

Biomass Technology for Electricity Generation in Community

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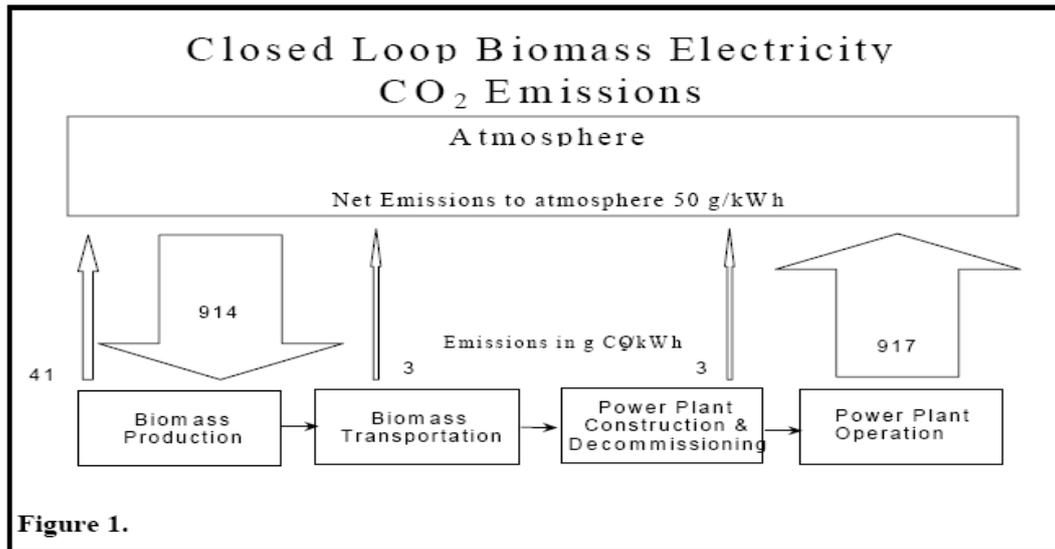
ABSTRACT

Technologies to produce electricity from biomass through combustion are state of the art. There are many applications with different power generation principle (steam turbine, steam screw type engines, ORC turbines) in operation. Caused by the logistic frame conditions of biomass production, storage and transportation as well as the possibility to use the thermal energy for community heating, decentralized power plants are the most economically solutions. Similar statuses have the bio-chemical conversion technologies (e.g. biogas technologies) or the physical-chemical conversion technologies like the production of plant oils and the power generation of the liquid/gaseous fuels in internal combustion engines. All these technologies are highly developed and reached readiness for marketing in Europe as well as in Asian countries.

Keywords: *Renewable Energy, Biomass, Conversion Technologies, Combined Heat & Power Generation*

1. INTRODUCTION

The strong increase of the worldwide energy demand, the predominant use of fossil sources and the known related consequences for the environment (e. g. acid rain, GHG emissions and global warming) and for national economies (e.g. dependency from energy source imports, increasing prices, competition between national economies to get the energy resources etc.) require a structural change of the fossil source based energy economies towards to a sustainable energy economy. Increasing the share of renewable energy in the energy balance enhances sustainability and biomass is one of the most important global renewable energy sources. The energetic utilization of biomass is a nearly carbon-neutral process as the CO₂ emitted during the conversion process has previously been absorbed by the plants from the atmosphere [1] (Fig. 1).



Source: Mann, M.K. and P.L. Spath, *Life Cycle Assessment of a Biomass Gasification Combined-Cycle Power System*. Draft. Golden, CO: National Renewable Energy Laboratory. 1997.

Fig. 1 Closed loop biomass electricity CO₂ emissions

If sufficient biomass resources are available, biomass is a clean and reliable power source for the generation of electricity. The conversion of the chemical bounded energy from the fuel into electricity occurs in so called CHP (combined-heat and power) plants. The presented report will give an overview about the available technologies for electricity generation from biomass sources as they are already widely used in Germany and also applicable in Asian countries.

2. BIOMASS FUELS AND CONVERSION ROUTES

Biomass fuels are in general any organic matter (excluding fossil fuels), that was or is a living organism and can potentially be used as an energy source. Examples for Biomass fuels are:

- wood and wood wastes,
- forest and mill residues,
- agricultural crops and wastes,
- animal wastes,
- livestock operation residues,
- aquatic plants,
- fast-growing trees and plants,
- municipal and industrial wastes

Biomass fuels distinguish between each other in a wide range and also exhibit a great difference towards solid fossil fuel. The essential difference is expressed by the lower heating value (LHV), the elementary composition and the physical properties of the feedstock. The results of the proximate- and ultimate-analysis of various biomass fuels are shown in Table 1.

Table 1 Comparison of fuel analysis for biomass samples and fossil fuels [2]

feedstock	LHV [MJ/kg]	Volatiles [%]	ash [%]	Ultimate analysis (mf) in %					
				C	H	N	O	S	Cl
fossil fuels									
hard coal	31,8	38,8	6,3	79,4	5,1	1,5	6,6	1,0	<0,2
brown coal	27,0	55,0	7,6	68,4	5,5	1,8	15,4	1,3	-
biomass fuels									
pine wood	18,7	84,0	0,3	50,9	6,6	0,2	42,0	0,02	0,01
miscanthus	17,8	81,0	2,7	47,2	6,5	0,7	41,7	0,13	0,23
com.reed	17,7	66,8	8,8	46,5	5,9	0,3	42,5	0,14	0,16
grain straw	17,5	80,1	4,6	47,0	6,2	0,4	41,7	0,1	0,34
wheat straw	17,1	79,6	5,3	46,7	6,3	0,4	41,2	0,1	0,4
rape straw	17,0	78,7	6,5	48,3	6,3	0,7	38,0	0,2	-
maize straw	16,8	-	5,3	45,6	6,4	0,3	43,3	0,04	0,16

Depending on the fuel characteristics various conversion routes (see Fig. 2) to produce electricity are possible. The thermo-chemical conversion processes require fuels with high heating values and for this reason lower water contents of the biomass fuels. The most common process is the direct combustion of the fuels to produce thermal energy, which can be used e.g. for steam production and in further steps for electricity generation by steam turbines, steam engines or other energy converter. Suitable fuels are woody biomass fuels as well as relative dry agricultural products like straw or byproducts from different process steps of agricultural products (e.g. rice husk). Gasification and pyrolysis processes provide just as the biochemical and physical-chemical processes secondary fuels. The biochemical conversion processes allow it to use fuels with higher water contents, because the microorganism, responsible for the decomposition of the biomass fuel, need wet conditions (e.g. biogas processes). Conventional physical-chemical processes are the production of briquettes or pellets by compacting of preferably dry biomass fuels or the extraction of oil from oil plants. In each case a further conversion (combustion) process is necessary to generate electricity from these secondary fuels.

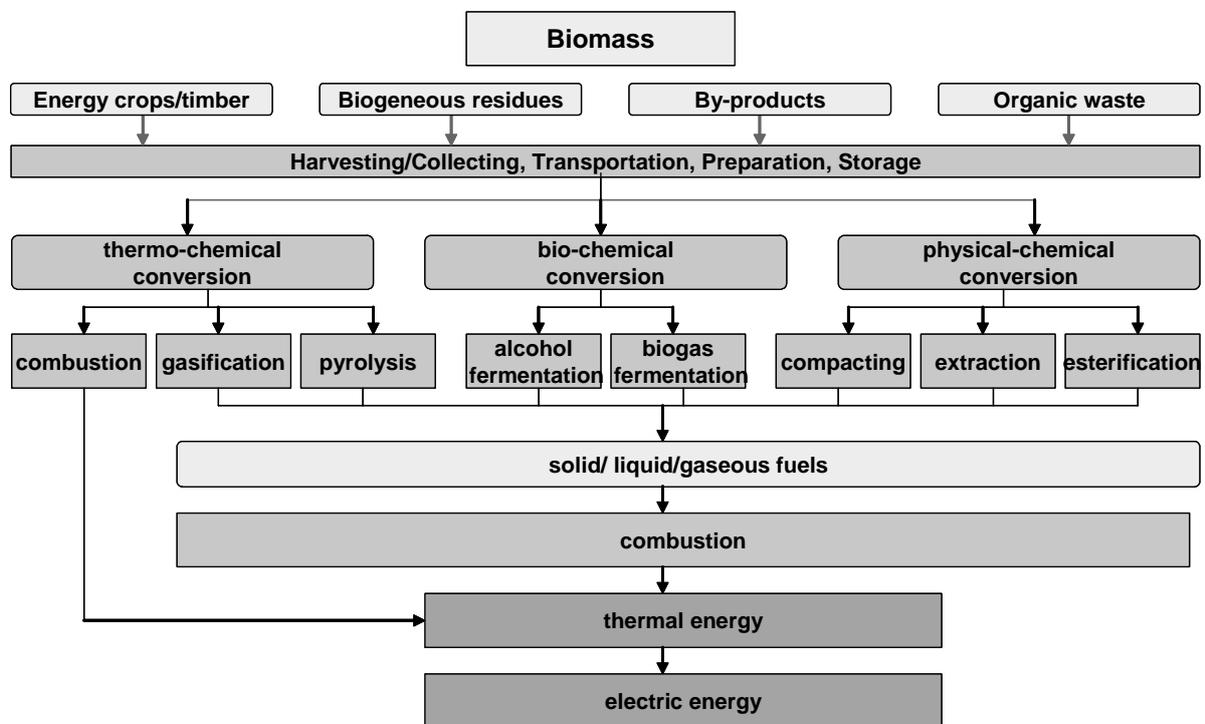


Fig. 2 Conversion routes for biomass fuels to produce electricity

3. TECHNOLOGIES FOR ELECTRICITY GENERATION FROM BIOMASS

As shown in Fig. 2 all technologies to produce energy from biomass use the combustion process to convert the energy from the fuel into thermal energy and in further steps into electrical energy. Combustion is the oldest and most developed conversion process to use biomass fuels. One advantage is that technologies, originally developed for the energetic utilization of solid, liquid and gaseous fossil fuels, can be also used for biomass fuels. Technologies like the gasification or pyrolysis of biomass fuels and the utilization of the secondary biomass fuel (synthesis gas, pyrolysis oil etc.) in internal combustion engines, stirling engines or fuel cells are under development, but until now most of them have not yet reached the technical and commercial readiness for marketing (experimental stage, pilot or demonstration plants).

Technologies for the bio-chemical and the physical-chemical conversion processes have a long tradition too. It is reported that the generation of biogas from organic wastes and feces had a tradition in China back to the time of the Western Han-Dynasty, approximately 2000 years ago [3]. And also physical-chemical Processes like the extraction of plant oils were already used in ancient times (e.g. more than 4000 years ago in Egypt). In Europe plant oil was used in the medieval times as lamp oil (displaced during the 19th century by petroleum). The first known use of vegetable oil to run an engine was demonstrated at the world fair 1900 in Paris when Rudolf Diesel presented his invention. But for a long time, there was no commercial use of Biomass as Energy source, because of the competition of cheap fossil energy sources. It was a kind of rediscovery when the biomass as energy source reached commercial interest after the 1973 oil crisis. Research Institutions and commercial enterprises started extensive R&D efforts to develop new and efficient conversion technologies for biomass fuels.

Today a multitude of highly developed conversion technologies are available to produce heat, power and fuels for the transportation sector from biomass sources. The electricity generation is mainly based on the combustion of primary or secondary fuels in so called CHP plants. The combustion technologies by itself are highly developed and state of the art. Various technologies for power generation can be combined with the biomass combustion processes. Table 2 shows the most common technologies for the power generation from solid/liquid and gaseous biofuels, their most suitable scope of application, power ranges, electrical efficiencies and development status.

Table 2 Technologies for electricity generation from biomass fuels [4]

Technology	Electrical efficiency [%]	Power Range [MWel]	Developm. status
Solid Biofuels			
Steam turbine	10 – 30	0,5 - 20	market
Steam engine	10 – 20	0,2 – 1,5	market
Steam screw engine	10 – 20	0,1 – 2,5	market
Stirling engine	8 – 22	0,01 – 0,15	pilot-/demo. plant
Organic Rankine Cycle (ORC)	10 - 15	0,1 - 3	market
Liquid/Gaseous Biofuels			
Gas turbine	approx. 25	> 10	demonstration plant
Micro gas turbine	approx. 20	0,05 – 1	laboratory testing
Gas engine	approx. 25	0,05 – 5	market
Fuel Cell	approx. 30	0,0005 - 5	pilot/demo. plant

Beside the co-combustion in existing coal fired power plants the decentralized utilization of Biomass in fuel adapted conversion technologies is the most promising possibility for the electricity generation. Because of the lower energy density of biomass fuels compared to fossil fuels an efficient use of the biomass requires that the distances for transportation of the fuels to the CHP are as short as possible. As shown in table 2 especially the conversion technologies for solid biofuels by combustion have a great importance for the electricity generation. The combination of combustion technologies,

steam generators and power generation facilities like steam turbines, steam engines, steam screw engines and ORC systems is already established at market and the power range between 0,1 – max. 20 MW meets the requirements of the decentralized utilization of biomass. Integrated systems combined with stirling engines, gas turbines or fuel cells are from the technological point of view available, but development is still necessary to reach the economic efficiency for the commercial introduction into the market.

4. EXAMPLES OF BIOMASS CHP PLANTS FOR ELECTRICITY GENERATION IN MECKLENBURG-VORPOMMERN

Mecklenburg Vorpommern is a federal state in the north-east of Germany and offers good possibilities for biomass production and their energetic utilization. The landscape is characterized by large agricultural and forestry areas where the biomass for decentralized utilization in community can be produced.

The German Renewable Energy Act created profitable conditions to produce electricity from Biomass in CHP plants (see Table 3) and a large number of Biomass CHP plants for wood with huge capacities were installed during the last years.

Table 3 allowance for electricity generated from biomass according the German Renewable Energy Act (EEG) [6]

	German EEG allowance in [Cent/kWh]				
	2004	2005	2006	2007	2008
Basis allowance for electricity from Biomass					
until 150 kW	11,5	11,33	11,16	10,99	10,83
from 150 until 500 kW	9,9	9,75	9,61	9,46	9,32
from 500 kW until 5 MW	8,9	8,77	8,64	8,51	8,38
From 5 MW until 20 MW	8,4	8,27	8,15	8,03	7,91
from 5 MW until 20 MW if waste wood is used	3,9	3,84	3,78	3,73	3,67
NAWARO Bonus					
until 500 kW			6		
500 kW until 5 MW			4		
from 500 kW until 5 MW wood as fuel			2,5		
CHP Bonus (für Kraft-Wärme-Kopplung)					
			2		
Technology Bonus					
			2		

The technology of biomass CHP plants is well established, but the profitability of a plant depends on various factors. Even if the largest amount of profit comes from selling electricity to the grid a comprehensive utilization of the thermal energy is necessary to increase the economic efficiency. During conventional power plants only convert about approx. 35% of the energy from the fuel into electrical energy (unused heat means losses), the logistic requirements of decentralized bioenergy utilization in small CHP plants enable the operator to convert between 80% and 90% of the energy in the fuel into electrical power and useful heat [5].

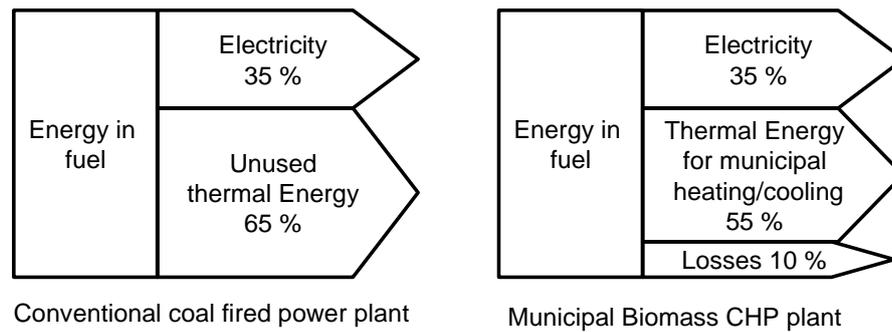


Fig. 3 Energy utilization in Municipal Biomass CHP plants [5]

In Germany e.g. the thermal energy provided from biomass CHP plants is usually used for community heating, hot water provision or as energy source for industrial processes in the surrounding of the plant. So the location of the CHP plant and the infrastructural preconditions of the location (grid connection for power feeding, consumer for thermal energy/district heating networks, the availability of enough biomass as energy source in the surrounding of the plant) are important decision criteria for planning a Biomass CHP plant. If these frame conditions receive attention and the capacities of biomass CHP plants are adapted to the site conditions the combined heat and power production is the most effective form of energetic biomass utilization.

4.1 Biomass CHP plant “Stadtwerke Neustrelitz” - electricity generation by steam turbine

One of the largest biomass fired CHP plants in Germany started operation 2006 in Neustrelitz (Mecklenburg-Vorpommern).



Fig. 4 Biomass CHP plant Neustrelitz

Neustrelitz is a district town with about 22000 inhabitants and surrounded by pine forests, where sufficient amounts of biomass to supply the plant with high quality woodchips as fuel can be produced. The CHP plant (total investment 17 Mio €) essentially consists of a biomass-fired steam boiler (grate furnace with a combustion capacity of 28.5 MW), a super heater (steam production 30 t/h, 485 °C, 66 bar) and a steam turbine with 7.5 MW electrical capacity. The annual fuel consumption of 85000 t woodchips is produced in the forests of the region. The produced electricity (the plant is operated continuously with full capacity) is feed into the grid and the operator get allowance according the German Renewable Energy Act (see table 3). The produced heat (in average 18 MW/h) is feed into the existing district heating network and used preferably for community heating. Fig. 5 shows a simplified flow chart of the CHP plant.

45.000.000 kWh electrical energy and 63.000.000 kWh thermal energy were produced in 2006 and the effect of fossil CO₂ reduction amounts to 14.500 t/a., but in the result of the increasing numbers and capacities of wood fired biomass CHP plants in Germany and the competition between the use of wood for energy and industry we recognize a raise of the prices for woodchips and particulate regional shortages of biomass supply for Biomass CHP plants in Germany. To ensure an economic operation and safe fuel supply also for the future the use of alternative biomass fuels (e.g. miscanthus) is currently tested in this plant. For further information see www.stadtwerke-neustrelitz.de.

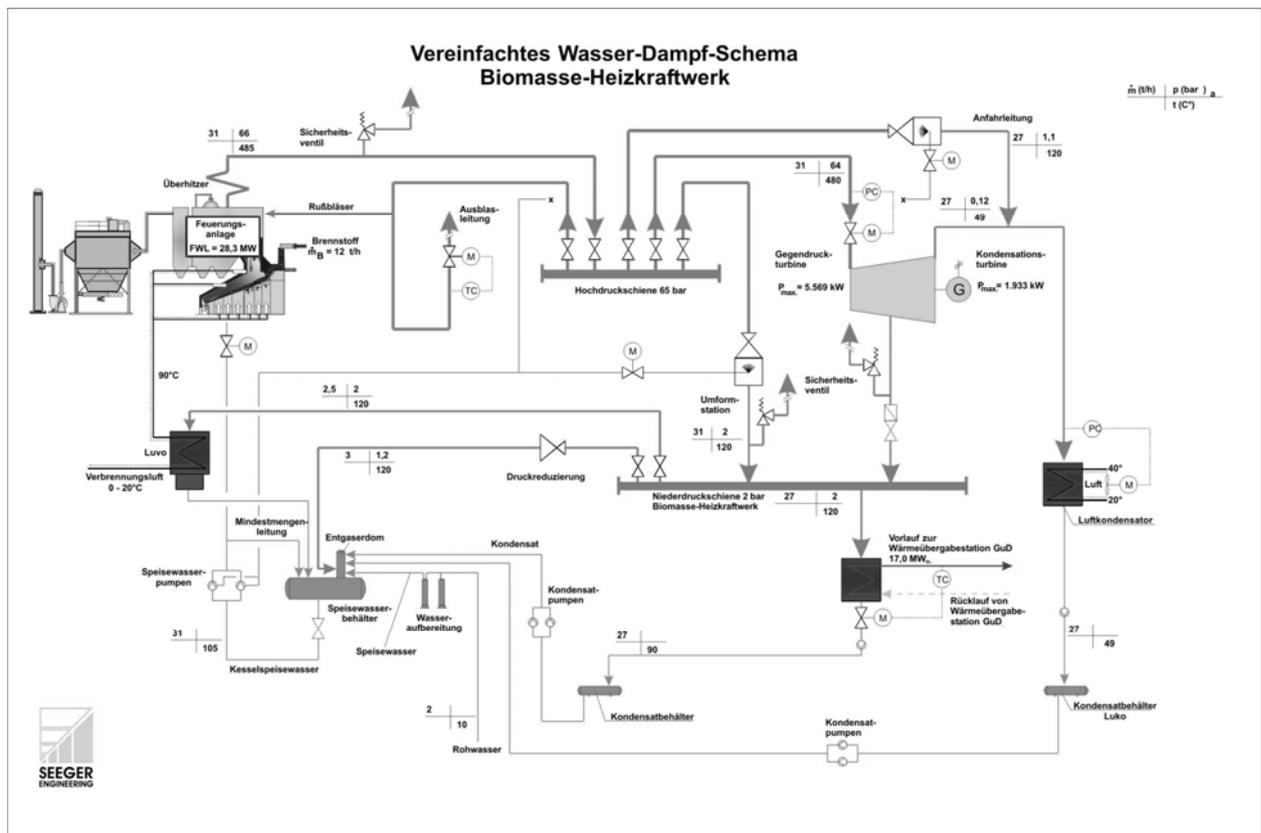


Fig. 5 simplified flow chart of the biomass CHP plant Neustrelitz

4.2 Biomass CHP plant “Friedland” – electricity generation by Organic Rankine Cycle

In 2001 a Biomass CHP plant, based on an Organic Rankine Cycle Process started Operation in Friedland, a very small town in Mecklenburg-Vorpommern with only about 7000 inhabitants.



Fig. 6 Biomass CHP plant Friedland

The CHP plant consists of a biomass-fired boiler (grate furnace with a combustion capacity of max. 10 MW, thermal oil cycle) a second ORC cycle and a ORC turbine with a max. capacity of 2 MW electricity generation. The plant is operated by the company GMK a producer and operator of several biomass CHP plants in the Germany. In opposite to the above introduced CHP plant in Neustrelitz (operation target there is maximum power output) is the CHP plant in Friedland partly heat lead operated. The ORC turbine can produce between 0.5 and 2 MW_{el} (allowance according the German Renewable Energy Act - see table 3), depending on the community heating demand (between 3 – 8 MW_{therm}). The annual fuel consumption is between 6000 – 20000 t wood chips.

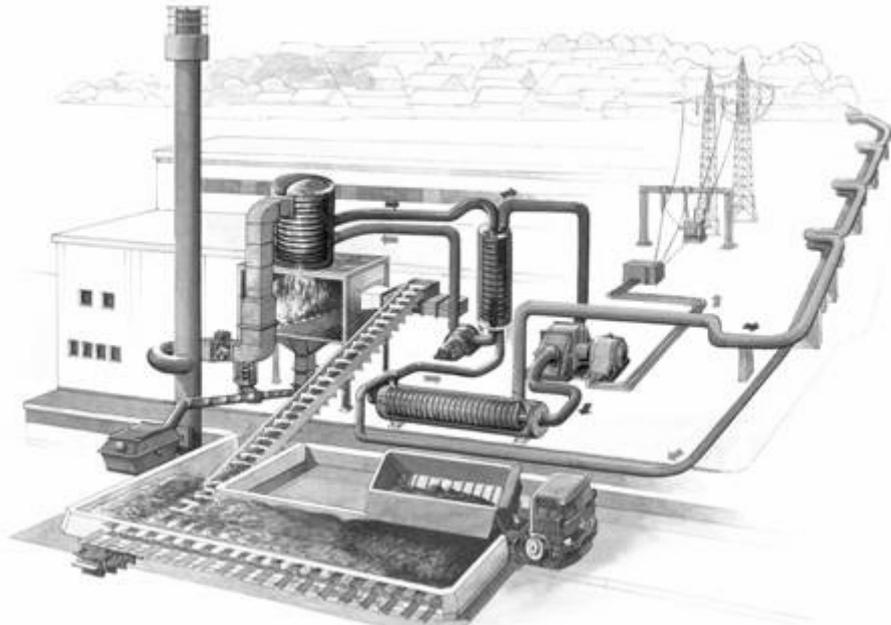


Fig. 7 Basic scheme of the ORC based biomass CHP plant Friedland

Because an existing district heating plant could be used for the upgrading by implementation of the ORC process the investment cost was only 1.25 Mio €

The operator of the CHP plant is confronted with the same difficult conditions (raise of the prices for woodchips and possible future shortages in supply) as the Stadtwerke Neustrelitz. To avoid bottlenecks in the future GMK started a research project to use energy biomass from rewetted peat lands (e.g. common reed and reed canary grass) as alternative biomass fuel. The research work is carried out in cooperation with scientists from Greifswald University and Stralsund University of Applied Sciences between January 2007 and December 2008. Examinations for the commercial utilization of common reed and reed canary grass will proceed under commercial conditions. For this purpose the reed and the reed canary grass will be used at first in various mixtures with wood chips. If procurable the share of reed/reed canary grass will be raised in relation to wood chips to the point off 100 % alternative biofuel utilization. For further information see <http://deutsch.gmk.info>.

4.3 Biogas CHP plant Ivenack – electricity generation by internal combustion engine

In Mecklenburg-Vorpommern about 50 biogas plants with an electrical power of 18 MW were in operation in 2005. Many of these biogas plants use agricultural substrates like maize silage and liquid manure from cattle or pork breeding farms as substrate. Figure 8 shows a biogas CHP plant with a capacity of 500 kW_e, planed and built by PRV Rossow, a company specialized in customer oriented biogas projects, in Ivenack in 2006. The total investment for this plant was 1.5 Mio €

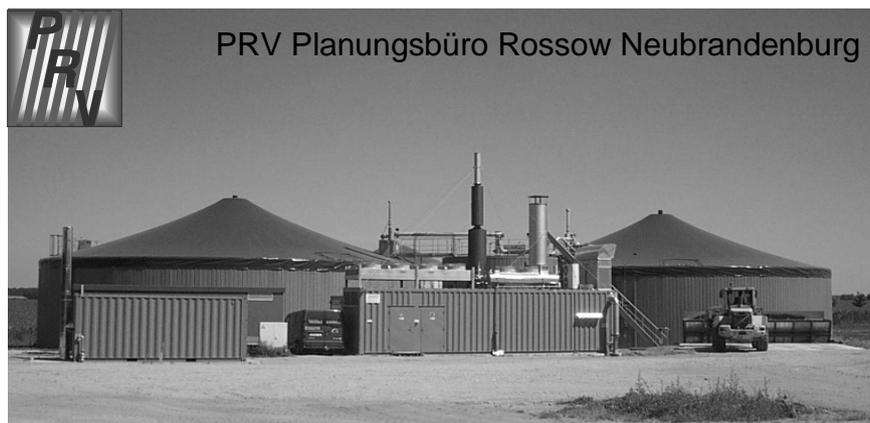


Fig. 8 Biogas CHP plant Ivenack

Two digesters (volume of 2500 m³ each) produce 2,000,000 m³ biogas (55% Methane) per year. Substrates used to produce the biogas are 4,000 t/a liquid manure from cattle breeding, 7,500 t/a maize silage and 400 t/a cereals. The Biogas is burned in an internal combustion engine with 500 kW_e capacity and produces 4,000,000 kWh/a electricity and 2,500,000 kWh/a thermal energy for community heating.

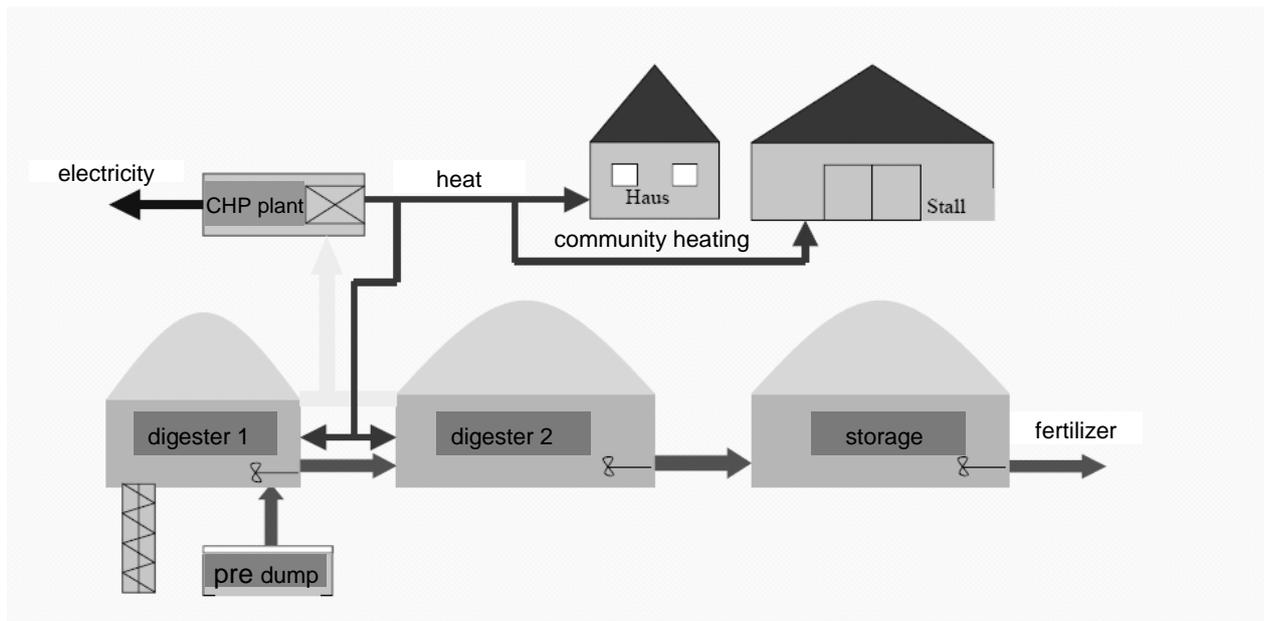


Fig. 9 Simplified schema of the biogas CHP plant Ivenack

The biogas plant is combined with a 130 kW photovoltaic field. The produced electricity from the biogas plant and the photovoltaic field is feed into the grid and the operator (commune Ivenack) get allowance according the German Renewable Energy Act (table 3).

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