technical approaches: the two-stage system (Fig.1) can accommodate more efficient microbial activity. This is because of antagonistic processes that occur. The two stages are one, hydrolysis which produces an acid environment can be autocatalytic and two methanogenesis which requires a neutral pH.

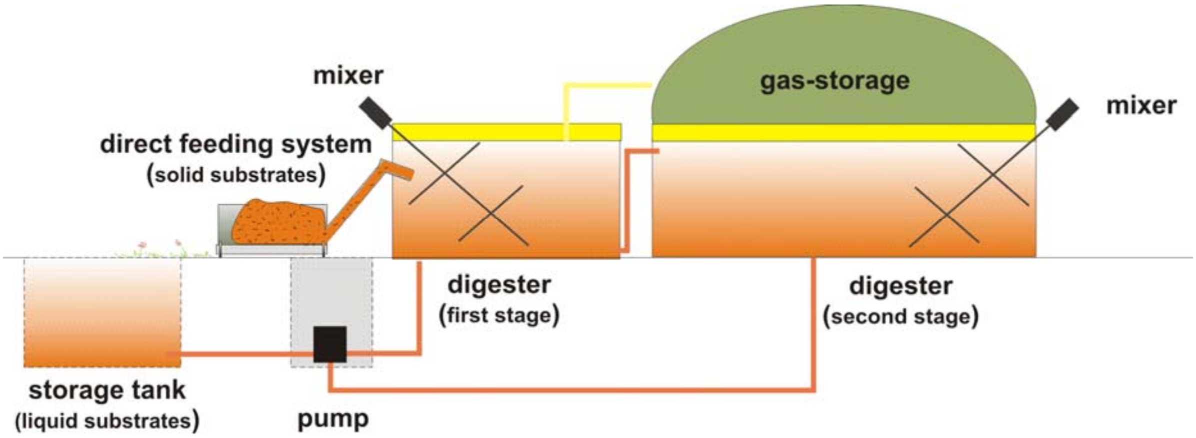

Figure 1 Typical biogas plant

However, a single-stage tank can be used which simplifies production and reduces the initial capital costs. There are variations on these designs (Fig.2). Some of the basic premises of biogas production are that a stable fermentation process and a high methane yield can only be achieved if the feedstock is well mixed, chopped and fed at a nearly constant rate through direct feeding systems into the digester. Most digesters operate better with a constant feedstock type and an input of about 5 to 15% w/w dry matter. However there is increasing use of solid inputs such as silage from maize or grass crops that requires the use of an effective mixer and input system. Gas has to be stored before use and sulphides and occasionally CO_2 are removed prior to use(Fig.1) At present most biogas plants produce electricity for the national grid (35% of the energy from biogas) and the heat which is about 60% of the energy can be exported for use as well as a small fraction being used to heat the digesters.

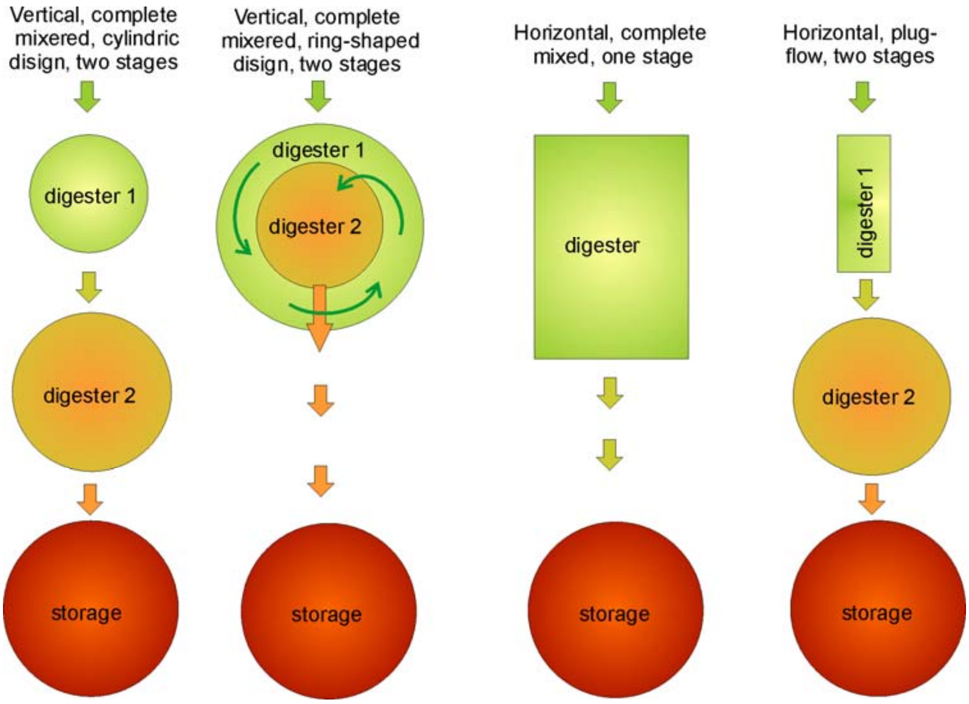

Figure 2 Current types of digesters designs in Europe

The vertical digester is a completely mixed digester usually made of reinforced concrete. The substrate is continuously mixed during the digestion process in order to keep the solids in suspension. Biogas accumulates at the top of the digester. The standard size of vertical digesters is between 500 and 3,000 m^3. In horizontal plug flow digesters the substrate flows semi-continuously through a horizontal tank. Plug-flow digesters are in most cases made of steel and have a volume between 50 and 150 m^3. Horizontal completely mixed digesters are usually made of reinforced concrete and have a volume between 1,000 and 2,000 m^3.

The important biogas plant parameters are grouped with their common units as follows:

Inputs outputs

- Feedstocks: $t.year^{-1}$
- Biogas production: Mio $m^3.year^{-1}$
- Hydraulic retention time : days
- Loading rate; volume load
- Biogas and Methane productivity see table $(m^3_N * m^3*d)^{-1}$

Electrical outputs

- Production of electrical energy: $MWh.year^{-1}$
- Own electrical consumption: $MWh.year^{-1}$
- Utilisation of performance %
- Specific electrical performance $(kW_{el}.(t\ DM)^{-1})$
- Utilisation of own electrical power as a percentage of total
- Sale of electrical energy: $MWh.year^{-1}$

Heat outputs

- Production of thermal energy: $MWh.year^{-1}$
- Own thermal consumption: $MWh.year^{-1}$
- Utilisation of own heat as a percentage of total
- Sale of thermal energy: $MWh.year^{-1}$

Introducing feedstocks into the digester is an important part of biogas plant functionality. The efficiency of biogas production mainly depends on the amount of high energy organic matter in a disintegrated condition fed into the digester. Feedstock mostly comprised of liquid based media containing about 5 to 15 % dry matter and this can be pumped with conventional pumping systems. Often a macerator can be included to increase structural breakdown of larger particles that can cause blockages and reduce the methane productivity and specific methane yield. Optimum particle size depends upon the feedstock type, but as hydrolysis is often the rate limiting step for energy crops or crop residue feedstocks then we shall consider particle sizes. Out of five particle sizes ranges of 0·088, 0·40, 1·0, 6·0 and 30·0 mm, the maximum quantity of biogas production was from 0·088 and 0·40 mm particles but with more degradable foliage large particles could be used. However, for more recalcitrant materials such as straws, large particles decreased biogas production. Methane content of biogas can be higher for more easily degradable materials than for straws(Sharma et al. 1988).

Anaerobic digestion can be performed at mesophilic temperatures between 35 and 38 °C or at thermophilic temperatures of about 55 °C for the methanogenesis stage. Most of the different types of methane producing bacteria prefer mesophilic temperatures. Anaerobic digestion at mesophilic temperatures are considered more stable. Thermophilic temperatures enable greater loading rates due to the faster degradation of the organic substrates and may cause an increase in process instability. The hydraulic retention time (HRT) is an important influence on the economic efficiency of biogas plants and on the methane yield. The HRT must be high enough to enable the near complete degradation of the biomass. On the other hand the HRT must be kept as low as possible, because a high HRT will require a higher digester volume to produce the same amount of energy. However, an increase in the feedstock dry matter content may allow a higher loading rate without decreasing HRT.
The HRT is defined as digester volume divided by the volume of daily feedstock input and is dependent on the type of digester. Vertical digesters require a slightly higher hydraulic retention time than horizontal digesters.
The volume load is defined as the amount of volatile solids that enters the digester related to the digester volume. A key influence of the economic efficiency of biogas plants is the specific methane yield. The specific methane yield is defined as the amount of methane that is produced per kg of volatile solids.

The important biogas plant fermentation parameters with current functional range are:

- pH hydrolysis: 4.0 – 6.5
- pH methanogenesis: 6.8 -7.4
- Redox potential -250 and lower
- Alkalinity or buffering capacity: over 4000 $mg.l^{-1}$ bicarbonate
- Organic acids from acetic C_2 to C_6 500 to 3000 ppm w/v
- Mesophilic temperatures 35 to 39^{o}C
- Thermophilic temperatures 50 to 55^{o}C
- HRT energy crops 60 – 120 days
- HRT manure & food wastes 10 to 30 days

3. Methodologies and task description

The structure and extent of the information required from the partners and their associate biogas plants is presented in this section. The performance and technical parameters of the agricultural biogas plants will be benchmarked. This will be composed of process engineering weak-point analysis to identify the critical points influencing the biogas yield and performance of the plant. As the biogas plants differ in structure and use it is necessary to set the context of the data with schematics of the biogas plants.

3.1 Benchmarking biogas parameters

The priority of benchmarking is to assess ways of improving performance from a starting point (benchmark 1). To achieve this quantitative analysis of biogas substrate inputs, fermentation, electricity and heat production as well as the analysis of the biogas composition and substrate composition before and after anaerobic digestion will be performed. Additional parameters to be evaluated are the installed biogas technology, the human resources requirements, and the economic efficiency (e.g. costs of produced m³ biogas resp. methane). This will be performed with the Ecogas software. A process engineering weak-point analysis will be done to identify the critical points influencing the biogas yield and performance of the plant.

There have been several definitions of benchmarking and some clarification is necessary before we proceed. Benchmarking for this report will be according to W.E. Deming's approach to quality control using four stages as below :

1. ***planning*** which will involves determining critical issues and parameters and developing an agreed approach to assess success using questionnaires/spreadsheets distributed under an agreed schedule. Lines of communication will be defined.
2. ***measuring*** will involve compiling information after agreeing the means of collection and terminology
3. ***analysis*** by a review the findings for the production of tables, charts and graphs to support the analysis. Identify performance and seek explanations for the gaps in performance. Communicate the findings as outlined in the communications strategy at the beginning of the project. Identify realistic opportunities for improvements
4. ***implementation and monitoring*** of the recommendation of the benchmarking process This will be conducted in WP3 and WP4.

The advantage of benchmarking is that we can overcome common concepts or ideas that are accepted as the normal, but have not been sufficiently scrutinised. The drawbacks can be that unexpected events such as sensor or pump failure may occur during an extensive data collection period and bias the retrieved information.

Planning occurred at the initial meeting in Vienna in 2007 and partners clearly recognised and defined the required information for benchmarking. Three clearly defined regions/topics were identified as :

1. inputs to the plant,
2. fermentation and
3. outputs from the plant

The final outcome from the meeting was that there should be a series of four types of data that should be collected. The agreed approach involved the requirement for :

1. comprehensive questionnaire to be filled in with the presence of the plant owner/operator (Appendix 4)
2. detailed information of the plants operational parameters were collected in a database (Appendix 5) over a period of about 1 month in 2007

3. Identifying current problems at each biogas plant by each science partner with the operator. Information of the plant operators' experience was collated in a weak point analysis database (Appendix 6).
4. In addition a schematic (Appendix 7) was required from each biogas plant to determine if the construction element may affect biogas production.

3.2 Analysis of benchmarking databases

The context of the results will note the feedstock content, dry matter composition and volatile solids present however this information cannot be benchmarked other than knowing the feedstocks may contribute to a variation in benchmarking performance of a biogas plant.
Digester performance can be measured by biogas and methane production.
Process stability is difficult to measure because of insufficient fermentation parameter measurements.
The energy efficiency of the biogas plant can be measured by data on the heat and electricity output and the inputs to the biogas plant and this information can then provide performance information for each biogas plant.
The data will be clearly presented in four sections, namely benchmarking data (appendix 5), weak point analysis data (Appendix 6) from the questionnaire (appendix 4) which comprises of economic and social aspects of biogas production. Finally a schematic of the biogas plants will be collated (appendix 7).

3.2.1 Benchmarking data

Data of the biogas production was analysed by focusing on the selected relevant parameters in Table 2. The database information was the analysed for the average, maximum and standard deviation value for the agreed biogas plant parameters. The minimum values were often zero because of the biogas plant maybe shut down for a small period for repairs.
This first benchmark will set the performance as an average value as well as a standard deviation and maximum value for comparative reference with the later benchmark 2. In addition any relationships between different plant parameters can be used as benchmarks to note any anomalies and attempt to identify the source or reason for the differences. The relationships between biogas plants for benchmark 1 will be presented in graphical form and the biogas plants will be referred to in coded terms for the purposes of this document.
In the first instance we collected the agreed parameters from each of the biogas plants as in Table 2.

Table 2. Process parameters collected for the benchmarking datasets

INPUT PARAMETERS	UNIT
outside air temperature	°C
Hydrolysis temperature	°C
digester temperature average	°C
digester temperature top	°C
digester temperature bottom	°C
post fermenter temperature middle	°C
storage temperature	°C
H_2S	ppm
O_2	Vol. %
OUPUT PARAMETERS	
electric energy produced per day	$MWh.d^{-1}$
Electrical efficiency	%
Heat energy produced per day	$MWh.d^{-1}$
CH_4 generation per day	$m^3.d^{-1}$
CH_4 volume in biogas	%
Methane at STP	$Nm^3.d^{-1}$
biogas generation per day	$m^3.d^{-1}$
biogas generation per day at STP	$Nm^3.d^{-1}$
BIOGAS PLANT INDEPENDENT PROCESS PARAMETERS	
specific methane yield	$m^3.kg^{-1}$ VS
hydraulic retention time	d
loading rate	kg $VS.m^{-3}$ digester $volume.d^{-1}$
methane productivity	Nm^3 $CH_4.m^{-3}$ digester $volume.d^{-1}$
Average degradation of carbon	%

Because of the effect that feedstocks can have on biogas production comprehensive information on feedstock data was also collected over a month in 2007, the period of benchmarking data (Table 3). Feedstock data was monitored as fresh matter weight, dry matter weight, organic dry matter and volatile solids and are classified into energy crops, animal manure and organic waste.

Table 3. List of feedstocks used at partners' biogas plants

FEEDSTOCK		
animal manure	**energy crops**	**organic waste**
cattle slurry	colza cake	apples
cooked solid manure	corn waste	biodiesel waste
liquid manure	Gps	bleaching earth
pig slurry	grass silage	blood
pig water	green rye	chicken manure liquid
poultry slurry	ground maize	dog food
turkey manure	ley crop silage	fat
	maize silage	fish waste
	maize corn	food waste
	Millet	fruit waste
	sbl. silage	glycerol
	sunflower silage	kitchen leftovers
	triticale silage	kiwi
		potatoes
		slaughterhouse waste
		sludge
		starch
		vegetable waste
		water
		others

3.3 Weak point

This data was collected from the biogas plant owners or operators and is presented in Appendix 6. Information will be classified into several groups.

3.4 Questionnaire

Data accumulated in the questionnaire (Appendix 4) provides and overall view (and in present in Appendix 10 and tabulated data in Appendix 11). The overview from the questionnaire may differ from the benchmarking data because the overview originates from a greater period than 1 month which is the time from for the accumulation of the benchmarking data. Information from the questionnaire was summarised and includes:

1. biogas plant production capacity (Appendix 1),
2. measured fermentation parameters (Appendix 2)
3. plant technology (Appendix 9) for each partner.

3.5 .Economic performance of the biogas plants

Benchmarking data as well as data from the questionnaire were used to calculate the economic performance of the biogas plants. The feedstock data and certain process parameters were provided by the benchmarking database. Further Information like the costs of feedstocks, type and useable volume of the fermenter or consumption of electricity of the plant were derived from the questionnaire. All economic data like the sum of investment, the running expenses and the revenue are provided from the questionnaire (Appendix 4).

The economic analyses were undertaken using the software tool "EcoGas". About ten years ago this tool was developed in Austria for planning and checking the profitability of biogas plants. In Austria each state-aided biogas plant has to pass the profitability check by EcoGas. Up to now there are five updates, as well as an Italian and an English version.

As the price system for the produced electricity varies from country to country and year to year the main focus of the economic analysis was on the specific production costs of electricity and methan respectively. Thereby the production costs were split up in capital costs, costs for feedstocks and other costs.

3.6 Summarised Schematic data from the biogas plants

This data was collected and analysed with some of the data from the benchmarking exercise to assess the interaction of plant design and feedstock of biogas plant performance.

4. Main results

The main results will be presented as three sections namely benchmarking data, weak point analysis and data from the questionnaire which comprises economic and social aspects of biogas production.

4.1 General performance characteristics of the biogas plants

For the first profile we need to identify both the size and different designs to evaluate our benchmarking information.

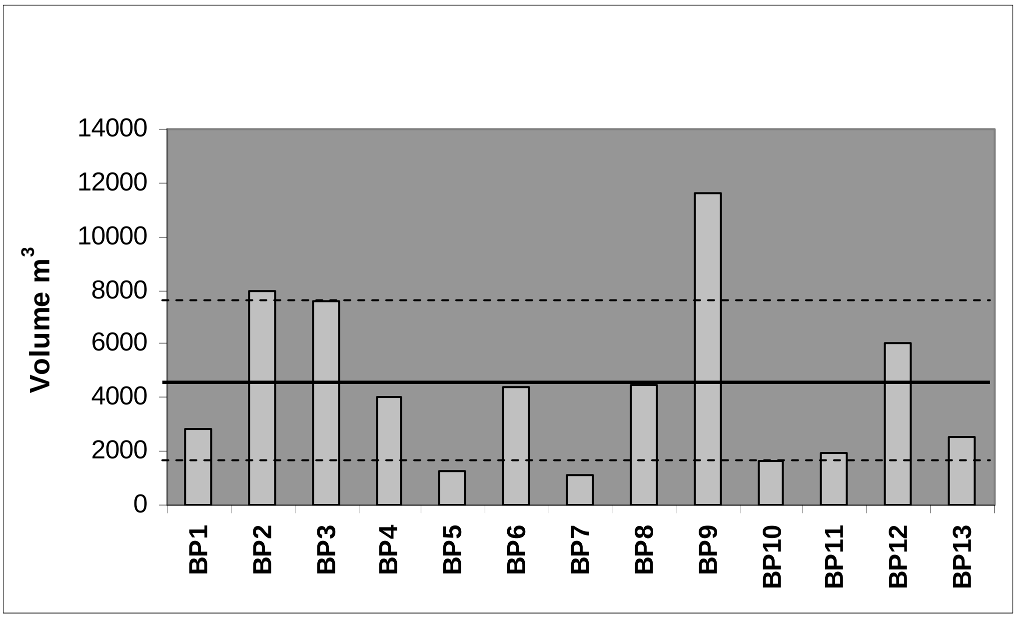

Figure 3 Profile of primary digester sizes (not including the hydrolysis phase) for 13 partners

The digester volumes vary from about 1000 m^3 to 12000 m^3 and average size of 4500 m^3. Most produce biogas and subsequent sold electricity equivalent to their size. There are some exceptions BP9 is considerably larger than other biogas plants with a 12000 m^3 volume, but only produces 11000 m^3 of biogas per day which is the same volume as an average plant with a 4000 m^3 digester. However BP9 has a double ring digester and the volumes are used in series, suggesting the plant is not receiving sufficient feedstock volume and is currently under utilised.

Table 4 gives a classification of each biogas plant by design features that include pretreatment of any kind (1=yes and 0=no). The number of tanks stages refers to whether there is a single (no stages =1) or two tanks for methanogenesis and hydrolysis (No of stages =2). The other option here is for the tank to be the newly designed ring tank (tank or ring =2) that has a tank within a tank, one each for either methanogenesis or hydrolysis (no ring =1). The manure, fruit or green crop fraction and fat or glycerol content are each expressed as a fraction of one.

Biogas plants 1,2 and 5 perform well from a specific methane yield, which reflects the conversion of VS to biogas and may require high HRT for such results. Conversely, high methane productivity identifies with a higher feedstock throughput for maximum biogas output per unit volume of digester.

Table 4 Partners biogas plant design, feedstocks and methane production

	Pre treatment	no of stages	tank or ring	post digester	specific CH4 yield $Nm^3.kg\ VS^{-1}$	CH4 Productivity $Nm^3.m^{-3}\ digester.d^{-1}$	Mwatt/dry ton	manure fraction	fruit/green crop fraction	Fat or glycerol fraction
BP1	0	1	1	1	0.695	1.888	2.253	0.27	0.23	0.44
BP2	1	1	1	1	0.756	1.210	0.958	0.55	0	0.01
BP3	1	1	1	1	0.405	1.360	2.033	0.8	0	0.2
BP4	1	2	1	1	0.499	1.469	1.708	0.69	0.18	0.11
BP5	1	1	1	0	0.593	1.041	1.582	0.92	0.01	0.01
BP6	0	2	2	0	0.382	0.716	1.918	0.24	0.55	0
BP7	1	1	1	1	0.388	2.079	0.881	0.81	0.15	0.04
BP8	0	1	1	0	0.496	1.470	0.661	0.93	0.01	0.01
BP9	0	2	2	0	0.254	0.538	0.834	0.09	0.72	0
BP10	0	1	1	0	0.331	0.840	0.913	0.21	0.58	0
BP11	0	1	1	1	0.331	0.840	0.913	0.4	0.56	0
BP12	1	1	1	1	0.132	0.490	0.178	0.64	0.36	0
BP13	1	1	1	0	0.285	0.702	1.476	0.53	0.02	0.09

4.2. Description of benchmarking data

Benchmarking data was collected from 13 biogas plant sites (BP1 to BP13). These biogas plants differ a little in both construction and use which is reported above. Firstly, all biogas plants were operating at about 5 to 12% dry solids, which classify them as 'wet' biogas plant systems. Of these plants two had final tanks that were within the outer hydrolysis tank. There were two biogas plants that were operating at thermophilic temperatures (55^{o}C). The other systems were either single or two process operating systems that may or may not have parallel tanks in the same stage (e.g. 2 methanogenesis stage tanks). Seven biogas plants had post digesters that can collect residual methane emissions.

4.2.1 Statistical profile of biogas plants

Table 4 shows the range of operational parameters for the 13 biogas plants.

Table 5. Statistical output of benchmarking data from 13 biogas plants

PARAMETER	UNIT	average	Standard deviation	maximum	minimum
produced electric energy	MWh/d	16	9	28	4
CH_4 [Nm³]	Nm³/d	4428	2182	7341	1354
total	t fm	103	79	256	25
total	t dm	12	11	36	1.74
specific methane yield	m³/kg VS	0.44	0.16	0.76	0.25
methane productivity	Nm³ CH_4.m^{-3} digester volume	1.3	0.6	2.6	0.49
Mesophilic digester temp average	°C	38.75	2.3	41.9	33.60
Thermophilic digester temp average	°C	51.1	0.20	51.2	51.0
Specific electrical yield	MW/dry ton	2.0	1.8	7.1	
CH4/ton fresh wt		54	28	106	0.67
MW/ton fresh wt		0.19	0.11	0.4	24

The range for the 13 biogas plants is often the same magnitude as the average value for the biogas plants. The information from these biogas plants revealed some differences but the most consistent response was the electricity produced from methane volume. This analysis does not reveal any serious discrepancies between biogas sites for electricity production. However the influence different feedstocks and reactor design will have a significant influence that makes comparison of biogas plants potentially difficult and some caution should be noted when doing so.
The influence of biogas plant digester temperature may play a role in biogas production. Although this was not true for the thermophilic digesters at 51^{o}C compared to the mesophilic digesters with an average value of about 39^{o}C for the specific methane yield and methane productivity. (Appendix 5)

4.2.2 Utilisation of biogas for electrical energy production

All biogas plants surveyed in this report produced electricity for their respective national grids using combined heat and power (CHP) units. Electrical performance can determine the main focus of most biogas plants which is the sale of electricity compared to the amount of electricity that could be produced given the capacity of the generators on site. Such evaluation can show if too much capital cost was spent on generating electricity capacity without being able to produce sellable energy. The means of comparing biogas plants is the measurement of electrical efficiency. Electric efficiency is the efficiency of converting biogas into electricity which depends on biogas quality and CHP size. To maximize the economy it would be necessary to maximize the hours of operation at full load. To calculate the level of electric efficiency, the gross energy of the methane is considered as 9.97 kWh per cubic metre of methane for comparison to the produced electricity.

$$\eta_{elec.} = \frac{prod.\ Electricity\ (kWh/y)}{prod.\ Methane\ (m^3/y) \times 9.97\ (kWh/m^3)} \times 100 \quad \text{Eq -1}$$

Table 6: Level of electric efficiency

Biogas plant		BP1	BP2	BP3	BP4	BP5	BP6	BP7
Prod. electricity	[MWh/d]	15,05	26,00	27,90	22,32	6,09	11,71	5,35
Prod. methane	[m³/d]	3859	6841	7341	5874	1354	3152	2286
Level of efficiency	[%]	39%	38%	38%	38%	45%	37%	23%

Biogas plant		BP8	BP9	BP10	BP11	BP12	BP13
Prod. electricity	[MWh/d]	23,73	23,72	12,33	4,38	18,83	6,67
Prod. methane	[m³/d]	6244	6241	4320	1589	6232	1754
Level of efficiency	[%]	38%	38%	29%	28%	30%	38%

Further benchmarking analysis of the biogas plants is possible to determine the utilisation of the CHP shown in Figure 4 as use of installed electrical capacity P_{inst} (kW) over the year, which requires knowledge of the operating hours used per year.

$$\eta_{util.} = \frac{\left(\frac{prod.\ Electricity\ (kWh/y)}{operat.\ hours\ (h/y)}\right)}{P_{inst.}(kW)} \times 100 \quad \text{Eq--2}$$

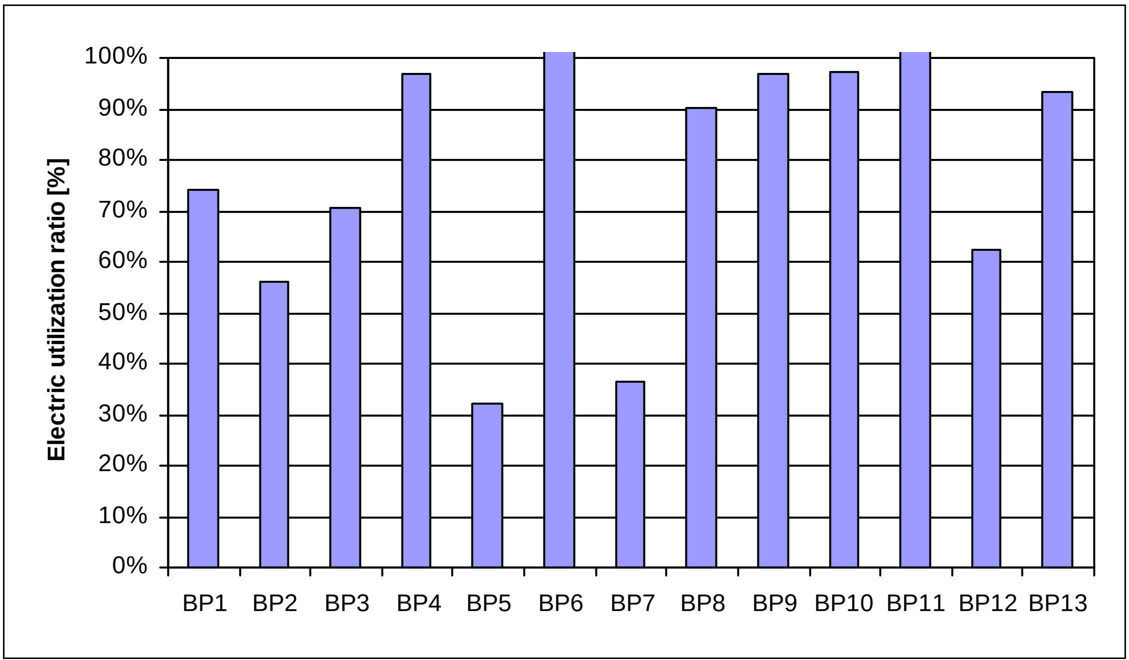

Figure 4 Overall utilisation of electrical capacity

To determine the efficiency of the CHP, it is necessary to calculate the theoretical share of full load, which describes the time the CHP operated at full load to produce this amount of electricity in hours (Eq3).

$$t_{fl} = \frac{W\ [kWh/y]}{P_{inst}\ [kW]}$$ --- Eq3

Normally the theoretical share of full load should be above 7000 hours/year which is about 80 % of the number of hours in one year.

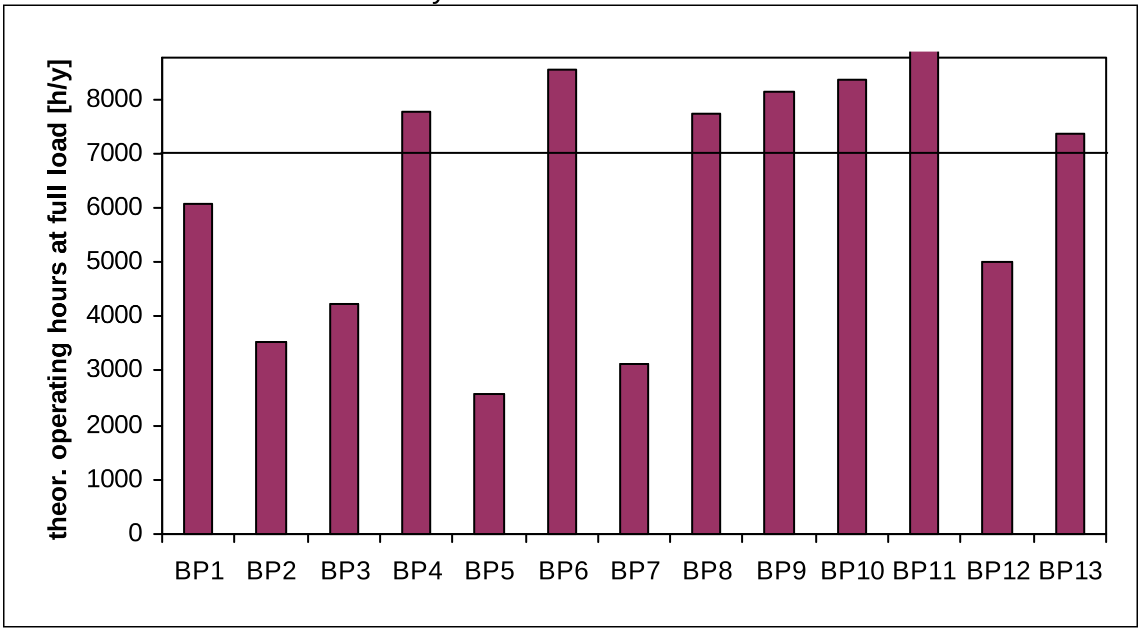

Figure 5 Theoretical time at full load

Electrical energy production follows a pattern of digester size and biogas output. Figure 5 demonstrates that biogas plants 1, 2, 3, 5, 7 and 12 miss the criteria of 80 % of the annual hours per year which can be considered as not utilising the capital investment.

Point 1 6 biogas plants do not operate their biogas plants at sufficient capacity

The remainder are nearer using 80 or 90% of their capacity. BP6 produces a larger amount of electricity proportional to its size, but does have a 55% input of energy crops.

Use of electricity on site is high for BP1, BP2, BP9 and BP12. A high amount of electricity use does not seem attribute to any particular feedstock or fresh material introduction system. Electric consumption at the biogas plant can include most devices in the periphery of a biogas plant such as pumps, mixers, cutters etc. Produced electric energy is therefore partly used to supply these devices which decreases electricity sold the public grid.

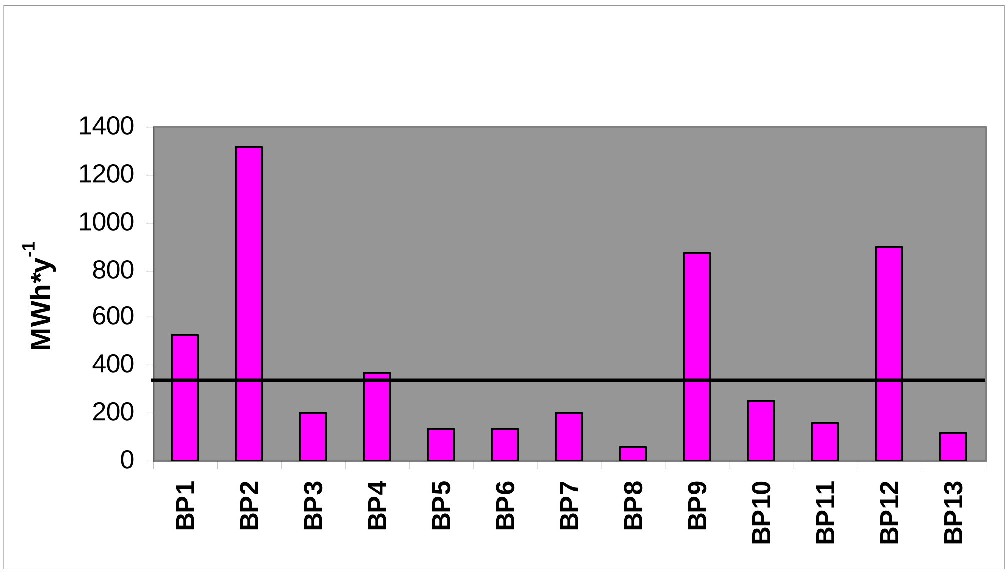

Figure 6 Own electricity use on site over a one year period

Use of electricity on site may reduce profits and identify potential equipment or process that may need to be investigated. Relatively from an electricity production perspective BP2, BP9 and BP12 use a high amount of electricity. Because of the range of biogas plant designs it is difficult to determine how to reduce own electrical energy use.

Thermal energy production should be a ratio to the electrical energy output for biogas plants and confirms the use of combined heat and power units for energy transformation from biogas. However, the smaller biogas plants BP5 , 6 and 11 have no thermal energy production. Thermal performance rather depends upon using this source of energy for sale, heating the digesters, effecting hygiene for regulatory purposes or for pretreatment. Low use on site may be a disadvantage unless all the heat is needed for sale. While 10 sites produce thermal energy only 4 sites sell this energy and 8 sites use the energy for their own consumption.

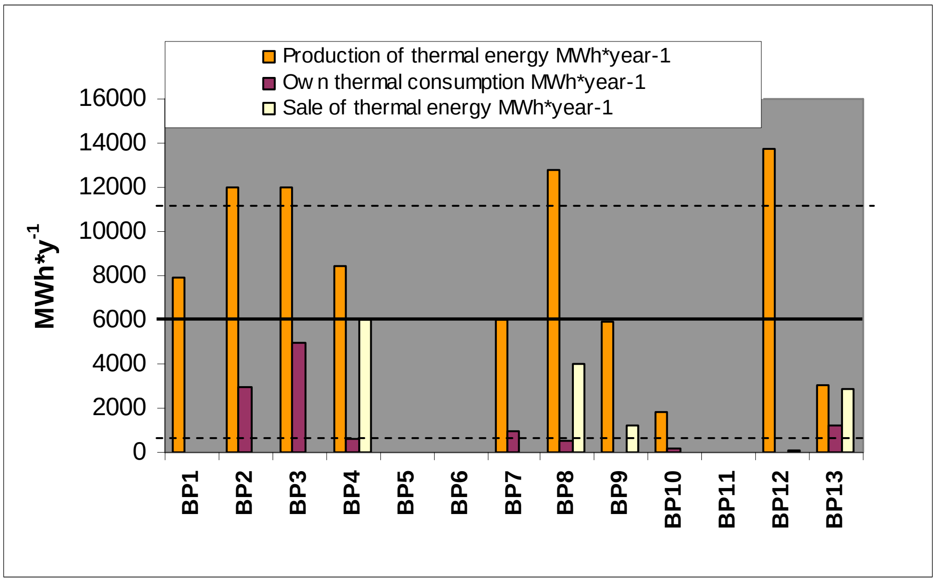

Figure 7 Comparison of thermal energy utilisation

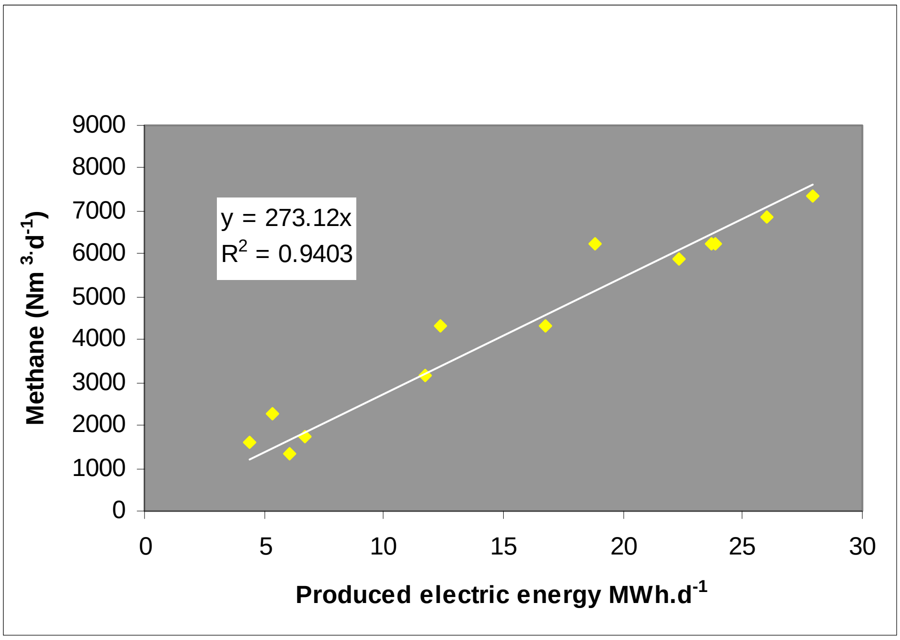

Figure 8 Conversion of methane to electrical energy in comparison with installed electric energy of the plants

Figure 8 shows a good correlation as r^2 of 0.95 and 272 m^3 of methane were required for 1 MW of electricity. Most biogas plants have several CHP units to adjust to the methane/biogas loading at the time. Often CHP units may not be used or operating to capacity(Figure 5). In addition the CHP unit may not be operating efficiently and this maybe a reflection of the biogas treatment process or the CHP engines operating efficiency.
Point 2 Four biogas sites BP 7, 10, 11 and 12 have reduced methane conversion to electricity and their performance could be increased by up to 25% when compared to other biogas plant systems.

4.2.3 Loading rate of the digester and the residence time of the feedstock

The biogas plant can also be benchmarked by the amount of feedstock that can be loaded. To draw a direct comparison the measurements are kg of VS for a cubic meter volume of the digester.

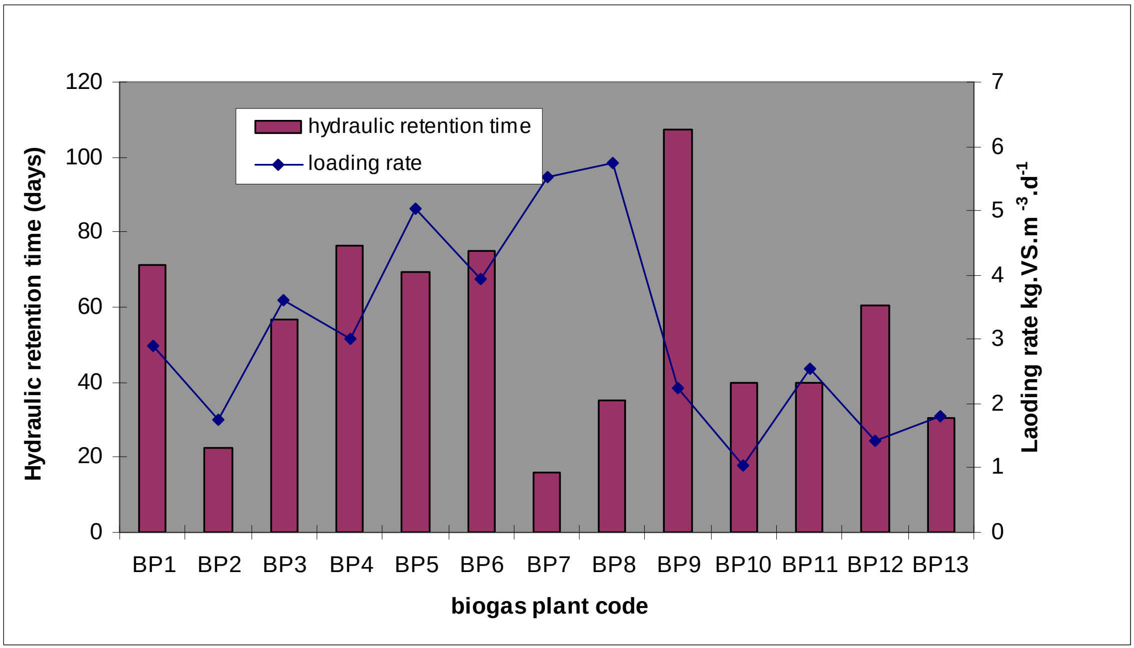

Figure 9 Comparison of loading rate to hydraulic retention time

There are two thermophilic biogas plants BP3 and BP7. The latter has a high loading rate (Fig.9) relative to the HRT suggesting a better fermentation. Although BP8 and BP12 have higher loading rates relative to their HRTs they did not operate at thermophilic temperatures. BP9 has a large volume of two sets of tanks placed within the other (a ring system) that are in series rather than parallel and hence a larger HRT relative to the loading rate. Analysis of feedstocks type reveal that those with a low HRT generally have over 50% manure by volume loaded whereas those with larger amounts of vegetable and fruit waste or fat had HRT over 50 days.

4.2.4 Specific methane yield

This value is a measure of the conversion of the accessible organic material measured as volatile solids and is also independent of the biogas digester design or operation. The units are methane volume per kg of VS.
The average performance of the biogas plants was 0.44 $m^3.kg^{-1}$ VS and is weighted by high values for BP1, BP2 and BP5. The majority of these biogas plants could be perceived as above average performed which is considered by current literature to be 0.3 $m^3.kg^{-1}$ VS. Some biogas plants provided gave specific methane yields and the standard deviation of those values. The standard deviation can be used as a measurement of fermentation or process stability.

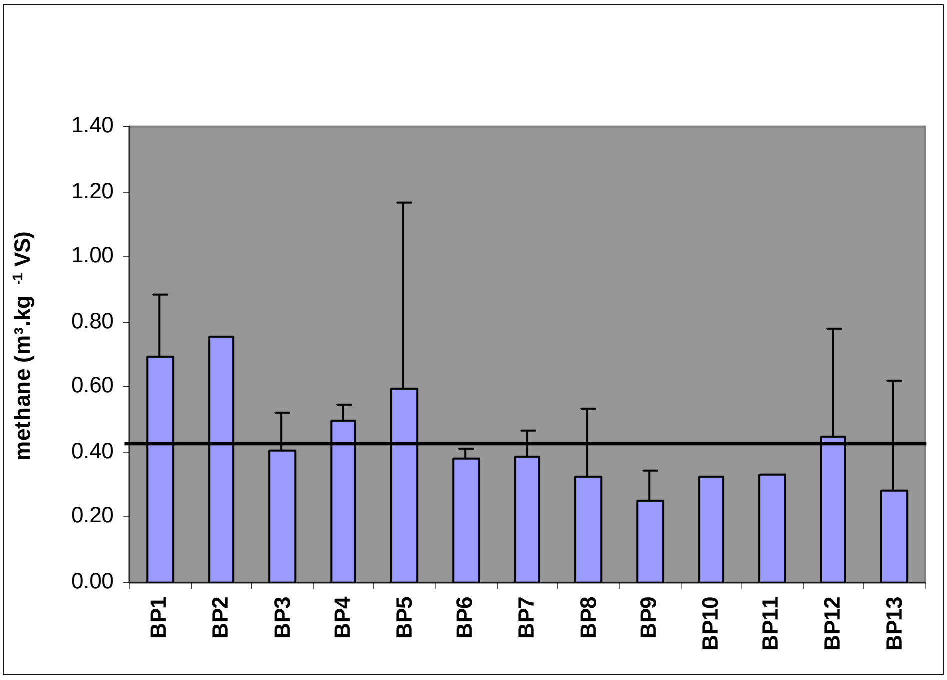

Figure 10 Distribution of specific methane yield showing one standard deviation error bars (for those biogas plants with sufficient data)

Biogas plants 4 and 6 could be considered as performing with a stable biogas output and hence stable fermentation process. Searching the benchmarking database revealed why there were differences in the stability of the specific methane yield. Biogas plants 4 and 6 had very stable inputs. Those for BP5, 12 and 13 were very variable and could account for the different standard deviation values.

Point 3 The average performance of biogas plants was 0.44 m^3 methane kg^{-1} VS. The majority of these biogas plants could be perceived as above average value of 0,3 $m^3.kg^{-1}$ VS. Biogas plants 1 and 2 gave the highest specific methane yield and BP12 has about 3 times lower output of methane kg^{-1} VS.
Point 4 The fermentation stability expressed as standard deviations from the mean value demonstrated a 7 to 100% range, identifying some biogas plants could increase there process stability.
Point 5 biogas plants have up to a 3 times difference in methane yield per unit mass of volatile solids.
Also a higher hydraulic retention time (HRT) is necessary to achieve a higher specific methane yield and so there is a dependency on whether the biogas plant has a post digester that collects biogas. However, methane may be produced in the digestate storage facility and this is potentially an environmental issue if the storage tank is not covered as is the emission of methane after spreading the digestate on land.
Theoretically the specific methane yield and methane productivity are diametrically opposed to each other. However for the data we accumulated shows no relationship present suggesting other factors have an influence.

4.2.5 Methane productivity

Methane production per cubic metre of digester tank is a biogas plant independent measurement. The highest performing digesters were BP7 2.08 $m^3.m^3$ (thermophilic) and BP10 2.62 $m^3.m^3$. BP10 has the highest input of fruit at 53% that may explain the high methane productivity.

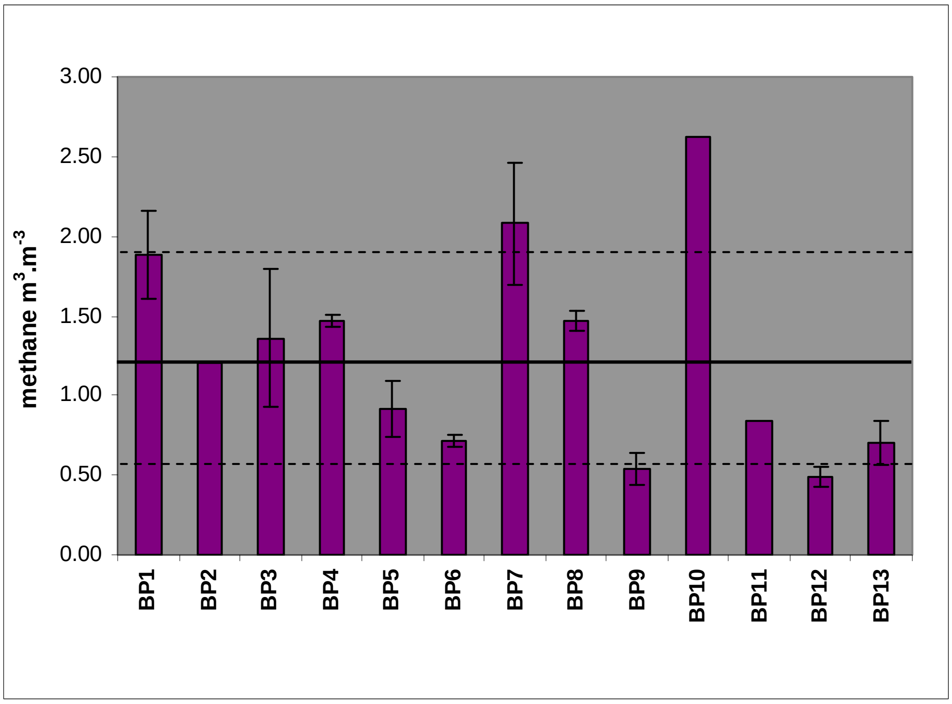

Figure 11 Distribution of methane productivity

Comparison of Figures 10 and 11 reveal that BP7 has the second highest methane productivity and good process stability. The coefficient of variation is 20% for the specific methane yield of 0.39 $m^3.kg\ VS^{-1}$. The feedstock includes 40% pig slurry and 40% cattle and 15% maize silage. The digesters reduce the VS by 60%, with a CH_4 productivity of 2.08 $m^3.m^3$.
Variability of methane productivity for each biogas plant shown in Figure 11. Variability is represented as one standard deviation from the mean value for each biogas plant.
BP4 and BP6 have low variability, but other biogas plants do not have similar values as for specific methane yield.
Point 6 The methane productivity has a mean of 1.25 and a range from 2.62 to 0.5 $m^3.m^3$.

4.2.6. Biogas quality

Analysis of the biogas from each plant shows an average of 59.1% v/v methane and 37% methane. Generally the CO2 value can be assumed to make up the 100%v/v. A maximum of 67% and a minimum of 51% v/v methane was recorded. Eight biogas plants added oxygen to the biogas.

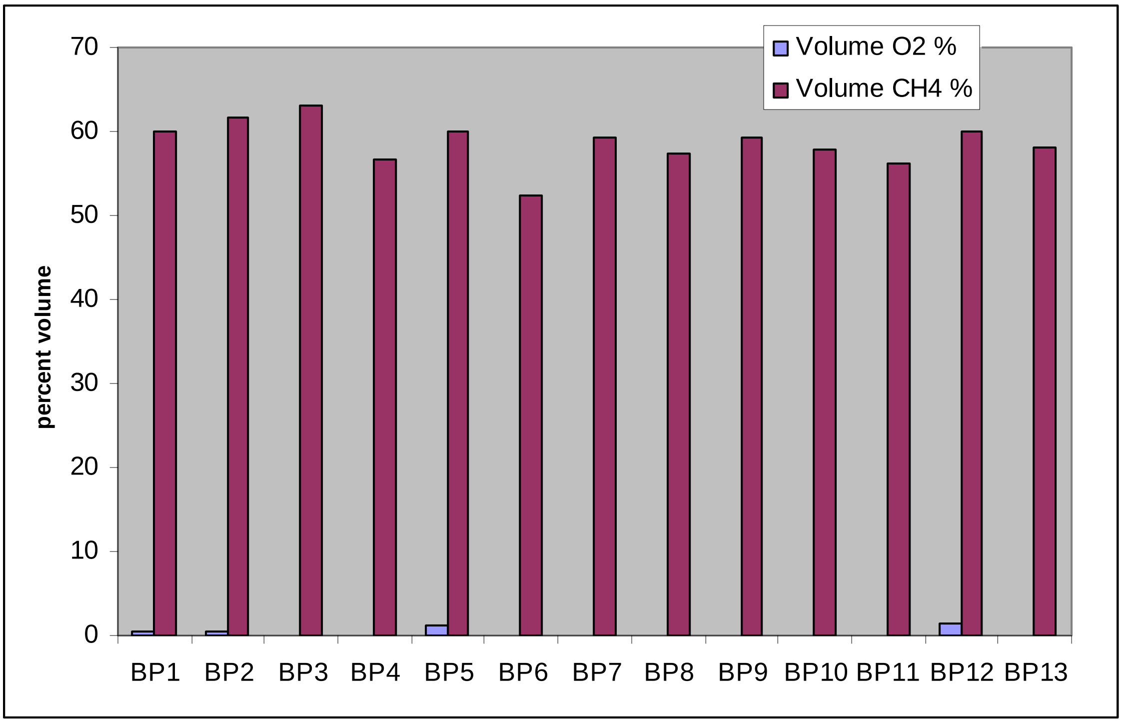

Figure 12 Biogas quality as percent methane and oxygen content

Biogas plants 4 and 6 have lower methane content in their biogas, but as graphs 10 & 11 show they have good methane yield and productivity.

4.2.7 Amount of degradation of volatile solids or available carbon

Figure 13 shows the degradation rates of VS after the main digester with an average of 66% and standard deviation of 14.9%. Analysis reveals there was no clear relationship to specific methane yield or methane productivity for the degradation of VS. VS degradation may also depend upon digester flows, first, the hydrodynamics of the digesters maybe such that VS are washed from the digester; this also includes the resident population of organisms that may produce methane. Hydrodynamics are an important diagnostic tool to identify short circuiting of the feedstock to be eluted from the digester. This may also include harmful pathogens that would be significantly reduced by residence in the digester. Hydrodynamic studies would also reveal the degree of effective mixing. Second, variation in feedstock co-digestion or degradation efficiency may contribute to the degradation efficiency. Third, the impact of the digester overall process may contribute to the degradation efficiency.

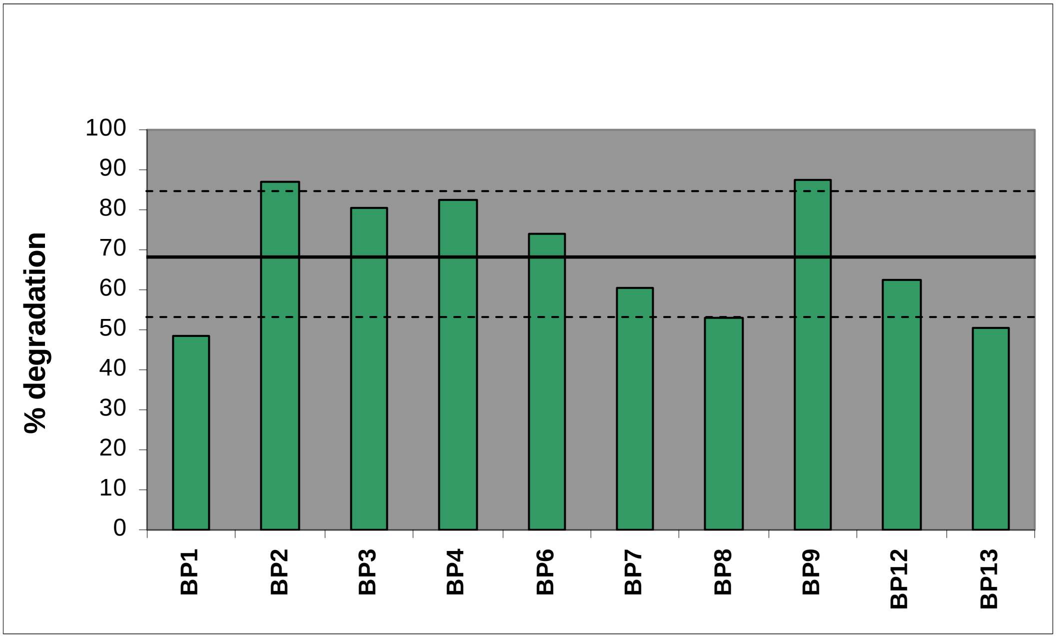

Figure 13 Degree of degradation of VS after main digester (BP2 values are from the drop in COD measurement)

The information from WP1 on degradation rates of feedstocks could be integrated into the efficiency report of a biogas plant. BP12 has the highest loading rate but also one of the highest degradation rates of VS.

Point 7 The average degradation rate was 68% with a range of 48 to 89% of the VS
Point 8 There was no relationship of measured fermentation parameters to the degree of VS degradation

4.2.8 Effects of the feedstock input

The primary objective of this analysis is to compare biogas plant inputs by tons of matter fresh weight and then diagnose how to improve methane yield for those biogas plants with high inputs relative to the methane output.

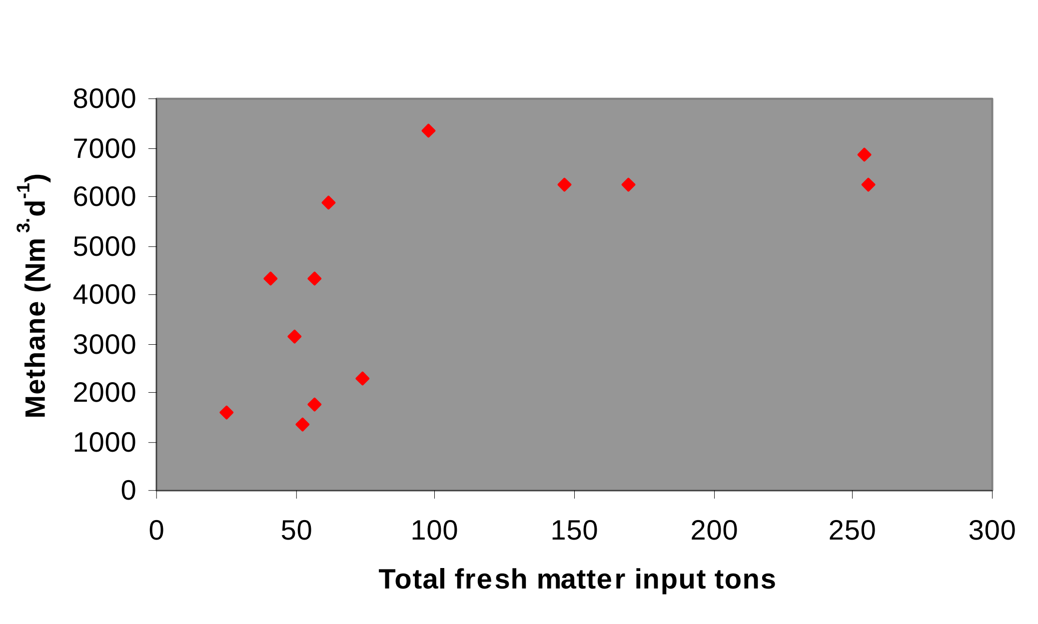

Figure 14 Distribution of fresh weight input for the 13 biogas plants

12

Figure 14 shows that three biogas plants have about 3 times and up to 5 times as much volume for the same amount of methane production as those adding about 100 $t.day^{-1}$. These biogas plants (from left to right are BP8, BP2 BP12 and BP9 respectively) have manure as a large fraction of their feedstock. If these biogas plants have large distances to be travelled this may substantially add to costs.

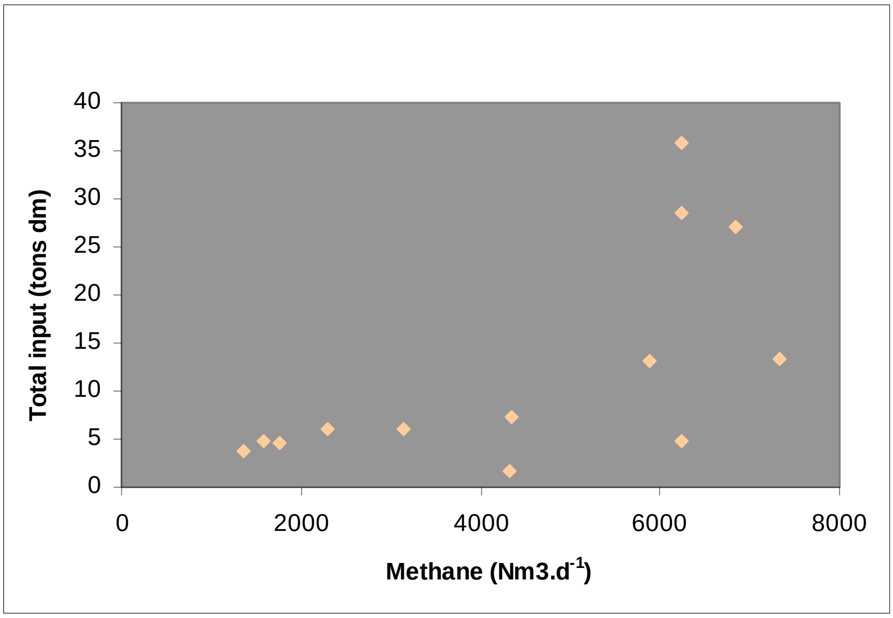

Figure 15 methane produced from dry weight input for 13 biogas plants

Figure 15 provides additional information as BP3 has the best methane output per unit of mass dry weight of feedstock. These biogas plants (from top to bottom are BP8 and BP2 respectively) have manure as their main feedstock.

Point 9 High levels of manure feedstock produce about 3 times less biogas per ton of dry matter input

4.2.9 Quantities of feedstock used at each biogas plant

There are a variety of feedstocks used as shown in Table 3. However to get a better understanding of the inputs they are presented as columns in a percentage format (Fig. 11). The biogas plants 4 to 8 and BP 13 have high amounts of pig slurry inputs (pink-orangey colour in Fig 11). Figure 11 shows all biogas plants have a high percentage of pig or cattle slurry (latter represented by a purple colour in Fig 11), which has a relatively high ammonia/ammonium composition that is good for chemically buffering the digester pH and ammonia inhibition of methane production(Batstone et al. 2002). The feedstocks are better represented graphically in pie chart configuration in Appendix 8

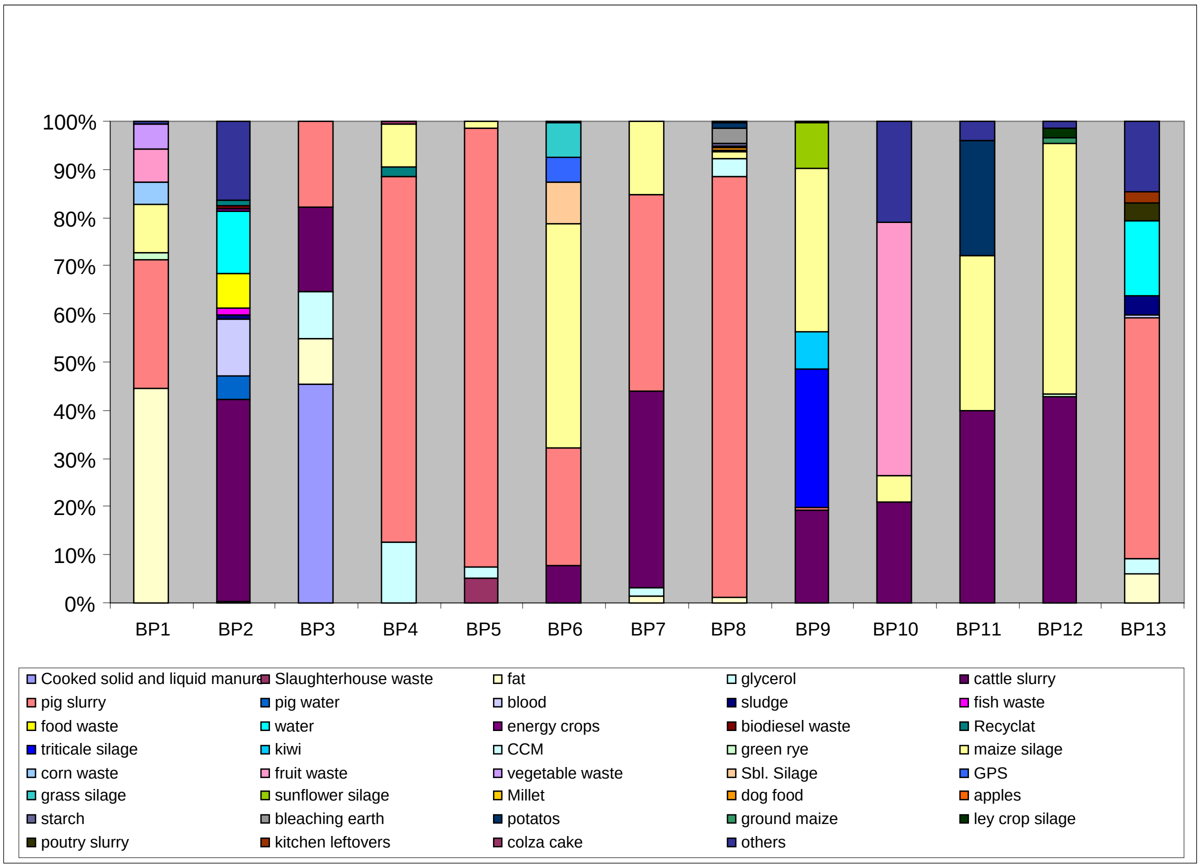

Figure 16 Variation in feedstocks fractions for biogas plants as fresh matter weight for the European partners

Further investigations were performed to assess if the inputs have a relationship to the biogas yield. The analysis revealed that methane productivity had an inverse relationship ($r=0.52$ $p<0.1$)) to the fraction of energy crop or fruit added. This suggests as expected that these energy crops require higher HRTs for biogas production in a commercial plant.

4.2.10 Further analysis of data

The basic parameters of performance were analysed by principal component analysis to determine the similarity of behaviour of the biogas plant parameters. The parameters were individually normalised by dividing by the standard deviation to prevent the magnitude of the data skewing results. Figure 12 shows the behaviour for the data received. There are expected association of loading rate, fresh weight added and dry weight added. But also the digester performance as methane productivity and the specific electrical performance are associated. **Point 10** This identifies that as the digester increases methane production (per m^3) the electricity produced per unit dry weight of feedstock increases and suggests the digester is not operating to full capacity because if the digesters had a higher loading rate then the electricity produced per unit dry weight mass should decrease. An expected association was HRT and specific methane yield, which states that as the retention time increases so does the methane output per unit mass of volatile solids.

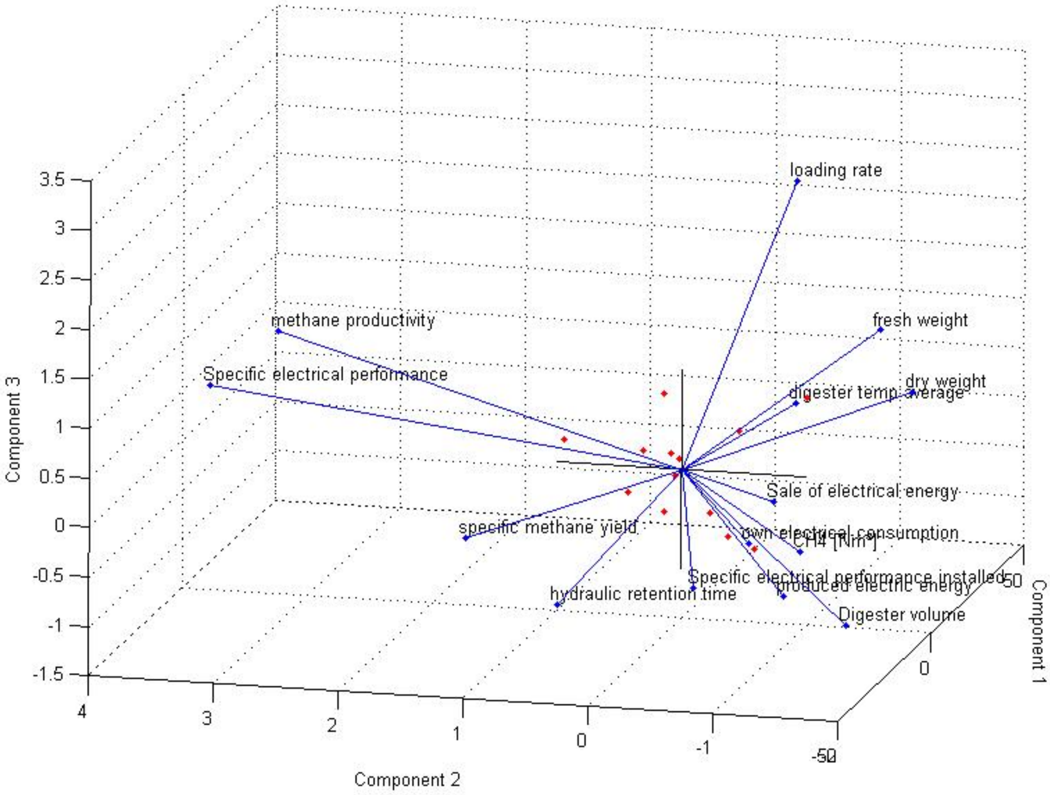

Figure 17 Biplot of the parameters after principal component analysis showing the biogas plants (red dots) and the biogas plant variables with the magnitude of the influence shown by the length of the blue line.

The expected biogas plant performance parameters were associated with electrical output from the biogas plant. These were sale of electricity, own electrical consumption, electrical performance installed, digester volume and methane volume.

To understand if the data could be used to develop a model multiple linear regression was used but did not reveal any models that may explain methane productivity or specific methane yield. However there was a relationship of specific electrical performance that could be explained but the model was skewed and therefore not representative. The problem building a model is most probably because of the low number of biogas plants in the survey.

Point 11 There was an inverse relationship of methane productivity to the fraction of energy crop feedstock.

4.3. Weak point analysis

There are a range of improvements that are targeted from each biogas plant that are summarised below. Many are similar but because of the complexity of each biogas plant generalisation of difficulties may be misleading. However monitoring, process control leading to optimisation of biogas output and pretreatment are generic aspects that affect most biogas plants.

Table 7 Weak point analysis

Partner & Plant	Weak points of the plant	Planned improvement (%);	planned demonstration
BOKU Mureck	High costs for substrates unoptimized feedstock mixture High storage costs of substrates Low CH4 content Insufficient process control: no gas meter, no H2 sensor i	30%	feedstock mixture, additives
BOKU Utzenaich	insufficient heat utilization		heat utilisation
IGER North Wyke	No optimisation procedure Sensors not implemented for monitoring Build software programme for process control	reduce process failure, improved performance (biogas yield 5-10 %)	automatic monitoring, management and early warning system
IGER Holsworthy	feedstock mixtures not optimised high NH3 concentration poor methanogen activity loading rate not optimised	reduce process failure	automatic monitoring, management and early warning system
ECBREC (IEO) Pawlowko	Digester loading outdated Insufficient HRT No solid substrate storage insufficient process control		sensor system, early warning
ECBREC (IEO) Pawlowko	Insufficient mixing in digesters Feeding interval is too big		optimisation of mixture though income analysis of waste
Partner & Plant	**Weak points of the plant**	**planned improvement (%);**	**planned demonstration**
ATB Fehrbellin	Solid cattle manure gives problem feeding Large -CH4 potential in digestate	-50% labour, +100% feeding security	new feeding technologies

ATB Fehrbellin	no usage of exhaust-heat of the CHP	90 % usage of CHP heat	Stela feed and turn dryer
UNIT Bagnod	No analysis of the substrates Great variability of the organic loading rate Low average organic load Low specific methane yield High HRT digestate tank not covered	10-20% more gas volume	Coverage of digestate storage tank
AH (DIAS) Foulum	No online gas analyser or sensor for pH, redox & conductivity installed	5-10%	Serial coupling digesters, on-line measurement
AH (DIAS) Lojstrup	High HRT High solids High nitrogen content	20%	Documentation of pre-treatment by pressure cooking+lime. NH3 stripping/scrubbing, post treatment
VUZT Knezice	unoptimized feedstock mixture & loading rate no redox or conductivity sensors or online gas analyser	21% in specific methane yield	feedstock mixture, additives, utilization of residual biogas

Partner & Plant	Weak points of the plant	planned improvement (%);	planned demonstration
Vogelsang / vTI Lamping	alternating substrates inhomogeneous substrate pretreatment alternating substrate quality inefficient fermenter mixing and high power consumption formation of surface layers	increase gas yield by x % reduce hydraulic retention time by x %	compare new feeding device with feeding by screw conveyor
Vogelsang / vTI Scherbing	Low choice of substrates & mixing (collecting pit) no automated feeding Unoptimized loading rate & mixing with no gas meter, or analyser or pH or Redox Mixing technology poor fermenter mixer repairs	reduce energy for feeding by 70%. labour for feeding by 50 %. reduce odour emission of bad. extend feedstock range	compare new feeding device with feeding by a mixing pit
Högl		operating time +80h/a; oil lifetime +50%; oil analyzes -50%	oil monitoring
			gas drying/cleaning
Wallsee		15%	heat utilisation
East Germany		+7% total electrical efficiency	ORC 80 kWe
ASG/PRI Bomers	Large variations in feedstock composition Poor digestibility of grass feedstock Gas leakages from end storage Variable HRT Poor mixing capacity Excess of digested slurry	10-50 % more gas yield	pretreatment: enzymes
ASG/PRI SNO	Lack of process monitoring data Excess heat production Occasional CHP's problems	+10% economical impact	Separation + drying of slurry

There are a range of weakpoints from the various biogas plants, the general focus is on the feedstock treatment and introduction into the digester. Resolution of this process stage appears to be the introduction and demonstration of feedstock mixers systems.
Process control is also of interest to the biogas plants, often from the perspective of variable rates and types of feedstocks. Again this will be addressed at various plants but the pilot scale system at North Wyke has the possibilities of extending the investigation because of the non-commercial nature of the operation.

4.4 Questionnaire analysis

4.4.1 Extend of monitoring at the biogas plants

Analysis of the questionnaire on the monitoring capabilities of the partners plants (Table 6) revealed that most have pH and volume measurement for a range of different storage and fermentation tanks. However few have the capacity to measure VS, VFAs, redox, conductivity and none were monitoring alkalinity.

4.4.2 Technology at the biogas plants

Information on the pumping technology, fermentation technology, mixer technology, process interferences and biogas treatment was extracted from the questionnaire and can be found in Appendix 9.

The pumping technology varies from site to site and the data structure does not enable numerical analysis. However, there were 24 rotary pumps, 5 centrifugal and 15 eccentric worm pumps. Only 3 single-stage spiral pumps were used. Many were used for varying times. The fermentation geometry and associated problems are presented in appendix 9 as are the range of mixer technologies used. A range of process interferences as noted from failure to pumping problems with no particular process inferences dominating. The primary means of treating biogas production is by adding air.

Table 6 The extent of process monitoring at the 13 selected biogas plants

	BP1	BP2	BP3	BP5	BP6	BP8	BP9	BP10	BP11	BP12	BP13	% at partners biogas plants
Fermentation-process surveillance	yes	yes	yes	yes	yes	yes	Partially	no	no	no	no	55
Fermentation sensor	yes	no	no	yes	no	no	no	no	no	no		18
pH sensor	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	91
Redox sensor	no	no	no	yes	no	no	no	no	no	no		9
Conductivity sensor	no	no	no	no	no	yes	no	no	yes	no		18
COD sensor	no	yes	no	yes	no	no	no	no	no	no		18
Turbidity sensor	no	no	no	no	no	no	no	no	no	no		0.0
Volatile FAs sensor	yes	no	no	yes	yes	yes	no	no	no	no		36
VS sensor	no	no	yes	yes	no	yes	no	no	no	no		27
Alkalinity sensor	no	no	no	no	no	no	no	no	no	no		0
Temperature sensor	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	100
Volume 1 sensor	yes	yes	yes	no	yes	yes	yes	yes	yes	no		73
Volume 2 sensor	yes	yes	yes	no	yes	yes	yes	yes	no	no		64
Volume 3 sensor	yes	yes	yes	no	yes	yes	yes	no	no	no		55
Volume 4 sensor	yes	yes	yes	no	no	yes	yes	no	no	no		46
Volume 5 sensor	no	yes	no	no	no	no	no	no	no	no		9

Table 6 shows that most biogas plants have a pH, temperature and volume sensors. While this provides some degree of understanding optimisation of biogas production is not possible without further information to process.

4.5 Economic performance of the biogas plants

Due to various circumstances there were differences in the quality of the economic data obtained by the questionnaire. Most of the biogas plants are commercial plants and understandably in some cases it was hard to get detailed economic data from the owners. Furthermore a few biogas plants work together with universities or private companies to carry out experiments. Thus the sum of investments or running expenses maybe different to an "ordinary" biogas plant. Nevertheless the calculated economic values are in the expected range. However, the economic results are different for producing energy from biogas in the different countries. Therefore the most independent of costs were assessed in three case studies of specific capital expenditure, specific costs per kWh electricity produced and specific costs per Nm³ methane produced.

Figure 18 shows the specific capital expenditure (€ per installed electrical capacity P_{inst}) for the 13 biogas plants. The average value is about 4,400 € per installed electric capacity P_{inst} (kW), that compares well to other studies (Walla and Schneeberger 2003). If we assume 8,000 operating hours per year for the CHP the average value would result in capital costs (5% discount rate, 15 years economic life) of 5.3 €-Cent per kWh of electricity.

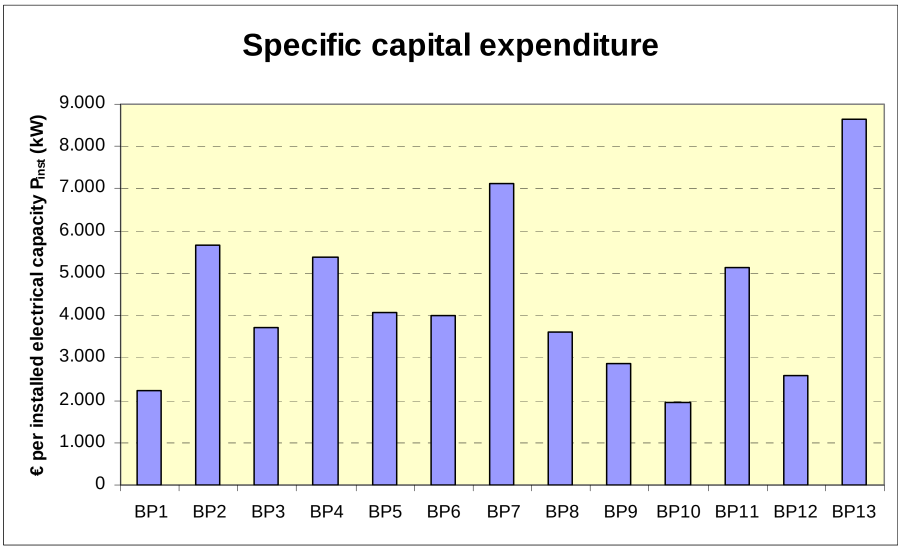

Figure 18 Capital expenditure per installed electric capacity P_{inst} (kW)

To calculate the total costs additional to the capital costs information about the costs of feedstock and other costs (insurance, labour costs, cost for maintenance and repairs, administration costs, costs for machinery, rental of the property, costs of spreading the fermentation residues, miscellaneous) were accumulated.

Figure 19 presents the specific total costs per kWh electricity produced for the 13 biogas plants. The average calculated total costs amounted to 19.5 €-Cent per kWh electricity produced with a wide range from about 10 to 39 €-Cent. Some of the biogas plants showed rather high capital costs due to high specific capital expenditure and/or poor electric efficiency and methane productivity. The capital costs have a mean value of 9.5 €-Cent with a range from 3.35 to 25.65 €-Cent.

The average costs of feedstock was 5.6 €-Cent per kWh electricity produced. The huge variation between the biogas plants (0.2 to 18.5 €-Cent) is caused by the great variety of feedstock sources used. Some of the biogas plants do not have to pay for the feedstock or get paid for waste processing. Due to rising prices for agricultural products these costs may increase in the next few years.

The stated other costs amount to a mean of 4.4 €-Cent per kWh electricity produced. The lowest value was 1.9 €-Cent and the highest 7.9 €-Cent.

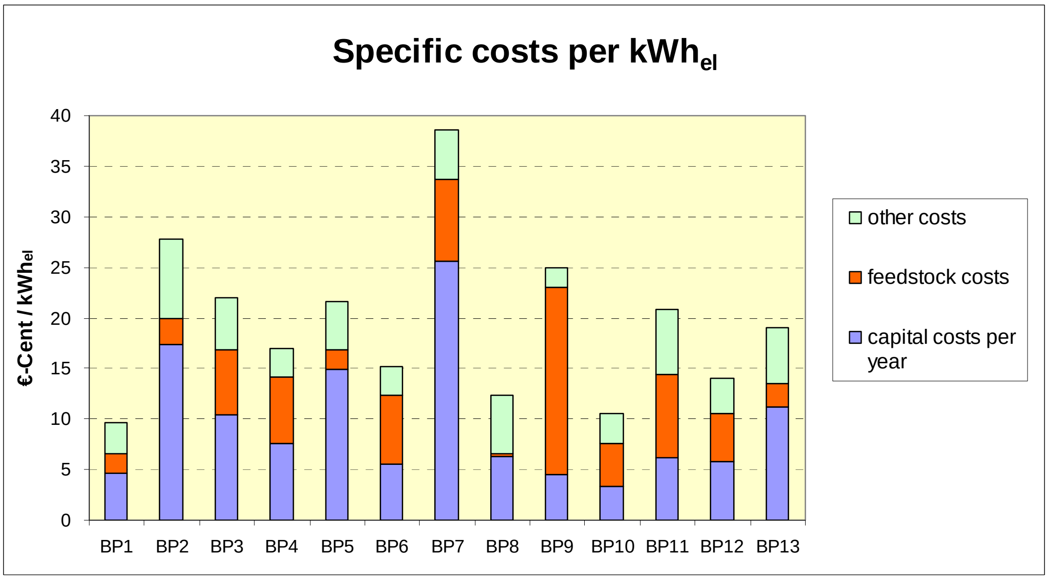

Figure 19 Specific costs per kWh$_{el}$

The specific costs per kWh electricity produced gave an important information of the profitability of a biogas plant producing electricity for the grid. If there are no additional revenues (e.g. sale of heat energy, waste processing, subsidies, green certificates) the price for electricity delivered to the grid should be above the specific costs per kWh$_{el}$. Almost 90% of the revenue of the 13 biogas plants comes from selling the produced electric energy, the rest is from selling or substitute heat energy and waste processing.

As the biogas plants demonstrated different electric efficiency additional specific costs per Nm³ methane were calculated (Figure 20). The average value was 67 €-Cent per Nm³ methane produced with a range from 30 to 106 €-Cent.

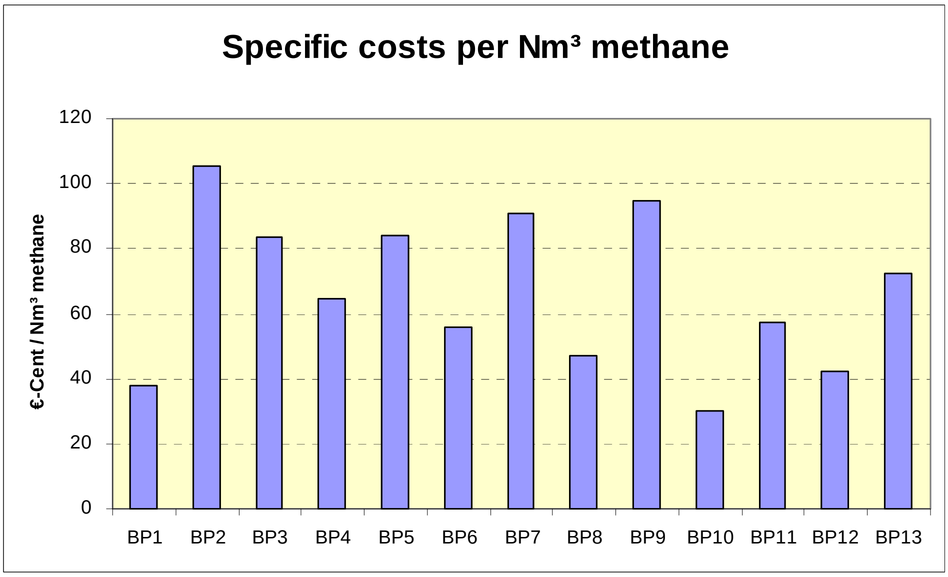

Figure 20 Specific costs per Nm³ methane

4.6 Schematic diagrams of the biogas plants

Influence of digester design on biogas production has been a parameter that has not been investigated and here we classified the different designs using a series of values as in Table 7. The plant design parameters were ascribed values for the presence or absence of the following: pre-treatment (1 or 0 respectively), number of stages in biogas plant, tank or ring based digester (1 or 2 respectively) and a presence or absence of a post digester (1 or 0 respectively). These values were investigated using principal component analysis (PCA) and included data from the month benchmarking dataset fraction. Further the feedstock was classified by the major type of input as either

1. manure
2. fruit/green crop and
3. fat or glycerol

Of the 13 biogas plants 7 had some type of pre-treatment, 3 had two-stage digesters, 2 had the new ring type digester design and 7 biogas plants had a post digester for methane collection.

Principal component analysis (PCA) was performed to see if there were any relationships or potential relationships in this reduced dimensionality approach. The data was complex and was not described easily. Further simple models or explanations of the data in Table 5 were investigated by multiple linear regression that could describe the specific methane yield or methane productivity. PCA demonstrated that there was a close association of fat and glycerol feedstock volume with the specific methane yield. Also the biogas plants that had manure as their main feedstock had installed pre-treatment and the use of a post digester capability. There were good associations of main feedstock types and partners biogas plants in the PCA analysis. Feedstock type had a greater influence than digester design. No models were possible from these initial approaches.

4.6.1 Modelling biogas production for the 13 biogas plants

A multiple linear regression modelling was investigated and described 34% of the variation for the specific methane yield using the fraction of fruit energy crop feedstock and manure and post digestion and pre-treatment. However the model was not accurate and the predicted values were skewed. This was also true for a model describing the methane productivity was only 23% of the variance was accounted for. The models were not validated because of the insufficient number of biogas plants, but nevertheless this modelling gave an indication of what maybe possible for predicting biogas output from inputs using operational biogas plants across Europe.

This may identify that the amount of livestock manure added as mostly cattle manure may act as an inoculum was important and suggested also that the methanogenesis organisms maybe washed from the digester to reduce methane production.

5. Conclusions

Data from benchmarking and the economic analysis draw some clear conclusions. Benchmarking can distinguish influences across a range of digester types with different inputs. The influences are classified in the groups below.

5.1 Benchmarking data

Here critical points from the analysis of benchmarking data are presented. This approach is based on numerical inputs and highlights those areas using a numerical perspective and includes graphical analysis of the benchmarking data.
These findings are listed under the four following points.

5.1.1 Electrical performance

1. The electrical capacity is underutilised and should be increased.
2. Underutilisation can be due to low biogas input or low CHP use.
3. Because of the range of biogas plant designs it is difficult to determine how to reduce own electrical energy use
4. Four biogas plants have CHP units that reduce methane conversion

5.1.2 Pretreatment and feedstock type

1. There is a need to improve the hydrolysis of energy crops as there was an inverse relationship of methane productivity to fraction of energy crop content.
2. Feedstock type has an influence on biogas plant performance.
3. High levels of manure feedstock reduces biogas yield by as much as 3 times per unit dry weight of feedstock added.
4. Increasing amounts of fat and glycerol present increase the biogas yield.

5.1.3 Fermentation performance

1. The specific biogas yield was considered good at 0.44 m^3.methane.kg^{-1} VS
2. There was a fermentation variability of 7 to over 100% of the specific methane yield.
3. Biogas plants have up to a 3 times difference in methane yield per unit mass of volatile solids.
4. The methane productivity has a mean of 1.3 and a range from 2.62 to 0.5 m^3.m^3
5. The average degradation rate was 68% with a range of 48 to 89% of the VS
6. The fermenter was not operating to full capacity because of the correlation between specific methane yield and methane productivity.
7. There was no relationship of VS degradation to the measured fermentation parameters.

5.1.4 Monitoring and process control

1. There was limited monitoring at the biogas plant and optimisation of biogas production is difficult without further information on the fermentation process
2. The fermentation stability expressed as standard deviations from the mean value demonstrated a 7 to 100% range, identifying some biogas plants could increase there process stability with better monitoring.

5.2 Questionnaire data

1. The questionnaire data also identified that the digesters were not operating to full capacity because as the digester increases methane productivity (per m^3) so does the specific electricity yield.
2. Some biogas sites have generators that have reduced conversion of biogas to electricity.

5.3 Economic efficiency of the biogas plants

1. The average specific capital expenditure (€ per installed electrical capacity P_{inst}) of the 13 biogas plants conform to common values. However, there are two plants with high and two with low specific capital expenditure.
2. The average total costs of 19.5 €-Cent per kWh electricity produced is slightly above the price paid for electricity from biogas plants in most of the countries involved.
3. Most biogas plants have the potential to improve economic performance by increasing biogas production and electric efficiency (>90% utilisation of fermenter and CHP capacity).

5.4 Weak point analysis

These conclusions are from collated information from the biogas plant operators experience. The findings reveal that there are numerous concerns but these are principally the two below and these should be investigated as part of WP4 to improve biogas production;

1. Pre-treatment
2. Monitoring and process control

5.5 Implementation of findings

Implementation of these findings will be addressed in WP4 onwards primarily as demonstration projects.

6.0 References

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Appendix 11 Tabulated Overview (from questionnaire)Overview table (080728_D08_overview-table_sum.xls)

Appendix 1 - Biogas Plants in the benchmarking process and their production capacity

Biogas plant number	**produced electric energy MWh.d^{-1}**	**Methane Nm^3.d^{-1}**	**fresh matter tons.d^{-1}**	**dry matter tons.d^{-1}**
BP1	16.7	4342	42	7
BP2	26.0	6841	254	27
BP3	27.9	7341	97	14
BP4	22.3	5874	62	13
BP5	6.1	1354	52	4
BP6	11.7	3152	48	6
BP7	5.3	2286	74	6
BP8	23.9	6236	259	36
BP9	23.7	6241	146	28
BP10	12.3	4320	57	2
BP11	4.4	1589	25	5
BP12	18.8	6126	435	106
BP13	6.7	1754	57	5

Appendix 2 - Basic fermentation parameters for all plants

PARAMETER	UNIT	AVERAGE	MAX	STDEV
outside temperature	°C	10.25	29.00	5.38
Hydrolysis temp.	°C	30.16	57.30	1.15
Mesophilic digester temp average	°C	38.75	2.3	41.9
Thermophilic digester temp average	°C	51.1	0.20	51.2
digester temp top	°C	38.92	43.50	2.25
digester temp bottom	°C	38.81	43.50	2.40
post fermenter temp middle	°C	22.00	44.00	31.11
storage temp.	°C	23.95	39.48	3.59
H2S	ppm	335.16	1000.00	388.39
O2	Vol. %	0.33	5.20	0.47
produced electric energy	$MWh.d^{-1}$	15.56	296.78	8.28
Heat energy	MWh	11.81	17.37	6.69
CH_4	$m^3.d^{-1}$	2954.31	0.00	1931.38
CH_4 [Nm^3]	$Nm^3.d^{-1}$	4556.14	13357.95	2135.59
CH_4 in biogas [%]	Vol. %	53.61	80.00	16.15
biogas [m^3]	$m^3.d^{-1}$	8179.51	12255.85	2982.59
Biogas gas [Nm^3]	$Nm^3.d^{-1}$	7659.53	21203.09	3516.86
specific methane yield	m^3/kg VS	0.42	4.68	0.17
hydraulic retention time	D	53.53	477.94	25.16
loading rate	kg VS/m3 digester volume $.d^{-1}$	4.45	35.26	4.68
methane productivity	Nm^3 $CH_4.m^3$ digester volume $.d^{-1}$	1.34	2.70	0.65
VS in fresh matter	%	13.18	67.07	7.94
VS in digester	%	3.13	5.88	1.66
VS in storage	%	3.81	8.13	2.16
degree of degradation of VS after main digester	%	79.59	100.00	15.28

Appendix 3 - Feedstock inputs as tonnes of fresh matter for all biogas plants

PARAMETER	UNIT	AVERAGE	MAX	STDEV
pig slurry	t fm	46.07	416.67	108.04
cattle slurry	t fm	34.18	249.73	70.42
corn waste	t fm	12.76	175.18	46.75
maize silage	t fm	12.73	67.20	20.61
colza cake	t fm	9.49	131.88	35.22
ley crop silage	t fm	9.42	131.88	0.00
ground maize	t fm	5.26	73.60	0.00
others	t fm	5.12	49.71	13.35
water	t fm	3.44	39.28	10.58
Cooked solid and liquid manure	t fm	3.16	44.22	0.00
triticale silage	t fm	3.02	42.23	0.00
fat	t fm	2.82	18.67	5.37
blood	t fm	2.56	35.55	9.49
fruit waste	t fm	2.35	30.00	8.00
CCM	t fm	1.66	17.28	4.77
food waste	t fm	1.60	22.37	0.00
glycerol	m3	1.44	9.34	2.90
bleaching earth	t fm	1.07	15.01	0.00
pig water	t fm	1.06	14.87	0.00
sunflower silage	t fm	0.98	13.76	3.68
potatoes	t fm	0.85	6.00	2.15
kiwi	t fm	0.82	11.45	0.00
sludge	t fm	0.40	3.40	1.05
Recyclat	t fm	0.31	3.15	0.87
Sbl. Silage	t fm	0.30	4.20	0.00
fish waste	t fm	0.26	3.61	0.00
grass silage	t fm	0.26	3.64	0.97
Slaughterhouse waste	t fm	0.20	2.78	0.00
GPS	t fm	0.19	2.59	0.69
Bio-diesel waste	t fm	0.18	2.53	0.00
dog food	t fm	0.18	2.53	0.00
starch	t fm	0.18	2.47	0.00
apples	t fm	0.16	2.24	0.00
vegetable waste	t fm	0.15	2.11	0.00
poultry slurry	t fm	0.15	2.10	0.00
kitchen leftovers	t fm	0.09	1.29	0.00
energy crops	t fm	0.07	1.05	0.00
green rye	t fm	0.04	0.56	0.00
Millet	t fm	0.01	0.10	0.00

** Inputs data from BP1 to BP13 used to calculate average values.*
*** Data sorted by descending average values.*

Appendix 4

1 Submitter:			
Address:			
	Plant operator	Planner	Producer
Name/ company			
Street			
Postal code/City/ federal state			
Phone			
Fax			
E-mail			

2 Approval			
2.1 Location		**2.2 Type of approval**	
Town	☐	Electricity law	☐
Outskirts of town	☐	Federal law of waste management	☐
Selected special area	☐	Trade law	☐
Industrial park	☐	Environmental impact assessment law	☐
		....	☐
2.3 Approval information		Date	
Submission of application			
Construction period			
First power input			
Official acceptance of the biogas plant			
Extension of the existing biogas plant			
Which extensions were made?			
....			

3 Type of business				
		Legal form	Number of partner companies	
Individual plant	☐			
Collective plant	☐			
Conventional farming	☐	Organic farming	☐	
Number of supplier:..............				

4 Capacity utilisation of the biogas plant

Capacity utilisation	Percentage
Capacity utilisation of the biogas plant	....%

If 100% - since when? ....

If not 100% - reason: ....
....

5 Bio mass – input and production

5.1 Farm manure (Information about of known data. If not available, generated standard values will be used)

Input		DM²-content	Ø Livestock population		Origin	Condition
Animal species	Amount [t FM¹/year]	[%]	Numbers	... days in stable	of.. own farm pf.. partner farm o.. others	L.. liquid manure S.. solid dung
Dairy cows						
Rearing-/ fattening cattle						
Fatting pigs						
Breeding sows						
Piglets						
Laying hens						
Broiler						
Horses						
...						
...						

[1]... Fresh matter

[2]... Dry matter

5.2 Renewable raw materials

5.2.1 Input and origin

Input		DM-content	Cultivation and yield		Origin	Costs free plant	Availability
Renewable raw materials	Amount [t FM[1]/year]	[%]	[ha/year]	[t FM/ha]	of.. own farm pf.. partner farm o.. others	[€/t FM]	Days/year
Maize silage							
Grass silage							
…							
…							
...							
...							
...							
...							
...							

5.2.2 Cultivation on set-a-side land

Crop	ha/year	Crop	ha/year
...		...	
...		...	

Additional expenses by denaturation and business diary, respectively:

Working time: ....hours/ha Material costs: ....€/ha

5.2.3 Energy crop bonus

Crop	ha/year	Crop	ha/year
...		...	
...		...	

Additional expenses by denaturation and business diary, respectively:

Working time: ....hours/ha Material costs: ....€/ha

5.2.4 Costs and demands of working time if purchased		
Substrate	t FM/year	Costs [€/t]
Cattle liquid manure		
Pig liquid manure		
Maize silage		
Grass silage		
...		
...		
...		

Duration of the contracts:..

Price: Fixed price ☐ Annual price ☐

☐ Delivery to the plant (crop, distance in km): ....

....

☐ Self-harvest (crop, distance in km, harvest- and transport costs): ....

....

Necessary expenditure of time: ....hours/year

☐ Self-collection (crop, distance in km, transport costs): ....

....

Necessary expenditure of time: ....hours/year

5.3 Cofermentation substrates						
Input		DM-content	Origin	Substrate costs	Receipts of disposal	Availability
Substrates	Amount [t FM[1]/year]	[%]	of.. own farm pf.. partner farm o.. others	[€/t FM]	[€/t FM]	days/year
Biowaste						
Leftovers						
Cookings fats						
...						
...						
...						
...						
...						

Duration of the contracts:..

Price: Fixed price ☐ Annual price ☐

☐ Delivery to the plant (crop, distance in km): ....

....

☐ Self-harvest (crop, distance in km, harvest- and transport costs): ....

....

Necessary expenditure of time: ....hours/year

5.4 Water		
Input	yes/no	If yes m³/month
Water	yes ☐ no ☐	

5.6 House sewage		
Input	yes/no	if yes m³/month
House sewage	yes ☐ no ☐	

5.7 Daily ration (t/d)	
Important: From each substrate a sample needs to be taken for nutrient analyses.	

6 Storage of the substrates

6.1 Stackable substrates

Substrate	Form of storage	Storage capacity [m³]
Maize silage	Tower silo ☐ Bunker silo ☐ Liquid storage ☐ others.................	
Grass silage	Tower silo ☐ Bunker silo ☐ Liquid storage ☐ others.................	
...	Tower silo ☐ Bunker silo ☐ Liquid storage ☐ others.................	
...	Tower silo ☐ Bunker silo ☐ Liquid storage ☐ others.................	
...	Tower silo ☐ Bunker silo ☐ Liquid storage ☐ others.................	

Cover bunker silo: ☐ Plastic film ☐ Natural green cover ☐ others: ……………………………….

Utilization of percolation water in the biogas plant yes ☐ no ☐ if yes amount ....m³

Estimated demand of working time for the storage of stackable substrates: ....hours/year

6.2 Liquid substrates

Substrate	Form of storage	Storage capacity [m³]	Cover
Liquid manure	Storage container ☐ others		yes ☐ no ☐
Leftovers	Storage container ☐ others		yes ☐ no ☐
...	Storage container ☐ others		yes ☐ no ☐
...	Storage container ☐ others		yes ☐ no ☐
...	Storage container ☐ others		yes ☐ no ☐

Estimated demand of working time for the storage of liquid substrates: .... hours/year

7 Transport, pretreatment and manipulation of the input substrates	
7.1 In-house transport	
Distance of the storage area to the biogas plant	
Silo-storage 1 2 3	.....m .....m .....m
Liquid-storage 1 2 3	.....m .....m .....m
.... 1 2 3	.....m .....m .....m
Means of transport	Transport capacity
Wheel loader, front loader	☐ ....m³
Crane	☐ ....m³
Conveyor belt	☐ ....m³
Pumps	☐ ....m³
Others	....
Estimated demand of working time for the in-house transport	..............................hours/week

7.2 Pretreatment	
Are substrates pretreated?	yes ☐ no ☐
Are substrates with trash processed?	yes ☐ no ☐

Crushing

Substrate	Amount [m³/d]	Crushing technology (e.g. mill, sieve, maze-rator,...)	Power [kW]	When will be crushed? (on the field, before fermen-tation,...)	Particle size [mm]
Maize silage					
Grass silage					
...					
...					
...					
Leftovers					
Biowaste					
...					
...					
...					

Runtime of the crushing technique	.... hours/week

Sanitation

Sanitation available Already sanitised substrates are used	yes ☐ no ☐ ☐
Type and location of sanitation	☐ Partly ☐ All substrates ☐ Before fermentation ☐ Between 2 fermentation steps ☐ After fermentation
	☐ Thermophile operational mode
Volume of the sanitation tank	....m³
Throughput sanitation	....m³/d
Sanitation passages Time per passage Temperature	..../d ....min ....°C
If all substrates are sanitised Type of heat recovery	 ....

Description of placement, fencing, washing facility etc. of the sanitation

....
....
....
....

Estimated demand of working time for the pretreatment .... hours/week

7.3 Substrate insertion						
Upstreamed pits						
Type of pit	Volume [m³]	Construc-tion (concrete, steel,...)	Mixer unit m = mechanically (submersible mixer, long-axis mixer, axial mixer, paddle-decoiler mixer) h = hydraulically p = pneumatic g = gravitation	Connected power [kW]	Running time	
					Stirring ...per day	Running time per interval [min]
Collecting pit						
Mixing pit						
Liquid manure pit						
Fat pit						
Pump pit						
...						
...						

Mixer controlled automatically yes ☐ no ☐

Which substrates are inserted:..

....

Are the pits open or closed?..

Are odour emissions produced? yes ☐ no ☐

If yes, what is done against this? biofilter, etc.:..

Pumping technology						
Construction of the pump	Number	Power [kW]	Turnover rate [t/h]	Pumping processes ...per day	Running time per interval [min]	Installation location (collecting pit, etc.)
Rotary piston pump ☐ Centrifugal pump ☐ eccentric-worm pump ☐ Bellow pump ☐ .... ☐						

Pumping process controlled automatically: yes ☐ no ☐

Registration of substrate volume yes ☐ no ☐

Type of data registration:...

Substrate allocation:
- only to fermenter(s) ☐
- fermenter and secondary fermenter ☐
- fermenter and final storage ☐
- variable from/to all vessels ☐

Estimated demand of working time for the substrate insertion .... hours/week

Solid matter feeding						
Construction of the solid matter feeding	Number	Power [kW]	Turnover rate [t/h]	Feeding processes ...per day	Running time per interval [min]	Installation location (main fer-menter, etc.)
Collecting pit ☐ Flushing pit ☐ Insertion pit ☐ Press piston ☐ Feed mixer wagon vertical mixer ☐ horizontal mixer ☐ Pushing container ☐ Others .... ☐						
Feeding process controlled automatically: yes ☐ no ☐						
Size of the solid matter intake:..m³						
Weighing machine existing: yes ☐ no ☐						
Flow meter existing: yes ☐ no ☐						
How often will the solid-matter bunker filled?...per day						
Demand of working time per bunker filling?.. per day						

8 Fermenter technology				
8.1 Fermenter	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Function	mf = main fermenter sf = secondary fer-menter			
Operation	p = parallel s = arranged in series			
Process temperature	[°C] summer/winter			
Useable volume	[m³]			
Type of construction	h = horizontal v = vertical			
Number of fermenta-tion chambers	s = single-chambered d = double-chambered m = multiple-chambered			
Fermenter geometry	r = roundly re = rectangularly q = quadratically			
Material	c = concrete, s = steel, f = ferroconcrete, ss = stainless steel			
Dimensions	Diameter, height			
Installation	a = aboveground u = underground p = partly countersinked			
8.2 Mixer	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Number	[Pieces]			
Type	m = mechanically (sub-mersible mixer, axial mixer, long-axis mixer, paddle mixer, decoiler mixer) h = hydraulically p = pneumatic g = gravitation			
Diameter of the mixer wing	[cm]			
Mixer speed	[pro min]			
Mixer power	[kW]			
Position	l = on the side d = through ceiling			
Mixing interval	Mixing per day [...times]			
	Running time per inter-val [min]			
Automated	yes ☐ no ☐			

8.3 Fermenter heating	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Type	n = none i = inside e = elevated c = integrated in the concrete at the: w = wall f = floor a = agitator o = lying-outside heat exchanger			
Material of the heating pipes	p = plastic ss = stainless steel s = steel			
Cooling facility	yes ☐ no ☐			
8.4 Fermenter insulation	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Material				
Location	f = floor s = shell c = ceiling			
Thickness	[cm]			
8.5 Bottom discharge	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Installed		yes ☐ no ☐	yes ☐ no ☐	yes ☐ no ☐
Type	m = mechanically h = hydraulically e.g. rack plus worm, slider			
Running time	Runs per day [....times]			
	Running time per interval [min]			
Power of the bottom discharge	[kW]			
Material discharge	[m³ per day]			
8.6 Fermenter cover	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Material	s = steel c = concrete fc = ferroconcrete h = gas hood			
8.7 Problems	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Floating layer		yes ☐ no ☐	yes ☐ no ☐	yes ☐ no ☐
Foam		yes ☐ no ☐	yes ☐ no ☐	yes ☐ no ☐

8.8 Process parameters	Characterisation	Fermenter 1	Fermenter 2	Fermenter 3
Self-heating		yes ☐ no ☐	yes ☐ no ☐	yes ☐ no ☐
Estimated residence time		.................days	.... days	.... days
Recycled material	Recirculation of fermentation residues	…………m^3/d	…………m^3/d	…………m^3/d

9 Process control	
9.1 Process control	
Process control	manual ☐ automatic ☐
Data recording If yes: Which parameter? How often measurements?	yes ☐ no ☐ ....
Fermentation-process surveillance (e.g. gas-measurement unit)	yes ☐ no ☐

9.2 Types of sensors used to monitor process				
	Location in plant	Online	Offline	used to control process
Fermentation				
pH				
redox				
conductivity				
COB				
BOD				
turbidity				
Volatile FAs				
VS				
Alkalinity				
Temperature				
Volume 1				
Volume 2				
Volume 3				
Volume 4				
Volume 5				
Other sensor measurements				

1	2
9.3 Process interferences	
yes ☐ no ☐ If yes: Numbers: .... Reason(s): .... Duration:	
Failures since start-up	yes ☐ no ☐
Most commonly weak point (mixer, ...)	
Automatic identification of process failurees?	
Estimated demand of working time for process control .... hours/week	
Important: From each fermenter a sample needs to be taken for measurements: e.g. tempera-ture, pH, VFA, H^+, FOS/TAC, redox potential, conductivity, NH_4^+, VS and other nutrients.	

10 Biogas – preparation, storage, safety	
10.1 Gas measurement	
Amount of biogas production	....m³/day ....m³/year
This value is	measured ☐ estimated ☐
Quality of the biogas	CH_4-concentration .... vol-% CO_2-concentration .... vol-% O_2-concentration .... vol-% H_2S-concentration .... ppm NH_3-concentration .... ppm H_2-concentration .... ppm
This value is	measured ☐ estimated ☐
Gas measurement and analysis	....
10.2 Biogas preparation	
Type of condensate separation	☐ Cooling tunnel.......................................m ☐ Biogas dehumidifier ☐ Others..
Desulphurisation ☐ Biological desulphurisation ☐ Addition of chemicals ☐ Others	yes ☐ no ☐ ☐ internal (air supply) ☐ external
If biological desulphurisation:	Air supply: ....% air of biogas
Air supply controlled by gas measurement?	yes ☐ no ☐
Injection by an estimated amount of air?	yes ☐ no ☐
Location of air supply:	Main fermenter ☐ Secondary fermenter ☐
10.3 Safety installations	
High-, low-pressure safeguard	☐ At the fermenter ☐ In the gas pipe ☐ Water trap ☐ Others ....
Operating pressure	....mbar
Gas flare is installed?	yes ☐ no ☐
Excess-gas burning capacity	..........................m³/hour

10.4 Biogas storage		
Gas storage	....m³ ....hours/day	
Number of gas storages	.... pieces	
Gas storage	☐ Integrated over the fermenter	☐ external storage
Integrated gas storage over	☐ Main fermenter ☐ Secondary fermenter ☐ Final storage	
Construction	☐ Foil storage under membrane roof ☐ Foil as roof over fermenter ☐ Foil as roof plus weatherproof foil ☐ Foils under a solid roof ☐ Others.............................	☐ Exposed and fixed foil pad ☐ Enclosed foil pad in extra building or tank ☐ Foil pad at intermediate ceiling above fermenter ☐ Foil bag hanging in e.g. tower silo ☐ Others.............................

11 Biogas utilisation	
11.1 Gas utilisation generally	
Gas utilisation with	☐ Combined heat and power unit (CHP) ☐ Gas boiler ☐ Others ....
Produced electric power	....kWh/year
Supplying the whole electric power produced?	yes ☐ no ☐
Measured supplied amount	....kWh/year
If known: consumption of electricity of the plant This value is	....kWh/year measured ☐ estimated ☐

11.2 Gas utilisation at the combined heat and power unit (CHP)					
Engine O = Gas-Otto-engine, I = Ignition-jet engine		Producer	Installed power [$kW_{el.}$]	Electric efficiency factor [%]	Engine operating time [hours/year]
Engine 1					
Engine 2					
Engine 3					
Engine 4					

11.3 Maintenance by usage of Ignition-jet engine	
Usage of ignition oil of fossil origin If no: origin	yes ☐ no ☐ ☐ RME ☐ Rape oil ☐ Others ....
Ignition oil consumption This value is	.... litre/year measured ☐ estimated ☐
Engine oil consumption This value is	.... litre/year measured ☐ estimated ☐
Costs for ignition oil Costs for engine oil	....€/year ....€/year
Ignition-oil change interval Engine-oil change interval	.... operating hours .... operating hours
Expenditure of time for maintenance/repairs	....h / annual
11.4 Maintenance by usage of gas-Otto-engines	
Engine oil consumption This value is	.... litre/year measured ☐ estimated ☐
Oil change interval	.... operating hours
Costs of engine oil	....€/year
Expenditure of time for maintenance/repairs	....h / annual

12 Heat production and utilisation	
12.1 Heat production	
Produced heat energy	....$kWh_{therm.}$/year
Heat consumption of the biogas plant This value is	.... $kWh_{therm.}$/year measured ☐ estimated ☐

12.2 Heat utilisation	
Utilisation of the heat for	☐ Heating Farmstead ☐ Stables ☐ Other buildings ☐ Biogas plant ☐ ☐ Drying ☐ Long-distance heating ☐ Others ....
Replaced energy sources	☐ Heating oil ☐ Liquid gas ☐ Natural gas ☐ Others ....
Dimension of heat utilisation	.... $kWh_{therm.}$/year

13 Fermentation residues – storage and utilisation		
13.1 Storage of fermentation residues		
Number of storage tanks	....pieces	at the plant
thereof open	................pieces with ....m³	yes ☐ no ☐
thereof covered	................pieces with....................m³	yes ☐ no ☐
thereof covered and connected to the gas system	................pieces with....................m³	yes ☐ no ☐
Filling of the tanks when more then one storage tank	☐ parallel	☐ batch- treatment
Storage capacity	....month	
Leak detection	yes ☐ no ☐	

13.2 Digestate analysis	
DM yes ☐ no ☐	P yes ☐ no ☐
N yes ☐ no ☐	K yes ☐ no ☐
Micronutrients	
S yes ☐ no ☐	K yes ☐ no ☐
Mg yes ☐ no ☐	B yes ☐ no ☐
Fe yes ☐ no ☐	Ca yes ☐ no ☐
Zn yes ☐ no ☐	Mn yes ☐ no ☐
Cu yes ☐ no ☐	Others

Na yes ☐ no ☐					
Trace elements	Ni yes ☐ no ☐		Cr yes ☐ no ☐	Others	
BOD yes ☐ no ☐			COD yes ☐ no ☐		
13.3 Who takes the fermentation residues ?					
Usage of the fermentation residues	☐ Own company ....m³/year ☐ Partner company ....m³/year ☐ Subcontracting firm ....m³/year ☐ Others ....m³/year				
If own or partner company costs of application	........€/m³				
If subcontracting firm or others: fermentation residue will be:	☐ collected by the costumer ☐ delivered ☐ delivered and distributed			Costs ....€/m³ ....€/m³ ....€/m³	Receipts ....€/m³ ....€/m³ ....€/m³
Demand of working time for fermentation-residue management? ....hours/year					

13.4 Use of fermentation residues	
Processing of the fermentation residues If yes: Procedure Connexion power Running time Investment costs Running costs Maintenance/repair costs Demand of working time	yes ☐ no ☐ Description:.. ....kW ....hours/year ....€ ....€/year ....€/year ....hours/year
Application of fermentation residues	☐ Piping ☐ Mobile application
If mobile application Tank lorries ☐ Solid application ☐ Other utilisation ☐	☐ Deflector ☐ Deflector with immediate surface treatment ☐ Liquid manure chisel ☐ Spreader with trailed hoses ☐ Spreader with semirigid hoses and share Description: .... Description: ....
Application for	☐ Grassland available area ....ha ☐ Tillage available area.................ha ☐ ....available area.................ha
Application rate	Grassland ....m³/growth ....m³/year Tillage ....m³/year
Nutrient investigation	☐ Which: .... ☐ How often: .... ☐ None
Subjective classification in comparison to previous farm manure	Growth effect ☐ Application qualities ☐ Odour ☐ 1 (very good) 2 (good) 3 (equal) 4 (worse)
Important: A sample of the fermentation residues needs to be taken for nutrient analyses.	

14 Profitability	
14.1 Investment	
Total investment (incl. silo, liquid manure technology, etc.)	............................€ ☐ excl. VAT ☐ incl. VAT
Product-related cost factors:	
Combined heat and power unit (CHP)	............................€ ☐ excl. VAT ☐ incl. VAT
Buildings and structural works	............................€ ☐ excl. VAT ☐ incl. VAT
Technical equipment	............................€ ☐ excl. VAT ☐ incl. VAT
Heat utilisation (drying plant, etc.)	............................€ ☐ excl. VAT ☐ incl. VAT
Bus bar	............................€ ☐ excl. VAT ☐ incl. VAT
Building ground	............................€ ☐ excl. VAT ☐ incl. VAT
Machinery	............................€ ☐ excl. VAT ☐ incl. VAT
14.2 Government aid	
Receipt of capital investment grant?	yes ☐ no ☐ ....€
Additional grant for plants with external heat utilisation?	yes ☐ no ☐.....................................€
Amount of total government aid	............................€ ☐ excl. VAT ☐ incl. VAT
Receipt of an incremental investment tax credit?	yes ☐ no ☐ ....€
14.3 Capital	
Equity	............................€
Outside capital	............................€
Rate (1x, 2x, 4x,...per year)	............................€ ....times/year
Interest rate	............................%
Duration	............................years
Extent of inserted internal labour	.... Working hours .... Machine hours .... €
14.4 Running expenses	
Expenditures for repairs, spares and maintenance	..............................€/year
thereof contractual maintenance	..............................€/year
Repairs in internal labour	..............................hours/year
Labour costs	...........................€/year (incl. employer's contribution)
Number of employees	.... Persons
Costs for electricity	..............................€/year

Insurance costs	..............................€/year
General administration costs (phone, paper,...)	..............................€/year
Accounting, tax and legal advice	..............................€/year
Rental of property	..............................€/year
Machine rental, machine lease	..............................€/year
Fuel for machinery	..............................€/year
Rental of power substation and counting station	..............................€/year
Business tax	..............................€/year
14.5 Profit	
Sale of electricity	............................€/kWh
Sale of heat	............................€/kWh
.....	
....	

15 Management	
Management	
Degree of automation	☐ high ☐ medium ☐ low
Demand of working time for the management and administration	.... hours/week

16 Reactions of near residents			
Evaluation of the biogas plant			
Complete biogas plant	☐ positiv	☐ negativ	
Odour emission	☐ high	☐ medium	☐ not relevant
Noise pollution	☐ high	☐ medium	☐ not relevant
Transport activity	☐ high	☐ medium	☐ not relevant

Appendix 6 Weak point analysis

These are reported as sent to the WP leader.

	Weak Points of the plant	implementation for demonstration	expected effects from the intended implementation [%]
BP1	alternating substrates	quickmix technology	optimized substrate feeding
	inhomogeneous substrate pretreatment	gasmeter	optimize substrate mixing
	alternating substrate quality	power measurement	reduced mixing power
	inefficient mixing of fermenter		no surface layers
	formation of surface layers		improved gas yield
	high power consumption of fermenter mixers		prevention of methane losses
	unoptimized combustion technique		avoidance of odour emissions
	no heat utilization		
	digestate storage not covered		
	odour emissions		
	loss of methane potential		
	no gasmeter		
	unoptimized process control		
BP2	feedstock mixtures not optimised	change feedstock mixture to reduce ammonia concentration (C:N ratio)	50% increase in biogas output from same volume input
	high ammonia concentration		
	poor methanogen activity		
	loading rate not optimised	optimise loading rate	
BP3	Long hydraulic retention time	regularly monitoring of VFA	better process stability
	High amount of solids	thermal-chemical pretreatment	better degradability
	High nitrogen content in biomass	thermal-chemical pretreatment with flashing of ammonia	Less inhibition of process
BP4	high costs for substrates	optimization of feedstock mixture, substitution of maize through glycerol	less costs for substrates (higher Methane content, reducing manpower) 40%
	unoptimized feedstock mixture		
	high costs for the storage of substrates		efficient utilization of heat in summer 30%
	low methane content		
	insufficient process control: no gasmeter, no H2 sensor	installation of further sensors	
	insufficient utilization of heat	installation of draff drying plant	
BP5	Insufficient mixing in digesters	installation of paddle mixers	5%
	Feeding interval is too big	Making it shorter	2%
	Filling method in one of the digesters is outdated	Improvement to direct rapid feeding	2%
	Insufficient HRT	Building of a second-stage digester	10%
	No proper solid substrate storage	Construction of a storage	5%
	Insufficient process control	Installation of a new control system and a biogas lab	2%

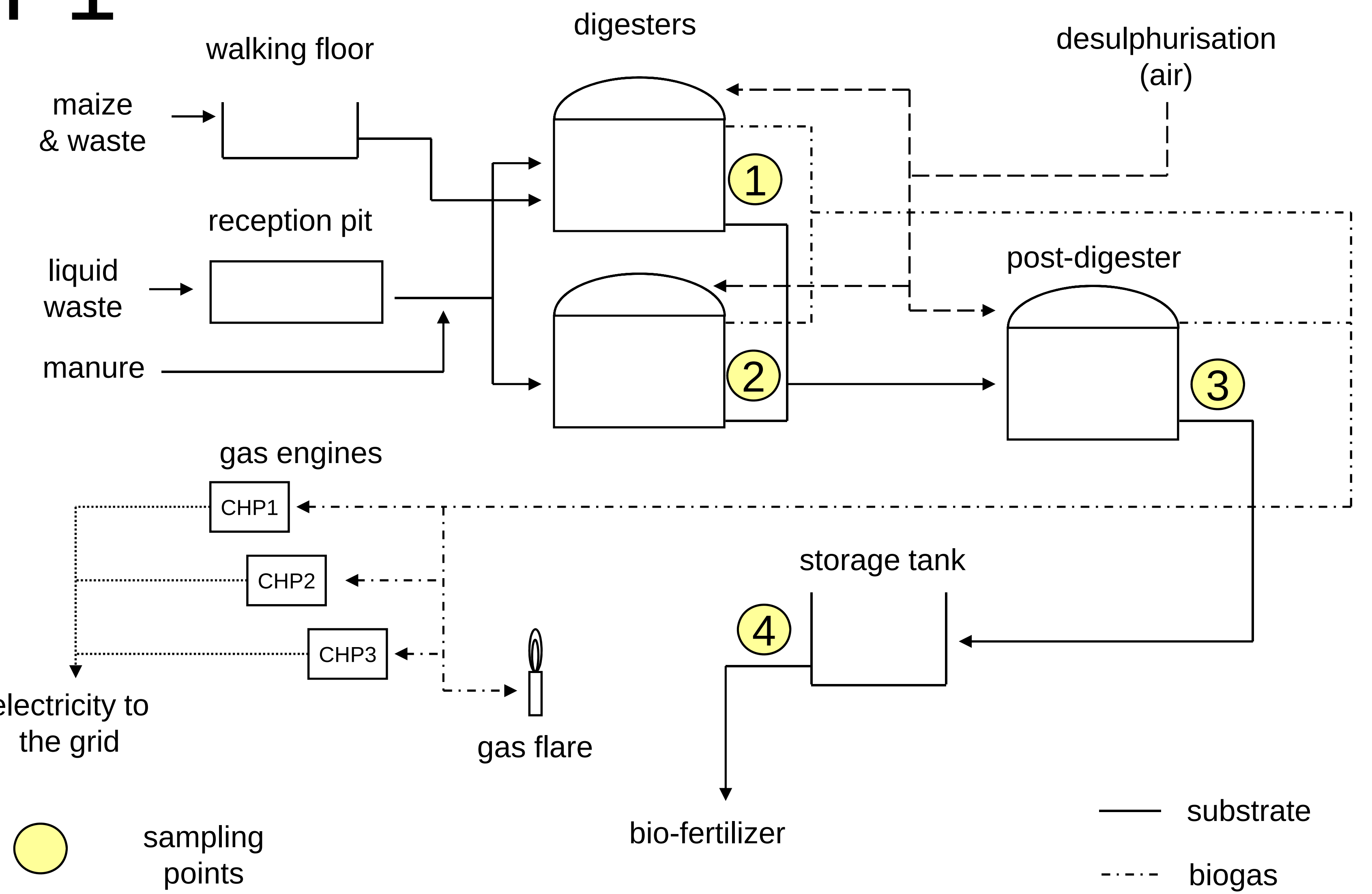
	Weak Points of the plant	implementation for demonstration	expected improvement [%]
BP7	No online gasanalyser	install gas analyser	better process stability
	No sensor for pH/redox/conductivity installed yet	install equipment	better process stability
BP8	great variety of substrates	Quick Mix with automatic control	reduce manpower
	mixing of substrates (collecting pit)	Gasometer	reduce process energy
	substrate mixture	Gas analyzer	optimize feeding strategy
	no automated feeding	Measurement of electric energy consumption	optimize loading rate
	Un-optimized mixing in fermenter		rise biogas yield
	temperature measurement		
	no gasmeter, no gas analyser		
	loading rate of fermenter		
	mixing technology (dived propeller mixer)		
	regular opening of fermenter for repairs of mixer		
	no pH or Redox		
	input of electric energy		
BP9	No knowledge of the analytical characteristics of the substrates by the personnel running the plant	Assistance in the evaluation of the chemical characteristics of the materials used to feed the digester	
	Great variability of the organic loading rate (1-3,4 kg SV per m3 digester volume per day) due to a lack in knowledge of the chemical characteristics of the input materials	To improve the organic loading rate	10-40% improvement in biogas production
	Low average organic load (2.2 kg SV per m3 digester volume per day)		
	Low specific methane yield (0,25 m3/kg SV)		
	Long retention time (~ 100 days)	To perform batch trials to assess the optimal retention time suitable for the different input biomasses used in the plant	To improve (up to 30%) the specific methane yield (m3/m3 digester volume), to improve the economics
	No coverage of digestate tank	To cover the digestate tank	To rise the biogas yield (1-10%), to reduce GHG and ammonia emissions
BP10	Large variations in feedstock composition, lack of uniformity	Discuss more uniformity with farmer	Ongoing
	Poor digestibility of rough grass feedstock for nature reserve areas	Pre-treatment with enzymes may help to improve digestibility	Increase of methane yield with 5%
	Gas leakages from end storage	Discuss new cover with farmer	Reduce methane leakages
	Variable retention time	Uniformize retention time in installation	Unclear
	Poor mixing capacity	Discuss extra or new mixer with farmer	Better process conditions and increasing process stability
	Excess of digested slurry due to co-digestion and national mineral regulations	Slurry processing (separation)	Increase of economic results
	Lack of installation extending options	Limited growing possibilities	Unclear

	Weak Points of the plant	implementation for demonstration	Expected improvement [%]
BP11	Lack of proces monitoring data (execpt temperature)	Digester is 'black-box'	More knowledge on process will improve efficiency
	Excess of heat production	Sub-optimal economic results	Use of heat in post-digesters will improve gas production
	Occasional problems with CHP's	Occasional 'down-periods' of CHPs	Lower amount running hours and electricity and heat production
BP12	"Rotacut" between liquid manure intermediate reservoir and pump irreparable out of order, hence it follows a huge fall of pressure	uninstall "Rotacut"	less power consumption of the pump. Approx. 5% of power consumption of this pump, but increase of reliability
	concentric screw pump does not manage to pump the volume flow, needed by "Börger" feeding device	change excentric screw pump	improved solid feedstock feeding and also reliability
	ill-conceived feeding-device leads to a lot of (very expensive) maintenance rates no automatic interruption of liquid manure pumping if no solid substrates are fed. Risk of pumping the liquid manure into the solid substrate storage ("Biotainer")	change feeding device; application of sensor	less maintenances needed, improved reliability, decreased labour force (approx. 8 person hours per day equals approx. 30% decrease)
	large amount of solid cattle manure leads to technical problems with the feeding device and to a large post-methanation potential of the digested output because of a sub-optimal feedstock conversion	feedstock pre-treatment device (biological and/or physical)	improved conversion of feedstock and hence, increased biogas yield and less problematic plant-feeding; increasd biogas production (up to 10%); decreased power consumption of mixers (approx. 30%); decreased power consumption of pumps (approx. 5%); increased reliability; decreased risk of swimming layer formation; decreased post-methanation potential (up to 50%)
	high concentration of inert gases (e.g. nitrogen) in biogas, due to aerobic desulfurization	usage of charcoal and/or pure oxygen for aerobic desulfurization (implementation not yet intended)	increased methane concentration of biogas → increased el. power of CHP (max. 1%)
	no usage of exhaust-gas of the 2.15MW-CHP	some kind of usage-facility (has to be defined in arrangement with plant-owner)	usage of approx. 1MW of thermal energy (usage of approx. 70 % of decoupled thermal energy, multiplicative increase of actual usage)
	loss of biogas and problematic stirring due to massive swimming layer in post-digester	*cf* 4)	decreased risk of swimming layer formation

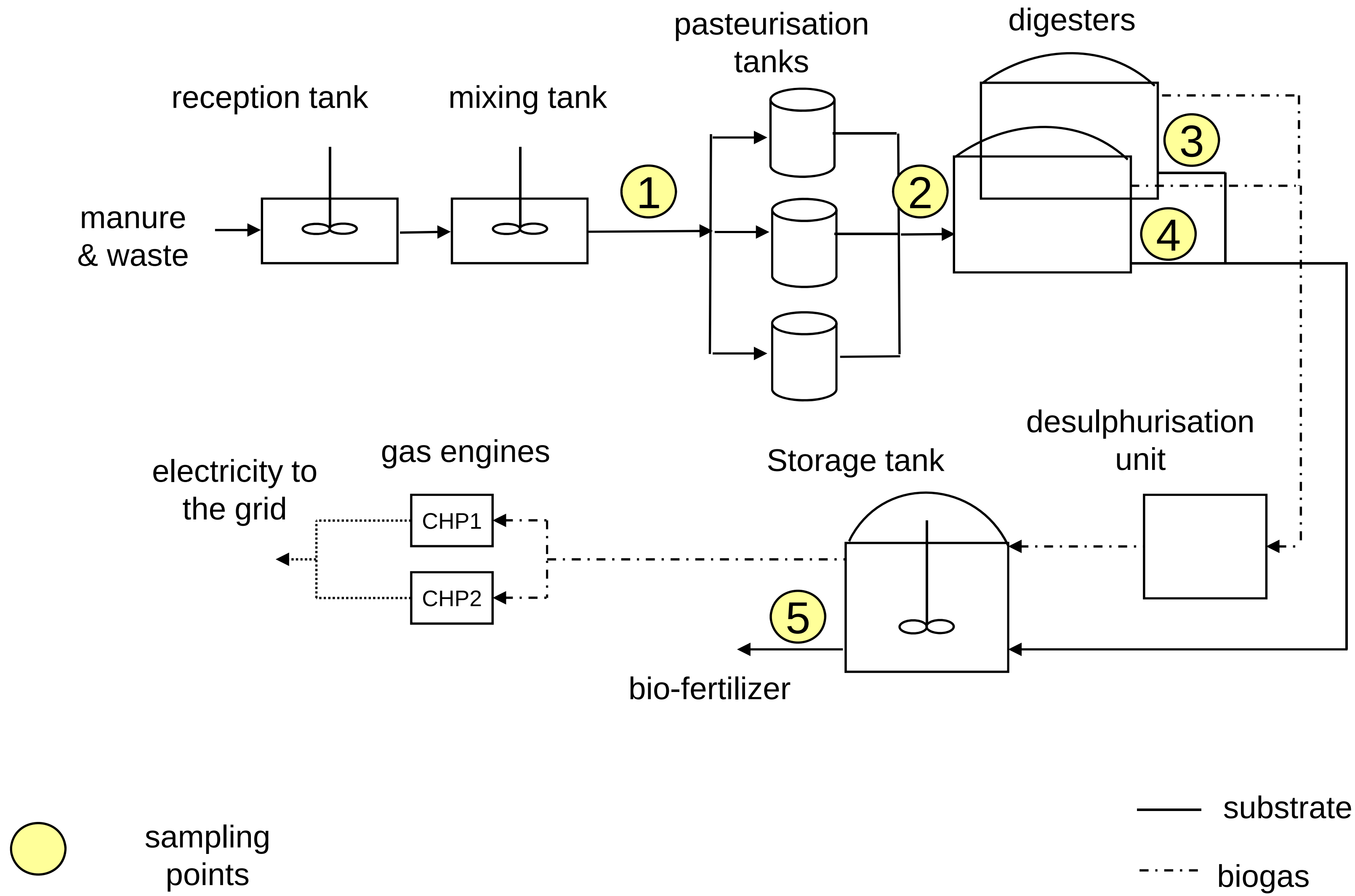
	Weak Points of the plant	implementation for demonstration	expected improvement [%]
BP13	unoptimized feedstock mixture	monitoring of chemical characteristics of feedstock	rise the specific methane yield (7%); better management of feedstock supply
	unoptimized loading rate	monitoring of chemical characteristics of feedstock mixture and its dosing	rise the specific methane yield (7%);
	no redox/conductivity measurement	installing sensors (depends on the BP owner)/monitoring redox and conductivity in a lab	stabilization of the process
	no online gas analyser	installing of gas analyser	
	no stable HRT for each feedstock	monitoring of chemical characteristics and dosing (amount, timing) of each feedstock	stabilization of the process
	short HRT	covering the first storage tank	rise the specific methane yield (7%); possibility of using other green energy crops than energy sorrel (maize, alfa-alfa)
BP15	no optimisation procedure	evaluate biogas plant process control using soft-sensor approach from 100% manure input to 100% energy crop (grass/maize) input	improvement of process stability
	sensors not implemented for monitoring	develop alkalinity measurements as a means of process control	improvement of biogas yield
	build software programme for process control	optimise feedstock mixtures	evaluation of soft-sensor approach for a range of inputs

Appendix 7

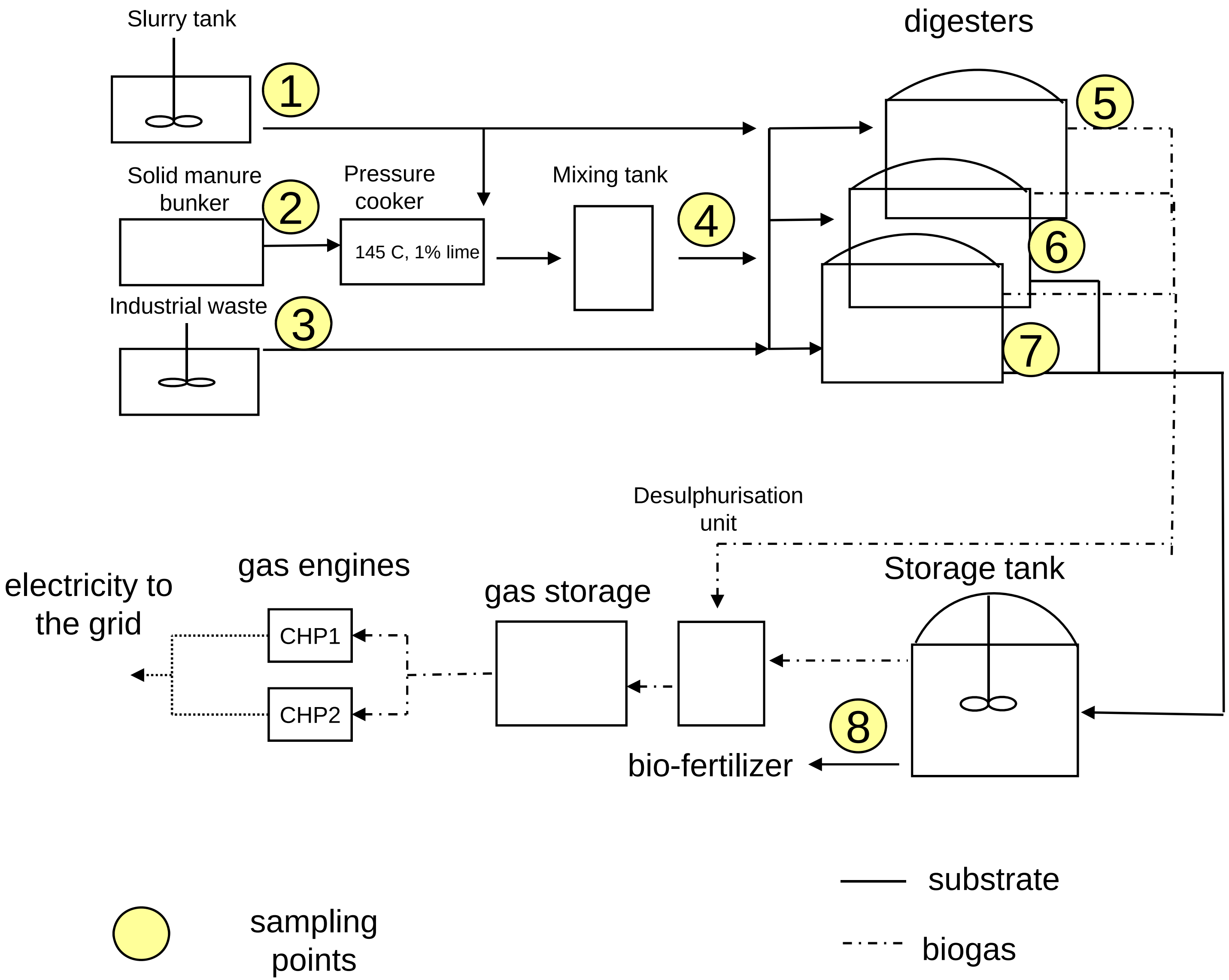
BP1



BP2

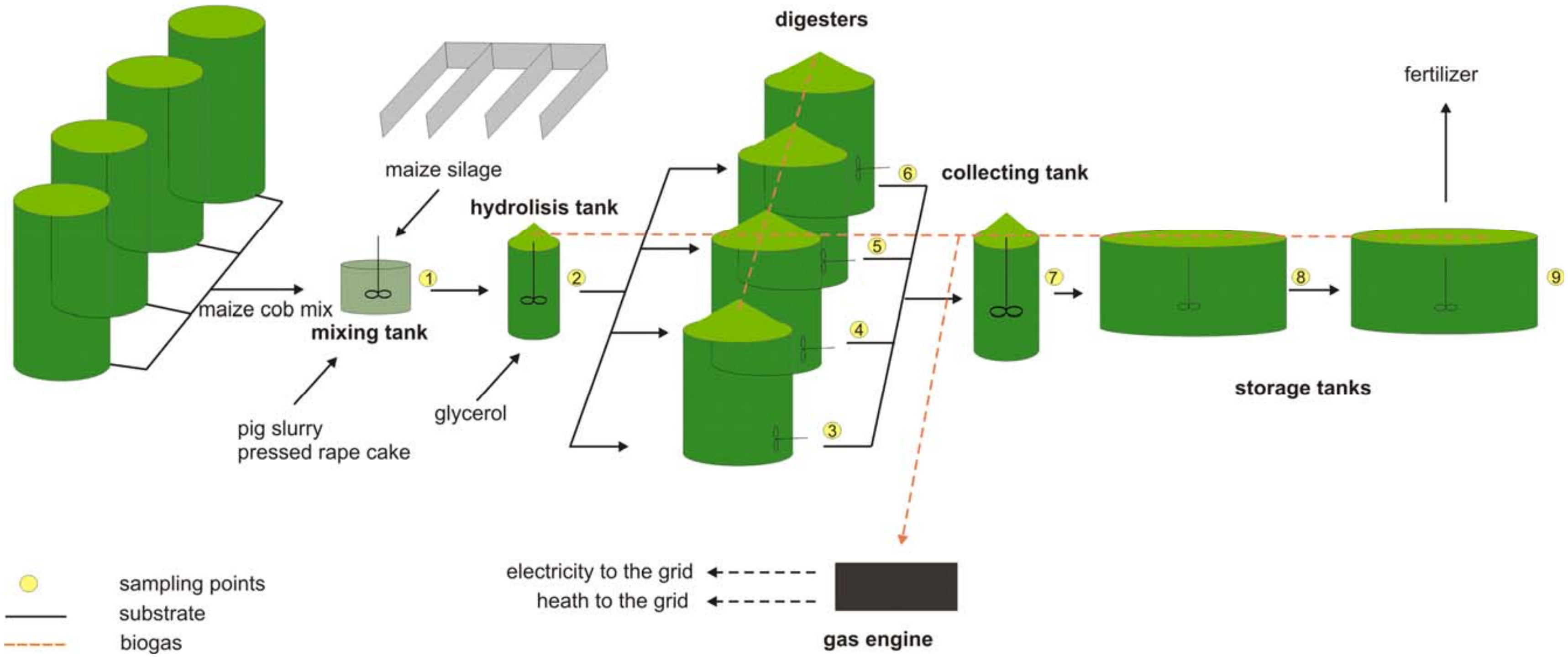

pasteurisation
tanks
digesters
reception tank
mixing tank
manure
& waste
1
2
3
4
desulphurisation
unit
gas engines
electricity to
the grid
Storage tank
CHP1
CHP2
5
bio-fertilizer
sampling
points
substrate
biogas

BP3

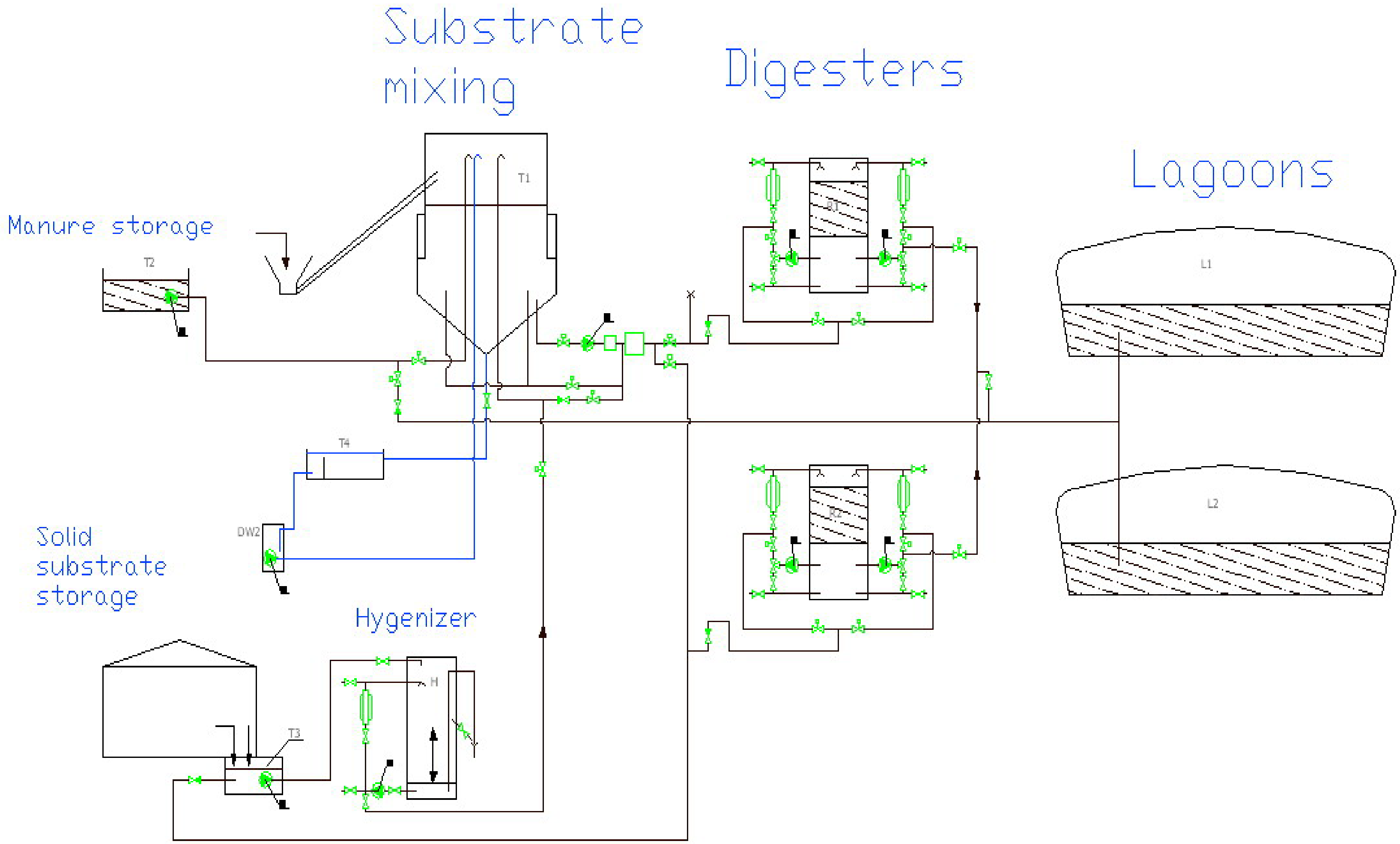


Slurry tank
digesters
1
5
Solid manure
bunker
2
Pressure
cooker
145 C, 1% lime
Mixing tank
4
6
Industrial waste
3
7
Desulphurisation
unit
electricity to
the grid
gas engines
gas storage
Storage tank
CHP1
CHP2
8
bio-fertilizer
sampling
points
substrate
biogas

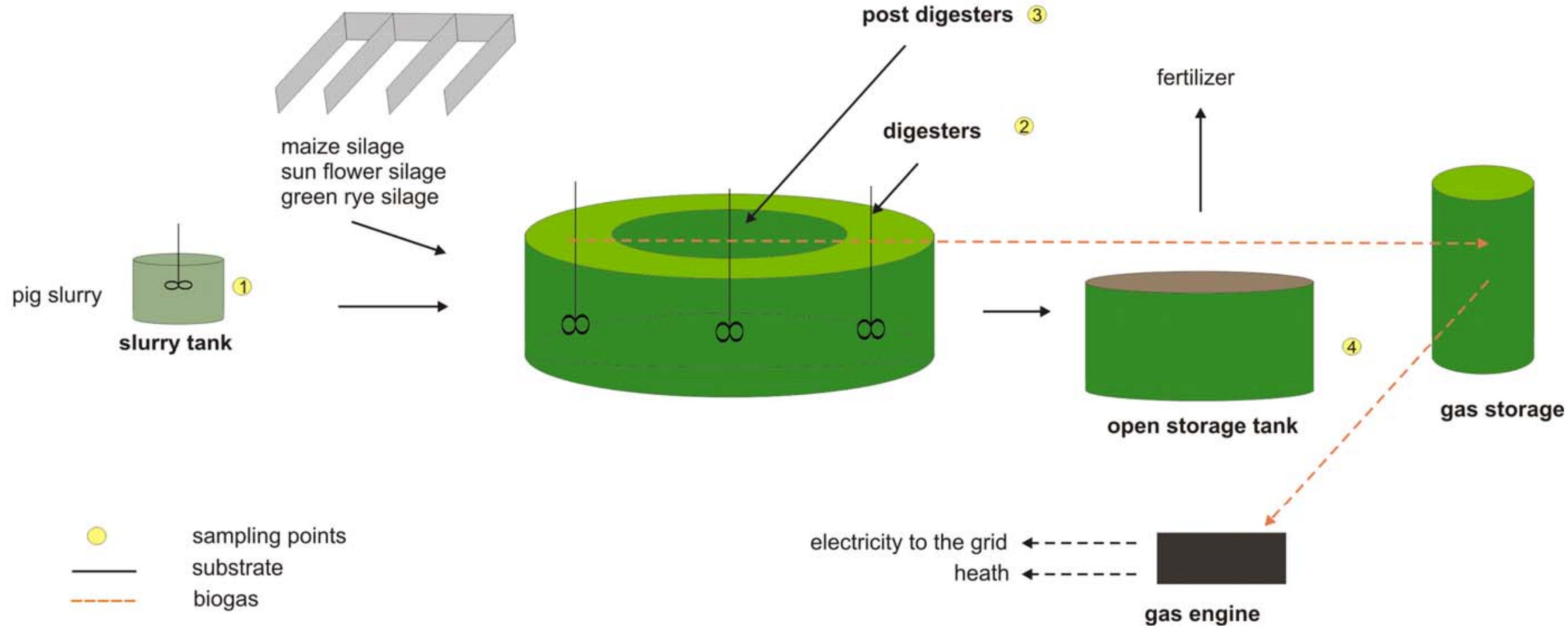
BP4


digesters
fertilizer
maize silage
collecting tank
hydrolisis tank
1
2
3
4
5
6
7
8
9
maize cob mix
mixing tank
storage tanks
glycerol
pig slurry
pressed rape cake
sampling points
substrate
biogas
electricity to the grid
heath to the grid
gas engine

BP5

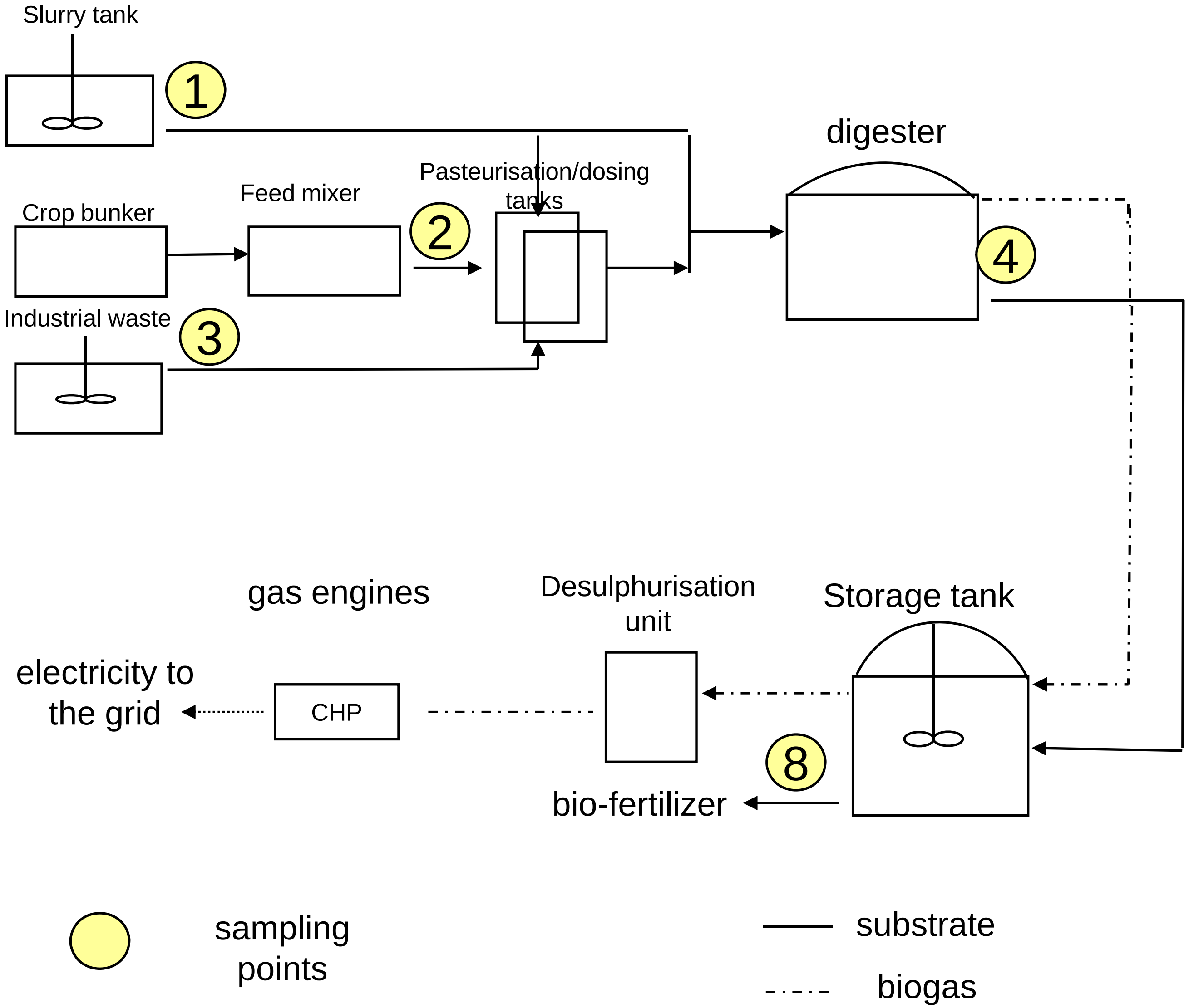

Substrate mixing
Digesters
Lagoons
Manure storage
T2
T1
T4
DW2
L1
L2
Solid substrate storage
Hygenizer
H
T3

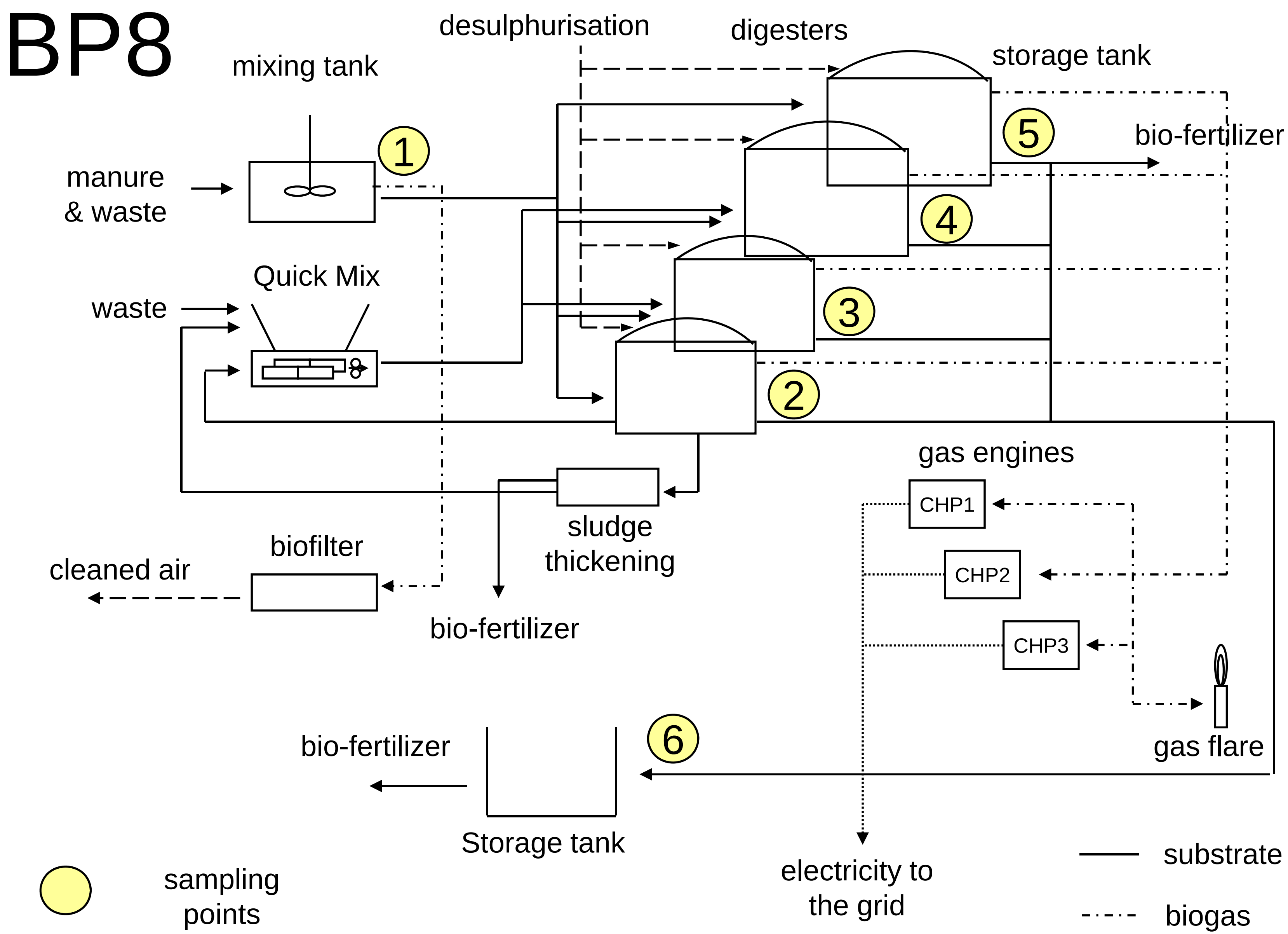
BP6



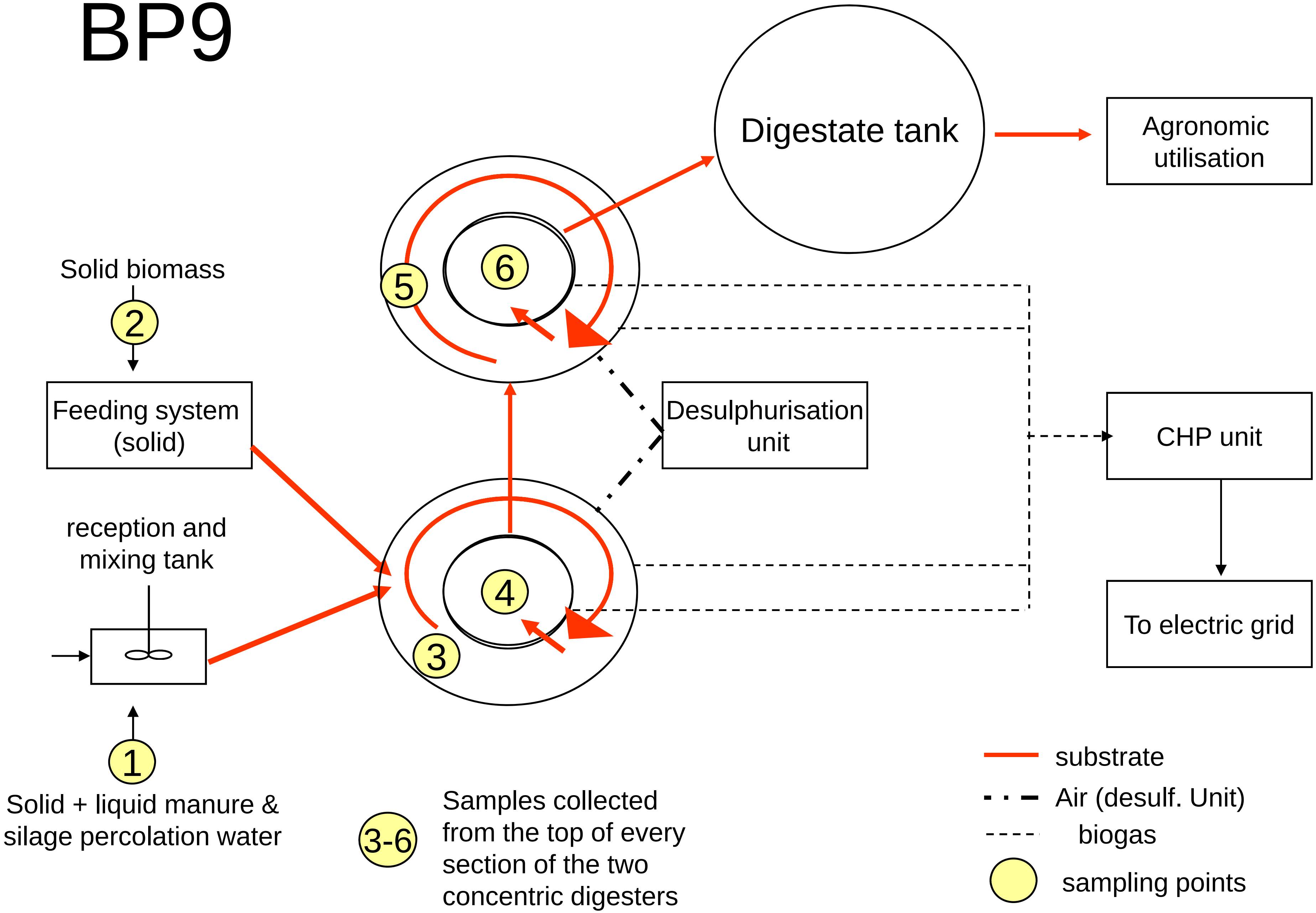
post digesters ③
fertilizer
digesters ②
maize silage
sun flower silage
green rye silage
pig slurry
①
slurry tank
④
gas storage
open storage tank
sampling points
substrate
biogas
electricity to the grid
heath
gas engine

BP7


Slurry tank
1
digester
Pasteurisation/dosing
tanks
Feed mixer
Crop bunker
2
4
Industrial waste
3
gas engines
Desulphurisation
unit
Storage tank
electricity to
the grid
CHP
8
bio-fertilizer
sampling
points
substrate
biogas

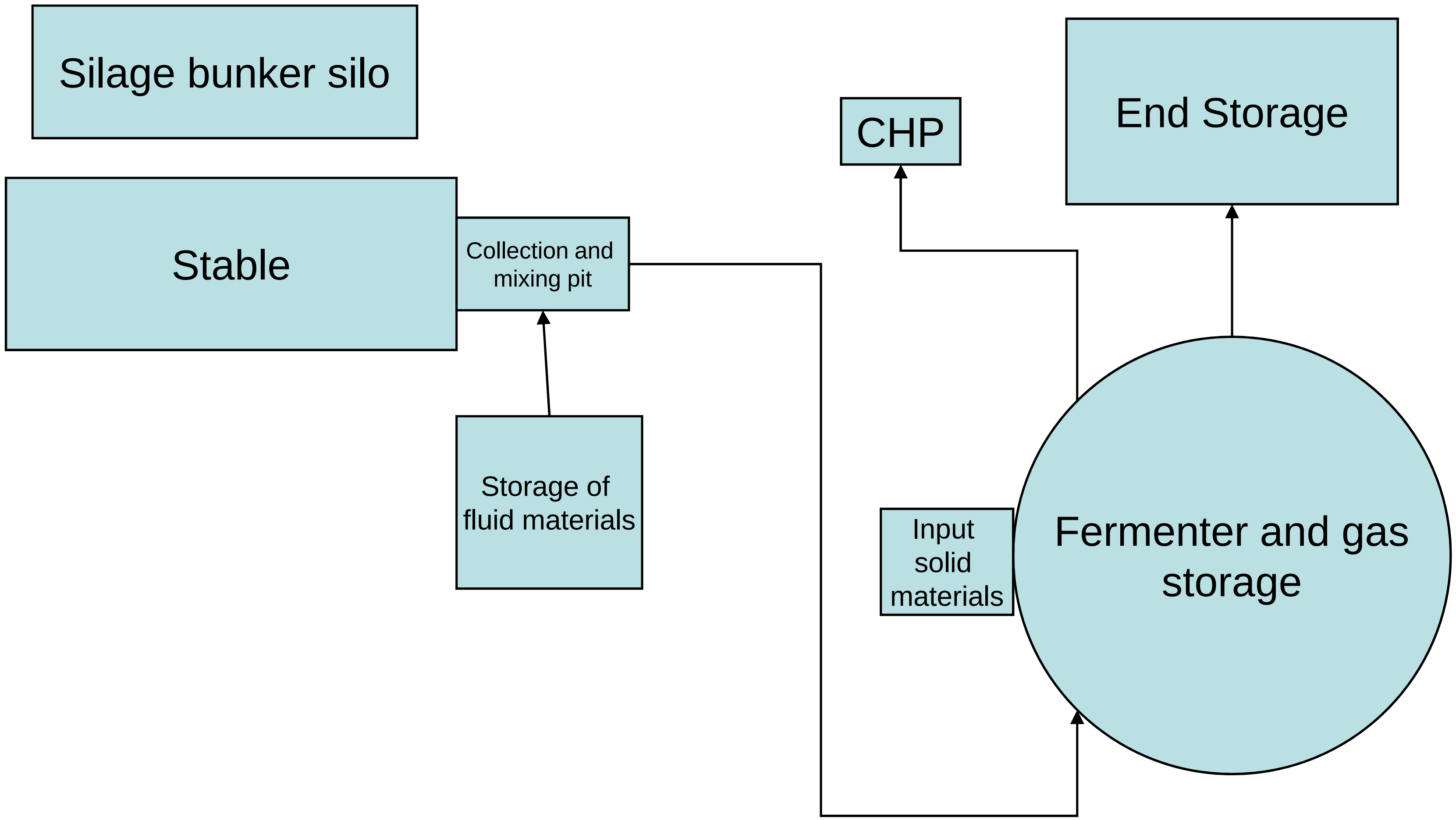

BP8
desulphurisation
digesters
mixing tank
storage tank
manure
& waste
1
5
bio-fertilizer
4
waste
Quick Mix
3
2
gas engines
CHP1
CHP2
CHP3
sludge
thickening
biofilter
cleaned air
bio-fertilizer
gas flare
6
bio-fertilizer
Storage tank
electricity to
the grid
substrate
biogas
sampling
points

BP9

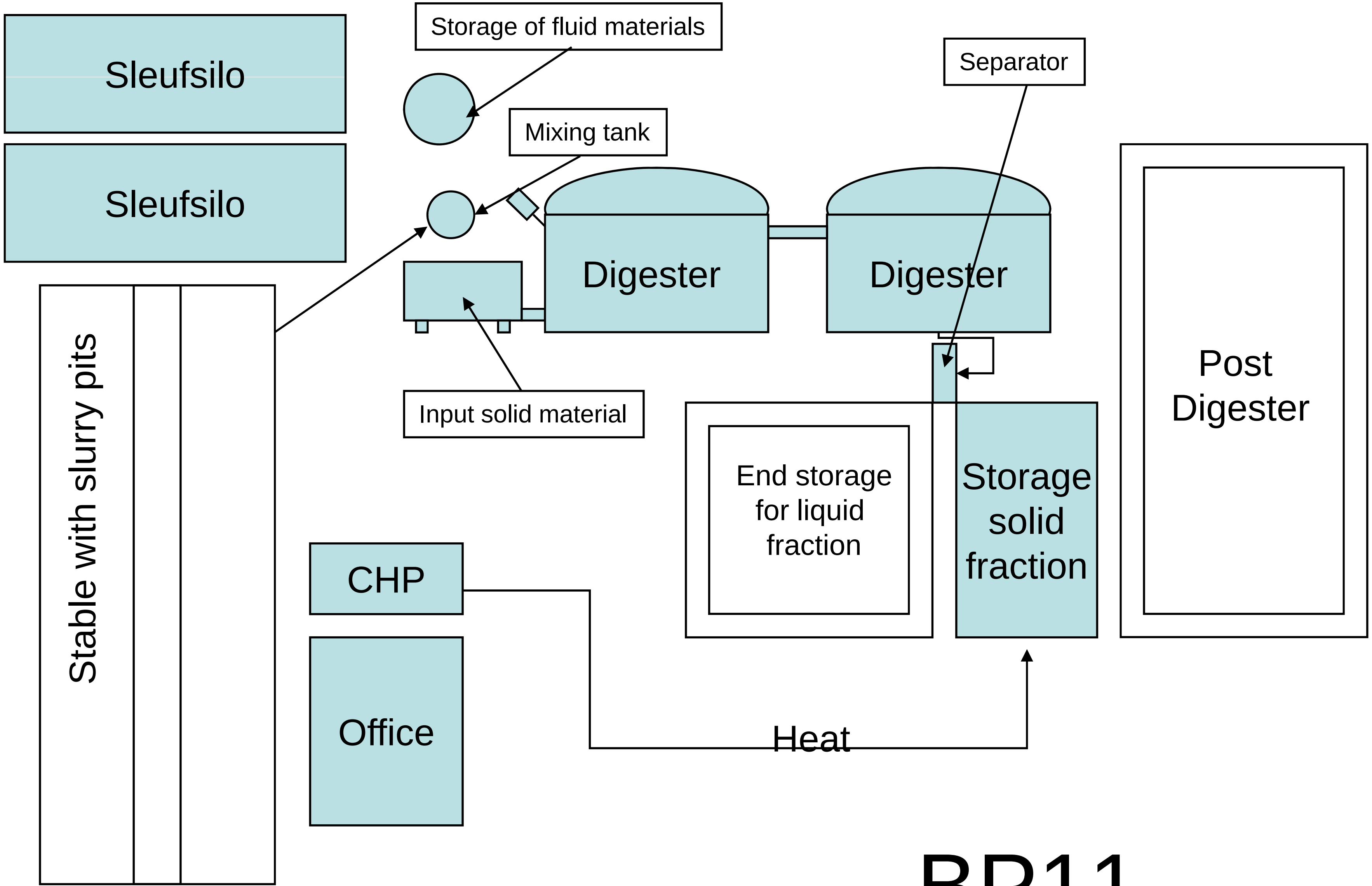


Digestate tank
Agronomic utilisation
Solid biomass
2
Feeding system (solid)
5
6
Desulphurisation unit
CHP unit
To electric grid
reception and mixing tank
4
3
1
Solid + liquid manure & silage percolation water
3-6
Samples collected from the top of every section of the two concentric digesters
substrate
Air (desulf. Unit)
biogas
sampling points

BP10

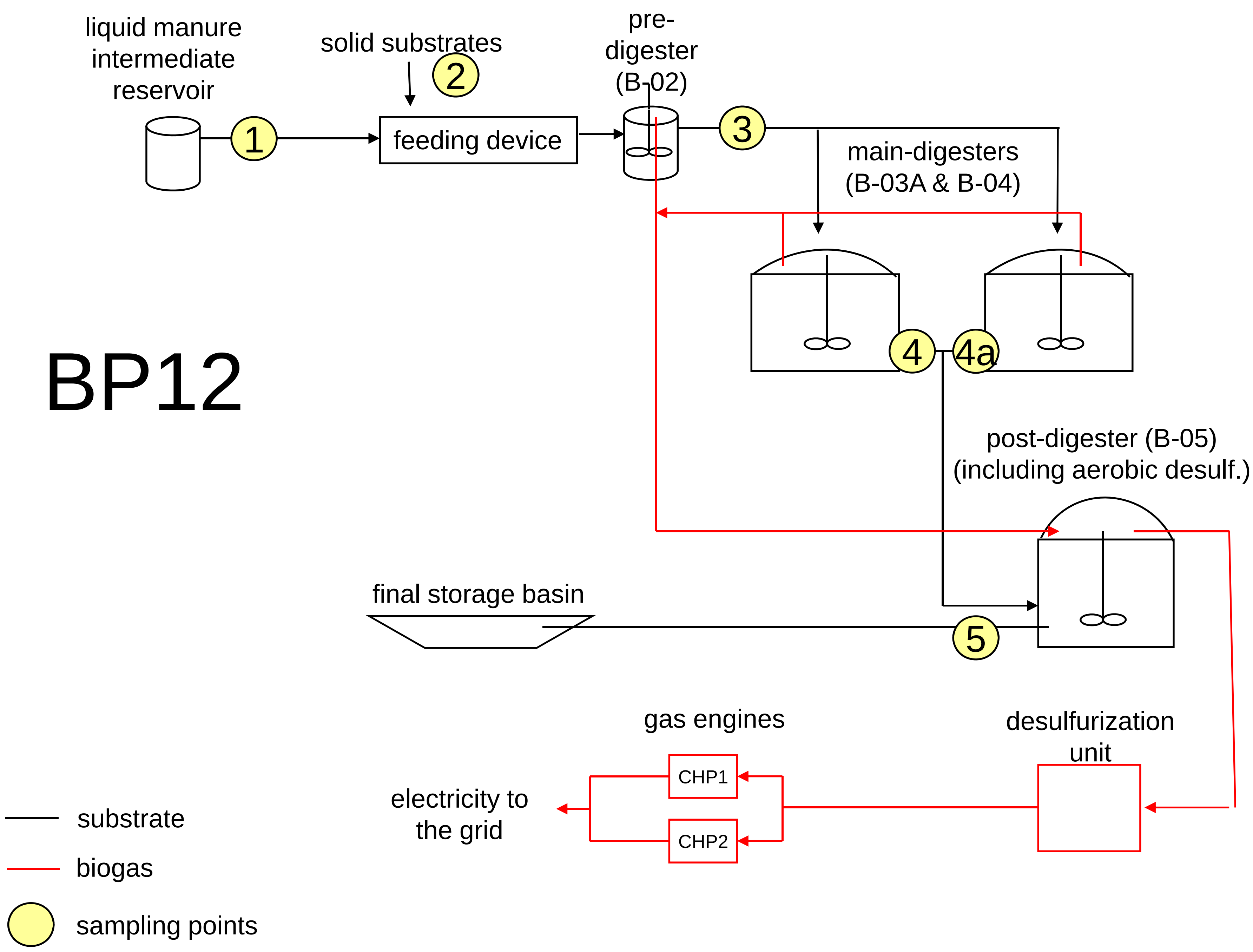


Drawing (not on scale)

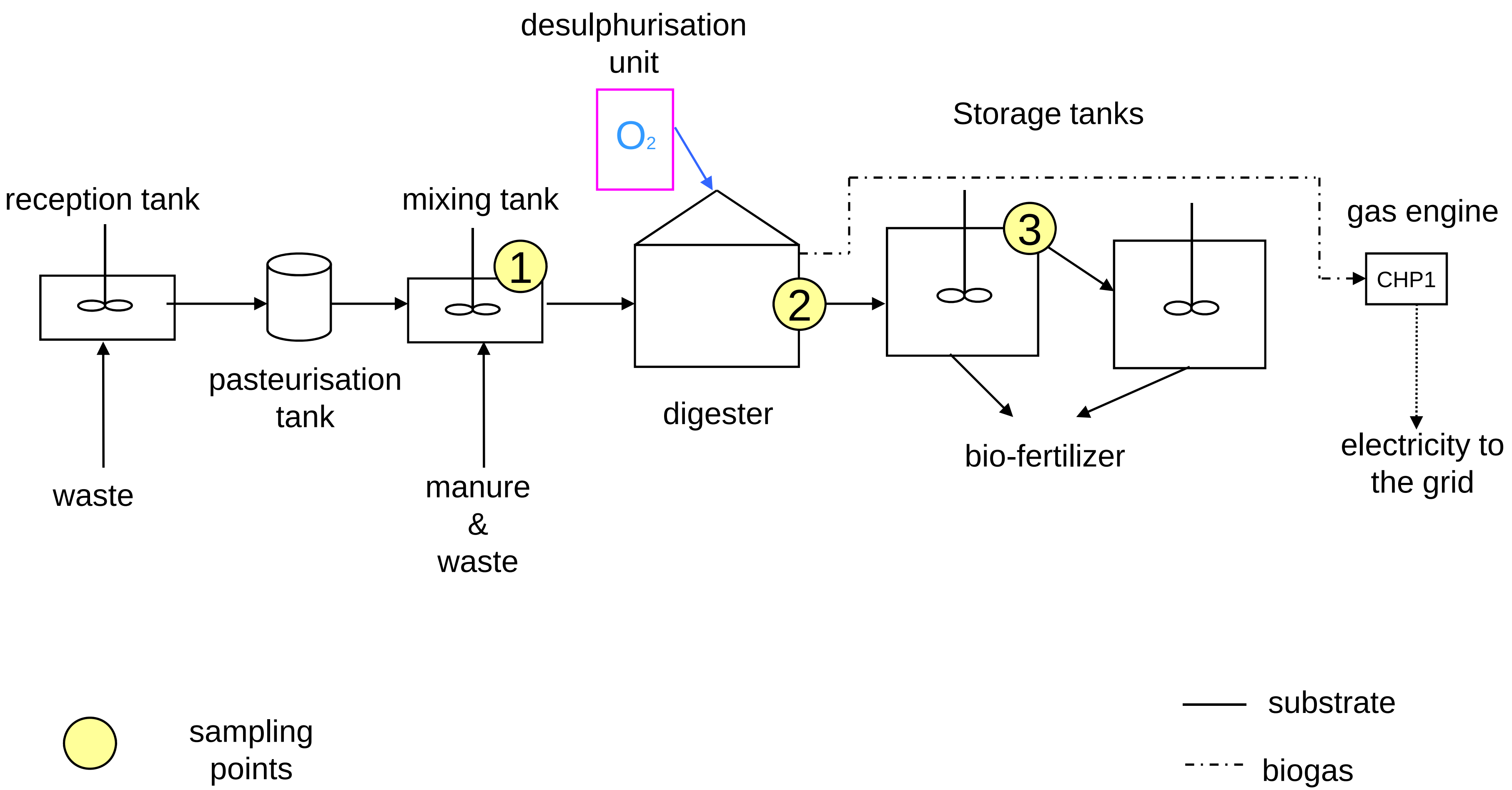


BP11

Drawing (not on scale)


liquid manure intermediate reservoir
solid substrates
pre-digester (B-02)
feeding device
main-digesters (B-03A & B-04)
1
2
3
4
4a
5
BP12
post-digester (B-05) (including aerobic desulf.)
final storage basin
gas engines
CHP1
CHP2
electricity to the grid
desulfurization unit
substrate
biogas
sampling points

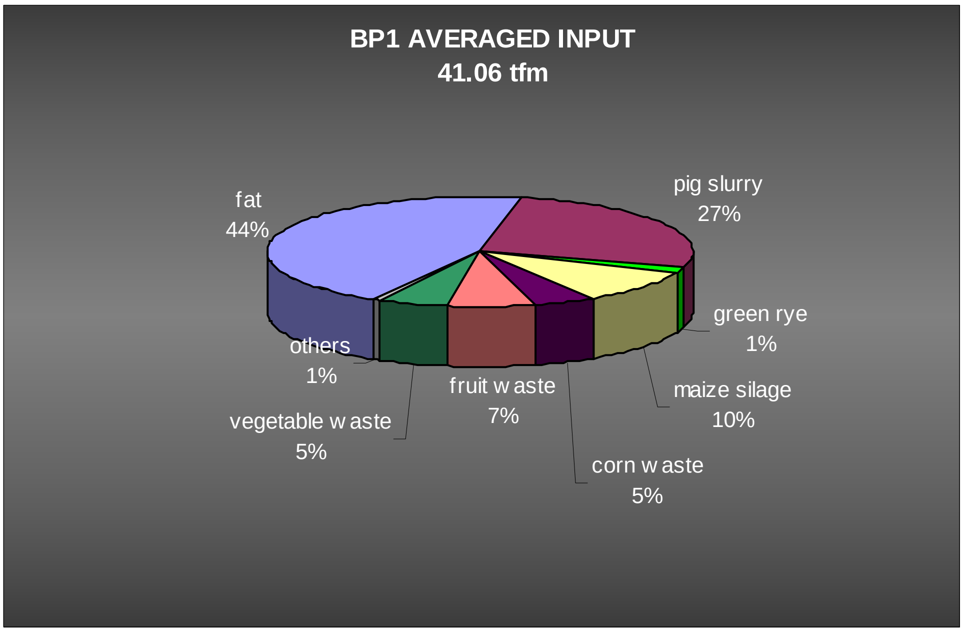
BP13

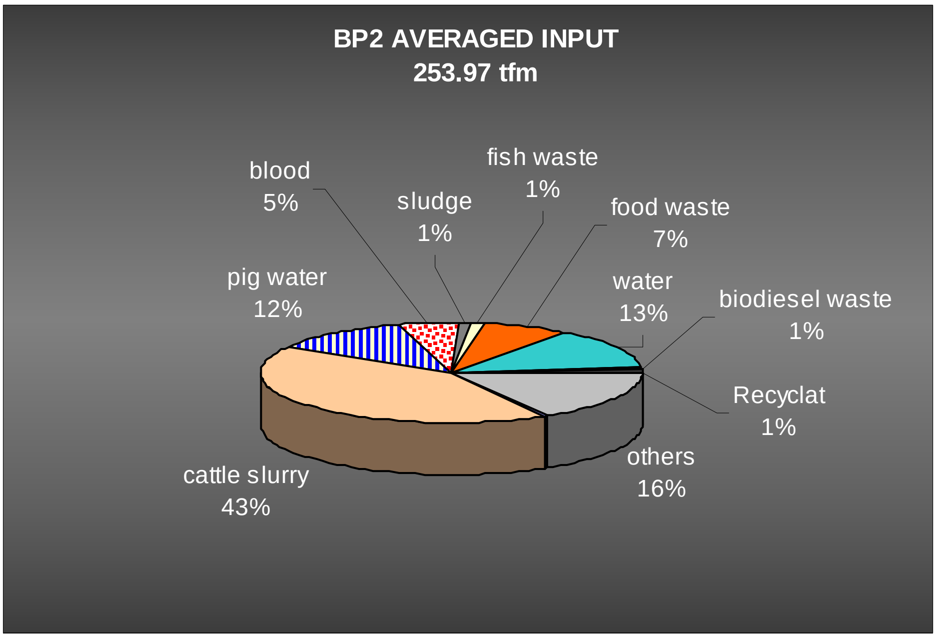


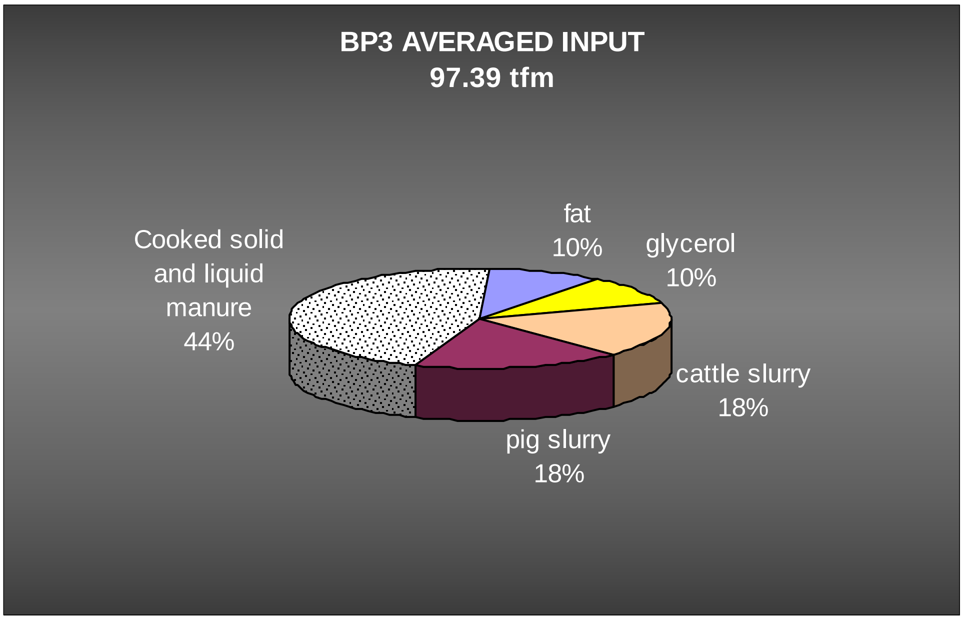
desulphurisation unit
O_2
Storage tanks
reception tank
mixing tank
gas engine
1
2
3
CHP1
pasteurisation tank
digester
waste
manure & waste
bio-fertilizer
electricity to the grid
sampling points
substrate
biogas

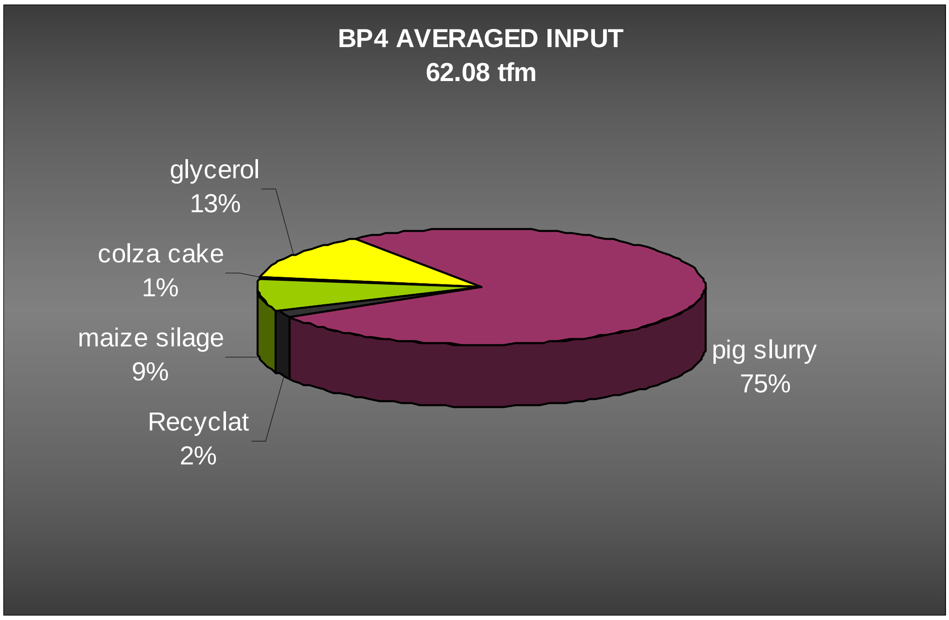
Appendix 8

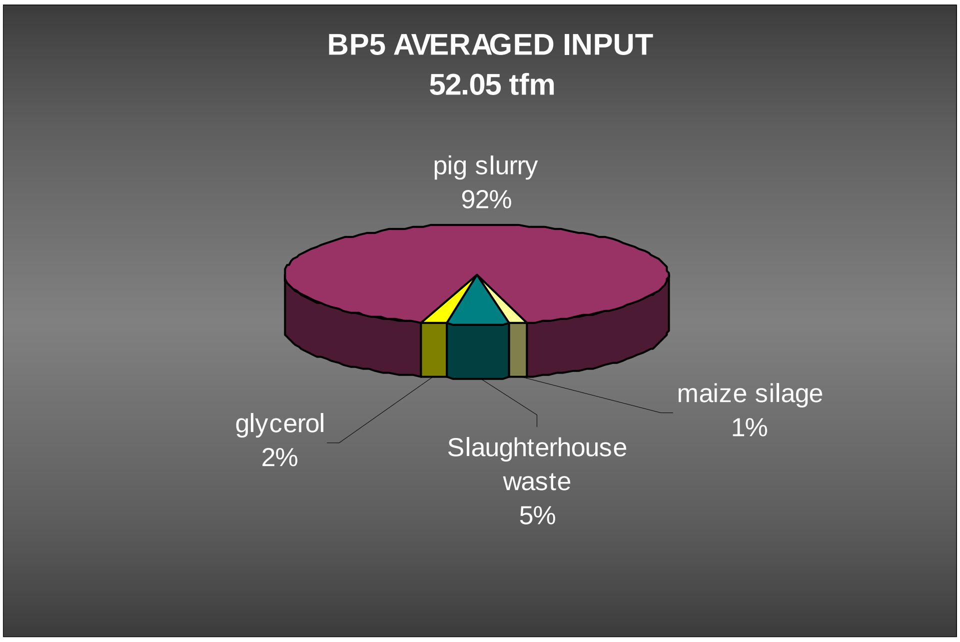
Feedstock pie charts showing total fresh matter input and the fraction of each feedstock.

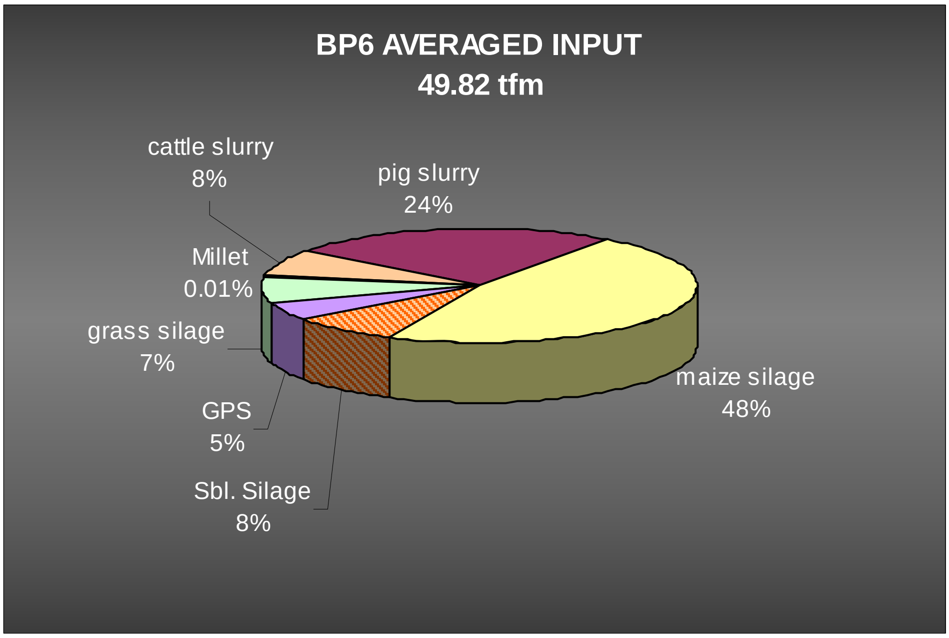


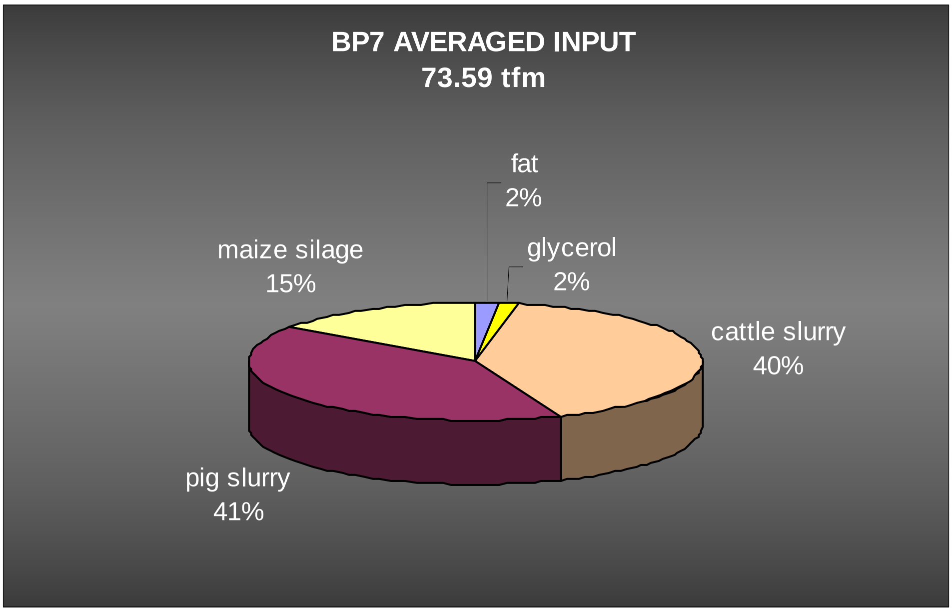


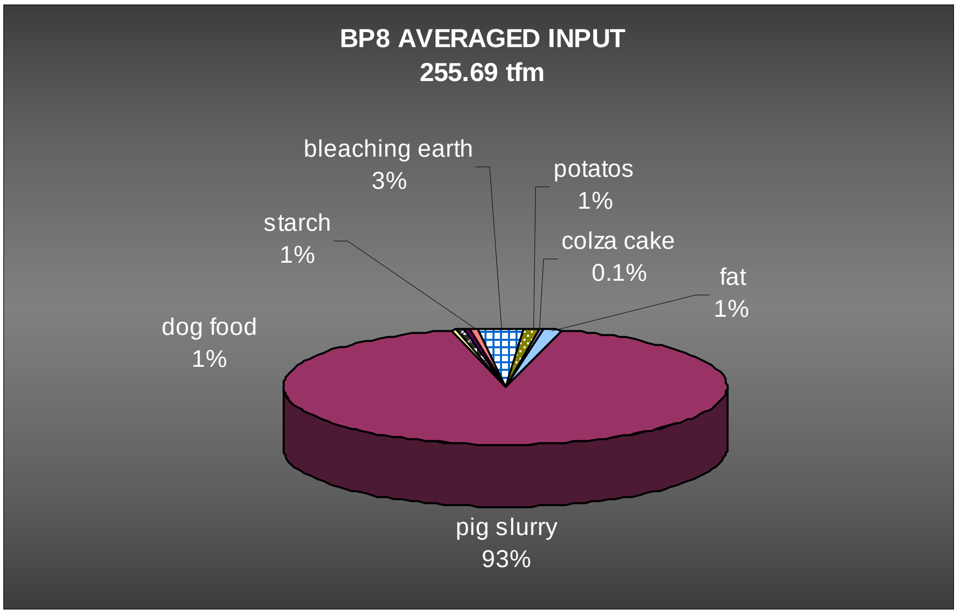

BP3 AVERAGED INPUT
97.39 tfm
fat
10%
glycerol
10%
Cooked solid
and liquid
manure
44%
cattle slurry
18%
pig slurry
18%

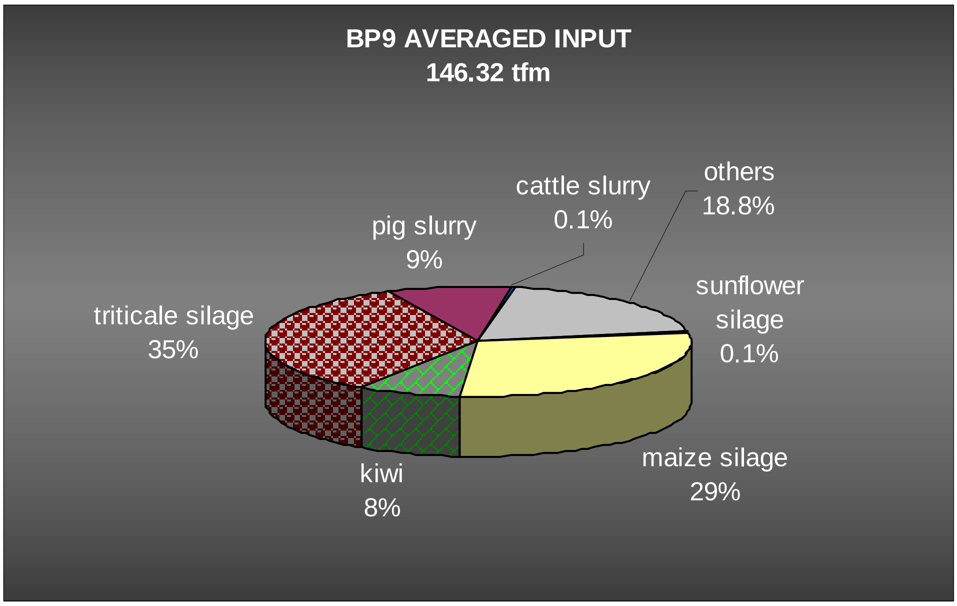

BP4 AVERAGED INPUT
62.08 tfm
glycerol
13%
colza cake
1%
maize silage
9%
Recyclat
2%
pig slurry
75%

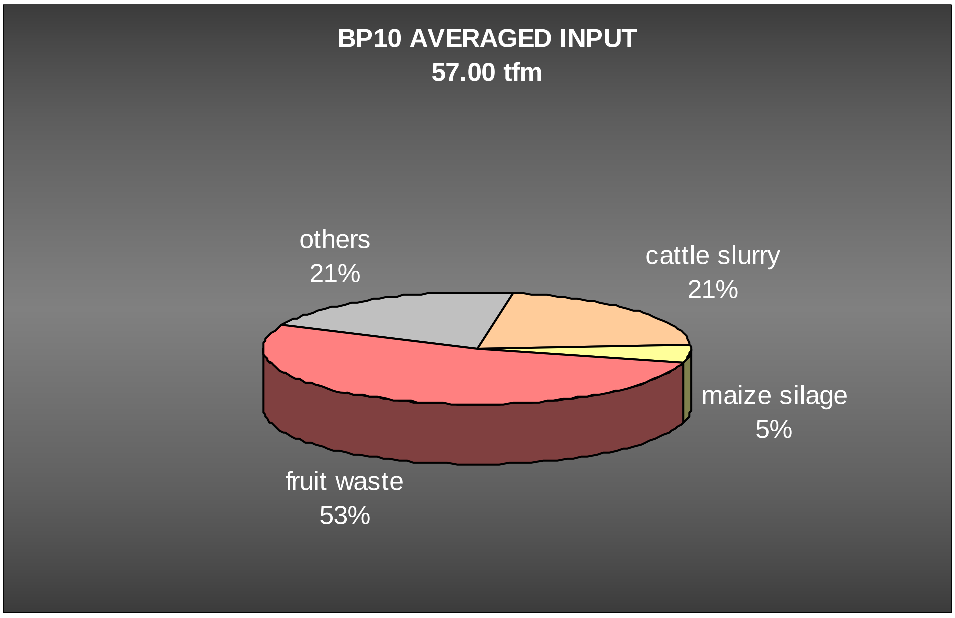

BP5 AVERAGED INPUT
52.05 tfm
pig slurry
92%
maize silage
1%
glycerol
2%
Slaughterhouse
waste
5%

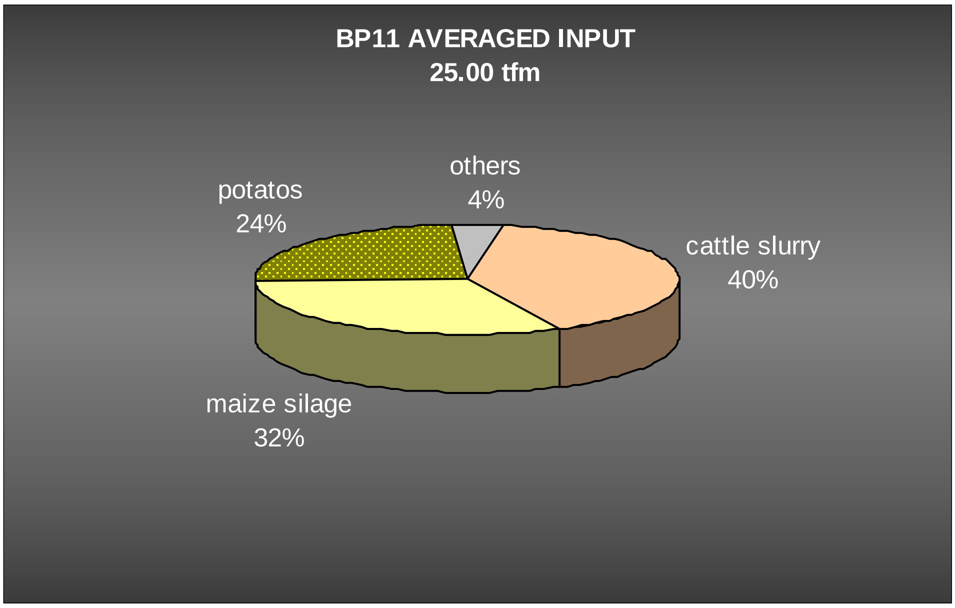

BP6 AVERAGED INPUT
49.82 tfm
cattle slurry
8%
pig slurry
24%
Millet
0.01%
grass silage
7%
GPS
5%
Sbl. Silage
8%
maize silage
48%

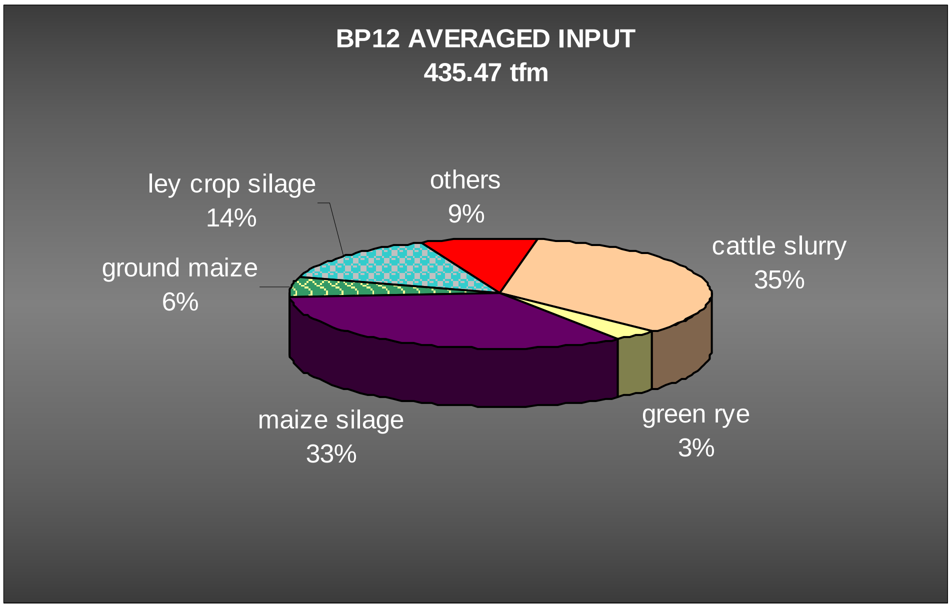

BP7 AVERAGED INPUT
73.59 tfm
fat
2%
glycerol
2%
maize silage
15%
cattle slurry
40%
pig slurry
41%

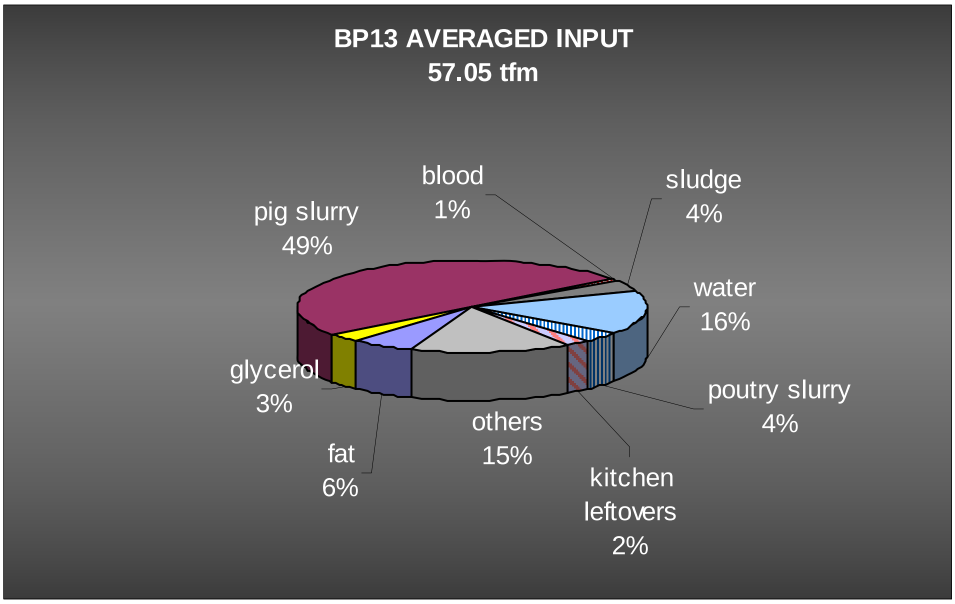

BP8 AVERAGED INPUT
255.69 tfm
bleaching earth
3%
potatos
1%
starch
1%
colza cake
0.1%
fat
1%
dog food
1%
pig slurry
93%


BP9 AVERAGED INPUT
146.32 tfm
cattle slurry
0.1%
others
18.8%
pig slurry
9%
sunflower
silage
0.1%
triticale silage
35%
maize silage
29%
kiwi
8%


BP10 AVERAGED INPUT
57.00 tfm
others
21%
cattle slurry
21%
maize silage
5%
fruit waste
53%


BP11 AVERAGED INPUT
25.00 tfm
others
4%
potatos
24%
cattle slurry
40%
maize silage
32%


BP12 AVERAGED INPUT
435.47 tfm
ley crop silage
14%
others
9%
ground maize
6%
cattle slurry
35%
maize silage
33%
green rye
3%


BP13 AVERAGED INPUT
57.05 tfm
blood
1%
sludge
4%
pig slurry
49%
water
16%
glycerol
3%
poutry slurry
4%
others
15%
fat
6%
kitchen
leftovers
2%

Appendix Technology

1.- Pumping technology

	BP1	BP2			BP3
Pump type	Rotary piston	Rotary piston	Centrifugal	Eccentric - worm	Eccentric - worm
number	3	1	3	4	1
power (KW)	1x22 / 2x11	10	100	7	8
turnover rate (t/h)	80 /40	35	200-700	20	10-40
pumping processes per day	12	1	1	mixing/transferring	
running time per interval	1-3 min	20 min/d	0-24h / 5 min (20 times/d)	60 min	
installation location	above the collecting pit	after digesters	collecting pit / mixing tank	pre and post pasteurisation	
pumping processes controlled automatically	yes	yes			yes
registration of substrate volume	sps-siemens; pc anywhere-alarm	flow meter			yes
substrate allocation	variable from/to all vessels	variable from/to all vessels			fermenter and secondary fermenter
estimated demand of working time for the substrate insertion (h/week)	5	-			5

	BP4		BP5	BP6	BP7
Pump type	centrifugal	eccentric - worm	rotary piston	eccentric - worm	eccentric - worm
number	1	4	10	1	3
power (KW)	7	7	13.5 & 15 & 18.5	7	3
turnover rate (t/h)	18	15		2.4	30
pumping processes per day	48	48		48	6
running time per interval	3 min	3 min			3 min
installation location	collecting pit	collecting pit			inside hall
pumping processes controlled automatically	yes		yes		yes
registration of substrate volume	yes		yes		yes
substrate allocation	only to fermenter		only to fermenters		fermenter and final storage
estimated demand of working time for the substrate insertion (h/week)	-		14		2

	BP8	BP9		BP10	BP11
Pump type	Rotary piston	Rotary piston	Submerged shredding and mixing	centrifugal	Rotary piston
number	5	1	1	1	3
power (KW)	11/15/11/11/11	18	22	15	10
turnover rate (t/h)	50-90	240	240	1-100	35
pumping processes per day	as needed	8	2	130	12
running time per interval	120 min	30 min	3 min	0.5 min	10
installation location	mixing pit / between F and mixing pit / pump room2 / pump room3 / piglets shed	connection between fermenters	liquid manure pit	mixing pit	
pumping processes controlled automatically	no	yes		yes	yes
registration of substrate volume	yes (IDM data registration)	no		yes (paper)	yes (day registration)
substrate allocation	variable from/to all vessels	only to fermenters		only to fermenters	only to fermenters
estimated demand of working time for the substrate insertion (h/week)	35	35		2	7

	BP12		BP13
Pump type	Rotary piston	Eccentric - worm	Single-stage spiral
number	1	2	3
power (KW)			5.5
turnover rate (t/h)			60
pumping processes per day			
running time per interval			
installation location	feeding device	pre digester and beneath the pit	Mixing pit first storage tank second storage tank
pumping processes controlled automatically	yes		yes
registration of substrate volume	no		no
substrate allocation	variable from/to all vessels		fermenter and final storage
estimated demand of working time for the substrate insertion (h/week)	-		-

2.- Fermenter technology

			BP1	BP2	BP3
Fermenter/s	Function		main F / main F	main F / main F	main F/main F/main F/secondary F
	Operation		arranged in series	parallel/parallel	3 main F parallel /arranged in series
	Process temperature (C)		39.5	35-40	51/51/51/39
	Volume (m3)		1400/900	4000/4000	3x1700 /2500
	Type of construction		vertical	vertical	horizontal
	Fermentation chambers		single chambered	single chambered	single chambered
	Geometry		roundly	cylindrical	roundly
	Material		concrete	steel	concrete
	Diameter (m)		18/14	17/17	
	Height (m)		6/6	17/17	
	Installation		partly countersinked	aboveground	mF aboveground / sF partly countersinked
mixer	number of pieces		2/2/1	1/1/3	3/3/3/1
	type		mechanically	paddle/paddle/submersible impeller	F1,F2,F3: mechanically, paddle F4: mechanically, submersible
	diameter of the wing (cm)		200/50/50	1000/1000/100	200/200/200/100
	speed (Hz)		35/35/35	15/15/300	
	power (kW)		1x 7.5; 1x 17/ 1x 11; 1x 17 / 1x 11	18/18/15 each one	7.5 each one
	position		on the side	through ceiling / through ceiling / on the side	F1,F2,F3: through ceiling / F4: on the side
	mixing interval	mixing per day	endurance run/ almost endurance run	almost constant/almost constant/50% of the time	constant
		running time per interval (min)	1440/1350/10	20	
	automated		yes	yes	yes
problems	floating layer		no/ no/ no	no/ no/ no	no/no/no/yes
	foam		yes/no/no	yes/yes/no	yes/yes/yes/no

			BP4	BP5	BP6
Fermenter/s	Function		main fermenter	main fermenter/main fermenter	main fermenter/ main fermenter
	Operation		parallel	parallel/parallel	
	Process temperature (C)		39.5	35.6/37	39
	Volume (m3)		1000	650/650	2100/2100
	Type of construction		horizontal	horizontal	
	Fermentation chambers		single chambered	single chambered	
	Geometry		roundly	roundly	ring shaped
	Material		stainless steel	steel	
	Diameter (m)		13		
	Height (m)		11.3		
	Installation		aboveground	aboveground	
mixer	number of pieces		2	1/1	3/2
	type		mechanically discharge chute with propeller mixer	Hydraulically / hidraulically	long shaft / paddle
	diameter of the wing (cm)		40	50/50	
	speed (Hz)		300		
	power (kW)		16	18.5/18.5	37/36
	position		on the side	through ceiling & on the side	
	mixing interval	mixing per day	5 h	24h	24h
		running time per interval (min)	20	20	198/ 84
	automated		yes	yes	
problems	floating layer		yes	yes/yes	
	foam		no	no/no	

			BP7	BP8	BP9
Fermenter/s	Function		main fermenter	m F/m F/ m F	main F / secondary F
	Operation		arranged in series	parallel	arranged in series
	Process temperature (C)		51	35-37	41/41
	Volume (m3)		1100	100/100/2500	5800/5800
	Type of construction		vertical	vertical	vertical
	Fermentation chambers		single chambered	single chambered	double chambered
	Geometry		roundly	roundly	roundly
	Material		steel/concrete	concrete	ferroconcrete
	Diameter (m)		10.6	21/21/28	36/36
	Height (m)		15.2	5/5/6	6/6
	Installation		aboveground	partly countersinked	aboveground
mixer	number of pieces		1	1/1/2	3/3
	type		long axis mixer	mechanically	2 paddle (1 horizontal and 1 vertical) and 1 long axis in each fermenter
	diameter of the wing (cm)			300	400/200/80
	speed (Hz)			33-38 / 31-40 / 23-35	
	power (kW)		13	15/15/ 2x15	25 (all)
	position		through ceiling	on the side	2 on the side and 1 through ceiling (vertical paddle)
	mixing interval	mixing per day	24h	24 h	48 times
		running time per interval (min)	continuously	endurance run	20
	automated		yes	yes	yes
problems	floating layer		yes/yes	no/no/no	no/no
	foam		no/no	yes/yes/yes	no/no

		BP 10	BP 11	BP12	BP13
Fermenter/s	Function	main fermenter	main F / secondary F	main F/ main F	main fermenter
	Operation		arranged in series	parallel	
	Process temperature (C)	40	40/40	37/37	40
	Volume (m3)	1650	950/950	3000/3000	2500
	Type of construction	vertical	vertical	vertical	vertical
	Fermentation chambers	single chambered	single chambered	single chambered	single chambered
	Geometry	roundly	roundly	cylindric	roundly
	Material	concrete	concrete	ferroconcrete	concrete
	Diameter (m)	18	16	16/16	22
	Height (m)	7	6	16/16	10.5
	Installation	partly countersinked	partly countersinked	aboveground	aboveground
mixer	number of pieces	3		1/1/2	2
	type	paddle / axiaal	paddle / axiaal	mechanically (long axis)	mechanically
	diameter of the wing (cm)	400/50/70	200/50		60
	speed (Hz)	30/750/750	10/100		
	power (kW)	15/22/PTO	9 / 6		
	position	on the side	on the side	on the side	on the side
	mixing interval: mixing per day	240/240/incidental	72/36 times		continuously
	mixing interval: running time per interval (min)	3/3/-	5/5		
	automated	yes/yes/no	yes	yes	no
problems	floating layer	no	no/no	only in fermenter 4	no
	foam	yes	yes/yes		no

3.- Process interferences

	BP1	BP2	BP3	BP4	BP5	BP7
numbers	1		1	no interferences	8	no interferences
reason(s)	Overfeeding; acetic acid content too high	Cleaning out the reception pit every 6 months. Cleaning the heat exchangers every 3 months.	overloading		pollution in digesters	
duration	2 weeks	24 h for each	1 month		3 days	
failures since start-up	partly	no	yes	no	yes	no
most commonly weak point	one engine (of 3); mixer	mixers			different points	feeding high DM material
automatic identification of process failures	yes	yes	no		no	no
estimated demand of working time for process control (h/week)	10	don't know	5	2-7	30	5

	BP8	BP9	BP10	BP11	BP12	BP13
numbers	2-3 per year	1		6	incountable	
reason(s)	mixer defect; fermenter is filled with solid material	crust formation	Foam when using (too much) fat as co-digestion	Accidification and foam due to lack of input and too much fat		pumps plugging, mixer and heat exchanger were burnt, level sensor did not run well
duration	1-2 days	4 days				
failures since start-up	yes	yes	no	no		yes
most commonly weak point	mixer and pumps	mixer	Mechanical slurry separator	overloop	Feeding tech. / almost no exhaust gas utilization	mixers and pumps
automatic identification of process failures	yes	yes	yes		yes	only of CHP
estimated demand of working time for process control (h/week)	21	25	7	15	-	10

**No recorded data from BP6*

4.- Biogas treatment

			BP1	BP2	BP3	BP4	BP5	BP6	BP7
type of condensate separation		**cooling tunnel**	x			x	x		
		biogas dehumidifier			x				x
		others	gas scrubber	a fridge is used					
desulphurisation	**biological**	**external**							
		internal (air supply)	0.2% air of biogas		3% air of biogas	1% air of biogas	Injection by estimated amount of air		
			controlled by gas measurement		controlled by gas measurement	Injection by estimated amount of air	location: main fermenter	x	3% air of biogas
			location: F1/F2/post-F		location: main fermenter	location: main fermenter	and secondary fermenter		
	Addition of chemicals		iron (as slurry)	Ferric Chloride					
	Others								

			BP8	BP9	BP10	BP11	BP12	BP13
type of condensate separation		**cooling tunnel**		x	x		x (2 tunnels)	
		biogas dehumidifier	x					
		others						
desulphurisation	**biological**	**external**				x	x	
		internal (air supply)	1% air of biogas Injection by estimated amount of air location: main and secondary F	0.02% air of biogas Injection by estimated amount of air location: main and secondary F	0.033% air of biogas controlled by gas/ injection by air location: main fermenter	x	controlled by gas measurement location: post digester	
	Addition of chemicals							
	Others		Activate carbon filter		active carbon filter			aerophilic

Partner	Biogasplant	Benchmarks	Demonstration

Partner: ATB

Biogasplant:

Fehrbellin
Start Data – 01/03/07, Finish Data 27/04/07

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	36.84	29.23	38.29
H2S	**ppm**	130.14	2.0	538.0
O2	**Vol. %**	1.43	0	2.60
produced electric energy	**$MWh.d^{-1}$**	18.83	3.79	30.39
CH4 [Nm³]	**$Nm^3.d^{-1}$**	6232	2970	7375
CH4 in [%]	**Vol. %**	55.43	47.00	62.00
biogas [m³]	**$m^3.d^{-1}$**	11278	5603	15616
specific methane yield	**$m^3.kg^{-1}$ VS**	0.45		
hydraulic retention time	**d**	60		
loading rate	**$kg\ VS.m^{-3}.d^{-1}$**	1.42		
methane productivity	**$Nm^3\ CH_4.m^{-3}$**	0.5	0.24	0.59
total	**t fm**	169.55		
total	**m³ fm**	207.37		
cattle slurry	**t fm**	144.16		
green rye	**t fm**	1.74		
maize silage	**t fm**	8.46		
ground maize	**t fm**	3.17		
ley crop silage	**t fm**	7.28		
others	**t fm**	4.74		
total	**t dm**	20.58		
cattle slurry	**t dm**	8.83		
green rye	**t dm**	1.04		
maize silage	**t dm**	1.38		
ground maize	**t dm**	2.52		
ley crop silage	**t dm**	2.79		
others	**t dm**	2.04		
total	**tVS**	17.75	16.80	361.69
VS in fresh matter	**%**	10.47	9.60	49.44
degree of degradation of VS after main digester	**%**	62.60	100.00	100.00

Benchmarks:

Input:

- Liquid cattle manure : 52,620 t FM/y (approx. 15.7% DM)
- maize silage: 3,087 t FM/y (approx. 29.9% DM)
- ground rye : 634 t FM/y(appox. 79.4% DM)
- ground maize : 1,158 t FM/y (approx. 88% DM)
- ley crop silage: 2,656 t FM/y (approx. 28% DM)
- forage residues: 1,731 t FM/y (approx. 41.5% DM)

In total: 61,884 t FM/y

Fermenter volume:

- 500m³ pre-digester
- two 3,000m³ main-digesters
- 6000m³ post-digester

Loading rate: 1.42 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time: 60 d

CH_4-Productivity: 0.50 $m^3_N*m^{-3}$

Spez. CH_4-Yield: 0.45 $m^3_N*kgVS^{-1}$

Biogas production: 11,269 $m^3.d^{-1}$ (average methane content 54.4%)

CHP power:

- CHP 1: 328kW_{el}
- CHP 2: 1050kW_{el}

Operation time: 8,000h/y

Demonstration:

1) application technology for enzymes and/or micro nutrients
2) feeding technology
3) usage of thermal energy of the 2nd CHP-exhaust-gas
4) possibly desulfurization technologies

BOKU

Ökoenergie Utzenaich

Start Data 01/06/06, Finish Data 31/08/06

PARAMETER	UNIT	AVERAGE	MIN	MAX
produced electric energy	**$MWh.d^{-1}$**	11.71	9.37	11.81
CH4 [Nm³]	**$Nm^3.d^{-1}$**	3151.91	1525.18	3418.05
CH4 in [%]	**Vol. %**	52.39	26.00	57.30
biogas [m³]	**$m^3.d^{-1}$**	6879.19	5370.00	7197.00
Biogasgas [Nm³]	**Nm^3**	5972.15	4661.95	6248.06
specific methane yield	**$m^3.kg^{-1}$ VS**	0.38	0.19	0.47
hydraulic retention time	**d**	74.88	58.87	80.41
loading rate	**kg $VS.m^{-3}.d^{-1}$**	3.95	2.71	4.90
methane productivity	**Nm^3 $CH_4.m^{-3}$**	0.72	0.35	0.78
total	**t fm**	49.82	34.42	57.74
cattle slurry	**t fm**	3.92	2.94	4.90
pig slurry	**t fm**	12.08	9.06	15.10
maize silage	**t fm**	23.29	15.70	26.86
Sbl. Silage	**t fm**	4.20	2.56	5.30
GPS	**t fm**	2.59	1.64	3.18
grass silage	**t fm**	3.64	2.47	4.18
Millet	**t fm**	0.10	67.27	113.95
total	**t dm**	6.10	0.01	7.68
cattle slurry	**t dm**	0.31	0.24	0.39
pig slurry	**t dm**	0.72	0.54	0.91
maize silage	**t dm**	6.20	4.20	7.68
Sbl. Silage	**t dm**	0.99	0.61	1.34
GPS	**t dm**	0.62	0.42	0.82
grass silage	**t dm**	0.70	0.47	0.80
Millet	**t dm**	0.02	0.01	0.02
degree of degradation of VS after main digester	**%**	74.12	71.99	75.70

Input :

-Cattle slurry : 1,431 t FM/y (approx. 8%DM)

-Pig slurry :4,409 t FM/y (approx. 6% DM)

-Maize silage : 8,501 t FM/y (approx. 26.6% DM)

-Sbl. Silage: 1,533 t FM/y (approx. 23.6% DM)

-GPS: 945 t FM/y (approx. 24% DM)

-Grass silage: 1,329 t FM/y (approx. 19% DM)

-Millet: 36.5 t FM/y (approx.20% DM)

-Liquid manure: 5,840 t FM/y

Fermenter volume:

F1: 2,100m³

F2: 2,300m³

Hydraulic retention time: 75 d

Loading rate: 3.95 $kgVS*m^{-3}*d^{-1}$

Spez. CH_4-Yield: 0.38 $m^3_N*kgVS^{-1}$

Biogas production: 5,972 $m^3.d^{-1}$ (average methane content 52.4%)

CHP power: 500 $kW_{el.}$

Operation time: 8,300 h/y

D1: on plant heat utilisation →

a) drying separated solids from digestade (Dorsed belt dryer)

b) drying wood ships

c) drying grain & maize

Ökostrom Mureck GmbH
Start Data 20/03/06, Finish data 30/09/07

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	°C	39.38	38.90	40.20
H2S	ppm	99.38	0.00	233.00
O2	Vol. %	0.02	0.00	0.20
produced electric energy	$MWh.d^{-1}$	22.32	0.00	24.82
CH4 [Nm³]	$Nm^3.d^{-1}$	5874.02	0.00	6532.37
CH4 in [%]	Vol. %	56.61	51.20	69.30
biogas [m³]	$m^3.d^{-1}$	10832.99	3794.71	12255.85
specific methane yield	$m^3.kg^{-1}$ VS	0.50	0.00	1.04
hydraulic retention time	d	76.46	34.65	410.68
loading rate	$kg\ VS.m^{-3}.d^{-1}$	2.99	1.35	4.47
methane productivity	$Nm^3\ CH_4.m^{-3}$	1.47	0.00	1.63
total	t fm	62.08	9.95	121.50
total	m³ fm	56.42	9.74	115.43
glycerol	l fm	6762.36	0.00	11022.00
pig slurry	t fm	40.39	0.00	89.00
Recyclat	t fm	1.14	0.00	46.00
CCM	t fm	6.02	0.00	20.00
maize silage	t fm	4.72	0.00	20.00
colza cake	t fm	0.29	0.00	1.40
total	t dm	13.07	5.95	19.31
glycerol	t dm	6.28	0.00	10.24
pig slurry	t dm	1.50	0.00	3.30
Recyclat	t dm	0.05	0.00	1.95
CCM	t dm	3.29	0.00	10.93
maize silage	t dm	1.68	0.00	4.64
colza cake	t dm	0.27	0.00	1.32
total	tVS	11.98	5.41	17.87
VS in fresh matter	%	19.77	9.42	67.07
VS in digester	%	3.37	1.97	3.75
degree of degradation of VS after main digester	%	82.48	67.75	95.24

Input

-Glycerol : 2468261.4 l FM/y

-Pig slurry : 14,742 t FM/y (approx. 4% DM)

-Recyclat : 416 t FM/y (approx. 4% DM)

-CCM : 2,197 t FM/y (approx. 55% DM)

-Maize silage : 1,723 t FM/y (approx. 35.6% DM)

-Colza cake : 106 t FM/y (approx. 93% DM)

Fermenter volume:

F1/2/3/4: 1,000 m^3

Loading rate: 2.99 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time: 76.5 d

CH_4-Productivity: 1.5 $m^3_N*m^{-3}$

Spez. CH_4-Yield: 0.5 $m^3_N*kgVS^{-1}$

Biogas production: 10,833$m^{3.d-1}$ (average methane content 56.6%)

CHP power: 1,000 kW_{el}

Operation time: 8,000 h/y

D1: Raw materials including by-products from biofuels based Biorefineries

D2: Fe (OH) → H_2S-removal

D3: Enzymes (opt)

D4: heat feeding in local grid

DIAS

Foulum

Start Data 30/09/07, Finish Data 08/12/07

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	51.00	51.00	51.00
H2S	**ppm**	393.48	200.00	600.00
produced electric energy	**$MWh.d^{-1}$**	5.35	1.80	7.13
CH4 [Nm³]	**$Nm^3.d^{-1}$**	2286.38	1082.04	2965.12
CH4 in [%]	**Vol. %**	59.23	56.80	65.60
Biogasgas [Nm³]	**Nm3**	3857.65	1905.00	4905.00
specific methane yield	**$m^3.kg^{-1}$ VS**	0.39	0.25	0.63
hydraulic retention time	**d**	15.90	9.81	37.78
loading rate	**kg $VS.m^{-3}.d^{-1}$**	5.52	2.36	8.70
methane productivity	**Nm^3 $CH_4.m^{-3}$**	2.08	0.98	2.70
total	**t fm**	73.59	29.12	112.15
total	**m³ fm**	73.59	29.12	112.15
fat	**t fm**	1.14	0.00	2.08
glycerol	**l fm**	1.14	0.00	2.08
cattle slurry	**t fm**	30.01	11.66	45.65
pig slurry	**t fm**	30.01	11.66	45.65
maize silage	**t fm**	11.29	4.73	16.70
total	**t dm**	6.07	2.59	9.57
total	**t oDM**	6.07	2.59	9.57
maize	**t oDM**	3.27	1.37	4.84
glycerol	**t oDM**	1.59	0.00	2.91
pig slurry	**t oDM**	1.20	0.47	1.83
total	**tVS**	6.07	2.59	9.57
VS in fresh matter	**%**	8.24	6.29	8.90
VS in digester	**%**	3.23	3.00	3.60
VS in storage	**%**	3.23	3.00	3.60
degree of degradation of VS after main digester	**%**	60.62	42.77	64.03

Input

-Fat :416.1 t FM/y

-Glycerol : 416.1 l FM/y

-Cattle slurry : 10,954 t FM/y

-Pig slurry : 10,954 t FM/y (approx. 4% oDM)

-Maize silage : 4,121 t FM/y (approx. 29% oDM)

Fermenter volume:

F1: 1,100 m^3

F2: 3,000 m^3

Loading rate: 5.52 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time: 16 d

CH_4-Productivity: 2.08 $m^3_N*m^{-3}$

Spez. CH_4-Yield: 0.39 $m^3_N*kgVS^{-1}$

Biogas production: 3,858 $m^3.d^{-1}$ (average methane content 59.2%)

CHP power: 625 kW_{el}

Operation time: 8600 h/y

DIAS
GFE

OjLojstrup

Start Data 30/09/07, Finish Data 08/12/07

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	51.28	0.00	52.63
H2S	**ppm**	200.00	200.00	200.00
produced electric energy	**$MWh.d^{-1}$**	27.90	10.88	50.76
CH4 [Nm³]	**$Nm^3.d^{-1}$**	7341.50	2862.18	13357.95
CH4 in [%]	**Vol. %**	63.00	63.00	63.00
Biogasgas [Nm³]	**Nm3**	11653.17	4543.15	21203.09
specific methane yield	**$m^3.kg^{-1}$ VS**	0.40	0.08	0.80
hydraulic retention time	**d**	56.95	36.73	76.70
loading rate	**kg $VS.m^{-3}.d^{-1}$**	17.71	7.25	35.26
methane productivity	**Nm^3 $CH_4.m^{-3}$**	1.36	0.53	2.47
total	**t fm**	97.39	70.40	147.00
total	**m³ fm**	97.39	70.40	147.00
Cooked solid & liq. manure	**t fm**	44.22	26.00	91.20
fat	**t fm**	9.34	2.20	20.65

Input

-Cooked solid and liquid manure : 16,140 t FM/y (approx. 13% oDM)

-Fat : 3,409 t FM/y (approx. 68% oDM)

-Glycerol : 3,409 l FM/y

-Cattle slurry : 6,296 t FM/y (approx. 3% oDM)

- Pig slurry : 6,296 t FM/y (approx. 3% oDM)

Fermenter volume:

F1/2/3: 1700 m^3

F4: 2500 m^3

Loading rate: 17.71 $kgVS*m^{-3}*d^{-1}$

glycerol	**l fm**	9.34	2.20	20.65
cattle slurry	**t fm**	17.25	0.00	28.95
pig slurry	**t fm**	17.25	0.00	28.95
total	**t oDM**	19.48	7.97	38.78
Cooked solid &liq. manure	**t oDM**	5.75	3.38	11.86
fat	**t oDM**	6.35	1.50	14.04
glycerol	**t oDM**	6.35	1.50	14.04
cattle slurry	**t oDM**	0.52	0.00	0.87
pig slurry	**t oDM**	0.52	0.00	0.87
total	**tVS**	19.48	7.97	38.78
VS in fresh matter	**%**	19.49	11.32	31.47
VS in digester	**%**	3.48	3.20	3.70
VS in storage	**%**	3.50	3.50	3.50
degree of degradation of VS after main digester	**%**	80.54	69.09	88.88

Hydraulic retention time: 57 d

CH_4-Productivity: 1.36 m^3_N*m^{-3}

Spez. CH_4-Yield: 0.4 m^3_N*$kgVS^{-1}$

Biogas production: 11,653 $m^3.d^{-1}$ (average methane content 63%)

CHP power:

Engine 1: 1,000 kW_{el}

Engine 2: 1,400 kW_{el}

Operation time: 6,000 h/y

EC BREC
Poland

Pawlowko village
Start Data 01/10/06, Finish Data 31/12/06

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	33.56	22.60	37.40
H2S	**ppm**	811.07	1.00	1000.00
O2	**Vol. %**	1.12	0.10	5.20
produced electric energy	**$MWh.d^{-1}$**	6.09	2.61	10.57
CH4 [Nm³]	**$Nm^3.d^{-1}$**	1353.64	0.00	1784.01
CH4 in [%]	**Vol. %**	60.11	32.00	80.00
$N\ CH_4\ m^3.d^{-1}$	**$m^3.d^{-1}$**	1187.06	0.00	3094.10
Biogasgas [Nm³]	**Nm3**	2255.07		
specific methane yield	**$m^3.kg^{-1}$ VS**	0.59	0.14	4.68
hydraulic retention time	**d**	69.17	22.44	477.94
loading rate	**$kg\ VS.m^{-3}.d^{-1}$**	0.01	0.00	0.01
methane productivity	**$Nm^3\ CH_4.m^{-3}$**	1.04	0.45	1.81
total	**t fm**	52.05	9.50	98.80
total	**m³ fm**	50.14	9.05	95.01
Slaughterhouse waste	**t fm**	2.78	0.00	12.51
glycerol	**l fm**	1.26	0.00	2.50
pig slurry	**t fm**	48.35	9.50	95.30
maize silage	**t fm**	0.70	0.00	4.50
total	**t dm**	3.85	0.35	9.57
Slaughterhouse waste	**t dm**	1.81	0.00	8.13
pig slurry	**t dm**	1.79	0.35	3.53
maize silage	**t dm**	0.25	0.00	1.61
total	**t oDM**	3.27	0.26	8.85
VS in fresh matter	**%**	6.67	2.68	17.22

Input

-Slaughterhouse waste : 1,015 t FM/y (approx. 65% DM)

-Glycerol : 460 l FM/y

-Pig slurry : 17,648 t FM/y (approx. 3.7% DM)

- Maize silage : 255.5 t FM/y (approx. 36% DM)

Fermenter volume:

F1: 650 m^3

F2: 650 m^3

Hydraulic retention time: 69 d

Loading rate: 0.01 $kgVS*m^{-3}*d^{-1}$

CH_4-Productivity: 1.04 $m^3_N*m^{-3}$

Spez. CH_4-Yield: 0.59 $m^3_N*kgVS^{-1}$

Biogas production: 1,464 $m^3.d^{-1}$

CHP power:

Engine 1: 240 kW_{el}

Engine 2: 625 kW_{el}

Operation time: ---

IGER

Holsworthy
Start Data 01/07/04, Finish Data 01/11/07

PARAMETER	UNIT	AVERAGE	MIN	MAX
produced electric energy	MWh.d-1	26.00	18.60	38.37
CH4 [Nm³]	Nm³.d-1	6840.88		
specific methane yield	m³.kg-1 VS	0.76		
Loading rate	kg VS.m-3.d-1	1.75		
methane productivity	Nm³ CH_4.m-3	0.86		
total	t fm	253.97	170.57	331.66
fat	t fm	0.77	0.14	2.70
cattle slurry	t fm	127.31	65.70	179.73
pig water	t fm	14.87	1.20	48.67
blood	t fm	35.55	23.30	47.97
sludge	t fm	3.40	1.02	17.23
fish waste	t fm	3.61	1.65	8.67
food waste	t fm	22.37	11.40	34.27
water	t fm	39.28	10.57	84.80
energy crops	t fm	1.05	0.27	3.93
biodiesel waste	t fm	2.53	0.72	8.18
Recyclat	t fm	3.15	1.33	8.53
others	t fm	49.71	17.43	97.62
total	t dm	27.14	0.00	0.00

Input
-Fat : 281.1 t FM/y
-Cattle slurry : 46,468.2 t FM/y
- Pig water : 5,427.6 t FM/y
-Blood : 12,975.8 t FM/y
-Sludge : 1,241 t FM/y
-Fish waste : 1,317.7 t FM/y
-Food waste : 8,165.1 t FM/y
-Water : 14,337.2 t FM/y
-Energy crops : 383.3 t FM/y
-Biodiesel waste : 923.5 t FM/y
-Recyclat : 1,149.8 t FM/y
-Others : 18,144.2 t FM/y

Fermenter volume:
F1: 4000 m^3
F2: 4000 m^3
Loading rate: 1.75 kgVS*m-3*d-1
Hydraulic retention time: 20- 25 d
CH4-Productivity: 0.86 m3N*m-3
Spez. CH4-Yield: 0.76 m3N/kgVS
Biogas production: 7,200–28,800 m3.d-1
CHP power:
Engine 1: 1048 kW_{el}
Engine 2: 1048 kW_{el}
Engine 3: 600 kW_{el}
Operation time:
Engine 1: 8000 h/y
Engine 2: 7000 h/y
Engine 3: 2000 h/y

D13 Improve the efficiency of the methane production by changing feedstocks mostly from manure to foodwaste

(*) Post-fermenter not included in total digester volume

UNIT

Azienda agricola Bagnod Roberto s.r.l
Start Data 31/10/07, Finish Data 11/01/08

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	41.88	41.03	43.50
produced electric energy	**$MWh.d^{-1}$**	23.72	11.50	25.08
CH4 [Nm³]	**$Nm^3.d^{-1}$**	6241.33	3025.79	6598.95
CH4 in [%]	**Vol. %**	56.07	52.80	58.70
Biogasgas [Nm³]	**Nm3**	11155.44	0.00	12472.59
specific methane yield	**$m^3.kg^{-1}$ VS**	0.25	0.00	0.53
hydraulic retention time	**d**	107.39	55.64	179.84
loading rate	**$kg\ VS.m^{-3}.d^{-1}$**	2.25	1.06	3.37
methane productivity	**$Nm^3\ CH_4.m^{-3}$**	0.54	0.00	0.57
total	**t fm**	146.32	0.00	247.58
total	**m³ fm**	110.36	0.00	208.50
cattle slurry	**t fm**	28.26	0.00	166.85
pig slurry	**t fm**	0.61	0.00	2.13
triticale silage	**t fm**	42.23	0.00	123.08
kiwi	**t fm**	11.45	0.00	40.00
maize silage	**t fm**	49.53	0.00	171.05
sunflower silage	**t fm**	13.76	0.00	45.33
others	**t fm**	0.46	0.00	0.50
total	**t dm**	28.45	0.00	42.98
cattle slurry	**t dm**	2.79	0.00	13.44
pig slurry	**t dm**	0.19	0.00	0.65
triticale silage	**t dm**	7.91	0.00	23.05
kiwi	**t dm**	1.67	0.00	5.83
maize silage	**t dm**	10.51	0.00	39.48
sunflower silage	**t dm**	3.65	0.00	9.62
others	**t dm**	0.03	0.00	0.03
total	**tVS**	25.79	0.00	39.15
VS in fresh matter	**%**	17.88	12.97	23.18
VS in digester	**%**	5.57	5.13	5.88
VS in storage	**%**	3.10	3.10	3.10
degree of degradation of VS after main digester	**%**	87.37	74.69	92.08

Input

-Cattle slurry:10,314.9 t FM/y (approx. 10% DM)

-Pig slurry : 222.7 t FM/y (approx. 31% DM)

-Triticale silage : 15,413.9 t FM/y (approx. 19% DM)

-Kiwi : 529.25 t FM/y (approx. 14.6% DM)

-Maize silage : 18,078.5 t FM/y (approx. 21% DM)

-Sunflower silage :5,022.4 t FM/y (approx. 26.5% DM)

-Percolation water : 167.9 t FM/y (approx. 6.5% DM)

Fermenter volume:

F1/2: 5,800 m^3

Loading rate: 2.25 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time: 107 d

CH_4-Productivity: 0.54 $m^3_N*m^{-3}$

Spez. CH_4-Yield: 0.25 $m^3_N*kgVS^{-1}$

Biogas production 11,155.5 $m^3.d^{-1}$ (average methane content 56%)

CHP power: 1,064 kW_{el}

Operation time: 8,400 h/y

D1: To reduce NH_3 and CH_4 emission and to recover the residual biogas from the digestate tank by means of a floating cover

Vogelsang

Lamping

Start Data Jan 07, Finish Data Dec 07

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	39.50	39.50	39.50
H2S	**ppm**	10.00	10.00	10.00
O2	**Vol. %**	0.40	0.40	0.40
produced electric energy	**$MWh.d^{-1}$**	16.72	11.83	20.37
CH4 [Nm³]	**$Nm^3.d^{-1}$**	4342.45	3013.79	5359.70
CH4 in [%]	**Vol. %**	60.00	60.00	60.00
biogas [m³]	**$m^3.d^{-1}$**	7237.41	5022.99	8932.84
specific methane yield	**$m^3.kg^{-1}$ VS**	0.70	0.40	0.97
hydraulic retention time	**d**	71.28	52.11	96.31
loading rate	**kg $VS.m^{-3}.d^{-1}$**	2.89	1.79	3.99
methane productivity	**Nm^3 $CH_4.m^{-3}$**	1.89	1.31	2.33
total	**t fm**	41.72	27.66	51.57
total	**m³ fm**	47.20	32.85	63.45
fat	**t fm**	18.67	5.12	28.49
pig slurry	**t fm**	11.11	11.11	11.11
green rye	**t fm**	0.56	0.00	1.33
maize silage	**t fm**	4.14	0.00	6.67
corn waste	**t fm**	2.03	0.00	4.92
fruit waste	**t fm**	2.83	0.00	7.31
vegetable waste	**t fm**	2.11	0.00	6.47
others	**t fm**	0.27	0.00	1.29
total	**t dm**	7.42	4.33	10.29
fat	**t dm**	3.07	0.84	4.68
pig slurry	**t dm**	0.93	0.93	0.93
green rye	**t dm**	0.11	0.00	0.25
maize silage	**t dm**	1.28	0.00	2.06
corn waste	**t dm**	1.22	0.00	2.95
fruit waste	**t dm**	0.57	0.00	1.47
vegetable waste	**t dm**	0.16	0.00	0.50
others	**t dm**	0.08	0.00	0.39
total	**t oDM**	6.76	3.85	9.49
total	**tVS**	6.65	4.13	9.18
VS in fresh matter	**%**	15.95	13.93	18.40
VS in storage	**%**	8.13	8.13	8.13
degree of degradation of VS after main digester	**%**	92.36	52.46	100.00

Input

-Fat : 6,814.6 t FM/y (approx. 16.5% DM)

-Pig slurry : 4,055.2 t FM/y (approx. 8.4% DM)

-Green rye : 204.4 t FM/y (approx. 19.6% DM)

-Maize silage : 1,511.1 t FM/y (approx. 31%DM)

-Corn waste : 740.9 t FM/y (approx. 20% DM)

-Vegetable waste : 770.2 t FM/y (approx. 7.6% DM)

-Others : 98.6t FM/y (approx. 29.6% DM)

Fermenter volume:

F1: 1,400 m^3

F2: 1,400 m^3

Post-fermenter: 900 1,400 m^3

Loading rate: 2.89 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time 71.3 d

CH_4-Productivity 1.9 $m^3_N*m^{-3}$

Spez. CH_4-Yield 0.7 $m^3_N*kgVS^{-1}$

Biogas production 7,237.4 $m^3.d^{-1}$ (average methane content 60%)

CHP power

Engine 1: 200 kW_{el}

Engine 2: 360 kW_{el}

Engine 3: 346 kW_{el}

Engine 4: 346 kW_{el}

Operation time

Engine 1: 8000 h/y

Engine 2: 8000 h/y

Engine 3: 8500 h/y

Engine 4: 8500 h/y

D1: demonstrate an innovative approach of feeding technology

a) compare innovative feeding device with conventional systems walking floor conveyor and mixing pit by feeding different substrates with regard to:

- o Energy consumption
- o Required mixing power in the digester
- o Biogas yield
- o Emission of bad odor
- o Feed regulating
- o Quality of preliminary treatment of the coferments for digestion

Vogelsang

Scherbring

Start Data 01/01/07, Finish Data 31/12/07 ***(*)***

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	35.00	35.00	35.00
H2S	**ppm**	100.00	100.00	100.00
produced electric energy	**$MWh.d^{-1}$**	24.73	22.15	296.78
CH4 [Nm³]	**$Nm^3.d^{-1}$**	6419.47	5829.86	6858.46
CH4 in [%]	**Vol. %**	62.00	62.00	62.00
biogas [m³]	**$m^3.d^{-1}$**	10353.98	9403.00	11062.03
specific methane yield	**$m^3.kg^{-1}$ VS**	0.52	0.43	0.67
hydraulic retention time	**d**	10.09	9.46	10.44
loading rate	**$kg\ VS/m3*d^{-1}$**	2.80	2.27	3.07
methane productivity	**$Nm^3\ CH_4.m^{-3}$**	1.43	1.30	1.52
total	**t fm**	450.48	436.51	923.33
total	**m³ fm**	461.43	445.27	1011.52
fat	**t fm**	6.00	6.00	73.33
pig slurry	**t fm**	416.67	416.67	500.00
corn waste	**t fm**	1.39	0.00	16.67
Dog food	**t fm**	2.53	0.00	33.33
Apples	**t fm**	2.24	0.00	26.67
Starch	**t fm**	2.47	0.00	33.33
Bleaching earth	**t fm**	15.01	8.30	183.33
potatos	**t fm**	5.85	0.00	73.33
total	**t dm**	58.30	54.46	258.70
fat	**t dm**	1.20	1.20	14.67
pig slurry	**t dm**	35.17	35.17	42.20
corn waste	**t dm**	0.86	0.00	10.33
Dog food	**t dm**	1.77	0.00	23.33
Apples	**t dm**	0.34	0.00	4.00
Starch	**t dm**	2.08	0.00	28.00
Bleaching earth	**t dm**	14.26	7.89	174.17
potatos	**t dm**	2.63	0.00	33.00
total	**t oDM**	58.30	54.46	258.70
total	**tVS**	12.77	9.53	137.44
VS in fresh matter	**%**	2.84	2.02	14.88
degree of degradation of VS after main digester	**%**	100.00	100.00	100.00

Input

-Fat : 2,190 t FM/y (approx. 20% DM)

-Pig slurry : 152,084.6 t FM/y (approx. 8.5% DM)

-Corn waste : 507.4 t FM/y (approx. 62% DM)

-Dog food : 923.5 t FM/y (approx. 70% DM)

-Apples : 817.6 t FM/y (approx. 15% DM)

-Starch : 901.6 t FM/y (approx. 84% DM)

-Bleaching earth : 5,478.7 t FM/y (approx. 95% DM)

-Potatos : 2,135.3 t FM/y (approx. 45% DM)

Fermentervolume

F1/F2/F3: 1000/1000/2500 m^3

Loading rate 3.02 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time: 10 d

CH_4-Productivity 1.43 $m^3_N*m^{-3}$

Spez. CH_4-Yield 0.52 $m^3_N*kgVS^{-1}$

Biogasproduction 10,354 $m^3.d^{-1}$ (average methane content 62%)

CHP power

Engine 1: 294 kW_{el}

Engine 2: 294 kW_{el}

Engine 3: 530 kW_{el}

Engine 4 (new in 2008): 1,300 kW_{el}

Operation time

Engine 1: 8600 h/y

Engine 2: 8600 h/y

Engine 3: 8600 h/y

D1: demonstrate an innovative approach of feeding technology

a) compare new feeding device with mixing pit by feeding a lot of different substrates with regard to:

- o Labour costs
- o Energy consumption
- o Required mixing power in the digester
- o Emission of bad odor
- o Range of coferments which can be processed

Feed regulating

(*) Data from 2007 only

VUZT

Knezice

Start Data 03/01/08, Finish Data 03/02/08

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	40.87	40.30	41.20
H2S	**ppm**	250.00	250.00	250.00
produced electric energy	**$MWh.d^{-1}$**	6.67	1.40	8.00
CH4 [Nm^3]	**$Nm^3.d^{-1}$**	1754.11	368.42	2105.26
CH4 in [%]	**Vol. %**	57.78	51.20	62.30
biogas [m^3]	**$m^3.d^{-1}$**	3041.24	620.24	4111.84
specific methane yield	**$m^3.kg^{-1}$ VS**	0.29	0.00	1.37
hydraulic retention time	**d**	30.69	0.00	115.10
loading rate	**kg $VS.m^{-3}.d^{-1}$**	1.81	0.00	4.54
methane productivity	**Nm^3 $CH_4.m^{-3}$**	0.70	0.15	0.84
total	**t fm**	57.05	0.00	201.32
total	**m^3 fm**	57.47	0.00	207.41
fat	**t fm**	3.50	0.00	9.76
glycerol	**l fm**	1.73	0.00	18.50
pig slurry	**t fm**	28.23	0.00	155.80
blood	**t fm**	0.33	0.00	2.30
sludge	**t fm**	2.25		
water	**t fm**	8.87	0.00	36.25
poutry slurry	**t fm**	2.10	0.00	28.80
kitchen leftovers	**t fm**	1.29	0.00	9.90
others	**t fm**	8.31	0.00	38.47
total	**t dm**	4.52	0.00	11.34
fat	**t dm**	0.52	0.00	1.46
glycerol	**t dm**	0.62	0.00	6.66
pig slurry	**t dm**	1.92	0.00	10.58
blood	**t dm**	0.04	0.00	0.30
sludge	**t dm**	0.73	0.00	0.00
water	**t dm**	0.75	0.00	3.07
poutry slurry	**t dm**	0.21	0.00	2.94
kitchen leftovers	**t dm**	0.12	0.00	0.93
others	**t dm**	1.60	0.00	7.40
total	**tVS**	4.52	0.00	11.34
VS in fresh matter	**%**	6.26	0.00	19.39
VS in digester	**%**	3.80	3.80	3.80
VS in storage	**%**	2.23	2.22	2.23
degree of degradation of VS after main digester	**%**	50.34	0.00	88.50

Input

-Fat : 1,277.5 t FM/y (approx. 14.9% DM)

-Glycerol :631.5 l FM

-Pig slurry : 10,304 t FM/y (approx. 6.8% oDM)

-Blood : 120.5 t FM/y (approx. 12.2% DM)

-Sludge : 821.25 t FM/y (approx. 32.5% DM)

-Water : 3,237.6 t FM/y (approx. 8.5% DM)

-Poutry slurry : 766.5 t FM/y (approx. 10% DM)

-Kitchen leftovers : 470.9 t FM/y (approx. 9.3% DM)

-Others : 3,033.2 t FM/y (approx. 19.3 % DM)

Fermenter volume:

F1: 2,500 m^3

Loading rate: 1.81 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time 30.7 d

CH_4-Productivity 0.70 $m^3_N*m^{-3}$

Spez. CH_4-Yield 0.29 $m^3_N*kgVS^{-1}$

Biogas production 3,041.3 $m^3.d^{-1}$ (average methane content 58%)

CHP power 330 kW_{el}

Operation time 7,900 h/y

D 1: input material optimalization

D 2: substrate feeding optimalization (crushing)

D 3: roofing storage tank 1 – increase of biogas production + odour reduction

SNO

SNO
Start Data 01/09/05

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	40.00		
H2S	**ppm**	200.00		
produced electric energy	**$MWh.d^{-1}$**	0.17		
Heat energy	**MWh**	4.38		
CH4	**$m3.d^{-1}$**	1588.62		
CH4 in [%]	**Vol. %**	58.00		
biogas [m³]	**$m^3.d^{-1}$**	2739.00		
specific methane yield	**$m^3.kg^{-1}$ VS**	120.80		
hydraulic retention time	**d**	40.00		
loading rate	**kg $VS.m^{-3}.d^{-1}$**	2.53		
methane productivity	**Nm^3 $CH_4.m^{-3}$**	0.84		
total	**t fm**	25.00		
cattle slurry	**t fm**	10.00		
maize silage	**t fm**	8.00		
potatos	**t fm**	6.00		
others	**t fm**	1.00		
total	**t dm**	4.80		
cattle slurry	**t dm**	0.90		
maize silage	**t dm**	2.40		
potatos	**t dm**	0.90		
others	**t dm**	0.60		

Input

-Cattle slurry : 3,650 t FM/y (approx. 9% DM)

-Maize silage : 2,920 t FM/y (approx. 30% oDM)

-Potatos: 2,190 t FM/y (approx. 15% DM)

-Soya fat : 365 t FM/y (approx. 60 % DM)

Fermenter volume

F1/F2: 950 m^3

Loading rate: 2.53 $kgVS*m^{-3}*d^{-1}$

Hydraulic retention time 40 d

CH_4-Productivity 0.84 $m^3_N*m^{-3}$

Spez. CH_4-Yield 120.8 $m^3_N*kgVS^{-1}$

Biogas production 2739$m^3.d^{-1}$ (average methane content 58%)

CHP power 180 kW_{el}

Operation time 8000 h/y

BOMERS	BOMERS Start Data 01/06/06	**Input** -Cattle slurry : 4,380 t FM/y (approx. 7% DM) -Maize silage : 1,095 t FM/y (approx. 30% oDM) -Fruit waste: 10,950 t FM/y (approx. 30% DM) -Others : 4,380 t FM/y (approx. 25 % DM) **Fermenter volume:** F1: 1650 m^3 **Loading rate:** 1.05 $kgVS*m^{-3}*d^{-1}$ **Hydraulic retention time** 40 d **CH_4-Productivity** 2.62 $m^3_N*m^{-3}$ **Spez. CH_4-Yield** 2.48 $m^3_N*kgVS^{-1}$ **Biogas production** 7200 $m^3.d^{-1}$ (average methane content 60%) **CHP power** 538 kW_{el} **Operation time** 8600 h/y	

PARAMETER	UNIT	AVERAGE	MIN	MAX
digester temp average	**°C**	40.00		
H2S	**ppm**	50.00		
produced electric energy	**$MWh.d^{-1}$**	0.25		
Heat energy	**MWh**	13.69		
CH4	**$m3.d^{-1}$**	4320.00		
CH4 in [%]	**Vol. %**	60.00		
biogas [m³]	**$m^3.d^{-1}$**	7200.00		
specific methane yield	**$m^3.kg^{-1}$ VS**	2.48		
hydraulic retention time	**d**	40.00	30.00	50.00
loading rate	**kg $VS.m^{-3}.d^{-1}$**	1.05		
methane productivity	**Nm^3 $CH_4.m^{-3}$**	2.62		
total	**t fm**	57.00		
cattle slurry	**t fm**	12.00		
maize silage	**t fm**	3.00		
fruit waste	**t fm**	30.00		
others	**t fm**	12.00		
total	**t dm**	1.74		
cattle slurry	**t dm**	0.84		
maize silage	**t dm**	0.90		
fruit waste	**t dm**	9.00		
others	**t dm**	3.00		

Table X: Overview on demonstration biogas plants

No.	Name	Digesters						Feeding device	Digestate storage (covered / uncovered)	Main feedstock		Desulfuri-sation: biological, chemical, scrubbing, etc.	CHP		Heat utili-sation	specials and additions
	Institute BGP-Company Location	volumes, type	material	shape	chryo-, meso- or thermo-philic	mixing technique	serial or parallel			substrate	amount in t FM/y		pilot injection or gas otto engine	capacity total / electric		
1	Vogelsang	1 x MainD 1400m³	fc	c	m	m(la)	serial	walking floor container	1 x 1400 m³ (uncovered)	TOTAL:	14.963	aerobic internal in fermenter and PostD	1st CHP: gas otto engine	450 / 200 KW	heating of BGP and heating of farm buildings	after enlargement of the plant: 2x1400m³ MainD, 2x900m³ PostD and 1x2500m³ digestate storage. (MainD-PostD parallel MainD-PostD) 4th CHP gas otto engine (747 / 347 KW) two feeding devices: QuickMix and walking floor container
	Lamping GbR									Fat	6.693					
	Essen/Oldb.	1 x MainD 900m³	fc	c	m	m(la)				Pig slurry	3.997					
										Maize silage	1.472		2nd CHP: gas otto engine	720 / 360 KW		
		1 x PostD 900m³	fc	c	m	m(la)				Fruit waste	1.019					
										Vegetable waste	762					
										Corn waste	725		3rd CHP: gas otto engine	747 / 347 KW		
										Green rye	199					
										others	97					
2	IGER	2 x MainD 4000m³	s	c	m	m(p)	MainD in parallel - PostD		1 x 3000m³ (covered)	TOTAL:	92.700	Chemical (addition of Ferric Chloride)	1st CHP: spark ignition engine	2758 / 1048 kW	heating of BGP	
	HOLSWORTHY									cattle slurry	46.466					
	Holsworthy	1 x PostD 3000m³	s	c	m	m(s)				others	18.145					
										water	14.338		2 ndCHP: spark ignition	2758 / 1048 kW		
										blood	12.974					
										food waste	8.164					
										pig water	5.429		3rd CHP: spark ignition engine	1579 / 600 kW		
										fish waste	1.318					
										sludge	1.240					
										Recyclat	1.151					
										biodiesel waste	924					
										energy crops	382					
										fat	282					
3	AAU	3 x MainD 1800m³	fc	c	t	m(la)	MainD in parallel - PostD	Eccentric worm pumps	25000 m³ (all un-covered of different sizes)	TOTAL:	43.000	aerobic external 20m³	1st CHP: gas otto engine	1000 / 400 kW	heating of BGP+steam for pressure cooking and heating of farm buildings (in winter)	
	Greenfarmenergy									liquid pig manure	20.000					
	O. løjstrup	1 x PostD 2500m³	fc	c	m/p	m(la)				Solid pig manure	10.000					
										Glycerol, fat et al.	8.000		2nd CHP: gas otto engine	1400 / 560 kW		
										solid manure (cattle/chicken)	5.000					

4	Boku Bioenergie Mureck Mureck	4 x MainD 1000m³ 1 x PostD 7000m³	s s	c c	m m	m(la) 	4 x MainD paralle l	prepa-ration pit / Glycerine is pumped directly	2x 7000m³ coverd	TOTAL: pig slury glycerol maize silage CCM colza cake	21.570 15.990 3.942 1.084 365 189	Normaly aerobic internal / at the moment iron oxide	1st CHP: gas otto engine	999 / 1050 kW	heating of BGP / district heating grid	
5	IEO Poldanor S.A. Pawlowko	2 x MainD 600m³ 1 x PostD 4000m³	fc soil	c r	m m	m(la) m(la)	MainD in paralle l - PostD	belt conveyor for solid & pumps for liquid	2 x 4000m³ (all covered)	TOTAL: liquid pig manure maize silage slaughterhouse wastes glycerin	18.136 13.769 3.121 912 335	aerobic internal in PostD	1st CHP: gas otto engine 2nd CHP: gas otto engine	1305 / 625 kW 600 / 240 kW	heating of BGP, heating of farm building and garage	
6	Boku Ökoenergie Utzenaich Utzenaich	MainD 2000m³ PostD 2000m³	fc fc	c* c*	m m	m(la) m(la)	serial	Eckart	6000m³ uncoverd	TOTAL: maize silage pig slury green rye silage sun flower silage	13.720 7.300 4.600 1.400 420	aerobic internal in Post D	1st CHP: gas otto engine	1030 / 500 kW	heating of BGP, corn drying, wood chips drying	* cylinder into cylinder: outer cylinder mainD, inner cylinder postD
7	AAU Foulum Foulum	MainD 1100m3 PostD 3000m³	fc fc	c c	t m/p	m(la) m(s)	MainD in paralle l - PostD	Eccentric worm pumps	3*3000 m³ (covered). 15000 m³ (uncovered)	TOTAL: liquid cattle manure liquid pig manure Maize silage Grass silage Other waste	22.500 14.000 5.000 2.000 1.000 500	aerobic internal in PostD and aerobic external 10m³	1st CHP: gas otto engine	1.645 / 625 kW	heating of BGP+rese arch centre Foulum	
8	Vogelsang Scherbring GmbH Essen/Oldb.	2 x MainD 1000m³ 1 x PostD 2500m³	fc fc	c c	m m	m(la) m(la)	paralle l	"Vogelsan g" QuickMix, mixing pit	1x 2500 m³ (covered)	TOTAL: Pig slurry Bleaching earth Fat Dog food Starch Apples Corn waste	18.984 8.165 5.479 2.190 924 902 818 507	aerobic internal in fermenter	1st CHP: gas otto engine 2nd CHP: gas otto engine 3rd CHP: gas otto engine	724 / 294 kW 724 / 294 kW 1020 / 530 KW	heating of BGP and heating of farm buildings	
9	UNIT Bagnod Roberto plant Piverone (To)	2 x mainD 5800m³	fc	c*	m	m(la)	MainD - MainD	"Siloking" (solids) / sub-merged shredding and mixing pump (liquids)	1 x 6000m³ (uncovered)	TOTAL: triticale silage mixture mais+sunflower maize silage liquid cattle manure solid cattle + pig manure kiwi	52.900 15.400 12.500 10.500 6.000 4.500 4.000	aerobic internal in both fermenters	1st CHP: gas otto engine	2111 / 1064 kW	heating of fermenters and farm buildings (in winter)	* cylinder into cylinder

10	Kraanswijk Biogas	1 x MainD 1650m³	fc	c	m	m(p)		Mixing pit and liquid manure pit combined with centrifugal pump	storage tank 3000m³ (covered)	TOTAL:	20.000	biological aerobic internal	1st CHP: gas otto engine	530 / 191 kW	heating of farmstead, stables, biogas plant; replacing natural gas	
	Groenlo									Fruitmix	10.000					
										liquid cattle manure	4.500					
										solid farmyard manure	3.500		2nd CHP: gas otto engine	991 / 347 kW		
										maize silage	1.000					
										grass silage	1.000					
11	SNO Energie BV	2 x MainD 950m³	fc	c	m	m(p)	MainD - MainD	Mixing pit combined with rotary piston pump	Two storage tanks: one 2500m³ and one 4000m³ (all covered)	TOTAL:	7.924	biological aerobic internal	1st CHP: gas otto engine	231 / 90 kW	heating of farmstead, biogas plant, drying; replacing natural gas	
	Makkinga									liquid cattle manure	5.000					
										maize silage	2.500					
										soy fat	269		2nd CHP: gas otto engine	231 / 90 kW		
										wheat	110					
										left overs cow feed	45					
12	ATB	PreD 500 m³	fc	c	m	m(la)	PreD - 2 x MainD - PostD	"Börger" power-feed SSR combined with rotary piston pump	4 x 6000m³ (all un-covered)	TOTAL:	61.884	aerobic internal in PostD and aerobic external 10m³	1st CHP: gas otto engine	800 / 328 kW	heating of BGP and heating of farm buildings (in winter)	
	Rhinmilch GmbH									liquid cattle manure	51.100					
	Fehrbellin	2 x MainD 3000m³	fc	c	m	m(la)				maize silage	3.087					
										ley crop silage	2.656		2nd CHP: gas otto engine	2150 / 1053 kW		
		PostD 6000m³	fc	c	m	m(la)				forage residues	1.731					
										solid cattle manure	1.519					
										ground maize	1.158					
										ground rye	634					
13	VUZT	1 x MainD 2500m³	fc	c		m				TOTAL:	20.805					
										pig slurry	10.203					
										water	3.332					
										others	3.123					
										fat	1.249					
										sludge	833					
										poutry slurry	833					
										glycerol	625					
										litchen leftovers	416					
										blood	208					

Index:

Material fc: ferro-concrete
s: steel
Shape c: cylindric
r: rectangular

Conditions m: mesophilic
p: psychrophilic
t: thermophilic

Mixing m(la): mechanically (long axis impeller)
m(s): mechanically (submerged resp. submergible impeller)
m(p): mechanically (paddle)