Improvement of the technical, economical and ecological efficiency of biogas production -future challenges for the agricultural engineering sector-

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GERMANY

1. Introduction

Within the framework of the EU Directive on Renewable Energy Sources (2009/28/EC), the Federal German Republic has committed to increase the share of renewables in end energy consumption from the current 11 to 18% by 2020. To achieve this goal the Federal Government has implemented this in its strategies "Integrated Energy and Climate Program" and the "National Action Plan for Renewable Energies (NREAPs)". Within the renewable energy sector in Germany biogas already provides a significant contribution. About 7000 agricultural biogas plants with a capacity of 2730 MW, which corresponds to the performance of two nuclear power plants, produced in 2010 approximately 2.1% of total electricity consumption in Germany or 12.8% of electricity production from renewable energy[1,4]. At the same time feeding in biomethane is encouraged, so that to expect a further expansion of the number of plants.

Biogas as compared with other bioenergy sources shows several advantages: It can be produced sustainably from various biomass and its energy may be used in many ways and needs. The success of the biogas technology is measured not only in the continuous growth of plant numbers, but also in the efficient and sustainable production of electricity, heat and fuel. Biogas plants are then economically and ecologically meaningful, if they are process-optimized operated and if resources are used effectively.

2. Economic and ecological conditions

2.1. Cost of biogas electricity generation

Figure 1 illustrates the structure of the cost of electricity generation in agricultural biogas plants [2]. The electricity generating costs decrease with increasing plant size and amount to about 15 to 25 Ct/kWh$_{el}$. While capital costs for 75 kW plant make half the cost, for the 1 MW installation it is only a quarter. The second major cost factor are the substrate preparation costs (including transportation). For the two large sized biogas plants substrates are the most important cost variable with approximately 50%, since both the specific capital costs are significantly lower than those of the 150 kW plant costs. In contrast, for the small "liquid manure plant", the share of substrate costs amounts only 22% of the total costs.

At a production cost of 15 Ct/kWh$_{el}$ biogas electricity competes with electricity from wind energy and photovoltaic plants. Figure 2 shows the course of the electricity production costs in the last 20 years by photovoltaic and biogas plants [3]. It is evident that the cost for photovoltaic plants could be drastically reduced by technological progress (efficiency) in the semiconductor industry and the mass production from 90 to 15 Ct/kWh$_{el}$. The cost of generating electricity from biogas is now at a similar level -despite the increase in efficiency for the process itself- but due to rising costs for the manufacturing of plant components and the substrates (biomass) preparation the generating costs increased.

2.2. Greenhouse gas emissions by biogas generation

The total emissions of the biogas production amount for the considered plants to approximately 0.27 to 0.29 kg CO_2eq/kWhel (Fig. 3). The construction of the biogas plant itself contributes only to a small proportion to the total emissions, this also applies to the substrate and digestate transportation. For the four shown plants no significant differences between the energy crop plants and the slurry-based plants are apparent: despite the significantly lower share of energy crops in the slurry plant (20 % energy crops versus 80% manure) the energy crop cultivation causes approximately 38% of total emissions, compared to 43-45% in the energy crop plant. In addition to the energy crop production, the diffuse emissions cause a significant proportion of the total greenhouse gas emissions. Since for both the CHP-slippage and leaks default values are used (in total 1.5% of the produced methane), no differences for these emissions appear. Another important factor is the operating energy requirement. Apart from the process electricity (purchased) the two small plants (75 and 150 kW) additionally ignition fuel is taken into account [2].

2.3. Greenhouse gas balances and GHG mitigation costs

Only the 75-kW plant (slurry based) shows after deducting the credit for heat and manure use negative CO_2eq emissions for the production of biogas electricity (Fig. 3). In contrast, the three energy crop plants cause emissions from 0.11 to 0.13 kg CO_2eq per kWh of biogas electricity. In comparison with emissions from fossil mix for the slurry plant, a 20% higher greenhouse gas saving is obtained than the energy crop plants (0.76 compared to 0.6 kg CO_2eq/kWh$_{el}$; not shown). The energy crop plants, however, differ significantly in terms of CO_2eq reduction costs: Due to declining electricity generation costs the mitigation decrease much with the plant size. For this reason, for the small slurry plant -despite of the significantly higher greenhouse gas savings- the mitigation costs range at the level of the smallest energy crop plant. However, none of the plants is able to achieve the threshold regarded as economically viable of max. 100 € per ton of saved CO_2 eq [2].

2.4. Further considerations

The ambitious goals for expanding renewable energy sources and the price pressure in the agricultural sector require a continuous development of biogas technology and its efficiency. This also applies to the upstream and downstream process steps. Despite of substantial improvements over the last years many biogas plants are not operating efficient enough. The main problems lie in conceptual errors, incorrect dimensioning of plants or single components, improper substrate and waste heat utilization and improper management.

Currently, in Germany about 2.3 million hectares [4] arable land are used for non-food production. About 3 to 4 million of the 17 million hectares (12 mio. arable, 5 mio. grassland) in the long term could be used for the production of energy crops. The bioenergy sector is however subject to criticism that they block valuable land that would be needed to feed the world population. From this limited land availability, there is the need for the development of concepts for the utilization of non land consuming substrates.

In addition to the increasing scarcity of fossil energy sources the reduction of greenhouse gas emissions is the main motivation for using renewable energy sources. It is not only of importance to reduce greenhouse gas emissions, but also to achieve this reduction at economically reasonable cost (about 100 €/kg CO_2). The biogas production may contribute to a significant reduction of greenhouse gas emissions. CO_2eq savings of 500 to 1000 g CO_2eq/kWhel are realistic. However, the CO_2eq mitigation costs are often above 100 € / t CO_2eq [2]. This also applies to small "animal manure plants". For those high electricity generating costs (high specific capital costs) compensate the high greenhouse gas savings.

From the above described state of the art and knowledge tasks and challenges for the agricultural engineering arise, that can contribute to improve environmental and economic efficiency. These exemplarily are shown below along the biogas production chain.

3. Challenges for the agricultural technology for development of the biogas sector

3.1. Optimization of harvest logistics due to separation of field and road transport

The harvest for the dominant biogas substrates corn silage (as well as whole crop silage) takes in each case about four weeks. During this time powerful technology with highest quality is needed. The separation of field and road transport leads at distances of more than 10 km to cost savings, lower emissions and reduced pollution of roads. Development is required for the biomass transfer from field boundaries to vessel. An important development is the Euro-NawaroMaus (a self-propelled loader for renewable raw materials) of ROPA Inc.: chopped biomass like corn silage or whole crop silage can be grabbed by the Euro-NawaroMaus at the filed sidelines and directly overloaded on large-volume road transport vehicles (lorries). In practical use, the overcharge capacity lies at about 15 m^3 per minute with a collecting width of 8 m. A further advantage of the split procedure is the equalization of the transportation campaign; even if there are not enough transport vehicles it still can be chopped.

3.2. Online measuring of substrate qualities at harvest

An important development for substrate harvest is the online nutritional determination by near-infrared-spectroscopy (NIRS). During the harvesting process the biomass can be measured online for current dry matter content, starch, crude fiber, crude protein, crude ash, crude fat and sugar. Thus, this measurement technique can also be used to determine the biogas yield. Already during the harvest, the detection unit can be used for accounting purposes and the disposition of the biomass needs [**5**] (Fig. 4). The data on the terminal board, these can be displayed and stored to order, or sent to a server.

3.3. Harvest machinery for lignocellulosic by-products (rapeseed, grain and corn straw)

The agricultural by-product straw has a significant energetic potential. Straw-producing crops such as cereals, corn and oilseeds are cultivated on estimated 8 million ha in Germany. Therefore it can be calculated with a nationwide total straw formation of about 50 million tons per year. The utilization of straw in biogas plants has the advantage, in comparison to straw burning, that the digestate still can be used as nutrients and humus improver for the soil. The lignin compounds can also make a valuable contribution to a balanced ratio of nutrients in the biogas plant. When about 1/3 to 1/4 of the straw is required for the reproduction of soil humus, about 35 to 45 million tons annually were available for energy production. Further development is required to collect and harvest of fine fraction of grain and rapeseed straw (spindles, husks, pods) and for the intercalation viable extraction of corn straw.

3.4. Cleaning, grinding, feeding and removal techniques for fodder and sugar beet

Fodder and sugar beets are very suitable substrates for biogas plants, caused by their biological properties. Beets do have, in comparison with maize higher biomass and methane yields per hectare, are improving the crop rotation system, are better to use in the growing season November and can fully automatic fed into biogas plants. The beets as well as the leafs can be used for biogas production, if an appropriate harvesting and processing technology is available. High demand exists for the development of mobile technology, with a high campaign performance and a single step soil and stones removal with a followed grinding step which produces a finely chopped beet squish that can be brought into a storage for liquids (silo, lagoon). Developments for the extraction technique are available, with the process of the CENO Inc. already a promising technology is on the market [**6**]. The automated "CENO Pumpentrolly" is a displacement pump with a homogenizer installed on a rolling cart that can be controlled by a winch. Thus, the pump can be inserted into the beet squish to pump the substrate via a high pressure hose from the lagoon directly into the plant.

3.5. Technical conditioning of substrates

Due to technical disintegration process and the resulting improved energy utilization of the substrate can reduce costs, conserve limited resources and thus reduce the impact on climate and environment. The term is understood in the process engineering sense as the crushing/ grinding or damaging the substrate structure by force exposure from outside. These procedures can be categorized by their mode of force in physical (mechanical and thermal), biological and chemical disintegration. It's expected for the agricultural biogas production to open a way for the digestion of lignocelluloses material in biogas plants and consequently to increase the biogas yield of this substrate.

The preconditioning of the substrate allows, in particular the use of "new" substrates for biogas production. Strongly lignocellulosic substrates such as straw are not or only partially fermentable without a proper preparation, because the microorganisms implies denying access to through the lignin structure of cellulose and hemicellulose. The "access" can be achieved by an extruder or thermo-pressure-hydrolysis (TPH).

Studies of Fraunhofer IKTS have shown, that the extruder technology improved operating performance and crushing effect on wet or ensiled substrates and wheat straw, compared to techniques such as grinding, crushing or cutting. According to manufacturer, the energy demand of the extruder for breaking up ensiled raw materials is about 6 to 14 kWh/t silage [**7**].

At the straw conditioning using thermo-pressure-hydrolysis, water works under subcritical conditions (120-220 °C and 2-20 bar) as a solvent for organic substances, mainly due to the declining responsible for temperature increases surface tension. Investigations of Testing and Research Institute Pirmasens showed that lignified biomasses can herewith be made available for biogas production. Under optimized conditions, decomposition at temperatures of 150 °C attained a high degree of hydrolysis of the hemicellulose fraction and an improved degradability of cellulose can be achieved. In comparison to untreated straw could be demonstrated to increase the biogas yield of up to 60% (see Figure 5) [**8**].

Moreover, the conditioned substrate can be conveyor by conventional systems to the biogas digester. And there will be no pronounced scum formation. Due to the nitrogen deficit and lack of other nutrients and trace elements, it should be fermented with co-substrates such as cattle manure [**8**]. It remains to be clarified whether the cost for the TPH can be covered by the energy plus from the straw.

The mechanical-thermal decomposition of biomass in the extruder was investigated by Fraunhofer IKTS and Lehmann Inc.. During extruding, the organic substrate is been treated between two counter-rotating screws and exposed to rapidly changing loads of pressure and temperature peaks [9], resulting a partial resolution structure. It was found that in addition to improving the biogas yield, the crushing of the biomass decreased the viscosity of the fermentation substrate, which reduces the mixing and energy demand. The technical disintegration is not currently widespread, which is due primarily to the still unexplained economic gains for investments based on lacking investigations.

In addition, other methods are slowly moving into disintegrating practice. First biogas plants are operating with thermal or electro-kinetic disintegration and even with ultrasound technology. Here investigations are still required concerning process engineering function and economical benefits. The use of chemical disintegration is, despite a positive impact on the biogas yield, due to technical and economical disadvantages not in application in agricultural biogas plants. Also for the use of enzyme preparations in biogas plant, which will weaken the substrate Structural and amount so as to enhance the degradation of biomass, the investigations are effective ways to use field and is only just at the beginning.

3.6. Fermentation technology

The commonly used stirred tank reactors were originally designed for the fermentation of liquid biomass, especially Cattle and pig manure. With increasing proportion of solids such as corn silage and solid manure, in the substrate mixture, the technical and energetic costs increased significantly. The optimization and development of biogas plants in terms of using solid biomass is therefore an important goal of manufacturers and sciences.

At ATB, Potsdam an upflow-reactor was developed, which is characterized by an upward flow of solids to be fermented. The method uses the buoyant force by the formation of biogas. By circulating the process fluid the distribution of microorganisms and their metabolic products can additionally be achieved. For easily degradable materials such as corn silage, the integration of a high-performance-methane-reactor is recommended. This can reduce excess fatty acids formed very effectively. The advantages are the lack of thorough mixing, the high adsorption capacity for solids as well as a largely undisturbed mechanical treatment of the microorganisms involved. The investigations have shown that reactor loads of 6 kg/(m^3 × d) can be achieved by methane yields of usual practice [**10**].

Even plants with fixed-bed high-performance reactors are on the market now -even 75 kW compact plants. The Company Röring Inc. has developed on the basis of their UDR (upflow-downflow-reflow) system a UDR mono-tube fermenter. This reactor design has an upward flow through a fixed bed, a downward flow through a fixed bed combined with a biomass-return function. With a diameter of only 3.80 m and a height of 15 m the reactor enables an extremely compact design (incl. with integrated gas storage). Currently several biogas plants manufacturers devote to the “compact” biogas plants up to 75 kW_{el}. With this they respond to the changing compensation structures in Germany, by designing smaller farm based plants for customized biogas production.

3.7. Optimization of fermentation biology through improved process control

The anaerobic digestion is a complex multistep process that is influenced by various microbiological, chemical and physical parameters. The control process therefore requires the collection of different measurements to generate information on the process flow of the different degradation steps. A further complication is that the individual degradation steps proceed at very different speeds. With the aim to improve the of processes management and stability many (research) projects are focused on new an appropriate process indicators and measurement methods to represent the kinetics of biological processes in real time in order to optimise and fasten up the needed process control methods.

3.8. Optimization of fermentation biology through the use of digestion supporting agents

In recent years, a large market for so-called digestion supporting agents has developed, which differ considerably in their composition (table 1). The exact mechanisms of action are, however, been largely unknown. An unambiguous classification is difficult, since individual agents have multiple effects. For example, the addition of ion exchangers can provide needed trace elements on the one hand and bind other inhibitory substances on the other [11]. Research projects are devoted to this field to determine the mode of action, depending on the particular fermentation conditions and the substrate used.

Table 1: Typical digestion supporting agents with examples and applications [11]

Type of supporting agent	**Example**	**Definition**
Trace elements	Iron, cobalt, nickel, zinc, e.g.	Trace elements are chemical elements that are necessary for optimal growth of microorganisms
Ion exchangers	Zeolites clay minerals	Reduce the concentration of potentially inhibitory / toxic fermentation ingredients
Microorganisms	Hydrolytic cultures	Complement the existing biological communities with organisms that cause an optimization of the

		process (speed, stability) and improvement of adaptation to new conditions or changes in substrate composition
Enzymes	Cellulase, Amylase, Protease, Xylanase	Enzymes cleave polymers and thereby improve the suspension characteristics, increase the rate of degradation and support the microbial activity

3.9. Prevention of leaks

A leakage of 1 m³ methane per hour equals for a biogas plant an annual optimization potential of up to 6000 EUR € by the escaping gas and about 90 tons of corn silage. Leaks occur on leaky gas fixtures of imaging plates, holes in gas storage films and leaking pipework and ducts. Leaks occur on leaky gas fixtures of imaging plates to holes in gas storage films and leaking pipework and ducts. An improperly sealed agitator bores can result in individual cases to methane emissions by about 5% of total amount of used methane. Based on an economic and ecological point of view investigations to leakages have to be continued and the findings have to be implemented in the improvement of structural and engineering design.

Not completely digested fermentation residues stored in open storage tanks can lead to significant methane losses in a magnitude of about 5% of the produced methane; even by multi-stage systems. The most effective counter-measures is the optimization of the process, digestate storages may alternatively be provided with permanently anchored or floating gas-tight covers [12]. According to the measured residual biogas yields from the constructed full cover system, on average, 330 Nm^3 more biogas (58% methane) can be available daily for a 1 MW$_{el.}$ biogas plant, corresponding to an additional 0.7 MWh$_{el}$ per day (255 MWh$_{el.}$ per year).

3.10. Biology adapted agitators and reduction of the power consumption

Investigations at five Bavarian biogas pilot-plants have shown a proportion for agitator energy demand of about 11 to 69 % based on the total electricity demand [**13**]. The specific power consumption of agitators was determined from 3 to 35 kWh/t, related to the substrate throughput. The wide range of these values already points to a significant improvement. Using the example of Table 2 shows that the choice of mixing technology can massively affect the energy requirements of agitating. The agitators in example 2 were found to be significantly less efficient, as installed in this system about three times the specific stirring power and the agitators were operated approximately three times longer. This results in more than 10 times the power requirement.

Tab. 2: Comparison of power consumption for stirring the main reactor of two biogas plants in practice [13]

	Unit	**Biogas plant 1**	**Biogas plant 2**
Substrate throughput	t/d	18.9	22.3
Agitators		Long axis agitator + Submersible propeller	2 x blender
Drive power	kW	11 + 15 = 26	2 x 15 = 30
Installed stirring performance / workload	kW/100 m^3	3.69	2.99
Measured stirring performance / workload	kW/100 m^3	0.72	2.00
Average operating hours of the agitators	h/d	3.5	10.1
Specific energy demand of agitators	**kWh/t**	**1.76**	**19.4**

The utilization of slow-speed stirring technology also has advantages for the biological biogas process. In biogas plants the hydrogenotrophic path of methanogenesis dominates at higher loading rates. A separation of this community, e.g. due to rapid and frequent stirring, can be detrimental for the biological process. However, new application areas for the initial substrate degradation can be created by the bacteria. Agitators should therefore run in biogas reactors at slow speed and stirring intervals substrate-specific optimized [14].

3.11. Increase of CHP efficiency

The figures 6 and 7 show the development of the electrical and thermal efficiencies of CHP (Gas-Otto engine and pilot-injection engine). While in the 80s of the last century the electrical efficiencies were still below 25 %, a massive technological progress started since the middle of the 90s. By optimizing the utilization of surplus heat from the cooling water circuit and the exhaust gases the overall efficiency of Gas-Otto CHP could be increased to 86% and by CHP with ignition-jet-systems to up to 92%. Currently the electrical efficiencies of leading manufacturers are of Gas-Otto CHP at 43 % and by 48 % for CHP ignition-jet-engines [3]. Thus nearly reaches the grad of efficiency of fuel cells. In particular, the fitting of flue gas turbines brought a further rise in efficiency by more than 10 %. The aim of efficiencies lies by over 50%.

The importance of the electrical efficiency for the efficiency of the whole system shows table 3. The replacement of a Gas-Otto CHP (190 kW) through a ignition jet CHP (256 kW) allows for the same gas consumption saving of about 20 % of substrate and therefore a higher profit of 108,000 € per year [15].

Table 3: Comparison of Gas-Otto and pilot injection CHP with (approximately) the same gas consumption [15]

Comparison of different CHP with a similar gas consumption	**Unit**	**Standard**	**Ignition jet turbo generator**
		Gas-Otto-engine	
Electrical output of the CHP	kW/h	190	265
Gas consumption at 52% methane	Nm^3/h	115	110
Ignition oil consumption bio diesel (per hour of operation)	l/Bh	0	2.5
Electrical efficiency	%	36	48
Electric power per ha of maize	kWh/ha	20,244	25,867
Kilowatt-hours per year (at 8000 working hours)	kWh/a	1,520,000	2,120,000
Feeding in returns at Ø 0,18 €/kWh	€/a	273,600	381,600
Difference in annually yield	€/a	**108,000**	

3.12. Further development and testing of digestate processing techniques

In many regions of Europe regional or individual farm nutrient surpluses occur. Incurred up 5 years ago these surpluses exclusively on a local concentration of livestock, now also farms and regions are affected by purchasing of substrates for biogas plants. In regions with surplus from livestock, the biogas plant serve for regionally decentralized collection and processing station. There can be processed excess digestate to nutrient concentrates. Local and regional burdens for the environment (nitrate and ammonia emissions, eutrophication of water bodies) can be avoided and, at the site of concentrate application, scarce resources (energy, phosphorus) are saved. Several methods are available for processing. However, there is a strong need for further development and testing in pilot plants, specifically the processing of the liquid digestate fraction [16].

3.13. Heat utilization from biogas plants

Beside the substrate composition, process efficiency and process energy requirement is the use of heat one of the most important modifiable factors for the reduction of greenhouse gases in biogas production. The drying of materials (animal feed, biomass combustion, fermentation residues, ...) is one of the best options throughout the year, to use the CHP heat in the low calorific range (60 to 90°C). The drying method must ensure high drying efficiency and low power consumption. The aim is a water evaporation performance of considerably below 1.0 kg water/kWh. In order to increase efficiency infrared emitters are being tested in pilot plants. The infrared rays help the evaporation by speeding up the drying of the surface and a rapid warming of the entire material to be dried.

3.14. "Intelligent monitoring" of plant technology components

With "intelligent monitoring systems" of the operating conditions of plant technology components downtime, repair costs and energy costs can be avoided or reduced. As an example may serve a condition monitoring system for pumps in order to optimize the maintenance intervals. An autonomous NFC (Near Field Communication) chip-enabled sensor records over a long period of time (about 2 years) all operational conditions of the pumps at the biogas plant. The sensor is located on a massive body panel, for example on the clutch bell housing or the housing of the pump. Thus it recognizes immediately the sound of the aggregate body. The data can be accessed and analyzed on the PC. The evaluation provides information about the timing, duration and intensity of all phases of operation. The operator can thus obtain a direct overview of the "health" of the pump [17].

3.15. Summarized assessment of the technical challenges for the agricultural engineering sector

For comparison the options for the agricultural engineering sector to the ecological and economic optimization of the biogas power generation are shown in table 5. Highest priority for research and development for the agricultural engineering sector is on those process steps of the generation of biogas that can help to reduce greenhouse gas emissions at low or neutral net costs. These are mainly the technical developments for the use of non land consuming substrates, techniques for the desintegration of lignocellulose, the avoidance of methane leakages, the further increase of the CHP efficiency and techniques for the efficient use of surplus heat.

Table 5: Assessment of development needs for the agricultural engineering sector

Process steps of the biogas production chain	**Need for research and development**	**Effect on net electricity generating costs**	**Contribution to GHG emission mitigation**
Harvest logistics	High	Lower	Low
Intelligent harvest technology	High	Slightly lower	Low
Alternative biomass	High	Neutral	Low
Harvesting of non land consuming substrates	Very high	Lower	Very high
Technical Desintegration of substrates	Very high	Neutral	High
Fermentation techniques	Very high	Slightly lower	High
Fermentation biology und auxiliaries	High	Slightly lower	High
Prevention of leakages	High	Lower	Very high
Mixing techniques	High	Slightly lower	High
CHP efficiency	Very high	Lower	Very high

Digestate processing	High	Lower	High
Heat use	Very high	Lower	Very high
Intelligent plant monitoring	Very high	Lower	Low

4. Summary and Conclusions

Within the renewable energy sector in Germany biogas already provides a significant contribution. About 7000 agricultural biogas plants with a total capacity of 2730 MW, which corresponds to the performance of two nuclear power plants, produced in 2010 approximately 2.1% of total electricity consumption in Germany.

Biogas as compared with other bioenergy sources shows several advantages: It can be produced sustainably from various biomass and its energy may be used in many ways and needs. The success of the biogas technology is measured not only in the continuous growth of plant numbers, but also to the efficient and sustainable production of electricity, heat and fuel. Biogas plants are then economically and ecologically meaningful, if they are process-optimized operated and if resources are used effectively.

The cost of producing biogas and photovoltaic electricity in Germany today are at similar levels. Despite the increase in the efficiency of biogas production, rising costs of the manufacturing of plant components and the substrates (biomass) further cost reductions are not expected any more. By technological advances in the semiconductor industry and mass production, however, the costs of photovoltaic power from 90 to 15 ct/kWh were reduced drastically. Thus increasing their competitiveness, unlike other renewable energy sources from biomass. Electricity generation in biogas plants will compete with other options for generating renewable energy when tending the net emissions of greenhouse gases to zero. This then results in economically acceptable mitigation costs of less than 100 €/t CO_2.

Highest priority for research and development for the agricultural engineering sector is on those process steps of the generation of biogas that can help to reduce greenhouse gas emissions at low or neutral net costs. These are mainly the technical developments for the use of non land consuming substrates, techniques for the desintegration of lignocellulose, the avoidance of methane leakages, the further increase of the CHP efficiency and techniques for the efficient use of surplus heat.

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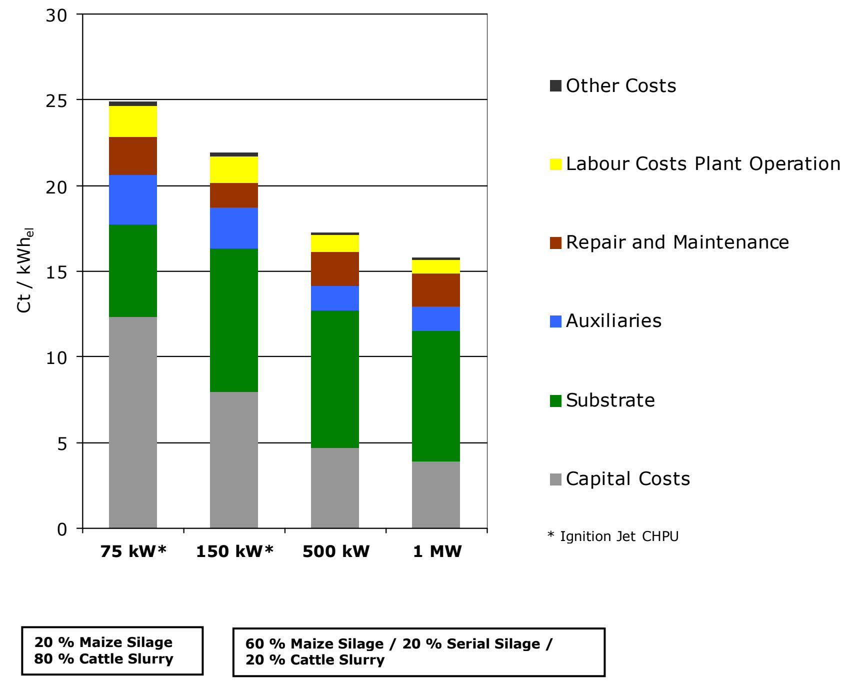

Figure 1 Electricity production costs of biogas plants (gross cost, without taking into account the income by heat sales) [2]

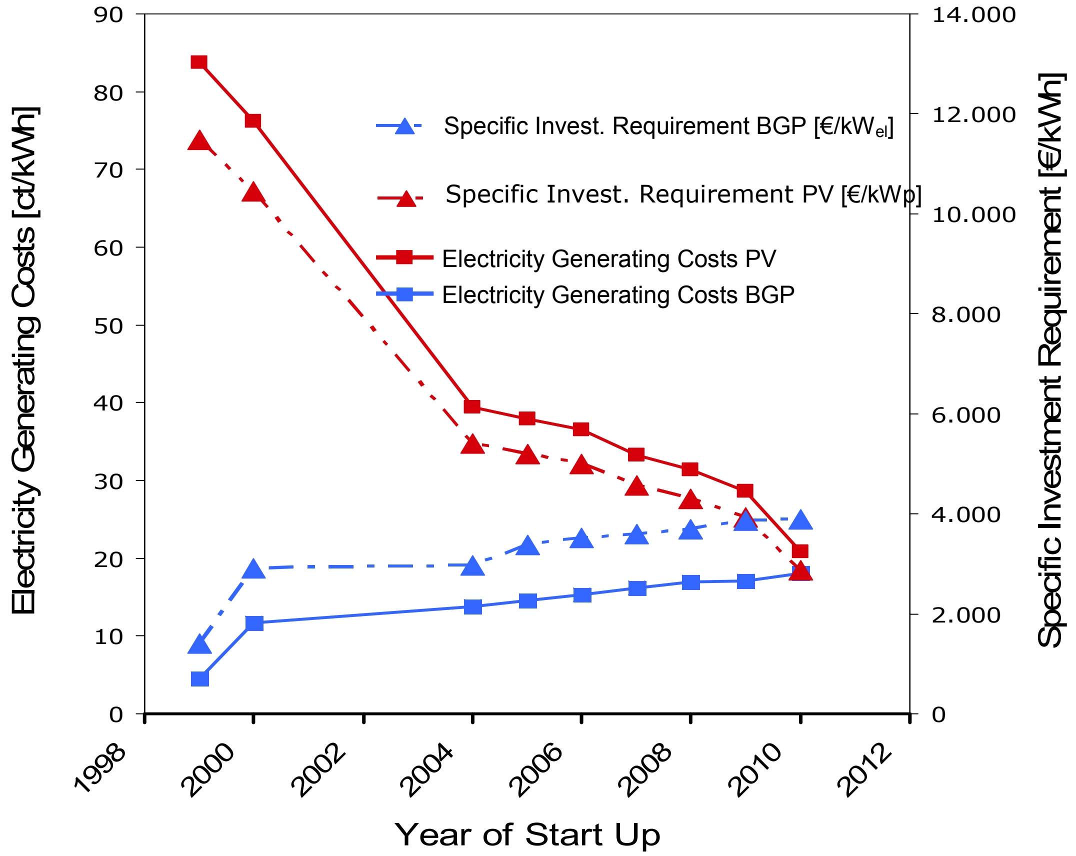

Figure 2 Development of costs for the biogas and photovoltaic power generation [3]

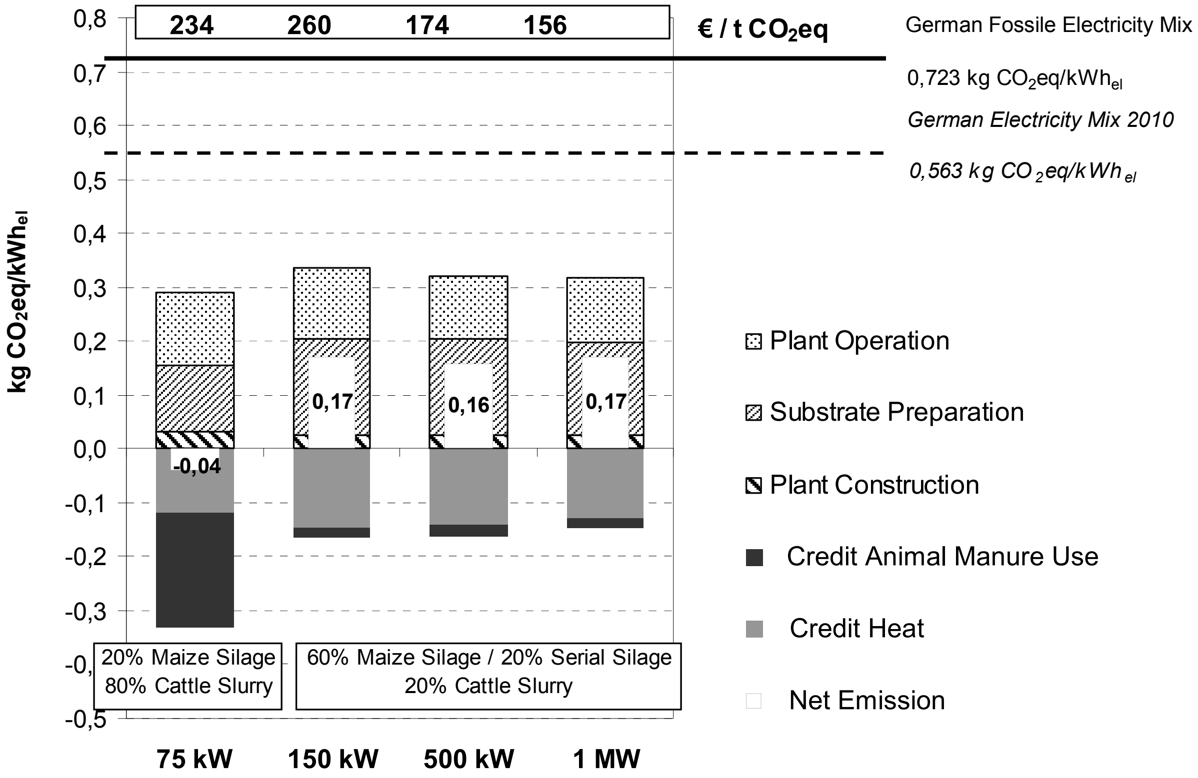

Figure 3 GHG-Balances and mitigation costs of biogas plants. The CO_2eq mitigation costs refer to the German fossil power mix [2]

NIR Sensor	
Status	ein
Aktuelle Trockensubstanz	33.0%
davon Stärke	31.7%
davon Rohfaser	19.4%
davon Rohprotein	7.4%
davon Rohasche	4.2%
davon Rohfett	2.7%
davon Zucker	0.0%

Figure 4 Online measuring of substrate qualities at harvest of Claas Inc [5]

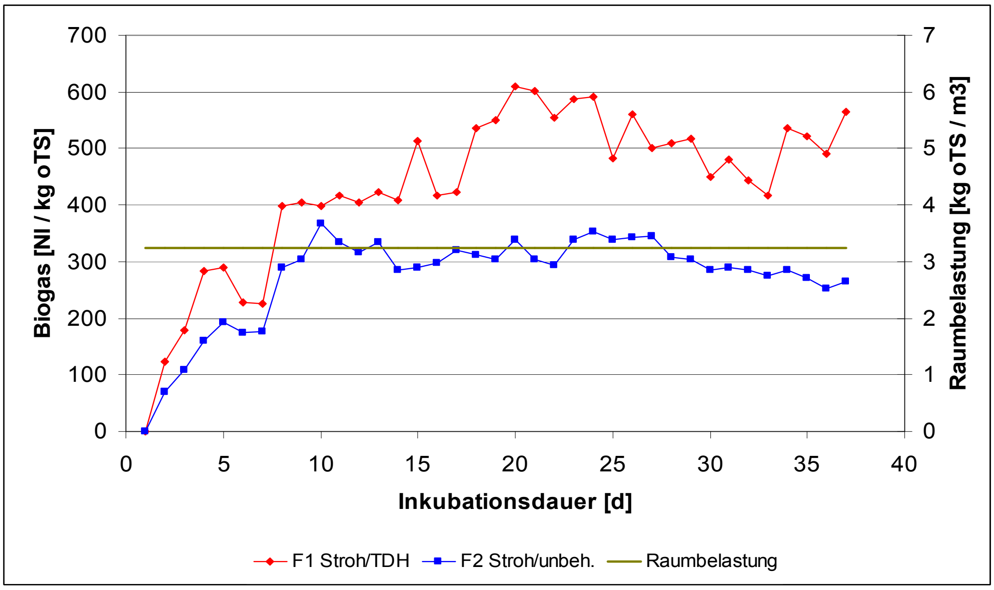

Figure 5 : Comparative dynamic fermentation test with thermo-pressure-hydrolysis treated and untreated wheat straw [8]

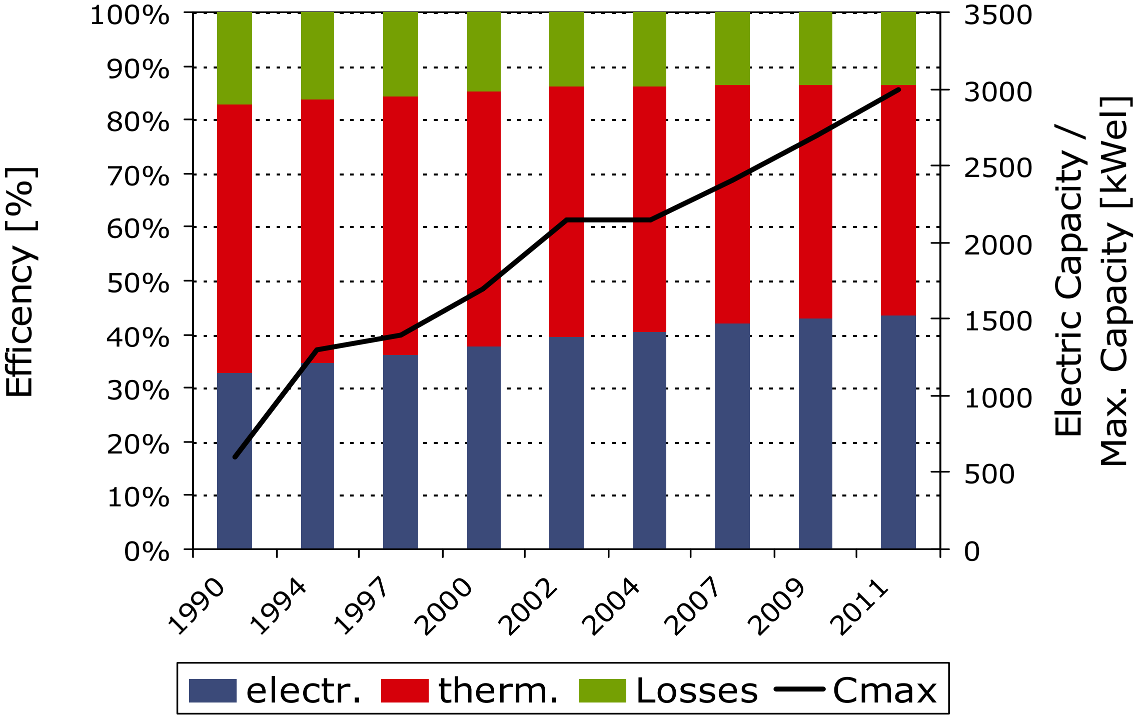

Figure 6 Technological development of the Gas-Otto-CHP´s of the Jenbacher Inc. **[3]**