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ENERGY

DECENTRALIZED BIOMASS COMBINED HEAT AND POWER PLANT TECHNOLOGIES

POTENTIAL APPLICATIONS, TECHNOLOGICAL AND ECONOMIC EVALUATION

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ELECTRICITY GENERATION FROM BIOMASS - TECHNOLOGIES AND RECENT DEVELOPMENTS IN AUSTRIA

Scientific studies and the successful implementation of electricity generation projects in the low power range realized during the past years, as well as changing economic conditions for decentralized combined heat and power plants using biomass have greatly improved the situation of electricity generation from biomass.

Decentralized thermal use of biomass is of great importance in Austria. In addition to small and large scale plants in the paper making and cellulose industries as well as in wood processing plants, biomass district heating installations with a rated output of 0.5 to 10 MW_{th} constitute an important factor in the supply of energy. During the past ten years, the sector of biomass district heating systems experienced annual increases of more than 10 per cent. By the end of 1997, 359 plants were already in operation.

However, electricity from biomass is generated at only about ten locations in Austria in major plants operated by the paper making and cellulose industries (with bark and waste lye as fuel) and in about 10 small and medium plants of the wood processing industry, at present. Biomass district heating plants currently produce only heat. On account of the abundance of forest in Austria and a highly decentralized demography, energy supply concepts based on decentralized biomass CHP plants seem to be particularly advantageous. Some of the reasons for the slack implementation of such concepts are:

- The lack of technologies for an economical electricity generation in the low power range and in plants with a low annual portion of full load operation.
- Lacking economic incentives for decentralized electricity generation in biomass CHP plants and, partly, supply tariffs to the public grid below the cost price of the thermal energy involved.
- Information deficits as to the state of the art technology of decentralized CHP plants using biomass.

USE OF BIOMASS FOR HEAT AND ELECTRICITY GENERATION IN THE EU AND IN AUSTRIA

	EU 1995	*EU Goal 2010*	*Austria 1995*
Use of biomass for heat generation (LHV value)	1,597.7 PJ/a	3,150.0 PJ/a	90.0 PJ/a
Use of biomass in electricity generation (LHV value)	283.9 PJ/a	2.520.0 PJ/a	20.0 PJ/a
Electricity generation from biomass	81.0 PJ_{el}/a	828.0 PJ_{el}/a	(1) 5.5 PJ_{el}/a
Total use of biomass (LHV value)	**1,881.6 PJ/a**	**5,670.0 PJ/a**	**110.0 PJ/a**

Sources: (AEBIOM, 1998; ÖSTAT, 1998; values for biomass adjusted according to OBERNBERGER, I., 1997)
(1) Value for 1996

During the past few years, there was an emphasis on the development and the further improvement of technologies for electricity generation in the 2 MW_{el} power range, which seem to be promising for the use of biomass in CHP plants. Plants of this type should be operated predominantly on a thermal basis in order to achieve a high total rate of efficiency. As potential operators of such plants usually have only limited financial and personnel resources these projects should fulfill the requirements of robustness, flawless operation, and controllability or automation, respectively.

The study ”*Decentralized Biomass CHP Technologies*“ commissioned by the Austrian Federal Ministry of Science and Transport and carried out by ”Ingenieurbüro BIOS Obernberger & Narodoslawsky OEG, Graz“ in cooperation with the ”Energieverwertungsagentur Wien, Austria“ evaluated and compared such concepts from a technological point of view (operation, control technology, maintenance, ecological aspects, state of development). In addition, a detailed economic evaluation of technologies, which are either already standard practice or will soon be marketable has been conducted.

At present, there are two marketable technologies for electricity generation from solid biomass: the steam turbine and the steam piston process. Three other technologies, i.e. the steam screw engine, the Stirling engine process, and the ORC-process have already reached a high state of development and are on the verge of marketability. Solid bed and fluidized bed combustion with gas engine or gas turbine can also reach this state of development as soon as the problem of process gas purification will be solved efficiently on the basis of practicable concepts. In addition, two other innovative technologies are in the process of development: the direct (inverse) gas turbine process and the indirect gas turbine process (hot air turbine process).

All the technologies that have been evaluated still show a great potential for economic and technological development. Therefore, the concepts involved also incorporate a certain potential as to the increase in efficiency and a reduction of costs.

EVALUATION OF TECHNOLOGY, ECONOMY, AND IMPLEMENTATION

The study conducted by the "Ingenieurbüro BIOS" was to evaluate various decentralized biomass CHP processes as to technology, economy, and realizability for different applications.
In addition, the study analyzed the potential for CHP biomass technologies in Austria and future strategies of realization. The study focussed on decentralized biomass CHP technologies that seem suitable for a power range up to 2 MW_{el}. The main interest rested on solid biomass, especially on wood.

TECHNOLOGICAL EVALUATION

The ***systems*** under study were analyzed in detail as to their strong and weak points with a view to the following criteria:

- Description of the technology
- Conditions for the possible integration into a biomass combustion system
- Potential power range and other parameters of operation
- Electrical and total plant efficiency
- Part load behavior of the plant
- Controllability and automation
- State of development of the technology
- Operation and maintenance costs
- Service live and robustness
- Emissions from the plant
- Specific costs for investments and electricity generation

ECONOMIC EVALUATION

As far as economic efficiency is concerned biomass CHP processes were analyzed in two different approaches.
On the one hand, the study ascertained the specific costs of investment and electricity generation on a general basis and contrasted these costs with the current tariffs in Austria and, on the other hand, case studies analyzing specific processes and applications were carried out on the basis of a dynamic evaluation of economic efficiency, which was rated by means of defined reference figures. The costs of electricity generation depend on several factors, such as the average annual full load time, fuel costs, public grants for initial costs, and plant size. The most important factor concerning economic efficiency, however, is the actual annual full load time. Plants using steam processes should operate at full load for at least 4,000 hours/year in order to reach supply costs of less than 1 ATS/kWh_{el} (assuming investment aid of 30 per cent and fuel costs of ATS 0.15 / KWh). At present, with the ORC process this break even point is situated at about 5,000 hours/year. All other technologies would require more hours of full load operation in order to be economically competitive. The case studies analyzed a district heating system with a Stirling engine, a steam screw engine process used in a medium-sized saw mill, an ORC process in a medium-sized wood processing plant, and a solid bed process with gas engine in a district heating plant.

The results of the study show that an economically efficient operation of such plants is hardly possible given the current supply tariffs and the lack of sufficient public funding of investment costs. However, the study also concluded that all technologies would be economically feasible with higher sup-

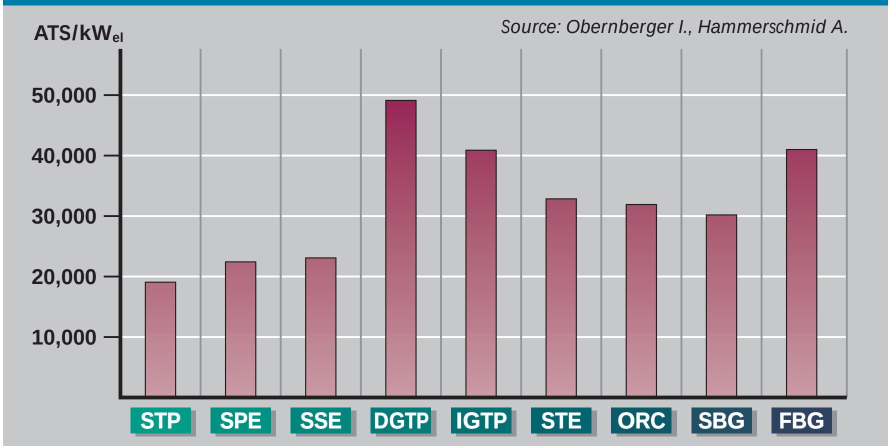
The following ***systems*** have been analyzed in the study:

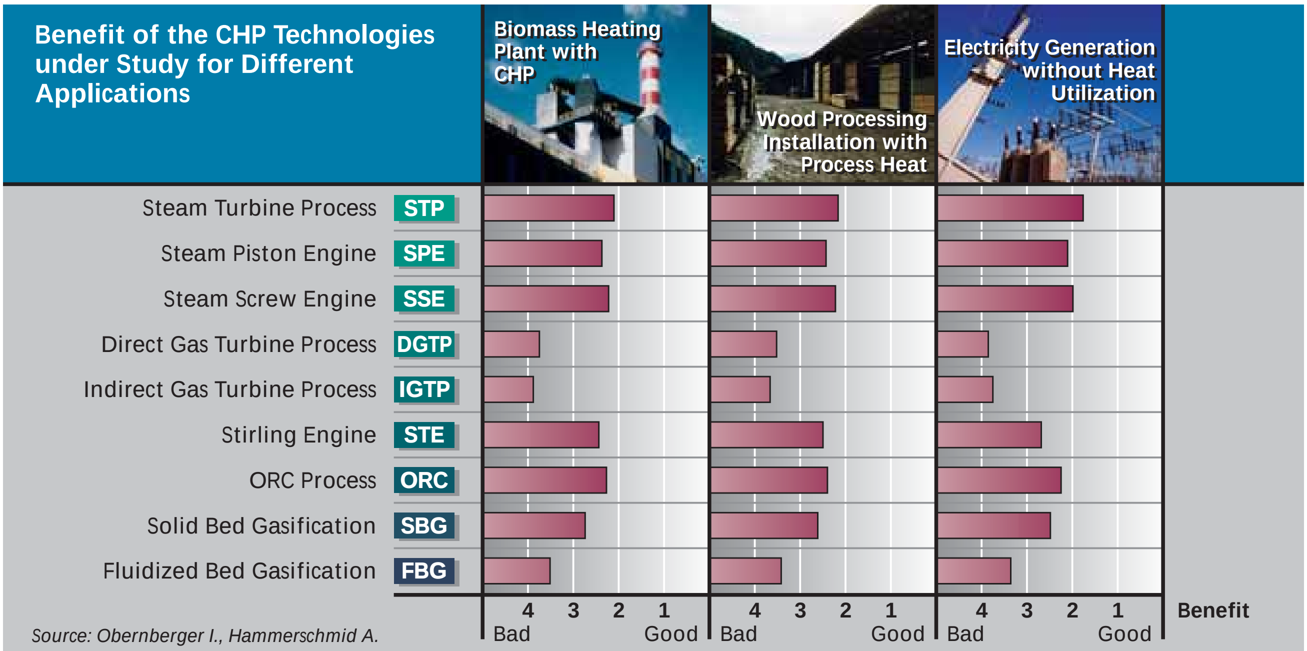
- **STP** *Steam turbine process*
- **SPE** *Steam piston engine*
- **SSE** *Steam screw engine*
- **DGTP** *Direct (inverse) gas turbine process*
- **IGTP** *Indirect gas turbine process (hot air turbine)*
- **STE** *Stirling engine*
- **ORC** *ORC (Organic Rankine Cycle) process*

Using process gas in gas engines or turbines:

- **SBG** *Solid bed gasification*
- **FBG** *Fluidized bed gasification*

Additional Investment Costs for Biomass CHP Technologies as compared to Conventional Biomass Heating Systems





ply tariffs and appropriate public funding. From an economic point of view, the two CHP plants using process heat (saw mill with steam screw engine and the wood processing plant with ORC technology) showed the best results on account of the high degree of capacity utilization. The most efficient technologies available today cause specific additional investment costs of approx. ATS 20,000/kW_{el} (additional costs of electricity generation as compared to a biomass water heating system with the same rated power). Depending on the prevailing conditions, specific costs of electricity generation of around ATS 0.5/ kW_{el} should be possible with such systems.

BENEFIT ANALYSIS

A benefit analysis was carried out in order to evaluate the usability of different CHP technologies for diverse applications. The possible applications analyzed in the study already cover a broad field of applications:

- Biomass heating plant with combined heat and power technology
- Electricity generation in small- and medium-scale wood processing plants with process heat utilization
- Electricity generation without heat utilization

The analysis used seven factors for evaluation (plant characteristics, operational data, control technology, maintenance, ecology, state of development, cost analysis) and these data were subdivided into more detailed subcategories, thus yielding a total of 19 different parameters. The results were weightet in cooperation with different R&D institutions, planners, and manufacturers in order to attain an objective evaluation. Finally, each parameter of the various technologies involved was rated on the basis of a school marks scale. The benefit of a given technology for a certain application was determined by multiplying the individual marks with the respective weighting factor and by summing up the resulting figures.

The figure above gives a summary of the evaluation of the different technologies for three applications. Steam processes and the ORC process show good results for all applications and, thus, prove to be very flexible and have a high potential for realization. The Stirling engine seems to be particularly promising for the use in biomass heating plants (to cover the electricity supply for individual households).
The inverse gas turbine process, the hot air turbine process, and the fluidized bed gasification process yield rather bad results for all three applications, which may be attributed to the low state of development of these technologies, high costs, and the complexity of such plants. Solid bed gasification with gas engine also seems to be promising for use in decentralized CHP plants but the technology still is at an early stage of development, at present.

OBJECTIVES

A law on the "Organization of electric power companies in Austria" (ElWOG), passed in 1998, stipulates that the share of electricity generated from domestic renewable energy sources (not including hydroelectric power) shall reach 3 per cent of the total amount of electricity supplied to end users by the year 2005. This would amount to approximately 1,500 GWh/year and correspond to about 10 per cent of the electricity currently generated in CHP plants in Austria. Among all renewable sources of energy biomass has the greatest potential for development concerning electricity generation. Assuming that biomass CHP plants were to supply 80 per cent of the goal stated in the law, and further assuming that such installations have an average full load time of 4,000 h/a, a total of 300 MW_{el} would be necessary to meet this goal. Considering the time involved in the planning of such CHP plants it becomes clear that it is high time to act in order to reach these objectives.

PROJECT: STIRLING HEATING PLANT

***Stirling engine test stand* at JOANNEUM RESEARCH, Graz, Austria, consisting of biomass combustion system, a Stirling engine mounted in the flue gas duct, and a hot water boiler.**

A project conducted by the Institute of Energy Research, Joanneum Research, which is being co-financed by the Ministry of Science and Transport is to develop a small-scale wood-powered Stirling power plant for decentralized electricity supply. While, in the higher power range, the steam power plant and ORC processes seem to be the best technology the Stirling technology with hot gas engines is particularly suitable for small-scale plants in the 500 kW_{el} range.

In the second phase of the project, the main objective was to design, construct, and test a Stirling engine for electricity generation in biomass combustion plants. The electrical energy generated in such CHP plants could be used in decentralized supply systems, especially for individual end users. Charging car batteries also could become an important task of decentralized biomass power plants.

The main objective of phase II was to develop a suitable concept and to design a Stirling-CHP pilot plant for heat and power generation. Joanneum Research in Graz, Austria developed a ***testing bench with measuring equipment*** in order to test the performance and efficiency of the engine.

The A-type Stirling engine was chosen because this particular design permitted the utilization of standard production components for the most cost intensive parts of the engine. The test engine used a standard crank case and crank shaft. The parts peculiar to the Stirling technology such as the heater, engine cooler, regenerator, the cylinders, the pistons with sealings, and the piston rods as well as the water-cooled rod sealings are new developments. The test engine has been integrated in an existing wood chip heating plant with a thermal output of approx. 50 kW. An automatic measuring equipment registered a comprehensive set of data for the analysis of the Stirling process. In the course of the test phase, the Stirling engine was in operation for about 100 hours. At 1,500 rpm and a boost pressure of 40 bar the Stirling engine with air (nitrogen) as a working fluid should reach an output of about 4 kW with an efficiency of 21 per cent. At a boost pressure of 21 bar and 600 rpm the measured shaft power was 2.6 kW with an efficiency of 23 per cent. The maximum shaft power measured during the test phase of the project was 2.9 kW at a boost pressure of 28 bar. In relation to the displacement of the power piston this corresponds to a specific Stirling engine output of 3.45 kW/L. By increasing the boost pressure to the design limit (40 bar) a shaft power of approx. 3.5 kW (specific Stirling engine power of 4.2 kW/L) was reached.

The objectives of phase II of the study have been realized with this test series. Potentials for improvement as to output and operational safety have been identified in the course of this phase of the study. Phase III of the project established paths of cooperation for the construction and implementation of the Stirling-heating plant technology with biomass combustion.

The objective of phase IV is a cooperation project with the industrial sector and aims at designing a 30 kW Stirling engine for the use in a biomass district heating plant. The Stirling engine will serve to implement the combined heat and power technology (CHP). If all of Austria's biomass district heating plants were to use this CHP technology, an important part of the objectives of the ElWOG law could already be realized.

POTENTIALS AND STRATEGIES

Steam screw engine with a rated power of 250 kW_{el}

Typical applications for biomass CHP plants would be the wood processing industry, local and district heating stations, industrial operations with high process heat consumption, as well as additional combustion of biomass in existing fossil fuel power stations.
All these applications show a high potential for implementation in Austria. Even the additional demand of solid biomass which will arise on account of the stipulations of the 1998 law on the "Organization of electric power companies" (ElWOG) could be fully met; in many cases biomass CHP installations will be used to replace conventional biomass hot water boilers, thus, only the additional fuel consumption for electricity generation is a relevant factor. In order to promote the installation of CHP projects two strategies could be applied. On the one hand, the legislative of the *Laender* must fix minimum tariffs for the supply of electricity generated from renewable sources of energy to the grid. On the other hand, public grants for environmentally friendly technologies could help to reduce the initial costs of environmentally relevant projects (e.g. substitution of renewable sources of energy for fossil ones). In the future, the granting of aids will be increasingly effected on the basis of public bidding procedures, which will increase the pressure on operators to reduce investment and operation costs and, thus, be an incentive to develop more competitive installations.

F I G U R E S / D A T A / F A C T S

PROJECT SPONSORS AND PUBLICATIONS

The study *"Decentralized Biomass CHP Technologies"* has been conducted by the "Ingenieurbüro BIOS", Graz, Austria (Ingwald Obernberger, Alfred Hammerschmid) in cooperation with the "Energieverwertungsagentur Wien, Austria" (Herbert Lechner, Alois Geisslhofer) and was comissioned by the Austrian Federal Ministry of Science and Transport (BMWV).

This study is volume 4 of the series *"Thermische Biomassenutzung"*, ISBN 3-7041-0261-X, published by dbv-Verlag at the Technical University Graz and is available (for ATS 385.- + ATS 60.- P&H) from:
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The project *"Development of a Small-Scale Stirling Power Plant with Wood Firing for Decentralized Electricity and Heat Generation"* is being realized by the Institute of Energy Research, Joanneum Research, Austria (Project Manager: E. Podesser) and is financed by the BMWV, the Land Steiermark, the Association of Austrian Power Companies, and the STEWEAG.

The final report on phase II of the project has been published in the series *"Reports on Energy and Environment Research"* by the Austrian Ministry of Science and Transport and is available from:
PROJEKTFABRIK,
Nedergasse 23, A-1190 Wien, Austria.

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