EESD - PART B - PROJECT

# "FUZZY LOGIC CONTROLLED CHP PLANT FOR BIOMASS FUELS BASED ON A HIGHLY EFFICIENT ORC PROCESS"

Contract No. NNE5/2000/475

### Final publishable report

period: 01-01-2001 - 30-06-2003

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> > Graz, 29-08-2003

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## 1 Aim

The project covers a combined heat and power plant based on biomass combustion in the small town of Lienz, Austria, featuring innovative technology. The town itself gets supplied with district heat, several industrial companies with process heat. The electricity produced is fed into the grid of the regional utility which is also a shareholder of the company realising and operating the CHP plant. In the town, many households have replaced their mainly oil-and coal-fired furnaces with biomass district heat, hence contributing to a substantial reduction of  $CO_2$  (about 23,000 t/a at the final development stage of the district heating network) and other harmful emissions like  $SO_2$ , CO, dust and  $NO_x$ .

The surrounding wood manufacturing industries as well as the local farmers produce large quantities of bark, sawmill side products and forest wood chips which ensure that the biomass fuel required (about 100,000 m<sup>3</sup>/a at the final development stage of the district heating network) can be covered by the local resources available supporting regional infrastructure and incomes.

The key objectives of the project were the following:

- Demonstration of the largest European biomass CHP plant based on an ORC process (Organic Rankine Cycle) with a nominal net capacity of 1,000 kW<sub>el</sub>. This ORC process represents a further improvement and an up-scaling by a factor 2.5 of the already successfully demonstrated 400 kW<sub>el</sub> unit in Admont, Austria, operating in both cases with silicone oil as organic working medium at medium pressure levels.
- Development, design and demonstration of a Fuzzy Logic process control system in combination with an Artificial Neuronal Network for analysing, forecasting and optimising the performance of the overall CHP plant in order to improve plant availability and efficiency as well as to reduce operating costs (first Fuzzy Logic controlled biomass CHP plant in Europe).
- First use of an internal heat recovering system, combining a thermal oil boiler with a thermal oil economiser and a combustion air pre-heater to increase the net electric efficiency to about 15 % (related to the NCV of the biomass fuel).
- Suitability for multi-fuel feed (bark, sawdust, wood residues, pellets) as well as for high variations of water content (10 wt.% (w.b.) to 55 wt.% (w.b.)).
- Demonstration of the technical maturity and economic competitiveness of the Fuzzy Logic controlled CHP technology and well organised dissemination of the results achieved.
- Performance of a technological and economic analysis of the system with a key focus on the innovative components as a basis for further improvements and a successful market introduction in short term.

In order to decrease harmful emissions an efficient, multi-stage flue gas cleaning system consisting of a multi-cyclone, an economiser and a wet electrostatic precipitator combined with a flue gas condensation unit has been implemented within the overall CHP plant.

Moreover this project contributes to achieving both the objectives addressed in the White Paper of the European Commission for renewable energy sources as well as the Kyoto objectives. In particular it concerns the following aims of the White Paper:

- The contribution from renewable energy sources to the European Union's primary energy consumption should be doubled by the year 2010 (based on the level of 1995).
- Energy utilisation from biomass should be tripled (based on the level of 1995).
- Electricity generation from renewable energy sources (RES) should increase ten times (based on the level of 1995).
- Support of the main priorities of EU energy policy: Security of energy supply, competitiveness and environmental protection.
- Strengthening combined heat and power production systems is directly addressed in this project.

### 2 Introduction

The project FUZZY LOGIC CONTROLLED CHP PLANT FOR BIOMASS FUELS BASED ON A HIGHLY EFFICIENT ORC PROCESS officially started on 01-01-2001 (project commencement date). On 11-09-2001 the submission of the signed EU contract (No. NNE5/2000/475) took place.

The biomass-fired combined heat and power (CHP) plant is located in Lienz, Eastern Tyrol, Austria, in a newly built boiler house (see Figure 1). The overall project covers a CHP plant based on biomass combustion in order to supply the town with district heat (about 60,000 MWh/a after completion of the network of pipes) and to produce electricity (about 7,200 MWh/a). It started heat supply operation in autumn 2001 and will cover the heat requirement of approximately 70 % of all buildings in the supply area by the end of 2003. The residential and industrial heating systems replaced are mainly oil-fired boilers; this therefore results in a considerable  $CO_2$  reduction on the part of the new biomass CHP plant. The owner and operator of the plant is Stadtwärme Lienz Produktions- und Vertriebs-GmbH. The shareholders of this company are Tiroler Wasserkraft AG (Tyrolian utility; 48 %), Steirische Gas-Wärme GmbH (Styrian utility; 48 %) and the town of Lienz (4 %).



**Figure 1:** View of the CHP plant Lienz

## **3** Technical description of the CHP plant Lienz

The CHP plant essentially consists of two biomass-fired boilers, an ORC process, a solar collector panel and an oil-fired peak load boiler as well as a heat recovery unit combined with a flue gas cleaning plant (see Figure 2).

The fuel conversion unit is composed of the two biomass combustion plants, a hot water boiler with a nominal capacity of 7,000 kW<sub>th</sub> and a thermal oil boiler with a nominal capacity of 6,000 kW<sub>th</sub>. The thermal oil boiler supplies the ORC process (with a nominal net electric power of 1,000 kW). The heat recovery unit with a nominal capacity of 2,000 kW<sub>th</sub> increases the overall plant efficiency and covers a thermal oil economiser, located behind the thermal oil boiler, and a hot water economiser which recovers energy from the flue gases of both biomass-fired boilers. The solar collector panel is installed on the roof of the CHP plants, consists of a 630 m<sup>2</sup> collector surface and achieves a thermal power of up to 350 kW<sub>th</sub>. An oil-fired boiler with a nominal capacity of 11,000 kW<sub>th</sub> is installed for peak load coverage and as a stand-by system (see Table 1 and Table 2).



Figure 2: Scheme of the overall CHP plant

<u>Explanations:</u> Ölkessel ... oil boiler; Biomassefeuerung ... biomass combustion unit; Thermoölkessel ... thermal oil boiler; TÖ-ECO ... thermal oil economiser; Luvo ... air preheater; Multizyklon ... multi-cyclone; ORC-Prozess ... ORC process; Heißwasserkessel ... hot water boiler; Rauchgasreinigung ... flue gas cleaning unit; ECO ... Economiser; Heißwasser ... hot water; Thermoöl ... thermal oil; Arbeitsmittel ORC ... working fluid ORC; Rauchgas ... flue gas; Entschwadungsluft ... air to avoid windrows at the stack outlet; Solaranlage ... solar plant; Sammler ... collector; Verteiler ... distributor; Hydr. Weiche ... hydraulic switch

#### **Table 1:**Technical data of the CHP plant Lienz

Explanations: ECO ... Economiser; given heat and electricity production data are related to the supply status after completion of the network of pipes.

Roofed storage capacity	5,000 m³
Open storage capacity	10,000 m³
Solar thermal collector	630 m²
Nominal power thermal oil boiler	6,000 kW
Nominal power thermal oil ECO	500 kW
Nominal power hot water boiler	7,000 kW
Nominal power hot water ECO	1,500 kW
Nominal power oil boiler (peak load coverage)	11,000 kW
Maximum thermal power solar thermal collector	350 kW
Net electric power ORC	1,000 kW
Production of heat from biomass	60,000 MWh/a
Production of heat from solar energy	250 MWh/a
Production of electricity from biomass	7,200 MWh/a

#### **Table 2:** General project data of the CHP plant Lienz

Explanations: the given biomass fuel consumption data are related to the supply status after completion of the network of pipes.

Primary energy				
Bark, saw dust, wood chips from local sawmills	90,000 m³/a			
Rural wood chips	10,000 m³/a			
Investment costs				
CHP plant	7.7 Mio €			
District heating grid	15.4 Mio €			

#### **Technological innovations**

First 1,000  $\rm kW_{el}$  biomass combined heat and power plant based on the ORC process worldwide

First use of a heat recovering system in combination with a thermal oil boiler to increase the electric efficiency

Use of a Fuzzy-Logic control system for process optimisation

Efficient, multi-stage flue gas cleaning system consisting of multi-cyclone, economiser and a wet electrostatic precipitator combined with a flue gas condensation unit

Figure 3 shows the annual heat and electricity output line as well as the energy supply of the different units installed.



Figure 3: Annual heat and electricity output line of the biomass CHP plant in Lienz

Forest and industrial wood chips, sawdust and bark (average water content between 30 and 55 wt.% (w.b.)) from the regional forestry and wood industries are utilised as biomass fuel. The total annual biomass fuel consumption will amount to about  $100,000 \text{ m}^3$  in the final

development stage. The oil-fired peak load boiler covers only approximately 4 % of the entire thermal energy production regarding the overall plant design. Concerning biomass storage, an open and a roofed area with a total storage capacity of 15,000 m<sup>3</sup> has been planned.

The network of pipes covers three stages of development, with a final total length of 37.5 km and about 900 units connected.

The flue gas cleaning unit consists of two stages. In the first stage the coarse fly ash particles are precipitated in multi-cyclones which are placed downstream of each biomass-fired boiler. In the second stage, fine fly ash and aerosol precipitation take place in a wet electrostatic filter integrated in a heat recovery and flue gas condensation unit. In this plant configuration, dust emissions in the clean flue gas of about 10 mg/Nm<sup>3</sup> (dry flue gas, 13 vol% O<sub>2</sub>) and the avoidance of water vapour formation at the chimney outlet at temperatures above -5 °C are achieved.

The main innovative part of the new biomass CHP plant is the ORC process with a nominal electric capacity of 1.0 MW and a nominal thermal capacity of about 4.6 MW. The ORC was manufactured and supplied by TURBODEN Srl, Brescia, Italy. The already mentioned upscaling could not only be achieved by an obvious transformation of the 400 kW<sub>el</sub> ORC process design, because the vapour and liquid volume flows as well as the surface areas of the heat exchangers of the 1,000 kW<sub>el</sub> machine (see Figure 4) would have become very large.

The principle of electricity generation by means of an ORC process corresponds to the conventional Rankine process. The substantial difference is that instead of water an organic working medium with favourable thermodynamic properties is used - hence the name Organic Rankine Cycle (ORC). The working principle and the different components of the ORC process are shown in Figure 5 and Figure 6. The ORC process is connected with the thermal oil boiler via a thermal oil cycle. The ORC unit itself operates as a completely closed process utilising a silicone oil as organic working medium. This pressurised organic working medium is vaporised and slightly superheated by the thermal oil in the evaporator and then expanded in an axial turbine which is directly connected to an asynchronous generator (see Figure 6). Subsequently, the expanded silicon oil passes through a regenerator (where in-cycle heat recuperation takes place) before it enters the condenser. The condensation of the working medium takes place at a temperature level which allows the heat recovered to be utilised as district heat (hot water feed temperature about 80 to 90 °C). The liquid working medium then passes the feed pumps to again achieve the appropriate pressure level of the hot end of the cycle.

The silicon oil used as a working medium in the ORC cycle is environmentally friendly. Furthermore, due to the favourable thermodynamic properties of the silicon oil, there is no danger of droplet erosion on the turbine blades. As the working medium is flammable, the ORC process is equipped with a special detection system for organic compounds whereby a small amount of air over all the flanges is sucked in and subsequently analysed using a flame ionisation detector. Through this safety measure the ORC is monitored continuously for leaks.

The main technical data of the ORC process, which is integrated in the biomass CHP plant Lienz, are summarised in Table 3.

#### **Table 3:**Technical data of the 1,000 kWel ORC process in Lienz

Explanations: the net electric efficiency is related to the thermal power supplied to the ORC (thermal oil input); the data presented are measurement data derived from test runs during the monitoring period.

Thermal power input (thermal oil)	5,800 kW		
Heating medium (thermal oil)	MARLOTHERM SH		
Average inlet temperature (at nominal load)	275 °C		
Average outlet temperature (at nominal load)	225 °C		
Working medium (silicone oil)	OCTAMETHYLTRISILOXANE		
Thermal power output (ORC condenser)	4,650 kW		
Cooling medium	WATER		
Average inlet temperature (at nominal load)	60 °C		
Average outlet temperature (at nominal load)	85 °C		
Net electric power (at nominal load)	1,050 kW		
Net electric efficiency (at nominal load)	18.1 %		



 Figure 4:
 Components of the 1,000 kW<sub>el</sub> ORC process in Lienz

 Explanations: Regenerator (left); evaporator (right, bottom) and turbine (right, above)



Figure 5: Working principle of the biomass-fired ORC process in Lienz



 Figure 6:
 View of the 1,000 kW<sub>el</sub> ORC plant

 Explanations:
 data source: TURBODEN Srl, Brescia, Italy

The design and integration of the ORC process in the entire plant took place with the objective to achieve a high capacity utilisation (large number of full load operating hours), a high overall electric efficiency and an economic operation as well.

A high capacity utilisation of the ORC in heat-controlled operation can be achieved by an appropriate dimensioning of the CHP system (see Figure 3). The CHP unit should be able to operate the whole year in order to achieve at least 5,000 full load operating hours. The ORC in Lienz is dimensioned to achieve about 7,000 full load operating hours at the final development stage of the district heating network.

In order to obtain a high electric efficiency (= net electric power produced / thermal power input) of the ORC unit itself, it is necessary to keep the back-pressure of the turbine as low as possible and thus to minimise the necessary temperature for district heat utilisation at the condenser of the ORC plant (approximately 80 °C feed water temperature). This can be achieved by optimising the operation and control of the district heating network in order to keep the necessary feed water temperature as low as possible as well as by an optimised hydraulic integration of the ORC in the district heating network. In order to achieve this goal, the ORC should be directly connected to the return of the district heating network and the feed water temperature at the ORC outlet should be kept as low as possible by placing the hot water economiser and the hot water boiler in series after the ORC. Following this approach, the ORC can be operated at feed water temperatures of about 80 °C for the whole year, although the feed water temperature required for the district heating network amounts to 90 to 95 °C in winter.

### 4 Performance of the CHP plant Lienz

The overall monitoring period, which covered 15 months of operation of the ORC process, started in April 2002 and ended in June 2003. Within this monitoring period mentioned all relevant operating parameters of the ORC process were recorded at periodic intervals and were evaluated in terms of the technological and energetic performance of the ORC plant.

The start-up of the ORC plant in February 2002 took place without any problems. In the first sixteen months of operation no substantial disturbances of the ORC plant occurred.

The overall electric efficiency of the CHP plant (= net electric power produced / fuel power input into the biomass-fired thermal oil boiler [NCV]) has been considerably increased by a new and improved coupling of the thermal oil boiler with a thermal oil economiser and a combustion air pre-heater (see Figure 5). Using this approach, the thermal efficiency of the biomass-fired thermal oil boiler amounts up to 84 % (= thermal power output / fuel power input [NCV]), which is more than 10 % higher than corresponding values from conventional biomass-fired thermal oil boilers. This increased thermal efficiency correspondingly also raises the overall electric efficiency of the CHP plant (= net electric power produced / fuel power input into the biomass-fired thermal oil boiler [NCV]) to about 15 % (see Figure 7). The respective data values of the process components have been measured at nominal load over a representative period of time.

As shown in Figure 7 the net electric efficiency amounts to about 15 % (related to the net calorific value of the biomass fuel), which equals a value of about 18 % (related to the thermal power input of the thermal oil). At 50 % of nominal load the respective net electric efficiency is about 14 % (related to the net calorific value of the biomass fuel), which equals about 17 % (related to the thermal power input of the thermal oil). This confirms the excellent

partial load efficiency of the ORC process (see Figure 8), which is of special relevance for heat controlled operation.



Figure 7: Energy flow chart for nominal load of the CHP plant Lienz



**Figure 8:** Trend of the net electric efficiency vs. the load of the ORC process according to measured data at the CHP plant Lienz

The total annual amount of net electric energy produced was about 2,300 MWh/a for the year 2002. Figure 9 shows the amount of net and auxiliary electric energy produced per month and additionally the cumulated value of the net electric energy produced (which amounts to about 4,600 MWh) for the whole monitoring period. The amount of auxiliary energy demanded was about 4.35 % of the gross electric energy production on average.

As shown in Figure 9, the ORC was started up for the first time in February 2002. The commissioning of the ORC took place in the beginning of April 2002.





During summer 2002 (June, July, August and half of September) some necessary modifications within the thermal oil boiler and thermal oil cycle were carried out and for this reason the ORC process was shut down for this time period. Obviously the planned further expansion and finalisation of the district heating network will further increase the electricity production of the ORC process.

The total annual amount of heat supplied to the district heating network amounted to 30,000 MWh in the year 2002. Due to the continuing extension of the district heating network, the heat and therefore also the electricity production will increase considerably in the following years. Figure 10 shows the amount of district heat generated per month (divided into the district heat generated from the ORC and from the remaining heat producers) as well as the cumulated value of district heat production over the overall monitoring period (which amounted to about 58,700 MWh).



**Figure 10:** Amount of district heat generated per month and cumulated district heat produced from the CHP plant in Lienz over the total monitoring period

### 5 Evaluation of solid, liquid and gaseous emissions

To determine the flows and compositions of solid (ashes), liquid (condensate) and gaseous emissions of the overall CHP plant several test runs were performed within the monitoring period, which started in February 2002 and ended in June 2003.

The ORC process does not cause any solid, liquid or gaseous emissions, since it is completely closed.

### 5.1 Solid and liquid emissions of the CHP plant Lienz

The combustion of biomass fuels (bark, wood chips and saw dust) implies the production of residues, the ashes. Several ash fractions can be distinguished which are collected at different stages. These fractions are the bottom ash (which is precipitated on the grate), the cyclone fly ash (which is precipitated in the boiler section and the multi-cyclone) and the filter fly ash (which is precipitated in the wet electrostatic precipitator and within the flue gas condensation unit).

The mixture of bottom ash and cyclone fly ash can be defined as useable ash, because the mixture of these two ash fractions keeps the respective Austrian limiting values concerning heavy metal concentrations for an ash utilisation on soils (see Table 5). The limiting values are defined in the following guidelines: The "Compost ordinance" of the Austrian Ministry for Agriculture and Forestry, Environment and Water Supply and Distribution [1] and the guidelines "The appropriate utilisation of plant ashes in forests" as well as "The appropriate

utilisation of plant ashes on arable land and grassland" of the Austrian Ministry for Agriculture and Forestry, Advisory Council for Soil Fertility and Soil Protection [2, 3].

Therefore, the usable ash of the CHP plant Lienz can be used as a soil amending and fertilising agent for agriculture and forest soils as well as for compost production. This leads to an almost complete closure of the mineral cycle which is achievable for thermal biomass utilisation. At the moment the usable ash is mainly utilised as an additive in the municipal compost production of Lienz. A part of the ash is also landfilled at present. Future plans foresee a complete utilisation of the useable ash on soils by establishing an appropriate handling and logistic systems with regional farmers.

Table 4 shows the results of ash and condensate analyses performed for the CHP plant Lienz.

In contrast to the useable ash, the filter fly ash (condensation sludge), which contains considerably higher heavy metal concentrations than the usable ash, has to be landfilled. This small ash fraction (< 10 % of the total ash amount) acts as a heavy metal accumulator and can therefore be seen as an "environmental filter".

The purified condensation water, which is pH-controlled (the pH-value is kept at 7.5 by alkali addition in order to minimise the dissolution of heavy metals) and separated from the sludge in a sedimentation unit, keeps the respective limiting values of the Austrian sewage water emission regulation [4] and can be discharged into the local sewage system.

Within the CHP plant Lienz the occurring useable ash is discharged by screw conveyors and a system of connected rods as well as a hutch chain conveyor to end up in dry form in an ash container. On site of the CHP plant, there are 2 ash containers with a volume of about 7 m<sup>3</sup> each available, which allow a continuous ash discharge.

It is a declared aim to utilise the total amount of bottom and cyclone fly ash in future in terms of a sustainable economy and a reasonable closure of the mineral cycle. From an ecological point of view the most suitable way of utilising usable ash is its direct or indirect utilisation on agricultural or forest soils.

#### **Table 4:** Results of ash and condensate analyses of the CHP plant Lienz

<u>Explanations:</u> d.b. ... dry based; - ...no data available; TOC ... total organic carbon; TIC ... total inorganic carbon; samples taken during test runs in December 2002.

Parameter	Bottom ash	Cyclone fly ash	Filter fly ash (condensation sludge)	Condensate
	[mg/kg d.b.]	[mg/kg d.b.]	[mg/kg d.b.]	[mg/l]
Si 141,566 5		53,478	13,909	<20
Са	246,067	270,361	255,287	84
Mg	53,715	33,694	27,417	31
К	53,899	39,356	6,384	567
Na	6,131	2,107	407	9.6
S	165	2,943	3,059	90
CI	15	2,707	507	40
Cu	62	75	669	<0.10
Zn	109	1,214	38,387	0.46
Pb	8.0	23	710	0.01
Cd	0.25	7.1	80	<0.01
Р	5,379	9,299	22,041	<1
Al	31,371	17,521	7,950	<0.5
Fe	20,171	15,283	12,773	0.58
Mn	7,274 10,205 15,525		15,525	1.4
Со	D 20 19 28		28	<0.05
Мо	1.7	2.0	1.8	<0.10
As	2.7	4.5	64	<0.05
Ni 44 51		87	0.03	
Cr	44	38	69	<0.02
V	43	28	24	<0.1
TIC	13,700	26,800	64,700	0.00
тос	13,600	61,300	84,000	329
NO <sub>2</sub>	-	-	-	22
NO <sub>3</sub>	-	-	-	<10
SO4 <sup>2-</sup>	-	-	-	267
$NH_4$	-	-	-	7.0
Cr <sub>VI</sub>	-	-	5.7	<0.02
	[-]	[-]	[-]	[-]
рН	-	-	11.22 (25°C)	7.87 (25°C)

Table 5 shows the heavy metal concentrations and limiting values of a representative sample of useable ash taken from the CHP plant Lienz. The results show that all limiting values for heavy metals are kept. Therefore, the useable ash may be used by local farmers as a secondary raw material with fertilising and limiting effects on agricultural and forest soils.

**Table 5:**Heavy metal concentrations in the usable ash (mixture of bottom ash and<br/>cyclone fly ash) of the CHP plant Lienz in comparison to limiting values for an<br/>ash utilisation on agricultural and forest soils

Parameter	Useable ash	Limiting value	Environmental compliance
	[119/109 0.0.]	[119/109 0.0.]	[,0]
Zn	871	1,500	58.1%
Cu	72	250	28.8%
Cr	58	250	23.2%
Pb	15	100	15.0%
V	46	100	46.0%
Со	23	100	23.0%
Ni	62	100	62.0%
Мо	2	20	10.0%
As	5	20	25.0%
Cd	4	8	50.0%

Explanations: d.b. ... dry based; limiting values according to the following relevant sources: [1], [2], [3]; sample taken during test runs in December 2002.

Table 6 shows the heavy metal concentrations and the pH-value of the condensate in comparison to the respective limiting values. It is obvious, that the condensate keeps the limiting values regarding heavy metal concentrations as well as regarding the pH-value.

**Table 6:**Heavy metal concentrations and pH-value in the condensate in comparison to<br/>limiting values for condensate discharged into the local sewage system

Parameter	Condensate [mg/l]	Limiting value [mg/l]	Environmental compliance [%]
Zn	0.46	2.00	22.8%
Cu	<0.10	0.50	20.0%
Cr	<0.02	0.50	4.0%
Pb	0.01	0.50	1.2%
Со	<0.05	0.50	10.0%
Ni	0.03	0.50	6.2%
As	<0.05	0.10	50.0%
Cd	<0.01	0.05	20.0%
	[-]	[-]	
рН	7.87 (25°C)	6.50 - 9.50	

Explanations: limiting values according to the following relevant source: [4]; sample taken during test runs in December 2002.

In case of a direct utilisation of the useable ash on agricultural soils, a maximum annual ash amount of 1.21 t/ha for grassland and of 1.61 t/ha for farmland have to be considered. These values are calculated according to the respective guideline [3] based on the analysis results of

the useable ash of the CHP plant Lienz. It is possible to double these amounts mentioned, if an ash utilisation has not taken place on the same field in the previous year.

In forests the maximum amount of ash to be utilised is 2 t/ha for a time period of 30 years or 3 t/ha for a time period of 50 years [2].

Regarding compost production, a maximum amount of 2 wt% of ash may be added to the basic raw material for composting [1].

Concluding, the following ash utilisation can be recommended regarding an environmentally sound and sustainable utilisation of the useable ash (mixture of the bottom ash and the cyclone fly ash) from the biomass CHP plant Lienz:

- Direct utilisation of the ash on agricultural land.
- Utilisation of the ash as an additive in the agricultural compost production.
- Direct utilisation of the ash in forests.
- Utilisation of the ash as an additive in the municipal compost production.

In order to achieve the aim of 100 % of sustainable ash utilisation in the CHP plant Lienz, an appropriate ash handling and treatment system is planned to be established within the next years, which includes ash sieving and ash wetting in order to offer the ash to the farmers in a standard quality, which is appropriate for direct utilisation on soils and is easy to handle for them.

### 5.2 Gaseous and particulate emissions of the CHP plant Lienz

Within the monitoring period mentioned, all relevant operating parameters of the CHP plant Lienz were recorded at periodic intervals and were evaluated regarding the technological and energetic performance of the plant. Moreover, dedicated test runs covering certain load conditions and load changes combined with emission measurements were performed. The measurements covered the gaseous emissions CO,  $CO_2$ ,  $NO_x$ ,  $C_xH_y$  and dust as well as ash and condensate analysis (see chapter 5.1).

Figure 11 and Table 7 show the results of a test performed at 10-12-2002, which can be considered as representative for the overall CHP plant. During this test run the gaseous emissions of the biomass combustion unit, which feeds the ORC process with thermal oil, have been measured at nominal load over a representative period of time. The measurement results show that the prescribed limiting values (in each case related to dry flue gas and 13 vol% O<sub>2</sub>) of 200 mg/Nm<sup>3</sup> for NO<sub>x</sub> (measured as NO<sub>2</sub>), 100 mg/Nm<sup>3</sup> for CO, 20 mg/Nm<sup>3</sup> for C<sub>x</sub>H<sub>y</sub> and 20 mg/Nm<sup>3</sup> for dust, both at nominal load and partial load operation, can be clearly kept. In most cases the measured values are far below the respective limiting values issued by the local authority [5, 6]. These results are also valid for the second biomass furnace installed, which is equipped with a hot water boiler.





<u>Explanations:</u>  $NO_x$  ... nitrogen oxide [ppm]; CO ... carbon monoxide [ppm];  $C_xH_y$  ... hydrocarbons [ppm];  $O_2$  ... oxygen content [vol%]; all values related to dry flue gas; measurements performed at 10-12-2002.

# **Table 7:**Comparison of $NO_x$ -, CO-, $C_xH_y$ - and dust concentrations in the flue gas with<br/>the respective limiting values

<u>Explanations:</u> NO<sub>x</sub> ... nitrogen oxide [mg/Nm<sup>3</sup>]; NO<sub>2</sub> ... nitrogen dioxide [mg/Nm<sup>3</sup>]; CO ... carbon monoxide [mg/Nm<sup>3</sup>]; C<sub>x</sub>H<sub>y</sub> ... hydrocarbons [mg/Nm<sup>3</sup>]; all values related to dry flue gas and 13 vol% oxygen content; dust emission value: average value of 3 measurements performed at 10-12-2003; measurements took place in the flue gas at chimney inlet; limiting values according to the following relevant sources: [5], [6]

Parameter	Thermal oil boiler [mg/Nm³]	Limiting value [mg/Nm³]	Environmental compliance [%]
NO <sub>x</sub> (as NO <sub>2</sub> ) CO CxHy	111.5 71.4 1.7	200.0 100.0 20.0	55.8% 71.4% 8.5%
	Total CHP plant [mg/Nm³]	Limiting value [mg/Nm³]	Environmental compliance [%]
Dust	5.6	20.0	28.0%

The thermal utilisation of biomass corresponds to the criteria of actual environmental protection, since biomass is a renewable and almost CO<sub>2</sub>-neutral source of energy. The

enhanced production of electricity and heat from biomass is a clear objective of the European and Austrian environmental and energy policy. The project contributes to the achievement of the  $CO_2$  reduction target defined in the Kyoto protocol (the biomass CHP plant Lienz reduces  $CO_2$  emissions by about 23,000 t/a) as well as to the goal defined in the Austrian Electricity Supply Act, which aims at an amount of 4 % of electricity to be provided from renewable energy carriers (excluding large hydro power plants) on the total electricity production in Austria in the year 2007. Furthermore, the reduction of emissions has improved the air quality in the entire region of Lienz, which in its turn has increased the quality of life of the local population.

### 6 Monitoring of the Fuzzy Logic control system

Various possibilities for applying control systems based on Fuzzy Logic have been investigated for the continuing development of thermal waste utilisation systems in the past. The aim of the EU-project "Fuzzy Logic controlled CHP plant for biomass fuels based on a highly efficient ORC-process" (contract No. NNE5/2000/475) was the optimisation of such a control system based on biomass fuels. The project partner, who was responsible for the development, implementation and monitoring of the innovative Fuzzy Logic control system, was the Technical University of Mining and Technology in Freiberg (TU BAF) in Germany.

### 6.1 Description of the structure of the Fuzzy Logic control system

Complex technical processes such as waste or biomass combustion control systems are difficult to manage and have a considerable influence on the environment as a result of their emissions and waste products (dust, condensate, etc). In order to guarantee effectiveness, these processes require the application of innovative technologies such as a Fuzzy Logic control system. Essential aims of thermal biomass utilisation - in addition to the important ecological considerations - are the maximum conversion of energy, justifiable plant and operational costs and improved primary measures for the reduction of emissions. Only if these aims can be reached, an optimised biomass combustion control system is achieved.

In comparison to processes carried out in conventional power plants, complications often arise in biomass combustion control systems as a result of the highly non-linear process curves displayed by flow and radiation in the combustion process. Furthermore, process models are also lacking which - together with extrapolations - could contribute to the description of the actual process.

Previously, the problem of combustion control systems in biomass combustion plants could be countered only with a combination of conventional control technology and manual intervention by the operating staff. The basic principle of Fuzzy Logic is particularly wellsuited to solve this interface problems.

Despite of a continuously increasing degree of automation, human perception and skills remain the final criteria in almost every aspect of life. Decision-making is made simpler by progress made in automation; however, these advances often mean high investment costs that are not always justifiable. The decision in favour of investments for automation systems reaches its limits when a sufficient degree of utilisation cannot be guaranteed from the very beginning of implementation of the process control system. Then the question must be asked,

whether these planned investments in very complex and inhomogeneous processes – in favour of an encompassing automation – could fully replace the expertise and abilities of experienced operational personnel.

An innovative, intelligent control design should not only be based on technical progress, but should also include operational experience and staff know-how. This aim can be fulfilled by the careful integration of Fuzzy Logic.

Unlike conventional control technologies, Fuzzy Logic does not require extensive mathematical algorithms for controlling complex, technical processes. Fuzzy Logic works at a verbal and technical level in which language as a characterising variable is included in the creation of a system.

Conventional control design processes require an automation with know-how of the process on the one hand and a good knowledge of mathematics and control system technology on the other hand. However, this demand can only rarely be met optimally by a single automating technician. In practice the task of automation is frequently carried out by two specialists (a control expert and a process expert). The control expert designs, plans and questions the process expert about his experiences. This process development step is often associated with a loss in communication and therefore connected knowledge when this task is not carried out by a well-organised team. The integration of experienced workers in the operation itself creates a feeling of shared responsibility for the control of the overall process, which represents an additional advantage. Moreover, the implementation of Fuzzy Logic and its integration in the process is actually nothing other than the utilisation of the available knowledge of the operating staff. This approach also brings an even greater interest in the desired function ability of fuzzy control and so requires the constructive cooperation of the operating personnel.

A process operator in biomass combustion processes has expert knowledge of the combustion process. If this process is automated, only the setting of the controller can make decisions concerning the quality of the product (temperature control, burnout of the fuel, etc) and no longer the operator alone. In this way a high degree of knowledge of control systems must be demanded of the process operation, if the plant is to be operated optimally. The operator must know the process and the reaction of the controller and must be able to predict it as well. Here at this point, it is different in case of the Fuzzy controller. The control process is described in the language of the expert (process operator) and not in abstract mathematical processes. The process operator can apply his operational experience completely to the control process. Compared to conventional control systems, the greater chances for success of Fuzzy Logic can be found in a working procedure of this type.

Optimisation of the process or the plant is carried out in the same manner as if the operators were gathering information. The operator conducts modifications, observes the reaction and makes corrections if necessary. This type of Fuzzy application - designated as an open application - provides the user the possibility of using Fuzzy Logic fully for the first time.

To fulfil the named advantages, the Fuzzy Logic basically consists of a linguistic and a technical level. Fuzzyfication and defuzzyfication were used for the smooth transition of information between the linguistic base of the process operator and the technical level. Defuzzyfication transforms a verbal manipulated variable back into an exact technical value while fuzzyfication goes ahead with the opposite step. Decisive for the working principle of

Fuzzy Logic is the availability of a verbal measured variable and the output of a real manipulated variable (see Figure 12).



Figure 12:Working principle of the Fuzzy Logic control system

The processing of several measured variables, up to the point of determining a manipulated variable, is assumed by the instrument "Fuzzy Inference". This type of information processing evaluates physical variables via a type of average formation that recreates the process assessment of the human brain in a similar way.

The system structure describes the data flow in the Fuzzy Logic system. The input interfaces are fuzzificating the input signals. Therefore, they convert the analogue values in affiliation grades. The fuzzification follows Fuzzy interfaces: The "if-then" rules are committed in the rule blocks and though the input values are committed in linguistic output values.

These are transformed in the output interfaces through a defuzzification in analogue values.

The structure of the fuzzy system with input interfaces, rule blocks and output interfaces is shown in Figure 13. The thin, connecting lines are symbolising the data flow.



### Input interfaces



The hardware of the Fuzzy Logic includes a CPU (central processing unit) as well as the input and output cards. In this specific case the hardware components were produced by Möller electric, because all other components were bought from this factory, too. By doing so, the compatibility of the system could be guaranteed. The central hardware units, that means the CPU named PS416-CPU-400, the electric power unit PS416-POW-400, one analogue input card (PS416-AIN-400) and the output card (PS416-AIO-400) are shown in Figure 14. The Fuzzy Logic control system was integrated with all input and output signals together with the rules on this unit shown.



Figure 14: Hardware component of the Fuzzy Logic control system

The integration of the Fuzzy Logic was depicted in the visualisation of the conventional control system, so that the plant engineers can see whether the Fuzzy Logic control system is switched on or not. Each of the Fuzzy Logic components can be turned on or off by the plant engineers.

### 6.2 Results of data analysis of the Fuzzy Logic implementation

The monitoring of the Fuzzy Logic control system started right after the commissioning of the Fuzzy controller (in October 2002) and was proceeded in extended form until the mid of July 2003.

The performance of the basic version was presented to the contract partners by TU BAF in October 2002. The presentation included the online comparison between the Fuzzy Logic control system and the conventional one, a check-up of the system definition ("design") and the linguistic variables, a check-up of the Fuzzy operators and methods of defuzzification, an analysis of the transfer behaviour, an analysis of the time response and an analysis procedure by means of the artificial neural network (ANN).

The artificial neural network (ANN) and genetic algorithm software was used to gain a competitive edge in solving prediction, classification, modelling and estimation or optimisation problems. That means an intensive use of technology which performs regression analysis on non-linear problems.

The Fuzzy Logic control system for the thermal oil boiler was put into operation after a security check-up and implementation of the Fuzzy Logic in the process control system in November 2002 (see Figure 15).



**Figure 15:** First test of the Fuzzy Logic controller for the thermal oil boiler of the CHP plant Lienz (06-11-2002)

The first test run started on 06-11-2002 between 02:45 pm and 05:15 pm and showed successfully the advantage of the new control system. It is shown in Figure 15 that the new control system rises the thermal power output up to  $6 \text{ MW}_{\text{th}}$  and stabilises the feed temperature of the thermal oil boiler at the target value. For controlling the actual values of the ventilation systems and the fuel supply, calculations including the levels of negative furnace pressure, O<sub>2</sub> concentration in the flue gas leaving the boiler as well as feed and return temperature of the thermal oil boiler were carried out.

The thermal oil boiler was working uninterruptedly with the Fuzzy Logic control system for 14 days after the successful first test run. Due to frequent adjustments of single parts of the CHP plant, a continuous adaptation of the Fuzzy Logic control system was required. For this reason the new parameters such as CO emissions and the thermal power output were included in the Fuzzy Logic control system. Additionally, a Fuzzy Logic control system, which is based on the experiences gained from the thermal oil boiler, was developed, installed and tested on the hot water boiler.



Figure 16: Comparison of the process control systems between 16-12-2002 and 19-12-2002 regarding relevant combustion process parameters of the thermal oil boiler at nominal load conditions

Figure 16 illustrates the negative furnace pressure level in the combustion chamber and the  $O_2$  concentration in the flue gas at the outlet of the thermal oil boiler with and without the Fuzzy Logic control system. Through the stabilised rotation of the flue gas ventilation system and the possible fast reaction of the secondary ventilation system, the occurring fluctuations of the respective levels of negative furnace pressure and  $O_2$  concentration in case of using Fuzzy Logic are lower than otherwise.

Concluding, the Fuzzy Logic based process control system was successfully implemented and tested for the operation at full and partial load of the biomass boilers of the CHP plant Lienz. The Fuzzy Logic process control system can reduce the emissions as well as stabilise (smoothen) the operation of the CHP plant and therefore increase the efficiency of the overall plant and its components. For the thermal oil boiler the efficiency could be increased by about 2 % in comparison to an operation with the conventional control system.

#### 6.3 Results from operation of the hydraulic system at partial load

The comparison between the conventional and the Fuzzy Logic controlled hydraulic system of the CHP plant Lienz was considered as representative for the measurement and evaluation period performed at 26-06-2003 with a Fuzzy Logic controlled hydraulic system and with a conventionally controlled hydraulic system regarding the operation of the ORC process. The comparability was given by the circumstance that the conventional control system was working under supervision of the authorised plant engineer. On the other hand the Fuzzy Logic control system was in operation on the same day. Both control systems were working at partial load operation with short periods in glow preservation mode within the time period



between 12:00 am and 07:00 pm.

<u>Explanations:</u>  $dT [^{\circ}K] \dots delta T [^{\circ}K]$ ; delta T gives the difference between the temperature levels of the feed and the return temperature of the water of the ORC condenser.

In Figure 17, the differences between the conventional hydraulic control and the Fuzzy Logic hydraulic control can be seen. The conventional control system works with higher rotation of the ORC pumps, because the difference (dT) between the levels of feed and return water temperature is relatively low. The consequence is that more thermal power for the district heating network, than really needed, is produced. An advantage, from this point of view, is that the heating process is stabilised, but the disadvantage is that the ORC process does not work efficiently because of the high fluctuations concerning ORC pump rotation, due to the relatively low difference between the feed and return temperature.

The Fuzzy Logic hydraulic control system reduced the return temperature of the ORC process, because the thermal power produced was reduced to the exact value of district heating power needed. The difference between the feed and the return temperature levels increased, following the ORC process was working more efficiently and the ORC pumps had

**Figure 17:** Test of the Fuzzy Logic control system for the hydraulic system at partial load operation

to work on a lower level therefore. The disadvantage of this control system is, that the heating process is connected directly with the demand of the thermal power of the district heating network, so that a small variation within the demand of the district heating network has a simultaneous effect on the heating process (as shown in Figure 17 between 04:30 pm and 05:30 pm).

Concluding, the auxiliary electric power consumption could be reduced and the electric power output of the ORC process slightly increased by applying the Fuzzy Logic to the hydraulic control system at partial load operation. Tests at full load operation could not be performed within the monitoring period but are foreseen for the winter period 2003/2004.

### 7 Economic analysis of the ORC process

Based on the project in Lienz and on experiences with other biomass CHP applications, comprehensive investigations concerning the economy of decentralised biomass CHP plants have been performed. In this section the electricity production costs of a biomass CHP plant based on a 1,000 kW<sub>el</sub> ORC process are exemplarily outlined.

The calculation of the production costs for electricity is based on the VDI guideline 2067 [7]. This cost calculation scheme distinguishes four types of costs:

- capital costs (depreciation, interest costs),
- consumption based costs (fuel, consumables),
- operation-based costs (personnel costs, costs for maintenance) and
- other costs (administration, insurance).

Technical data and important side constraints for the cost calculations are shown in Table 8. These data are taken in order to secure realistic figures for a biomass CHP plant. For a more detailed presentation of the calculation of electricity production cost see [8, 9].

The capital costs are based on additional investment costs and consider only the surplus investment costs of a CHP plant in comparison to a conventional biomass combustion plant with a hot water boiler and the same thermal output. The additional investment costs form the correct basis for the calculation of the electricity production costs of a CHP plant. This approach seems to be meaningful because decentralised biomass CHP plants (nominal electric capacity below 2.0 MW<sub>el</sub>) primarily produce process or district heat. An electricity-controlled operation of decentralised biomass-fired CHP plants is neither economically nor ecologically meaningful due to the limited electric efficiencies achievable with such systems. In contrast, the overall efficiency of a heat controlled biomass CHP plant can be very high (up to 90 %). Consequently, electricity production is an alternative and implementation depends mainly on the profitability of the additional investment necessary. Additionally, it is possible to separate costs for electricity production from costs for heat production and to make them independent of the combustion system used. This approach allows clear comparisons of costs for heat only and CHP applications and forms the basis for a correct calculation of the electricity production costs.

The additional investment costs of a biomass CHP plant based on a 1,000  $kW_{el}$  ORC process compared to a conventional biomass heating plant with the same thermal output are shown in

Table 8 without consideration of subsidies. Table 9 gives an overview of the electricity production costs calculated from the total annual surplus costs for the biomass CHP plant in comparison to a conventional biomass heating plant with the same thermal output.

**Table 8:**Overview of the technical data and surplus investment costs of a biomass-fired<br/>CHP plant based on a 1,000 kW<sub>el</sub> ORC process in comparison to a conventional<br/>biomass-fired heat only plant (hot water boiler) with the same thermal power<br/>output

TECHNICAL DATA			
Nominal electric capacity	P <sub>el</sub>	[kW <sub>el</sub> ]	1,000
Overall net electric efficiency - CHP plant	Vel	[%]	15
Total efficiency (heat and electricity)		[%]	80
Total thermal efficiency for a biomass heating plant (reference)		[%]	85
Full load operating hours of the CHP plant		[h/a]	5,000
Annual electricity production	Q <sub>el</sub>	[kWh/a]	5,000,000
Generated amount of heat	$Q_{th}$	[kWh/a]	21,666,700
Total primary energy needed	Q <sub>fuel</sub>	[kWh/a]	33,333,300
Primary energy needed for electricity production	$Q_{\mathit{fuel-CHP}}$	[kWh/a]	7,843,100
ADDITIONAL INVESTMENT COSTS			
(compared to a conventional biomass heating plant)			
Thermal oil boiler, thermal oil cycle and economiser		[€]	650,000
Installation inclusive fittings		[€]	65,000
ORC-module		[€]	1,360,000
Generator		[€]	included
Control system		[€]	36,000
Grid connection (transformer, etc.)		[€]	130,000
Engineering		[€]	204,000
Others (buildings, hydraulic system)		[€]	320,000
Investment costs	Ι	[€]	2,765,000
Spezific Investment costs	I <sub>spec</sub>	[€/kW <sub>el</sub> ]	2,765

An average fuel price of  $15.0 \notin$ /MWh (NCV), an interest rate of 6 % p.a. and a service life of the CHP unit of 10 years were taken as a basis. The service life is derived from the fact that the feed-in tariffs for electricity from biomass are secured for at least 10 years according to present Austrian regulations. The biomass fuel price represents the price of a mixture of bark, industrial wood chips and forest wood chips, which is a representative fuel blend for Austrian conditions taking a secured long-term fuel availability into consideration. Only the amount of additional fuel needed for electricity production is considered (see Table 8), taking into account that the overall average efficiency of a biomass CHP plant is usually slightly lower than that of a heat only application (80 % instead of 85 %). The annual costs for consumables (such as lubricants and sealings), maintenance and other expenditures are calculated by taking a percentage of the additional investment costs based on operational experience. The personnel costs and the amount of electricity needed for the thermal oil circulation are derived

from experiences already gained from the CHP plant in Lienz as well as from the CHP plant in Admont. Concerning the capacity utilisation of the ORC unit, 5,000 full load operating hours have been considered for the base case scenario.

**Table 9:**Calculation of the specific electricity production costs of the biomass-fired CHP<br/>plant based on a 1,000  $kW_{el}$  ORC process as surplus costs in comparison to a<br/>conventional biomass-fired heat only plant (hot water boiler) with the same<br/>thermal power output

<u>Explanations</u>: basic data taken from Table 8; no investment subsidies considered; costs for maintenance, consumption and operation based costs derived from experience [8], [9]; calculation based on VDI guideline 2067, I ... investment costs

Capital costs			
Real interest rate	i <sub>r</sub>	[%/a]	6
Useful life of CHP	n	[a]	10
Total capital costs	K <sub>k</sub>	[€/a]	375,675
Spec. capital costs		[€/kWh <sub>el</sub> ]	0.075
Consumption based costs			
Fuel costs (15.0 €/MWh <sub>fuel</sub> )		[€/a]	117,647
Consumables - ORC (0.3 % of I)		[€/a]	8,295
Electricity demand - thermal oil cycle		[€/a]	18,000
Total consumption based costs	K <sub>v</sub>	[€/a]	143,942
Spec. consumption based costs		[€/kWh <sub>el</sub> ]	0.029
Operation based costs			
Personnel costs (400 hours; 30 €/h)		[€/h]	12,000
Maintenance costs (2.0 % of I)		[€/a]	55,300
Total operation based costs	K <sub>b</sub>	[€/a]	67,300
Spec. operation based costs		[€/kWh <sub>el</sub> ]	0.013
Other costs			
Administration and insurance costs (0.7 % of I)		[€/a]	19,355
Total other costs	K <sub>s</sub>	[€/a]	19,355
Spec. other costs		[€/kWh <sub>el</sub> ]	0.004
Total electricity production costs	K <sub>ges</sub>	[€/a]	606,271
Spec. total electricity production costs		[€/kWh <sub>el</sub> ]	0.121

As shown in Table 9 the specific electricity production costs calculated amount to  $121 \notin MWh_{el}$ . For an ORC unit with a nominal electric capacity of 500 kW and the same basic conditions, the specific electricity production costs increase by approximately 15 % mainly due to higher specific investment costs (economy-of-scale effect). The most relevant cost factor is the capital costs, representing more than 60 % of the overall specific electricity production costs. The contribution of the fuel costs, as a second relevant influencing parameter, to the specific electricity production costs amounts to about 20 %.

The capacity utilisation of the CHP plant influences the electricity production costs to a high extent (see Figure 18) and represents the most important influencing variable. 5,000 full load operating hours per year can be recommended as a minimum value for economic operation. In

heat controlled CHP systems this requirement makes a correct design of the plant capacity, based on the annual heat output line, essential. Of special interest are decentralised biomass CHP units for the wood processing and wood manufacturing industry (where high amounts of process heat are required) as well as for larger biomass district heating plants (where the base load boiler could be changed to a CHP unit).



**Figure 18:** Specific electricity production costs vs. the capacity utilisation (electric full load operating hours) for a 1,000 kW<sub>el</sub> ORC plant in heat controlled operation



Figure 19: Specific electricity production costs vs. the biomass fuel costs for a  $1,000 \text{ kW}_{el}$  ORC plant in heat controlled operation

Another important factor influencing the electricity production costs is the fuel price (see Figure 19). Consequently, it is recommended that the feed-in tariffs for electricity from biomass should be defined according to the fuel used, as the prices for bark (7 to  $9 \notin$ /MWh NCV), industrial wood chips (12 to  $16 \notin$ /MWh NCV) and forest wood chips (18 to  $22 \notin$ /MWh NCV) vary strongly.

By comparing the specific electricity production costs calculated with the feed-in tariffs granted in different central European countries (investment subsidies have also to be taken into account, if available), an economically viable operation of such plants is possible in Austria, Germany, Switzerland, the UK and Northern Italy, if the framework conditions pointed out are fulfilled (heat controlled operation and high capacity utilisation).

Concerning future objectives, a further reduction of the investment costs of ORC plants (up to about 25 %) seems realistic within the next years based on the experiences and the optimisation potential gained from demonstration projects, especially when a small series production can be achieved.

### 8 Overall management of the project

The co-ordinator of the project (Stadtwärme Lienz Produktions- und Vertriebs-GmbH, who owns and operates the overall CHP plant Lienz) was responsible for the overall management of the project described, for the publication and dissemination of the results obtained in the course of this demonstration project as well as for the completion and submission of the project reports to the EU.

In the course of the whole project duration a couple of meetings between Stadtwaerme Lienz, the principal contractors and other contractors (which are responsible for the design of the non-innovative components of the plant) took place in order to organise the engineering, commissioning and monitoring of the different parts within the project (see Figure 20).

The cooperation as well as the overall project management between all project partners mentioned can be evaluated as very good. Regarding the objectives of the EU demonstration project, it has to be stated that all milestones have been achieved, most of them according to schedule (see Figure 20). Occurring, exceptional delays (in particular for the Fuzzy-Logic control system) were compensated through intensive task forces. Discussion forums and development workshops were held on basis of personal meetings on a highly professional level. The communication, data exchange and online monitoring of the CHP plant have been established via the use of modern communication technology (appropriate software, E-Mail, Internet, etc).

		0	)urati	on / c	ritical path				: see milestone list			
Workpackage	1st year			2nd year				3rd year				
descriptions	<u>, </u> NW	400	0200	1 <u>1</u>	1 <u>3</u>	16	19 20	22 23 24	25 26 27	28 29 30	<u>33</u> 32	35 35 35
Workpackage 1: Development and Design	A	1	≯									
Task 1.1 Overall design CHP plant												
Task 1.2 Detailed design of the ORC process			•									
Task 1.3 Development and design of the Fuzzy Logic control system												
Workpackage 2: Manufacture		Ŷ		$\diamond$								
Task 2.1 Manufacture of the ORC process			÷	•								
Task 2.2 Setup of a modular Fuzzy Logic memory-programmed control system			4	•								
Workpackage 3: Assembly/installation/erection			<	त ग	∳							
Task 3.1 Erection of the ORC process												
Task 3.2 Final installation of hardware and software components												
Workpackage 4: Commissioning					Ţ	•						
Task 4.1 Commissioning of the ORC process												
Task 4.2 Test of basic version and commissioning of the Fuzzy controller						Ρ						
Workpackage 5: Monitoring, economic and technological evaluation, exploitation of results						٧	ļ		ļ	$\geq$	•	
Task 5.1 Monitoring of the overall plant performance												
Task 5.2 Monitoring of the ORC process												
Task 5.3 Monitoring of the Fuzzy Logic control system												
Task 5.4 Technological and economic analysis of the innovative units												
Task 5.5 Exploitation of results achieved												
Workpackage 6: Management, dissemination and market introduction	Y				<u> </u>							
Task 6.1 Overall management of the project											•	
Task 6.2 Dissemination of results											•	
Task 6.3 Preparation of follow-up projects as a basis for market introduction												

# Figure 20: Comparison of the project time and workplan - as scheduled and as performed

<u>Explanations</u>: the grey-coloured bars represent the scheduled duration for each task of the work packages mentioned; in comparison to the planned time table, the red-coloured bars show the real project procedure with slight deviations in terms of starting points and durations for each task of the work packages mentioned.

The list of milestones comprises the following topics:

• Work package 1:

Completed plant design covering a ready set of drawings of all components of the CHP plant fitting together.

Developed and structured verbal knowledge as the basis to integrate plant-specific knowledge in control design.

• Work package 2:

ORC process ready for installation.

Combination of all elements of the modular Fuzzy memory programmed control system and of the process management system.

• Work package 3:

Completed installation, assembly and erection of the ORC process and successful final installation of the Fuzzy Logic control system ready for start-up.

- Work package 4: Commissioning of the Fuzzy Logic controlled CHP plant based on an ORC process.
- Work package 5:

Completion of the monitoring phase covering a comprehensive evaluation of the overall plant performance as well as of the innovative units in particular and completion of the performance of a technological and economic analysis as a basis for future optimisation and market introduction.

• Work package 6:

Dissemination and exploitation of the results achieved. Final report to the European Union.

#### 8.1 Dissemination and exploitation of results achieved

The successful development of the project led to several awards and activities concerning the exploitation and dissemination of results. The overall project as well as the city of Lienz have won a considerable number of prices and awards (8 in total), due to the relevance and technological excellence of this demonstration project for other potential future projects in Austria, Italy and the EU regarding decentralised CHP production from biomass. Among the prices gained, the most important one is the Energy Globe Award Austria 2002.

The most important dissemination activities, cover the arrangement of an Open Day with a highly positive feedback and interest from local, national and international visitors and the performance of the 11<sup>th</sup> Austrian Biomass Day in Lienz, which took place from 28-10-2002 to 30-10-2002 on site with more than 20 presentations from national and international experts and a guided tour through the CHP plant. Up to now more than 100 national and international excursions through the CHP plant have been guided. Moreover, information brochures and leaflets about the CHP plant Lienz have been published and distributed.

Ongoing activities are the already mentioned dissemination of information brochures about the CHP plant and its innovative technological components among interested persons as well as the performance of guided tours through the CHP plant. Additionally, a number of papers were published and lectures were held at biomass and energy technology conferences and seminars to inform a broad audience about the new and innovative technology. A compilation about the most relevant publications can be found in chapter 8.3.

### 8.2 Degree of success and outlook

The dissemination of project results achieved was performed in co-operation of all 4 project partners: Stadtwärme Lienz Produktions- und Vertriebs-GmbH (STADTWAERME LIENZ), BIOS BIOENERGIESYSTEME GmbH (BIOS), TURBODEN Srl (TURBODEN) and TECHNISCHE UNIVERSITÄT Bergakademie Freiberg (TU BAF).

Immediately after the commissioning of the CHP plant the partners STADTWAERME LIENZ, TURBODEN and BIOS started the exploitation of results achieved by organising guided tours through the plant and by searching for follow-up projects. The results obtained from the technological analysis (see chapter 4) are directly utilised for the preparation of such follow-up projects (improved replications).

Summing up, the most important results achieved are the following:

- A verification of the excellent partial load behaviour of the ORC process has taken place.
- The ORC process can be considered as a mature and reliable CHP technology with a proven record of success.
- The thermal oil boiler operating at atmospheric pressure reduces personnel costs in comparison to the operation of a conventional steam boiler.

- Additionally, the operation and maintenance costs of the ORC process are low in comparison to a conventional steam turbine due to the high degree of automation given and due to the closed cycle operation of the ORC system, which minimises operation costs.
- The implementation of the internal heat recovering system, by combining the thermal oil boiler with a thermal oil economiser and a combustion air pre-heater, increased the net electric efficiency of the overall CHP plant to about 15 % (related to the NCV of the biomass fuel), which is a considerable improvement compared to the first ORC implementation in Admont, where the overall electric efficiency amounts only to about 13 %.
- From an ecological point of view, the project has also contributed to a considerable reduction of CO<sub>2</sub>-, NO<sub>x</sub>- and dust emissions in particular by the implementation of the biomass CHP plant Lienz. Regarding the environmental performance, this project has significantly increased the regional air quality and therefore also the quality of life in the supply area.

Further biomass CHP projects based on the ORC technology, which are already implemented in Austria are located in Fussach, where a combined electricity and cold production from biomass takes place (nominal electric capacity 1,100 kW<sub>el</sub>), and near Vienna (nominal electric capacity 1,000 kW<sub>el</sub>). Both of these projects already use the ORC technology development. TURBODEN was also responsible for the manufacturing and supply of these ORC units in question.

It is also to mention that one shareholder of STADTWAERME LIENZ, the "Tiroler Wasserkraft AG" (Tyrolian utility) is currently in the engineering and design phase for the erection of 2 further ORC processes integrated in CHP plants based on biomass fuels in Tyrol, Austria (Längenfeld and Zams-Landeck). Moreover, 6 additional ORC units with nominal electric capacities between 500 and 1,500 kW<sub>el</sub> are currently under construction in Austria and Italy as well as 5 new ORC plants between 300 and 1,000 kW<sub>el</sub> are to be realised in 2003 in Germany.

Summing up, it can be stated that the new biomass CHP technology based on the ORC process is an economically and technologically interesting solution for decentralised applications. The potential for such plants is large if one considers that more than 400 biomass district heating plants are in operation and that about 50 biomass-fired boilers with a nominal capacity above 1.0 MW<sub>th</sub> are installed in Austria, at present. But also in other countries with comparable side constraints (like in Germany, Switzerland, Northern Italy and the new Eastern European member states) a huge future potential is given.

A basic requirement for an ecological and cost-effective operation of such CHP plants is that not only the electricity but also the heat produced by the ORC process can be utilised as process or district heat (heat-controlled operation of the overall system). The greatest application potential of biomass-fired CHP plants based on ORC cycles is given in mediumsized wood manufacturing and wood processing enterprises, decentralised waste-wood combustion plants as well as biomass district heating plants (newly erected or adapted existing plants).

The future development aims focus on a further improvement of the electric efficiency by increased operation temperature and pressure levels, by two-stage ORC cycles as well as by

combined hot air turbine - ORC cycles. These development potentials seem interesting as well as promising and will be exploited from the project partners within the next years. BIOS performs the engineering for most of the biomass CHP projects mentioned above and therefore utilises its competence and experience gained successfully.

The data gained and monitoring results achieved of the Fuzzy Logic control system (see chapter 6) will also be exploited commercially after successful demonstration. This approach follows a logical market introduction and product development process, in which a public institution (TU BAF) is responsible for the R&D activities as well as for the implementation of this innovative control system and a commercial company (Ingenieurbüro für Prozessoptimierung, Dr. Gierend - IPG) is engaged in the prosperous dissemination of the finalised product.

The most important results achieved from TU BAF for the Fuzzy Logic control system are the following:

- The Fuzzy Logic based process control system was successfully implemented and tested for the operation at full and partial load of the biomass boilers as well as for the hydraulic system of the CHP plant Lienz.
- The Fuzzy Logic process control system can reduce the emissions as well as stabilise (smoothen) the operation of the CHP plant and therefore increase the efficiency of the overall plant and its components. For the thermal oil boiler the efficiency could be increased by about 2 % in comparison to an operation with the conventional control system.

In future IPG will not only attend the further implementation of the Fuzzy Logic in the CHP plant Lienz (monitoring, enlargement of functions as well as optimisation of the control system), but is also strongly interested in further applications of this new and innovative process control system for other projects, based on thermal utilisation of biomass or thermal waste treatment.

Summing up the facts mentioned, the future application and dissemination potentials underline the success of the correspondent project group as well as of the overall demonstration project.

### 8.3 List of publications

The following papers and information brochures have been published in the course of the project:

- [1.] OBERNBERGER Ingwald, THONHOFER Peter, REISENHOFER Erwin, 2002: Description and evaluation of the new 1,000 kWel Organic Rankine Cycle process integrated in the biomass CHP plant in Lienz, Austria. In: Euroheat & Power, Volume 10/2002, pp.18-25
- [2.] OBERNBERGER Ingwald, THONHOFER Peter, REISENHOFER Erwin, 2002: Holz-Heizkraftwerk Lienz demonstriert ORC-Prozess. In: Holz-Zentralblatt Nr. 146, DRW-Verlag Weinbrenner GesmbH&Co, Leinfelden-Echterdingern, Deutschland
- [3.] REISINGER HEINZ, POINTNER Gerold, 2002: Wärme und Strom für die Stadt Lienz. Informationsbroschüre, 1. Auflage, Stadtwärme Lienz Produktions und Vertriebs GmbH (Hrsg.), Lienz, Österreich
- [4.] OBERNBERGER Ingwald, 2003: Biomasse-Kraft-Wärme-Kopplung auf ORC-Basis Vorstellung der EU-Demonstrationsprojekte Holzindustrie STIA/Admont und Fernheizkraftwerk Lienz in Österreich: In: Tagungsband zum 12. Symposium "Energie aus Biomasse – Biogas, Flüssigkraftstoffe, Festbrennstoffe", Kloster Banz, Deutschland, OTTI Energie-Kolleg (Hrsg.), Regensburg, Deutschland

Comprehensive information sections about the ORC technology and the CHP plant Lienz are available via Internet from the following homepages:

- [1.] <u>http://www.bios-bioenergy.at</u>
- [2.] <u>http://www.turboden.com</u>
- [3.] <u>http://www.stadtwaerme-lienz.at</u>

### 9 Literature

- 1 REPUBLIK ÖSTERREICH, 2001: Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über Qualitätsanforderungen an Komposte aus Abfällen (Kompostverordnung); BGBl. Nr. 292/2001, Teil II, Wien, am 14.08.2001, Österreich
- 2 BMLFUW (BUNDESMINISTERIUM FÜR LAND- UND FORSTWIRTSCHAFT, UMWELT UND WASSERWIRTSCHAFT WIEN, FACHBEIRAT FÜR BODENFRUCHTBARKEIT UND BODENSCHUTZ), 1996: Der sachgerechte Einsatz von Pflanzenaschen im Wald; Geschäftsstelle: Agentur für Gesundheit und Ernährungssicherheit GmbH und Bundesamt für Ernährungssicherheit, Wien, Österreich
- 3 BMLFUW (BUNDESMINISTERIUM FÜR LAND- UND FORSTWIRTSCHAFT, UMWELT UND WASSERWIRTSCHAFT WIEN, FACHBEIRAT FÜR BODENFRUCHTBARKEIT UND BODENSCHUTZ), 1998: Der sachgerechte Einsatz von Pflanzenaschen im Acker- und Grünland; Geschäftsstelle: Agentur für Gesundheit und Ernährungssicherheit GmbH und Bundesamt für Ernährungssicherheit, Wien, Österreich
- 4 REPUBLIK ÖSTERREICH, 2000: Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über die Begrenzung von Abwasseremissionen aus der Reinigung von Abluft und wässrigen Kondensaten (AEV Abluftreinigung), BGBl. Nr. 218/2000, Teil II, Wien, am 18.07.2000, Österreich
- 5 BEZIRKSHAUPTMANNSCHAFT LIENZ, 2001: Bescheid GZ 209-1141/19; Abteilung für Gewerbe/Tourismus, Bezirkshauptmannschaft Lienz, Lienz, Österreich
- 6 KOMMUNALKREDIT AUSTRIA AG, 2001: Technische Auflagen der Kommunalkredit Austria AG des Förderungsvertrages zum Antrag GZ A0.10302; Kommunalkredit Austria AG, Wien, Österreich
- 7 VEREIN DEUTSCHER INGENIEUERE (VDI), 1983: Berechnung der Kosten von Wärmeversorgungsanlagen – Betriebstechnische und wirtschaftliche Grundlagen; Richtlinie, VDI-Verlag GmbH, Düsseldorf, Deutschland
- 8 OBERNBERGER I., HAMMMERSCHMID A., 1999: Dezentrale Biomasse-Kraft-Wärme-Kopplungstechnologien Potential, Einsatzgebiete, technische und wirtschaftliche Bewertung; Schriftenreihe "Thermische Biomassenutzung", Band 4, ISBN3-7041-0261-X, dbv-Verlag der Technischen Universität Graz, Graz, Österreich
- 9 OBERNBERGER I., BINI R., NEUNER H., PREVEDEN Z., 2001: Biomass fired CHP plant based on an ORC cycle – project ORC-STIA-Admont; final report of the EU-THERMIE project No. BM/120/98, European Commission, DG TREN (ed.), Brussels, Belgium