Co-fermentation of organic substrates in the decentralized production of regenerative energy

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1. Einleitung

In Germany the fermentation and composting of organic waste has become an integral part of waste disposal. According to information provided by the Federal Environment Agency of Germany (Umweltbundesamtes), in 1998/99 this encompassed about 7.5 million Mg of organic waste from private households and associated businesses, plus plant and vegetable waste from parks and gardens. In addition, about 2.3 million Mg dry weight of clarification sludge in 2000, 220 million m³/a of liquid manure and other diverse organic substrates from agriculture, commerce and industry were also subjected to fermentation or composting (see Fig. 1).

In principle, organic waste can be treated in composting plants or in biogas plants (digesters), of which currently about 1300 [1] are operated commercially in Germany. The large majority of biogas (fermentation) plants are used in agriculture.

For the treatment of organic waste from municipal refuse collection, co-fermentation plays a subordinate role. Gallert et. al. [2] report that approximately a mere 400,000 Mg/a are treated anaerobically (i.e. fermented). However, in view of the large amounts of clarification sludge and liquid manure which are usually fermented together with other organic substrates, co-fermentation plays an important role in the production of secondary fertilizer and regenerative energy.

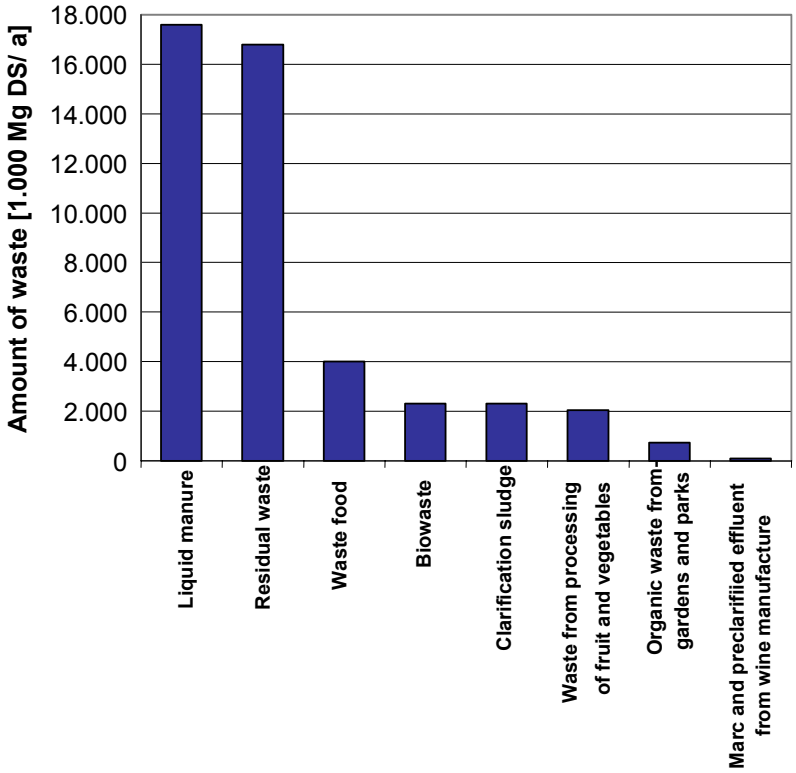


Fig. 1: Substrates produced in Germany which quantitatively are of particular importance. These (and other) substrates can be used in co-fermentation plants. The actual amounts of substrate co-fermented in Germany is, however, considerably less.

2. Plants for co-fermentation of organic waste

Biogas plants have long been used in agriculture for the treatment of animal excrement, for the anaerobic stabilisation of clarification sludge, and for treating effluent heavily contaminated with organic material[1]. The substrates to be fermented here are, as a rule, pumpable. More recently, a wide range of process has become available for fermenting solid, liquid and pasty substrates/waste. Depending on the substrate(s) to be fermented and the size of the plant, a wide range of different processing methods are used.

These range from simple agricultural biogas plants, which, despite low specific investment costs and a narrow range of possible substrates, can be very effective (see Fig. 1 and 2), to more sophisticated plants (see Fig. 3 and 4), which through preliminary treatment of the waste (e.g. particle size reduction, sanitisation) can treat a wider range of substrates, finally to industrial plants, which by using even more sophisticated mechanical pre-treatment are capable of fermenting solid waste and waste containing interfering substances (see Fig. 5 and 6).

In order to provide a better understanding, in Section 3 the concept of co-fermentation at the BVR plant (near Dresden, Germany) will be presented as an example. In respect to accepting and processing solid, pasty and liquid waste the plant is particularly flexible and efficient.

Fig. 2: Agricultural biogas plant, overview.
(Source: Biogas Weser-ems GmbH, 26203 Friesoythe)

Fig. 2: Agricultural biogas plant, digester with integtrated gas storage tank.
(Source: Biogas Weser-ems GmbH, 26203 Friesoythe)

Fig. 3: Biogas plant for the fermentation of liquid manure and food waste, Sagard on Rügen.
(Source: Nehlsen Servicecenter Nord Ost GmbH, NL Rügen).

[1] There have been numerous promising attempts in the past few decades at treating domestic waste and domestic-like commercial waste, but only in a few cases has the applied technology proved itself to be viable.

Fig. 4: Biogas plant, Sagard on Rügen. Waste delivery point and sanitisation.
(Source: Nehlsen Servicecenter Nord Ost GmbH, NL Rügen).

Abb. 5: Co-fermentation plant for solid, liquid and pasty waste, as well as for clarification sludge. Overview.
(Source: Bio-Verwertungsgesellschaft Radeberg mbH)

Abb. 6: Co- fermentation plant, Radeberg. Mechanical pre-treatment of solid waste.
(Source: Bio-Verwertungsgesellschaft Radeberg mbH).

3. Co-substrates and biogas yields

In Co-fermentation plants a wide range of liquid, pasty and solid substrates can be processed. However, the degree of substrate degradation and the yield of biogas can vary greatly, depending on dry solids content, dry organic content, substrate composition (fats, proteins, carbohydrates, mineral content etc.), and their bioavailability (see Fig. 7 and Table 1). For example, from maize straw, up to 400 m³ CH_4/Mg original substance can be won, while liquid manure from cattle, with 8% solids, will yield a mere 10 – 15 m³ CH_4/m³.

Substrate composition can be altered through pre-treatment or storage. While liquid manure and clarification sludge undergo a succession of different degradation processes before being used in a biogas plant, household organic waste changes little. As a result, the degree of degradation achieved under anaerobic conditions varies considerably, for example, between clarification sludge and fresh organic waste from households. While under anaerobic conditions a maximum degradation of 60% is currently achievable with clarification sludge, with household organic waste it is over 90% [3]. Compared with biogenic waste with a dry solids content of up to 50 % or more, clarification sludge and liquid manure are dilute substrates (dry solids content, 5 – 10 %). Thus, the addition of solid organic waste to clarification sludge and liquid manure can increase substrate solids content without significantly increasing hydraulic stress in the digester tower. Thanks to the higher content of

readily degradable organic substances, a higher yield of biogas, based on digester volume, can be achieved.

In Figure 8 the potential yield of biogas from a number of, in Germany quantitatively important, substrates is shown. From just the substrates show here approximately 4,300 MW of electricity could be generated every year, corresponding to the output of 6 – 7 medium-sized power stations.

The German biogas trade association ("Fachverband Biogas Deutschland"), estimates that the contribution made by co-fermentation to electricity generation in Germany could be increased from its present level of 0.7% to 13%, if besides organic agricultural waste all potential co-substrates were to be used and about 20% of agricultural land were cultivated with energy crops specifically for co-fermentation.

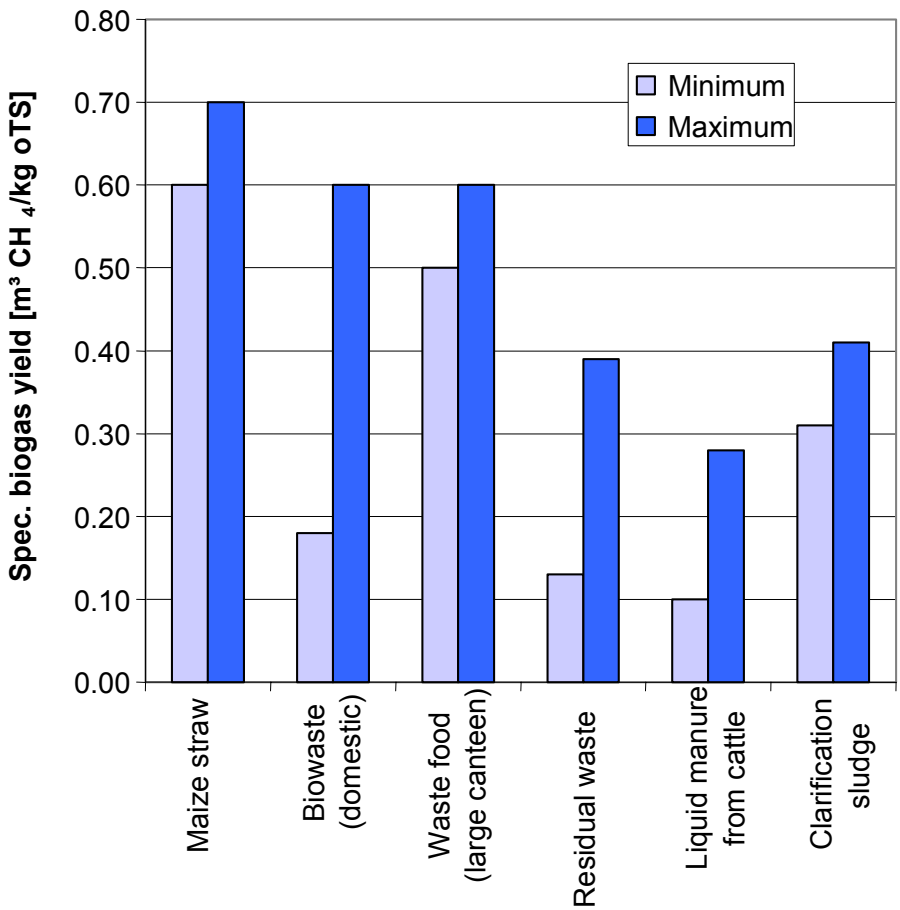


Fig. 7: Variation of the specific Biogas yield from organic waste

Tab. 1: Fluctuation in the specific yield of biogas from selected substrates for co-fermentation.

	TS		oTS		Biogas			
	[%]		[%]		m³ CH4/kg TS		m³ CH4/kg oTS	
Substrat	von	bis	von	bis	von	bis	von	bis
Liquid chicken manure	10	34	70	80	0,13	0,34	0,18	0,43
Horse manure (fresh)	28		25		0,08	0,10	0,30	0,40
Liquid cattle manure	6	17	44	90	0,04	0,25	0,10	0,28
Sheep droppings (fresh)	18	30	80	85	0,32	0,43	0,40	0,50
Cattle dung (fresh)	12	40	65	85	0,12	0,33	0,18	0,50
Liquid manure from pigs	3	13	52	85	0,07	0,32	0,13	0,38
Raw glycerine (RME man.)	>98		90	93	0,62	0,67	0,69	0,72
Potato tops	25		79		0,40	0,47	0,50	0,60
Beet (turnip) tops	15	18	78	80	0,19	0,40	0,24	0,50
Diverse cereals	85	90	85	89	0,26	0,53	0,30	0,60
Clover	20		80		0,32	0,40	0,40	0,50
Maize straw	86		72		0,43	0,50	0,60	0,70
Silo maize	33	44		95			0,33	0,39
Maize silage		35		90			0,30	0,36
Apple slop	2	15	90	95	0,30		0,33	
Apple pomace	25		86					
spent grains from beer	20	22	87	90	0,22	0,63	0,25	0,70
Spent hops (dried)	97	97,5	90		0,45	0,50	0,50	0,55
Filtration silica gel (beer)	30		6,3		0,02	0,02	0,30	0,35
Vegetable waste	5	25	76	90	0,18		0,24	0,40
Old bread	90		96	98	0,67	0,74	0,70	0,75
Coco bean shells	95		91					
Potato slop	12	15	90		0,22	0,50	0,24	0,55
Cereal slop	6	15	87	90	0,52		0,60	
foliage			82		0,33		0,40	
Melasse	80		95		0,29		0,30	
Whey	4	95	80	92			0,48	0,60
fruit pomace	45		93		0,25	0,48	0,27	0,52
Oil seed residue (pressed)	92		97		0,56	0,60	0,58	0,62
Raps extraction residue	88		93		0,24	0,59	0,26	0,63
Grape pomace	40	50	80	95				
Caster extraction residue	90		81					
Food waste (from large kitchens)	9	40	55	98	0,20	0,64	0,36	0,65
Vinasse	63		53					
Organic waste (domestic)	30	75	30	90	0,05	0,54	0,18	0,60
Park and garden waste (fresh)	12	42	87	97	0,18	0,49	0,21	0,50
Clippings (sedge)	37		93		0,47		0,50	
Blood meal	90		80					
Flotation sludge	5	24	93	98	0,56	0,78	0,60	0,80
Stomach contents (pig)	12	15	80	84	0,16	0,25	0,20	0,30
Rumen content (untreated)	11	19	80	88	0,21	0,35	0,26	0,40
Rumen content (pressed)	20	45	90		0,54	0,63	0,60	0,70
Slaughter house waste							0,20	0,43
Fish processing waste							0,30	
Animal cadaver meal	8	25	90		0,45	0,72	0,50	0,80
Separator fat (gelatine production)	25		92					
Fat (from fat separators)	2	70	70	100	0,29	0,70	0,42	1,00
Grass silage	21	37	76	92	0,25	0,48	0,33	0,52
Grass silage	50	54		90			0,30	0,36
Hay		90		86			0,30	0,36
Market waste	5	25	76	90			0,30	0,40
Clarification sludge	1	5	60	75	0,21	0,28	0,23	0,41
Residual waste	55	57	46	78	0,06	0,30	0,13	0,39
Production waste from food and animal feed industries							0,19	0,48

Remarks

[1)] Original data in l Biogas/ kg org. dry wt. or m³ biogas/ kg org. dry wt. were converted assuming a methane content of 60 vol% CH_4 in biogas umgerechnet.

[2)] The original data in m³ CH_4/ kg org. dry wt. were additionally converted to m³ CH4/ kg org. dry wt. along with the given org. dry wt. amount.

Sources [4 - 10]

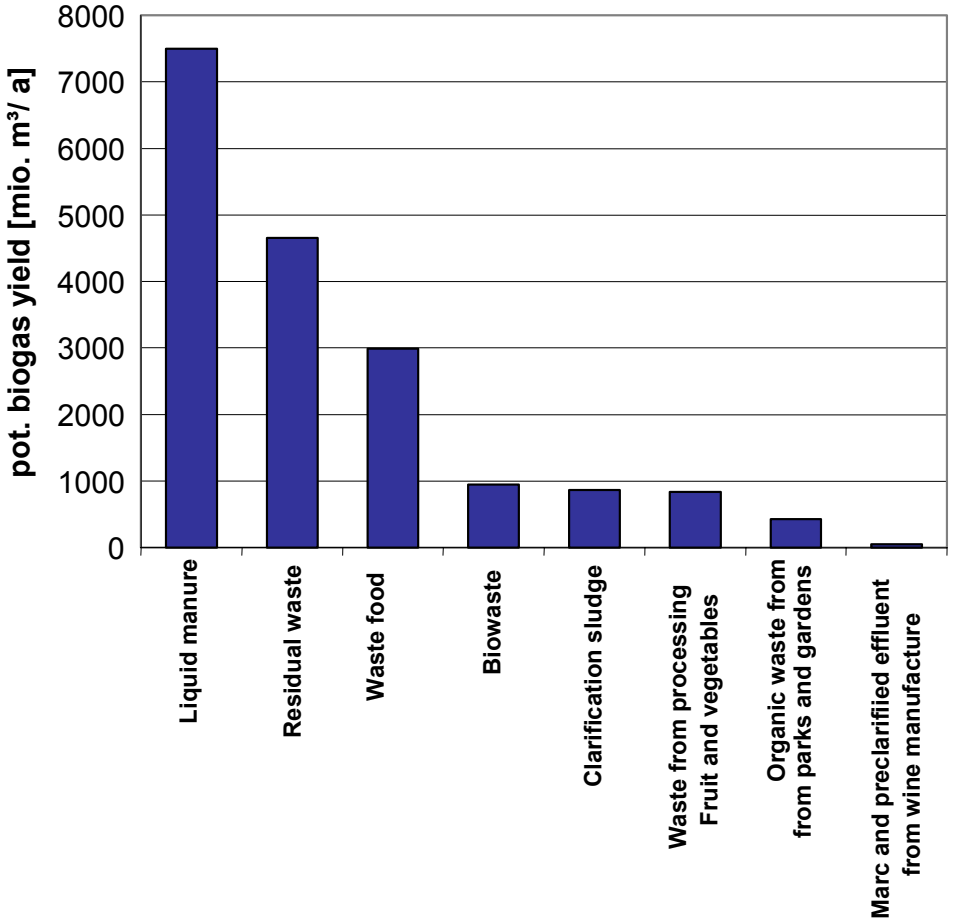


Fig. 8: Potential biogas yield of quantitatively important substrates in Germany.

3. Operational experience am Beispiel der Co-Vergärungsanlage der BVR, Dresden/Germany

The starting point of the considerations for planning the BVR co-fermentation plant was the extension of the sewage treatment plant in Radeberg including plans for erecting an anaerobic sludge stabilising plant in a sludge digestion tower. Another reason was the apparent need for treatment capacities for various types of biological waste. During a first step various plant designs for mono- and co-treatment of sewage sludge and biological waste in fermentation and composting plants were investigated. Not only ecological standpoints but also primarily economic aspects were examined. As a result of these investigations, the following sewage sludge and biological waste fermentation concept was developed as the most advantageous concept from ecological and primarily economic standpoints.

The co-fermentation plant was erected during reconstruction and extension of the sewage treatment plant in Radeberg. Based on the federal Water Resources Law (WHG) and the

State of Saxon's Water Law (SächsWG), the fermentation plant was approved as part of the sewage treatment plant, including a waste treatment plant as approved in the official plans for the extension of the Radeberg sewage treatment plant.

During planning great importance was attached to the flexibility of the fermentation plant. The target was to be able to process as wide a range of wastes as possible. Aside from the liquid and paste-like wastes such as e.g. grease trap contents usually processed in co-fermentation plants, the plant was designed to be able to accept solid biological wastes such as e.g. those which accumulate during the municipal collection of bio-waste containers, extremely soiled biological wastes and industrial wastes such as food waste, incontinence waste etc. that are not usually processed in fermentation gas plants. The approved acceptance catalogue included over 70 types of waste.

It had to be possible to process biological wastes with and separately from sewage sludge. Therefore the plant was equipped with two fermenters (see chapter 2, Fig. 5,) that can also be operated separately. The plant was erected by Linde KCA Dresden and started operating in the middle of 1999.

A basic flow diagram of the co-fermentation plant is shown in Fig. 7. At the moment approx. 35,000 m^3 of sewage sludge (TS content 5 – 6%) and approx. 15 – 20,000 Mg of biological wastes are processed annually in the plant.

Sewage sludges, liquid and paste-like as well as solid biological wastes are accepted separately in the plant. The dewatered sewage sludge is accepted by the Radeberg sewage treatment plant. Liquid and paste-like wastes can be stored in various, partially heated tanks. Solid biological wastes are accepted in a flat bunker. An initial rough sorting is carried out in the flat bin. Unsuitable charges can be separated here with the wheel loader and disposed.

From the flat bin the wastes are fed into the charging hopper of the shredder with a wheel loader (see fig. 10 and 11). Then the shredded wastes are transported via ascending belts to Fe-separation and into the pulper (see fig. 12). In the pulper waste materials are dissolved and the waste is shredded further.

Stones, bones etc. are removed out of the waste suspension via a heavy medium sewer port. Then the waste suspension reaches a sieve drum with various perforated segments via a weir. Sand and light-density materials are removed out of the suspension here (see. fig 13 and 14). The waste suspension reaches a mash tank.

The processed wastes are transferred from the tanks via a macerator into the hygienisation tank (see fig. 15). Hygienisation is carried out at a grain size < 10 mm at 70°C for over 1 hour.

After hygienisation the biological waste suspension is transferred together with the sewage sludge into the two fermenters. The sewage sludge can be fermented separately from the biological waste as well. This ensures that the biological waste can be marketed as compost in case the costs for sewage sludge utilisation increase sharply. After the material is completely fermented (mesophilic, residence time 15 –20 d), it is de-watered by centrifuging. The centrifuged water is cleaned in the Radeberg municipal sewage treatment plant, the solid is re-composted externally and utilised as secondary fertiliser.

The fermentation gas generated during fermentation is converted into electricity by two block heat and power plants (see fig. 16). Excess electricity is fed into the mains. The generated heat is used for heating the sludge digestion towers, for hygienisation, for supplying the sewage treatment plant with heat and for heating the service building. The exhaust air from the treatment plant is captured centrally and cleaned by means of biological filters (see fig. 17).

Besides the biological waste normally processed in co-fermentation plants, such as fat separator contents, stillage, market waste, etc., the BVR biogas plant can also process waste that demands highly sophisticated processing technology, such as diapers from old people's homes, for example (see Fig. 18).

Depending on the waste processed, pre-processing plant capacity can vary widely. For example, with a water receiver of 12 – 15 m³ in the pulper, it was possible to process 1.0 – 1.3 Mg of incontinence waste in a single operation (batch process), while the viscosity of the mash prohibited any more. With a mixture of 10 – 20 % incontinence waste and 80 – 90 % organic waste from municipal collection it was possible to process 4.5 – 5.5 Mg per batch. The specific costs of processing for particular kinds of waste can thus vary widely.

Figure 19 shows the amounts of mash from organic waste, clarification sludge and fat separator waste fed into the plant over a period of about one year. The mash from organic waste consisted of varying proportions of household organic waste from municipal collection, organic market waste and organic waste from a number of different production processes. The proportion of fat separator waste remained more-or-less constant over the period of one year. The amounts of sewage clarification sludge and organic waste were subject to large fluctuations.

As can be seen from Fig. 20, the total amount of mash, distributed equally between the two fermenters, fluctuates by more than 30% during the period under observation, from 200 to over 300 m³/d. The fluctuations in waste volume are due partly to seasonal variations in the amounts available (e.g. organic waste from municipal collection) and partly to variations volume in the market. Despite the plant disposing over 8 buffer tanks, with a total capacity of approximately 1000 m³, it is not possible to avoid such fluctuations in feed rate with their negative effect on operational efficiency. The problem could only be reduced by the use of storable substrates, such as maize straw.

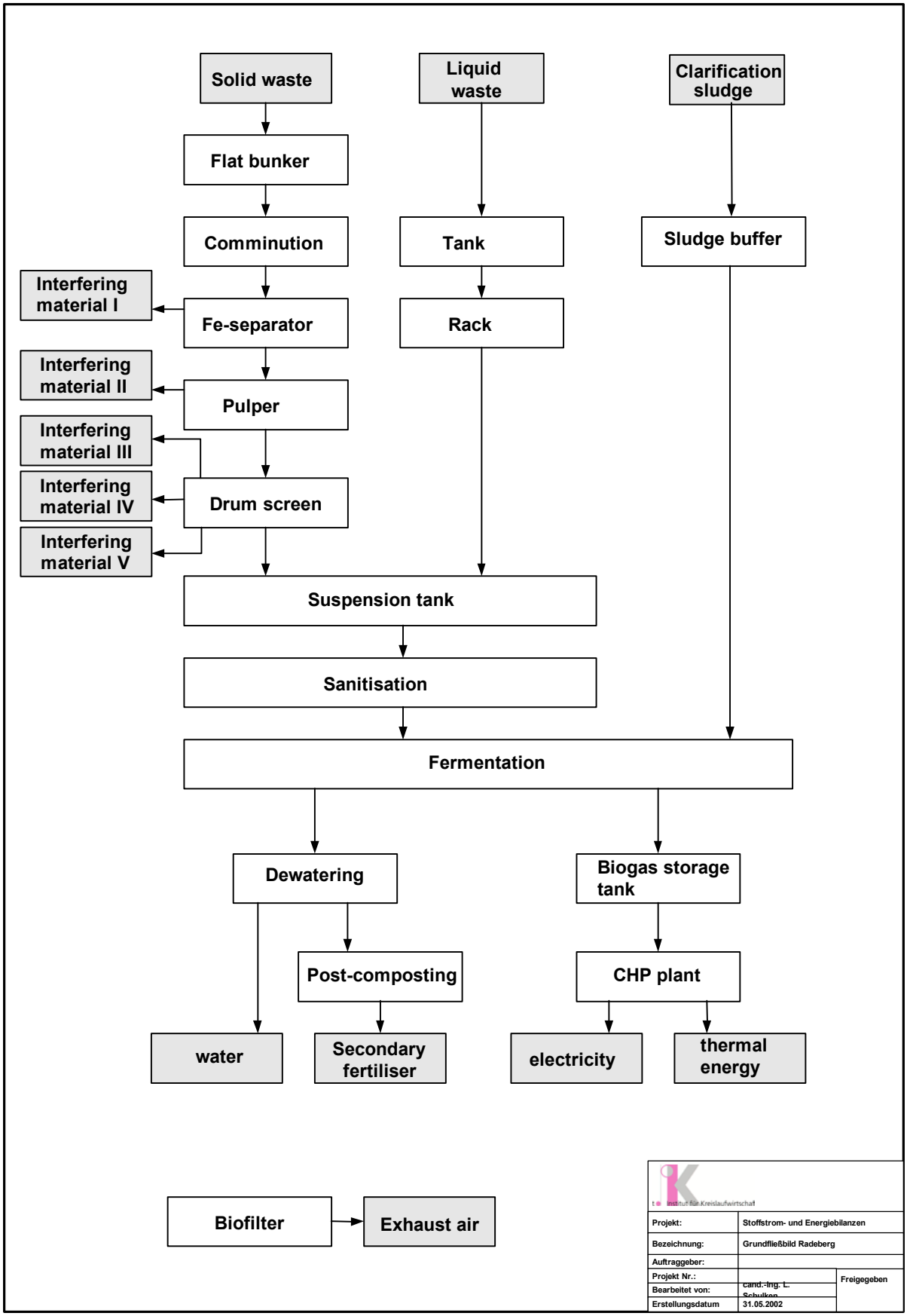


Fig. 9: Simplified basic flow diagram of the BVR co-fermentation plant, Radeberg.

Fig. 10: Flat bunker with a wheel loader.

Fig. 11: Comminution unit for solid organic waste.

Fig. 12: Pulper for mashing biological waste

Fig. 13: Fine-grain interfering substances, removed by sieve (mainly sand).

Fig. 14: Bulky interfering substances (lots of plastic) in dewatering container.

Fig. 15: Sanitisation in batch process using two sanitisation tanks.

Fig. 16: Combined heat and power (CHP) plant for the production of electricity and thermal energy

Fig. 17: Biofilter for purifying smelly air removed from inside the plant.

Fig. 18: Trial comminution of incontinence waste from old people's homes

Despite the variations in quantity and composition of the mash being fermented, methane concentrations in the produced biogas are stable. The biogas itself is very suitable for fuelling a CHP plant. In contrast to methane concentration, biogas production, and with it the specific biogas yield per cubic metre of mash, varies widely. There is thus optimisation potential for plant operation in the controlled composition of the mash.

The mixed processing of different types of organic waste, fat separator waste and sewage sludge results in a balanced nutrient composition. Mean solids P_2O_5 content is about 3.3%, while nitrogen content is about 3%. The fermented, dewatered sludge is composted with structure-rich material and utilised as fertiliser. The use of such fertiliser, made from recycled materials, helps to conserve natural sources, for example of phosphate, which are predicted, at the current rate of use, to last just another 30 years [11]. Other sources talking about approx. 80 years.

The chances of utilising the spent sludge from co-fermentation as an agricultural fertiliser depend decisively on the its heavy metal content. Fig. 21 shows a comparison of threshold

values for heavy metals as laid down in German statutory regulations relating to clarification sludge (AbfKlärV), the EU target threshold values for clarification sludge used in agriculture, and the actual values for spent sludge from the Radeberg co-fermentation plant. The comparison shows the Radeberg sludge to contain very low levels of heavy metals, thus making it well suited for agricultural use. They are between 62 and 96% below the EU's target threshold values for the year 2025.

Altogether, it can be concluded that the co-fermentation of biological waste and sewage sludge, under the given conditions, is technically feasible and economically viable. For the sewage sludge produced by the sewage works and for a wide range of biological waste the co-fermentation plant offers a reliable and secure means of disposal. Through the production of regenerative energy and thus reducing emissions of greenhouse gases, the plant also makes a positive contribution to climate protection.

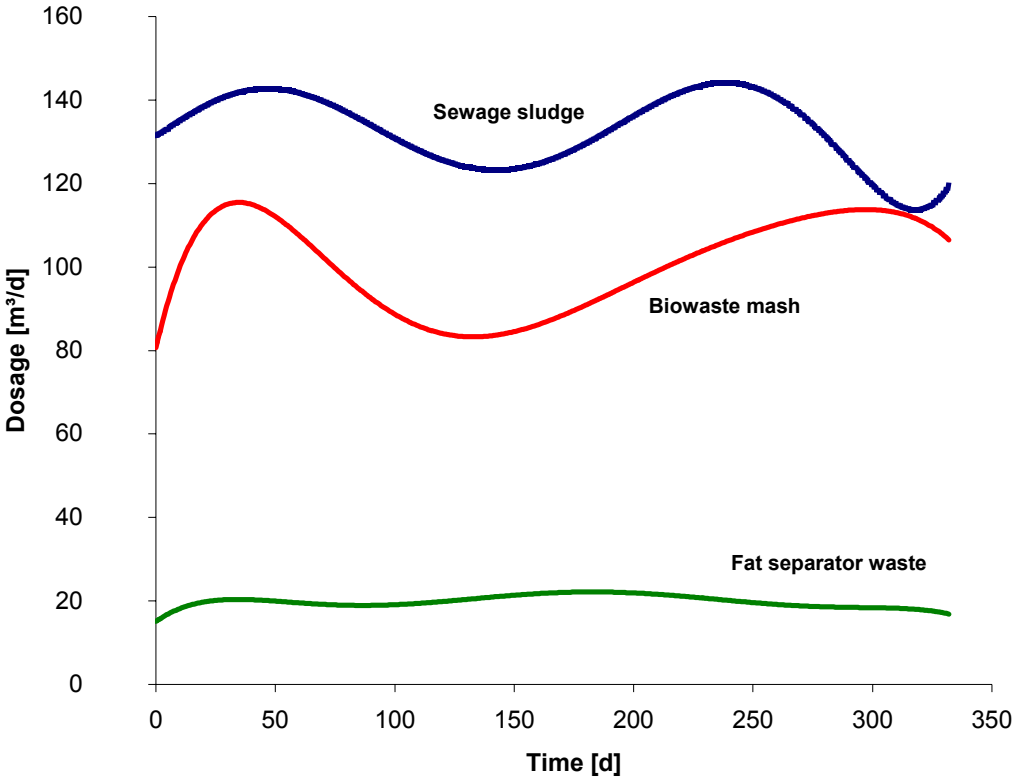


Fig. 19: Amounts of biowaste mash, fat separator waste and sewage sludge processed.

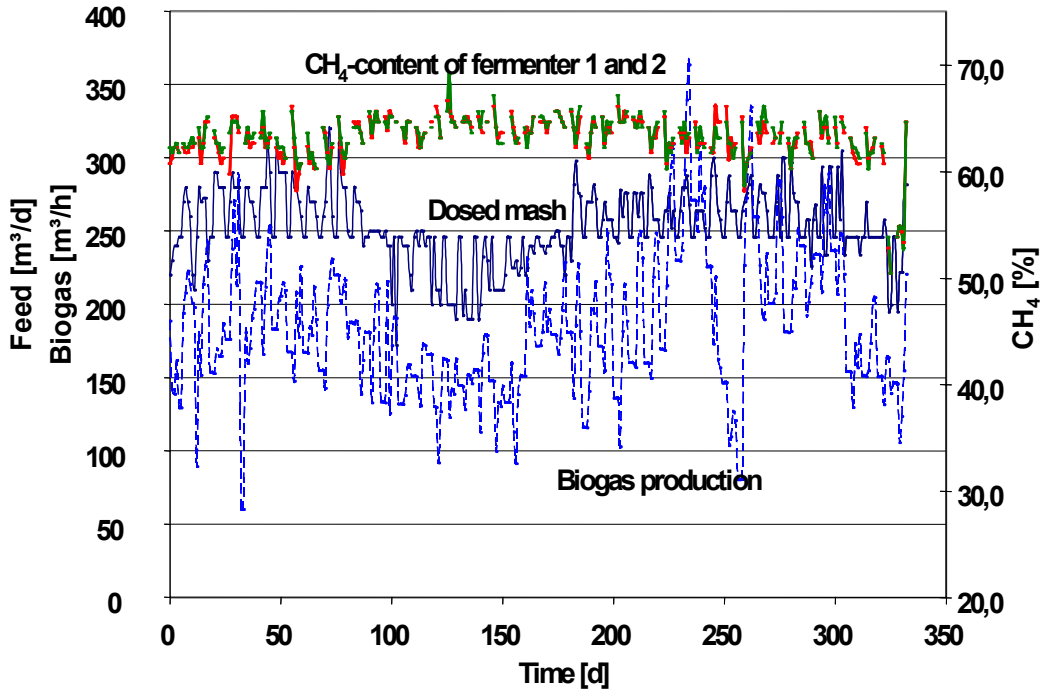
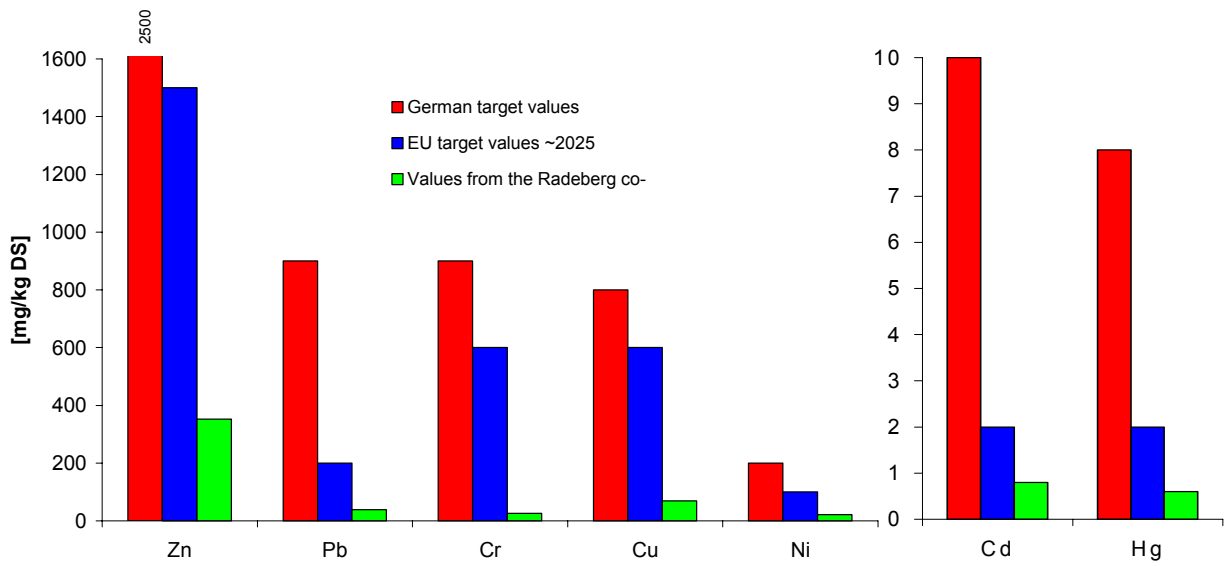


Fig. 20: Biogas production, methane content of biogas in both fermenters (R1 and R2), and the

Fig. 20: Biogas production, methane content of biogas in both fermenters, and the amount of mash feed (consisting of varying proportions of biowaste mash, sewage sludge and fat



separator waste).

Fig. 21: Comparison of threshold and target values for heavy metal content in clarification sludge used in agriculture with the values for spent sludge from the Radeberg co-fermentation plant.

5. Summary

The utilization of organic waste is an integral part of the cyclic flow of materials in an economy based on the principle of long-term sustainability. With the technology currently available it is possible to utilize in fermentation plants a very wide range of substrates from the solid waste and waste water, as well as from agriculture. In respect to size and technical standards, plant design can be also be greatly varied to meet a wide range of conditions and requirements that depend on a particular project. Such plants are particularly suitable for decentralised use.

Specific yields of biogas from various substrates fluctuate strongly. For example, from maize straw up to 400 m³ CH_4/Mg original substance can be won, while liquid manure from cattle with 8% solids will yield a mere 10 – 15 m³ CH_4/m³.

In Germany, households alone produce approximately 4 million Mg of organic waste annually, which, if fermented, could be used to generate up to 560,000 MWh[3] of electricity. If liquid manure and other organic waste were also used, this figure could be substantially increased still further. The German biogas trade association ("Fachverband Biogas Deutschland"), estimates that the contribution made by co-fermentation to electricity generation in Germany could be increased from its present 0.7% to 13%, if besides organic agricultural waste all potential co-substrates were to be used and about 20% of agricultural land were cultivated with energy crops specifically for co-fermentation.

The Radeberg co-fermentation plant provides an example of how a single such plant can treat, both economically and ecologically, a wide range of liquid, slurry and solid substrates, producing in the process both renewable energy and high-quality fertilizer.

Current German limits on pollutant contamination for fertilizer derived from secondary raw materials, as well as the corresponding long-term limits set by the European Union, can be readily complied with or considerably improved on.

By producing energy from renewable resources, fermentation plants make an active contribution to combating climate change. In view of shrinking reserves of mineral phosphate, the use of fertilizer from secondary raw materials is also a very positive development.

6. Literature

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