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Gaseous fuels from renewable energies as a basis of distributed cogeneration of heat and power (CHP)

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„Gaseous fuels from Renewable Energies as a Basis of distributed Cogeneration of Heat and power (CHP)”

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1 Aim of the research

The practically utilizable reserves of fossil fuels are limited. The energy mix of the future depends on an efficient use of biomass and waste for supplying electricity, heat and cold.

Since 2004 a network has been operating on the branch of gaseous fuels which are producible from renewable energy sources. The network is promoted by the BMWA via the FKZ 01SF0307.

The following research institutes and universities from 4 countries are co-operating in the project’s framework.

- DBI-Gastechnologisches Institut gGmbH Freiberg (Project co-ordinator)
- University of Chemistry and Technology Prague, Czech Republic
- University Miskolc, Hungary
- Institute of Oil and Gas Krakow, Poland
- Technische Universität Bergakademie Freiberg
- Technische Universität Dresden
- Fraunhofer Institut Fertigungstechnik und Angewandte Materialforschung Dresden
- Institut für Polymerforschung Dresden
- Institut für Agrartechnik Bornim e.V.
- Fördergesellschaft Erneuerbare Energien e.V. Berlin
- MITGAS Mitteldeutsche Gasversorgung GmbH

An analysis of the state of the art was made regarding the generation and respectively the extraction of methane-rich gases like digester gas, sewage gas, landfill gas, mine gas and hydrogen-rich gas produced by gasification (gasification gas).

The conditioning of the gas to a quality which allows the feeding into existing natural gas networks is technically possible, but it is also associated with high costs. Alternatively, the material and energetic use was investigated at locations close to the production of biomass and waste. Comparative statements concerning the complete chain from gas production over necessary refining steps until the use in CHP-technologies (gas turbines, gas engines, fuel cells) are focussed. The new quality is achieved by the consideration of the local consumption and net structures of heat and cold supply. (fig. 1)

An enlargeable database will be available as a result of the project at the end of 2006. It contains the necessary amount of auxiliary energy demand and emissions and prices for current products, technical data concerning the full load and part load behaviour..

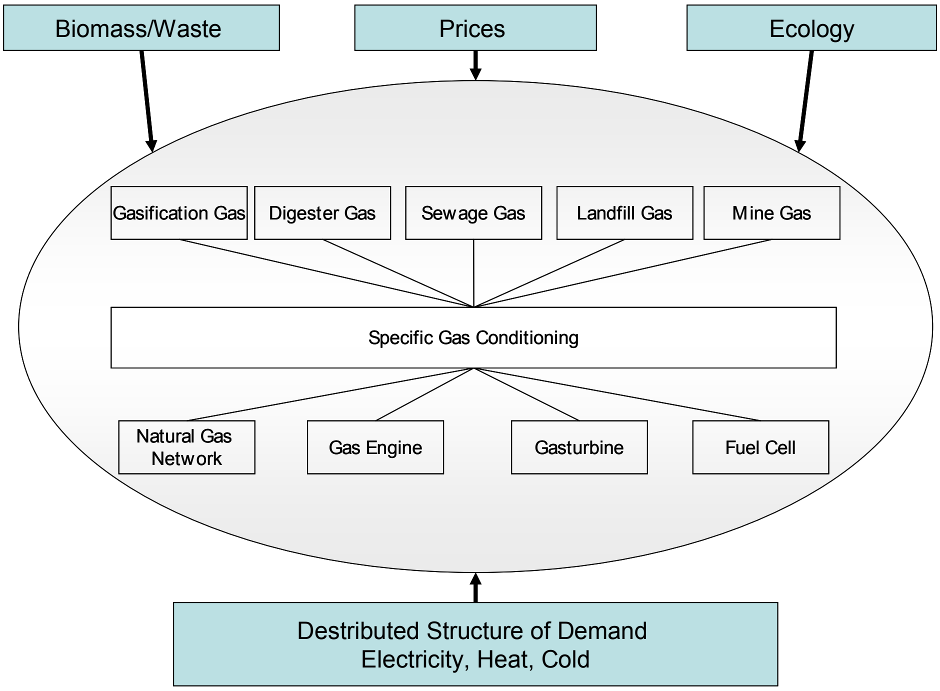

fig. 1 Structure of the investigations

2 Basically Structure of the Relational Database

The database is structured into three fields of activities.

- general facts
- provision of energy
- conversion of energy

The section „general facts" (fig. 2) contains the following information:

- *"Region"*: countries or regions for which information is implemented into the database
- *"Anbieter"*: Overview over the manufacturer or provider of equipment and parts of equipment
- *"Anfallpoteniale"*: existing potential for the region
- *"Rohstoffe"*: Compilation of renewable raw materials for fuel gases production regarding to possible output, specification of substrate, output in case of conditioning to bio-Methane and raw gas composition

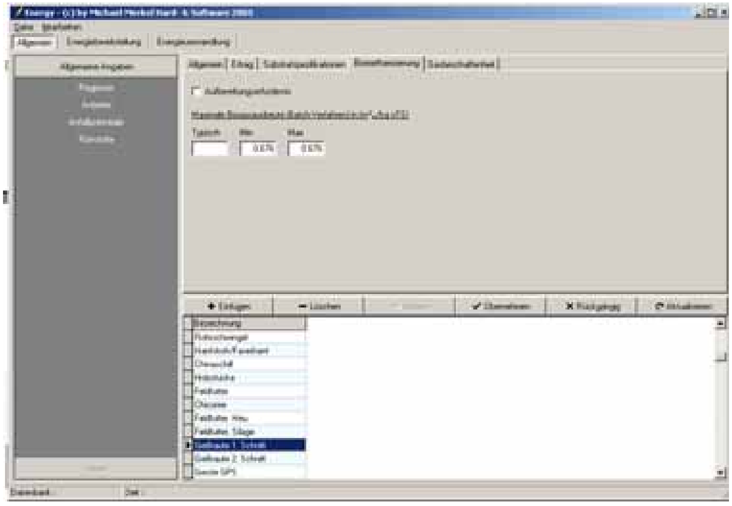

fig. 2 Example for the mask “general facts”

Input and delivery of information concerning the current knowledge are possible for several production processes of the six investigated gas types using the mask “energy providing”. Information about raw gas production (plant parameters, provider, kind of substrate or mixtures of substrate, output gas quality and quantity) and gas conversion related to the following energy transformation inside the CHP-devices or via special membrane technologies can be provided. . (fig. 3)

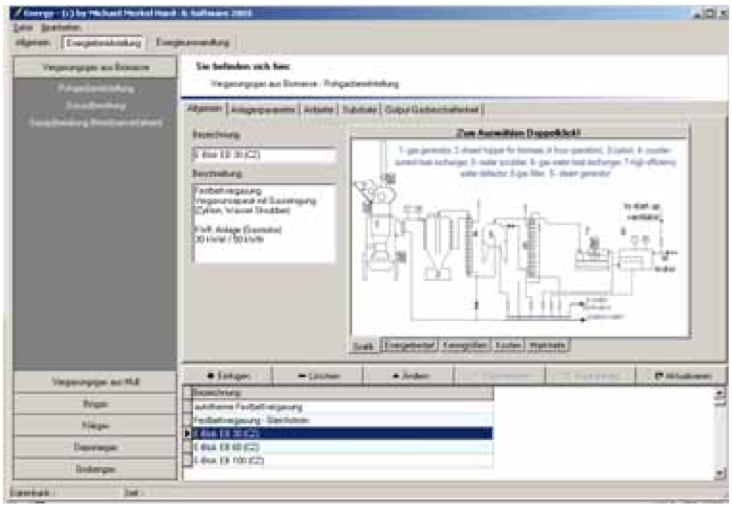

fig. 3 Example for the mask “energy providing”

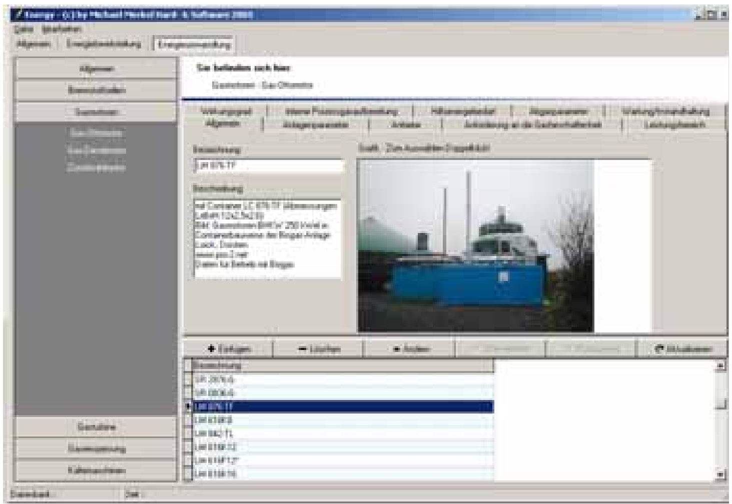

fig. 4 Example for the mask “energy conversion”

The field of activity „energy conversion“ includes the state of the art for devices for CHP up to 5 MW, the whole chain of conversion of gaseous fuels based on renewable energy into a gas with natural gas quality and chiller devices up to 500 kW as well. Information concerning

- the needed input gas quality
- the resulting quality and parameters of waste gas
- the thermal and electrical efficiency
- maintenance

is integrated in the same way as general plant parameters.

3 Exemplarely results

3.1 Gasfication Technologies in the Czech Republic

Currently 60 % of the energy production from renewable energy in the Czech Republic is based on biomass. Only 1.5 % of the whole energy demand is covered by renewable energy sources. The biomass potential is in the range of 190 PJ per year. The current prices for biomass including the transport costs are between 2.5 €/GJ for agricultural waste material and 6.1 €/GJ for energy products of agriculture /2/.

Up to now, the gasification technology is only implemented in some pilot plants in the Czech Republic. Since 1996 a fluidized bed gasification has been running in interaction with a gas engine in Skotnice. A flow of 22 to 28 kg/h biomass or waste is necessary at the inlet side.

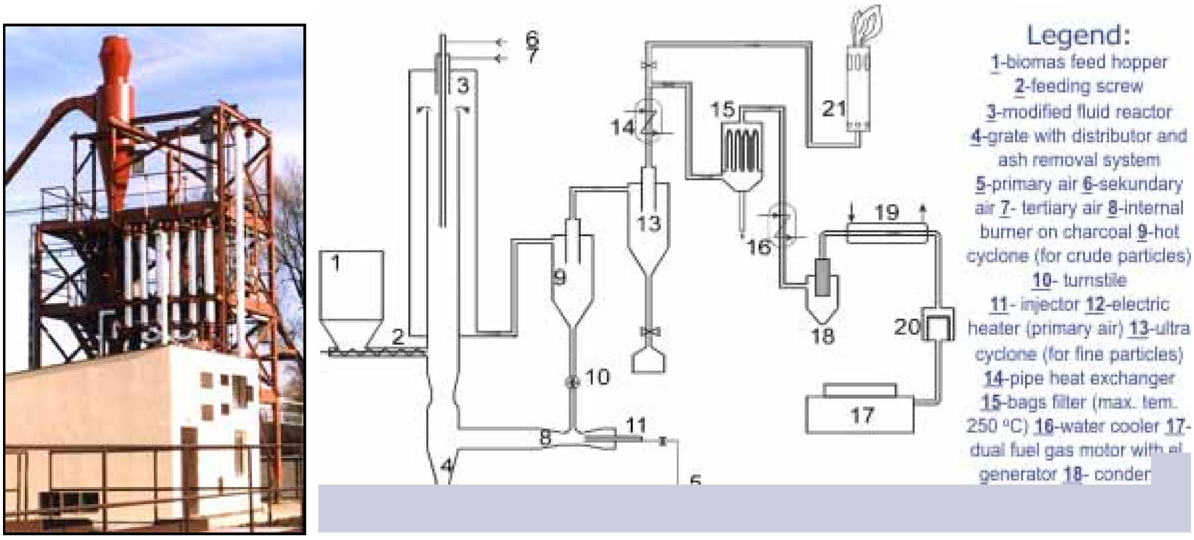

fig. 5 Biofluid –pilot plant Skotnice, gasification of biomass and waste/2/

Since 2000 another fluidized bed gasification plant has been operating near to Prachovice. Refuse Derived Fuel RDF is used as fuel. For the production of gasification gas 700 kg/h RDF are necessary. The plant works with air as fumigator. The reaction temperature is in the range of 750 to 850 °C. The produced gas is used for the furnaces of the direct connected lime kiln. Under nominal load conditions the thermal output is 2.68 MW_{th}.(fig. 6)

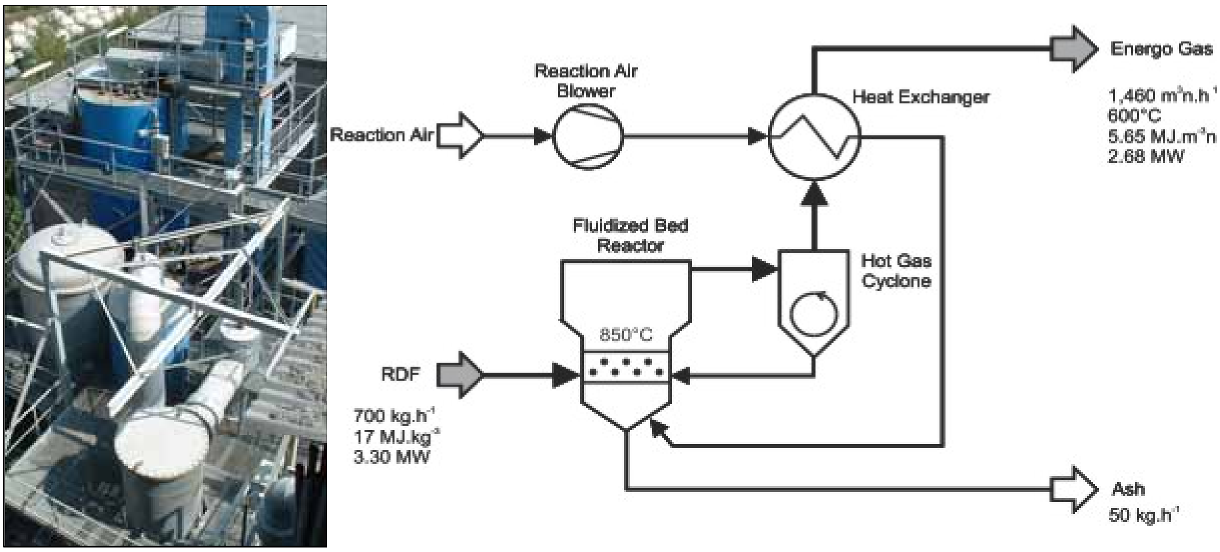

fig. 6 Biofluid - pilot plant (Prachovice, CZ), gasification of waste /2/

The fixed bed gasification plants E-Blok EB 30, 60 und 100 are available as a first kind of series unit charged with wood pieces. The production of gasification gas will be regulated depending on the downstream of the gas engine with an electrical performance from 30 to 95 kW (thermal output 50 to 160 kW). The investment costs are in the range of 100 to 184 €/t a_{max}. (s. a. fig. 3)

3.2 Landfill gas in Hungary

In Hungary 20 to 21 mill. m³ waste are generated per year. 85 % of the regularly collected waste is deposited on landfills. The most of the collected waste is directly delivered to landfills. Only 10 % of the Hungarian landfills are in conform to the European environmental regulations. Therefore 2540 landfills need to be closed. 50 landfills are allowed to be operated until 2009. The modernisation of 40 landfills is necessary for an operation time after 2009. 8 new landfills and 14 new reload stations have to be built.

Currently 22 landfills (0.85 % of all dumps) are equipped with collecting systems for landfill gas. Due to environmental reasons the collected gas is burned or used for the production of room heating and domestic hot water production. In 2006 four of the landfills with gas collecting systems will be equipped additionally with gas engine units for power generation. At two sites landfill gas and sewage gas from the local waste water treatment plant are in parallel use.

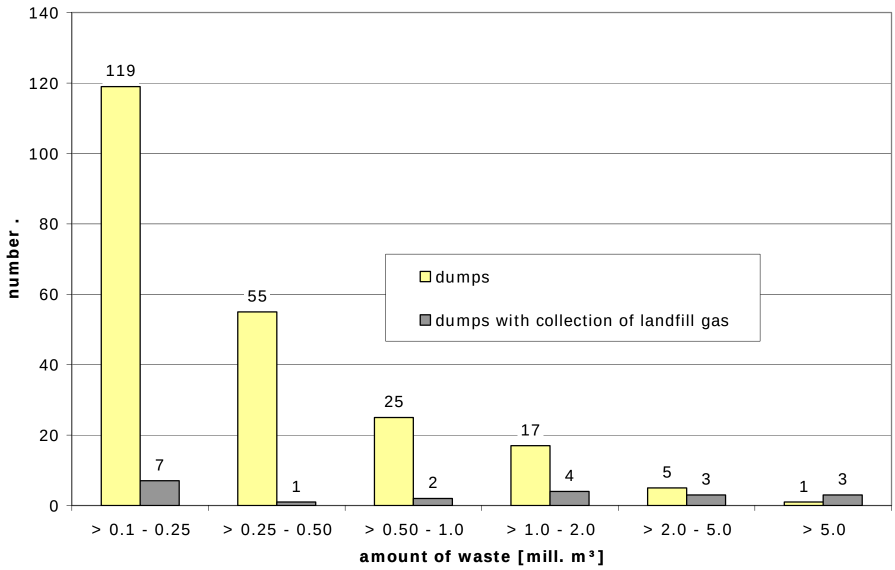

fig. 7 Dumps > 0.1 mill. m³ in Hungary - distribution and collection of the landfill gas /3/

The information about the modern landfill Hódmezövásárhely is documented in /3/. Waste was collected from 125 982 inhabitants of the rural district around. The free capacity of the landfill is enough for the expected waste amount of 50 years.

The gas is collected using horizontal and vertical tubes., The tubes are connected via a pipe trench to the central vacuum station (suction performance 50 m³/h).

fig. 8 Landfill near Hódmezővásárhely /3/

The gas composition is registered continousely. Oxygen content > 2 % is related with a safety shutdown. The gas composition depends on the time of day, the weather situation, and the season. The following concentrations are representative for March 2006: CH_4 50-52%, O_2 1%, CO_2 47-19 %. The hydrosulphide content is problematically.

At present, 5 % of the landfill gas are used for the heating system of the plant and for domestic hot water production. For reducing environmental impacts it is necessary to burn the of surplus gas volume in to a tube furnace (reduction of CH_4-emissions). The energetic use of landfill gas will be started in 2006. Two gas engines with a gas flow of 100 m^3 /h per unit (150 kW_{el}, 100 kW_{th}) will be put into operation. Because of the high hydrosulphide content an increasing number of maintenance cycles is expected.

3.3 Biogas CHP plants in Germany

10 % of the power generation based on renewable energy (see fig. 9) account for gases (biogas – 5.1 %, sewage gas – 1.4 %, landfill gas – 3.5 %). The amount of power generation based on gasification of biomass and waste is marginal. This type of technology is limited to pilot plants.

The gases are mainly used in block-CHP modules which based on modified pilot injection gas engines (η_{el} = 36 - 42 %) and spark ignition engines (η_{el} = 32 - 41 %). At present, in Germany 200 different types of serial produced block-CHP modules are offered by over 20 manufactures. It has to be taken into account that most Block-CHP modules are operated by engines of only 5 main manufactures. The block-CHP modules differ mainly concerning the motor management system and the concepts of cooling and heat utilization.

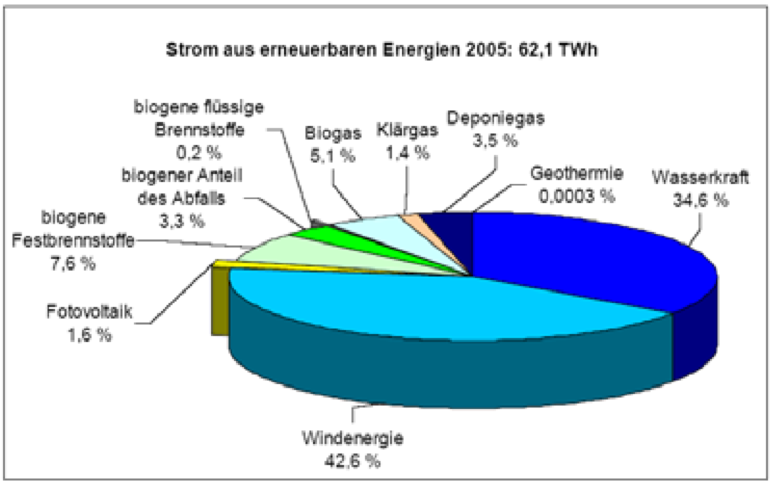

fig. 9 Structure of power generation based on renewable energy in Germany 2005 /4/

Since the renewable energy law has been coming into effect, most of the block-CHP plants based on pilot injection gas engines. There is a trend towards spark ignition engines because stable techniques with rape oil injection are missing on the market. The installed performance of the modules increased in the same time. There are positive experiences with spark ignition engines of a performance above 500 kW_{el}. These units are industrial engines and are equipped with integrated control systems. Due to investment costs and efficiency there is a trend from two Block-CHP units towards one Block-CHP unit per site. The manufactures' introductions say that theoretically it is possible to actuate a spark ignition engine with a CH_4-content of 50 %. But practically a CH_4-content of over 55 % is necessary due to self-startproblems in case of lower concentrations.

The comprehensive analysis of the state of the art of the digester gas utilization in Germany is published in /6/. The investigation is based on the evaluation of the measurement results of 59 digester gas CHP plants during one year. The actual receipts and expenditures allow the evaluation of the economic situation in the same way. The heat utilization mainly takes place in-process. Mostly the sale of thermal energy is an additional business only. This fact is supported by the business assessment illustrated in /6/ (see fig. 10). The income resulting from sale of thermal energy partly falls clearly below 5 % of the whole income.

Objects whose economic efficiency is aligned with the hundred per cent utilization of thermal energy partly have problems with pilot injection gas engines. The reason for this is that the effective thermal performance on site is significantly lower then the manufacturer's data (up to 50 % less performance). The calculation of the efficiency data seems to be based on theoretical simulations only. Obviously the influence of surface contamination at the heat exchanger units is taken into account inadequately.

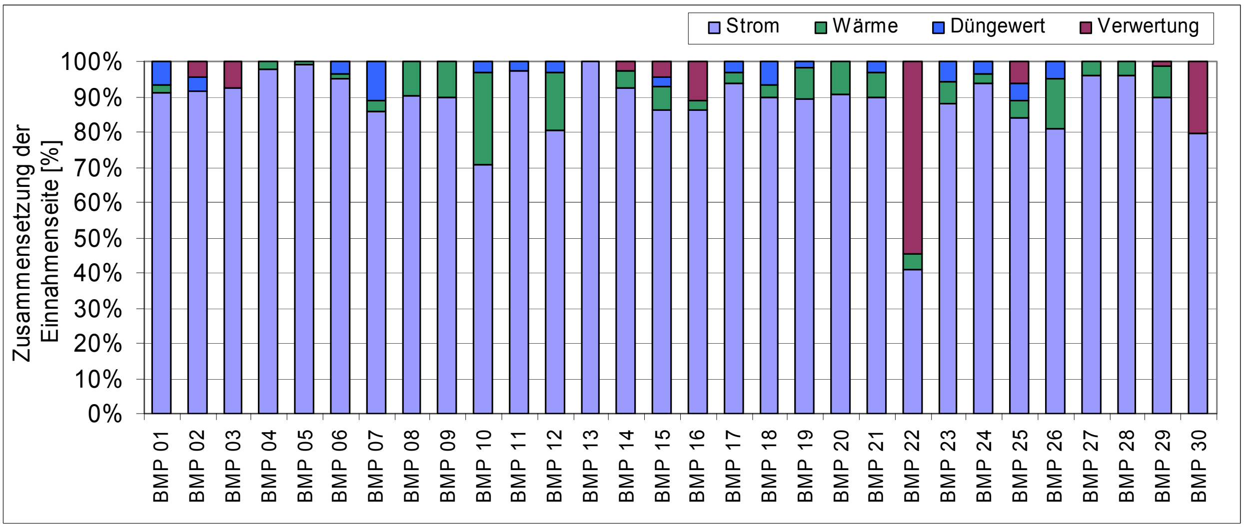

fig. 10 Relative composition of the receipts of 30 selected digester gas plants /6/

(Strom – power; Wärme – heat; Düngewert - manuring; Verwertung –recycling)

The maintenance costs remarkable influence the overall economic efficiency. The evaluation of various all-inclusive maintenance contracts inside the 500 kW-class of engine based Block-CHP shows maintenance costs in the range of 5.4 to 8.3 € per operating hour.

Serial-produced micro-gas turbines for renewable gas applications are available worldwide in the capacity range of 30 to 100 kW_{el} (e. g. Capstone Turbine Corporation, Turbec - ABB/Volvo) worldwide. Simultaneous the waste gas cooling process can provide until 167 kW_{th} at a thermal level of 60 °C. In principle also a waste heat use inside absorption chillers is possible because the exergetic level of the waste gas flow is relatively high. The manufacturers' instructions show electricity efficiency values from 25 to 30 % and overall efficiency values until 81 %. A part load operation is possible from 100 to 50 %. The specific costs are in the range of 1200 to 1535 €/ kW_{el} (without gas compression, facility and peripheral equipment) or 1900 to 2630 €/ kW_{el} for complete units. For standard units a methane content > 65 % is necessary. Due to following disadvantages the number of gas turbine power plants in Germany is significantly lower than the number of engine based block-CHP plants:

- higher investment costs
- necessity of a gas compressor
- lower electrical efficiency in the case of nominal load

The advantages are lower maintenance costs, a lower efficiency decrease under part load conditions, lower noise emissions, lower weight and lower required space.

The state of the art of fuel cells with fuel-applications for digester gas, sewage gas or landfill gas is in the most cases in a pilot or prototype state. There are only some exceptions. The experiences with phosphor acid fuel cells of UTC (former ONSI) and Fuji are well documented. In Germany a modified ONSI PC 25 C has been operating with digester gas on site at the sewage treatment plant in Köln - Rodenkirchen since March 2000. The raw sewage gas at the outlet side of the fermenter unit is cleaned in a purification plant.

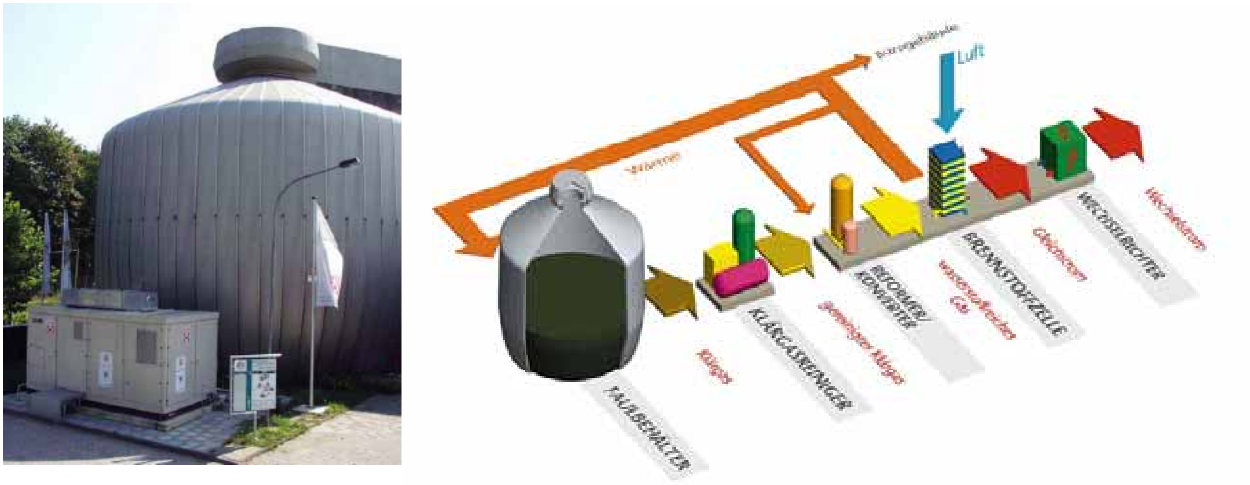

fig. 11 Sewage gas – PAFC plant Köln Rodenkirchen /7/

The following data for 36 000 operating hours until March 2006 are published in /7/ :

- 73 % overall availability
- 82 % availability of the fuel cell system
- appr. 78 % availability of the purification plant for sewage gas

The nominal electrical capacity is 200 kW. The average capacity during the operating period was approximately 150 kW. Due to the degradation processes at the fuel cell stack the electrical efficiency decreases so longer the fuel cell is operated . The decrease of the electrical efficiency from 39 % in 2000 to 35 % in 2006 is comparable with an PAFC operating with natural gas.

3.4 Analysis of biogas process chains with ENERGY

Methane-based renewable gaseous fuels, i.e. biogas, have the capability to make a substantial contribute to heat and power supply. They can be used for distributed cogeneration or be upgraded to substitute natural gas. Biogas is produced by fermentation of renewable primary products, crop residues, manure, organic residues and wastewater. Biogas yield and gas quality depends on type and properties of the substrates. The database ENERGY contains specifications of more than 120 different types of substrates. The data is based on fermentation tests of the Leibniz-Institute of Agricultural Engineering according to the VDI guideline 4630 „fermentation of organic materials". Additional data is gained from technical literature, statistic agencies and the "Kuratorium für Technik und Bauwesen in der Landwirtschaft" (KTBL).

table 1 Substrate data in ENERGY

Category	Parameters	Units
Substrat specifications	Dry-weight content (TS) Organic dry-weight content (oTS) Elementary fraction (C, N, P, S) Minerals (K, Mg)	% fresh matter (FM) % FM % TS g/l
Fermentation	Biogas yield	Nm^3/kg oTS
Gas specification	Main components (CH_4, CO_2, O_2) Trace components (NH_3, H_2S, halogene, siloxane)	Vol-% ppm or mg/m^3
Yield	Crop yield Biogas yield (calculated) Energy yield (LHV)	Dt/ha*a, t/GVE*a, kg/product Nm^3/ha*a, Nm^3/GVE*a, Nm^3/product GJ/ha*a, MJ/GVE*a, MJ/product

The stored data of substrate specifications, fermentation and biogas composition is the basis for the analysis of different process chains with ENERGY. Additional data like crop yield and specific amounts of agricultural and industrial residues can be used for the calculation of regional and corporate energy potentials (table 1).

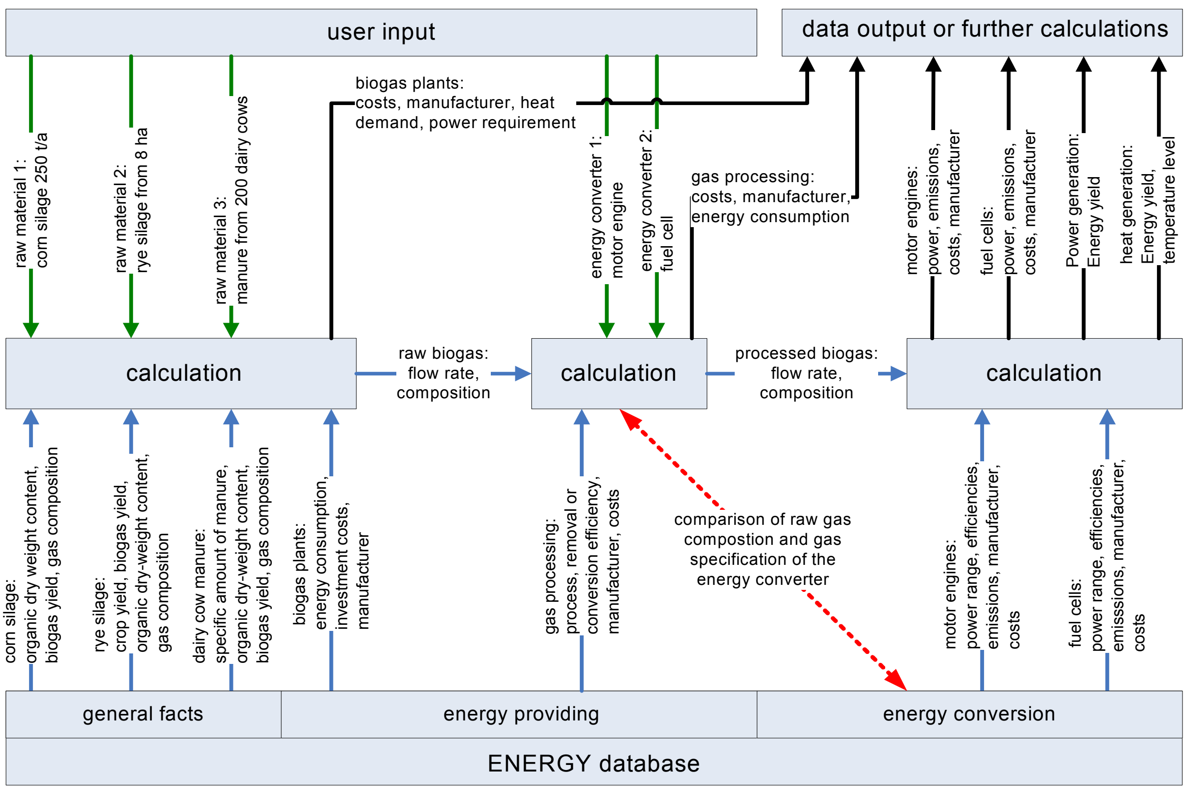

fig. 12 Example of an ENERGY database application for the evaluation of different biogas process chains

As an example application, the analysis of potential energetic use of agricultural land and residues with ENERGY is briefly described (fig. 12)

At first, the user has to choose the type of substrate. Then he has to specify the acreage or the amount of biomass. Optional data input, derived from fermentation test, is possible. Otherwise, the biogas flow rate and composition is calculated with the stored data of biogas yield and composition. Next, the type of energy converter has to be selected. If biogas composition and gas specification of the energy converter differs, there is a need for gas processing, i.e. purification. Data of different gas processing units is available in ENERGY. The expected energy yield (Power, heat, cooling) for the different processes and power converters are calculated from the processed biogas (methane) flow and the energy converter properties. The data output contains additional information concerning costs and emissions. Further calculations with regard to local power, heating, and cooling demands is possible but not implemented yet.

4 Review

An important contribution to the common energy supply is possible via the utilisation of gaseous fuels produced from renewable energies in distributed Block-CHP units as well as the conditioning of the renewable fuel gas to a quality which allows the feeding into existing natural gas networks. With the ENERGY-database a new tool was created. This tool allows the comparison of possible process chains depending on local available resources. The database can take into account useful solutions either from the energetic or economic point of view. The database is enlargeable and can achieve a high degree of benefit by the continuous update of the data and the implementation of new algorithms of analysis.

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