

# THERMIE-A-PROJECT

## **„Biomass fired CHP plant based on an ORC cycle - Project: ORC-STIA-Admont“**

Contract no.: BM/120/98/AT/IT

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Admont, 26th March 2001

# **Biomass fired CHP plant based on an ORC cycle -**

## **Project: ORC-STIA-Admont**

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### **1. Aim**

The project mainly focuses on the implementation of a biomass-fired CHP plant based on an ORC process (Organic Rankine Cycle) as a first demonstration within the European Community. An ecological and cost-effective operation of the process is only possible, if not only the electricity but also the heat produced by the ORC process can be utilised. The proper integration of the ORC process into the heat supply system and the installation of a flue gas condensation unit result in a maximum increase in the total efficiency of the whole process. The plant supplies STIA-Holzindustrie GmbH with process and space heat and the Benedictine monastery of Admont with space heat from biomass. Furthermore, the ORC process covers almost half of the electricity demand ( $\approx 45\%$ ) of STIA-Holzindustrie GmbH on a renewable basis. Only sawdust and chemically untreated wood residuals arising in-house are fired at the plant. In this way it is possible to substitute fossil fuels at the Benedictine monastery of Admont (heavy heating oil) and at STIA-Holzindustrie GmbH (light heating oil) as well as electricity from fossil fuels. A further aim of the project is the reduction of NO<sub>x</sub> and dust emissions. Apart from primary measures, an innovative SNCR process based on glue water injection has been tested to reduce NO<sub>x</sub> emissions. Moreover, for efficient reduction of dust emissions with the flue gas a rotational particle separator, which also represents a new and innovative technology, has been tested for the first time in large-scale biomass combustion plants. The rotational particle separator has a significantly lower cut-diameter than conventional multi-cyclones and therefore aims at higher dust precipitation efficiencies.

### **2. Introduction**

The biomass-fired combined heat and power production plant is located at the site of STIA-Holzindustrie GmbH in Admont, Styria, Austria in a newly built boiler house (see Figure 1). From there a district heating supplies the Benedictine monastery of Admont and the process heat consumers at STIA. The short pipe network (about 470 m only) guarantees low heat losses and a very high installed thermal power per meter pipe network.

Before the realisation of the new biomass-fired CHP plant STIA-Holzindustrie GmbH covered its process and space heat demand for the production sheds and warehouses with one biomass-fired and two oil-fired (light heating oil) furnaces. The heat supply of the Benedictine monastery of Admont was provided by three oil-fired (heavy heating oil) furnaces. As these old combustion units did not meet the technical standards required any more, STIA-Holzindustrie GmbH decided to substitute them by a new and completely biomass-based CHP system.



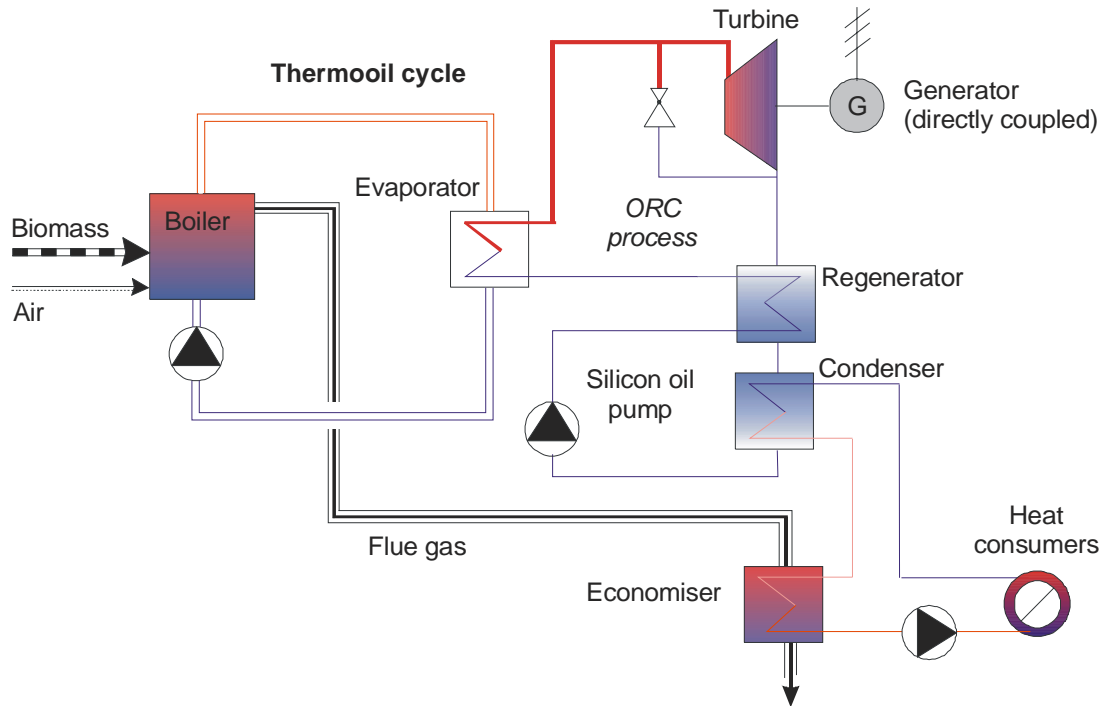
**Figure 1: View of the Admont CHP plant with fuel storage hall and boiler house**

### **3. Technical description**

The overall plant consists of two combustion units, one with a thermal oil boiler (nominal capacity  $3.2 \text{ MW}_{\text{th}}$ ) and the other with a hot-water boiler (nominal capacity  $4.0 \text{ MW}_{\text{th}}$ ). Each furnace is followed by a dust precipitator combined with a common flue gas condensation unit. The ORC plant is connected with the thermal oil boiler via a thermal oil cycle and has an electric nominal capacity of  $400 \text{ kW}_{\text{el}}$ . After the successful start-up of the new CHP plant the two oil-fired combustion units at STIA were shut down and are now only used as stand-by units. Furthermore, the three oil-fired furnaces at the Benedictine monastery of Admont were shut down.

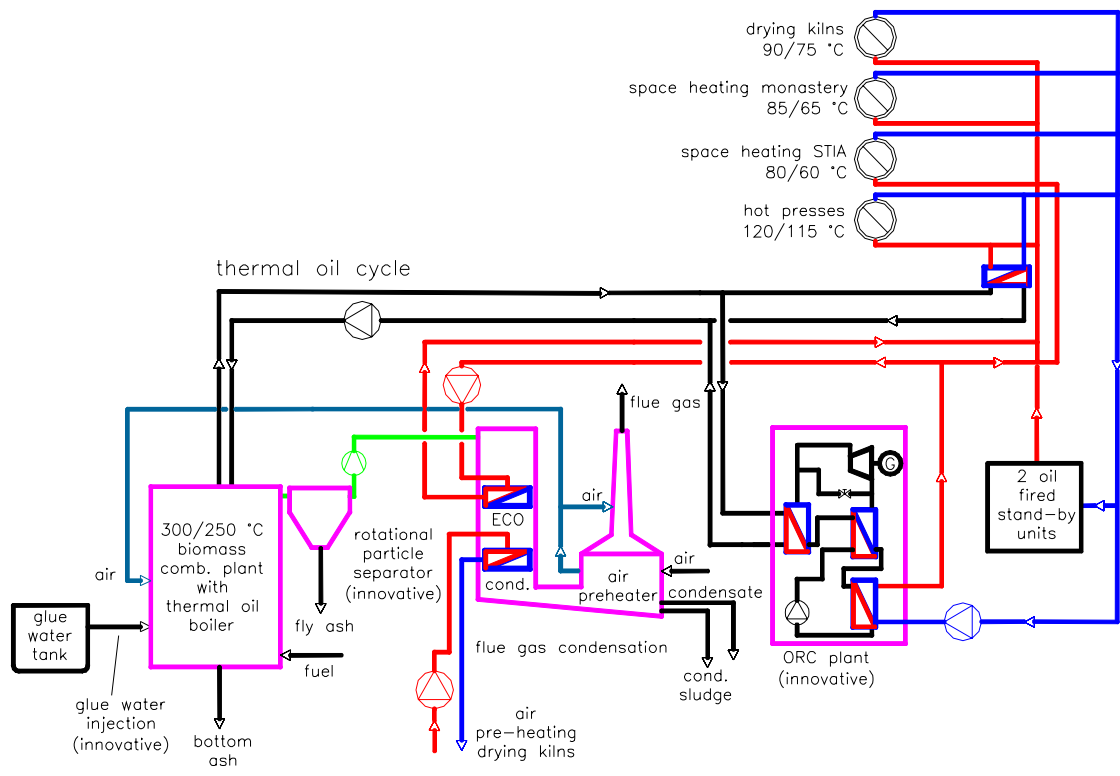
The main innovative component of the process is the biomass-fired CHP plant based on an ORC process (nominal electric capacity  $400 \text{ kW}$ , nominal thermal capacity  $2.25 \text{ MW}$ ). Figure 2 outlines the working principle of the ORC cycle. The ORC process is connected with the biomass-fueled furnace via a thermal oil cycle and the thermal oil boiler (nominal capacity  $3.2 \text{ MW}$ ;  $0.95 \text{ MW}$  of the thermal oil power are directly utilised via hot presses). The ORC unit itself operates as a completely closed process utilising a silicon oil as organic working medium. This pressurised organic working medium is vaporised by the thermal oil in the evaporator and then expanded in a two-stage axial turbine which is directly connected to an asynchronous generator. Subsequently, the expanded silicon oil passes through a regenerator (where cycle-internal heat recuperation takes place) before it enters the condenser. There condensation of the working medium takes place at a temperature level which allows the heat recovered to be utilised (hot water feed temperature about  $80$  to  $90^\circ\text{C}$ ). The liquid working medium then passes the feed pumps to achieve the appropriate pressure level of the hot end of the cycle again.

One innovative aspect of the biomass CHP plant is the choice of a new, environmentally friendly and suitable organic working medium necessitated by the higher temperature levels on the hot and cold side of the ORC process as compared to electricity-only applications (as applied in geothermal applications). A further innovative aspect is the first demonstration of docking an ORC plant to a biomass-fired furnace via a thermal oil cycle.



**Figure 2: Working principle of the biomass-fired ORC process**

The further innovative components of the plant comprise a glue water injection system into the secondary combustion chamber of the biomass-fired furnace and the rotational particle separator. Due to the urea content of the glue water this waste stream can be used as a  $\text{NO}_x$ -reducing agent similar to conventional SNCR processes but with a lower  $\text{NO}_x$  reduction potential. It can be considered as an innovative technology since no experience has yet been gathered regarding this method. The rotational particle separator is a new technology for the efficient precipitation of solid and liquid particles  $> 0.1 \mu\text{m}$  from gas streams. Since this is the first time that it is used in a large-scale biomass combustion plant and at temperatures of about  $200^\circ\text{C}$ , it can also be considered as an innovative technology. Both systems, the rotational particle separator as well as the glue water injection system into the secondary combustion chamber have been installed and tested at the CHP plant but had finally to be removed again due to operational problems that could not get solved (mechanical instability of the filter element of the RPS; pipe blockage in the glue water injection system due to its unfavourable rheological properties and its high contamination with sawdust and dust particles). The RPS was replaced by a multi-cyclone and the glue water will be directly added to the fuel instead of injecting it directly into the furnace.



**Figure 3: Process flowsheet of the overall biomass CHP plant at STIA, Admont**



**Figure 4: Delivery of the ORC plant**

Explanations: left hand: evaporator; right hand: regenerator; center in front: turbine (white) and generator (green); center back: condenser

Apart from the thermal oil boiler unit mentioned above, a second biomass furnace with a hot-water boiler (nominal capacity: 4.0 MW) is installed. The flue gas of both units enters a common flue gas condensation plant which has been designed in order to achieve an efficient energy recovery of the flue gas and to optimise thermal efficiency. The basic thermal load is covered by the thermal oil boiler. If the heat consumption exceeds the capacity of the thermal oil boiler, the hot-water boiler unit is set into operation. This basic load design of the ORC unit ensures about 7,200 full load operating hours per year as soon as the process heat consumers (drying chambers) have reached their full thermal capacity. Figure 3 shows the process flowsheet of the overall CHP plant and Figure 4 a photograph of the ORC plant at its delivery.

## 4. Performance of the plant

The combustion system and the flue gas condensation unit started operation in autumn 1998, the ORC plant in August 1999.

### Combustion units:

In general the operation of the CHP plant was satisfactory throughout the monitoring phase. To determine the energy efficiencies of the single units of the CHP plant Admont, several test runs were performed. During these test runs the thermal efficiency of the combustion plants and the electricity demand of both combustion units as well as of the whole installation (combustion units and flue gas condensation unit) were determined. The results of the test runs performed in February 1999 show, that the specific energy consumption of the combustion units was between 3 and 6 W/kW thermal energy produced for the hot water boiler and between 5 and 8.5 W/kW thermal energy produced for the thermal oil boiler. In the thermal power range between 2,500 kW<sub>th</sub> (about 30% of the nominal capacity) up to the nominal capacity of the overall plant, the total specific electric energy demand of the combustion units and the flue gas condensation unit varied between 10 and 13 W/kW thermal energy produced. Compared with other state-of-the-art biomass combustion plants, these electricity consumption values are very low which stresses the good efficiency of the plant regarding auxiliary energy consumption. The thermal efficiencies of the two combustion units (= heat produced / fuel energy input based on LCV) amounted to 89% (hot water boiler) and 70 to 75% (thermal oil boiler), which are good values compared with other state-of-the-art installations. Taking the heat recovery potential of the flue gas condensation unit into consideration, the overall thermal efficiency of the plant exceeds the 90,0 % level.

The gaseous emissions of the two biomass combustion plants measured after the flue gas cleaning unit at nominal load and partial load (50%) revealed the following results (all values related to 13 Vol% O<sub>2</sub> and dry flue gas):

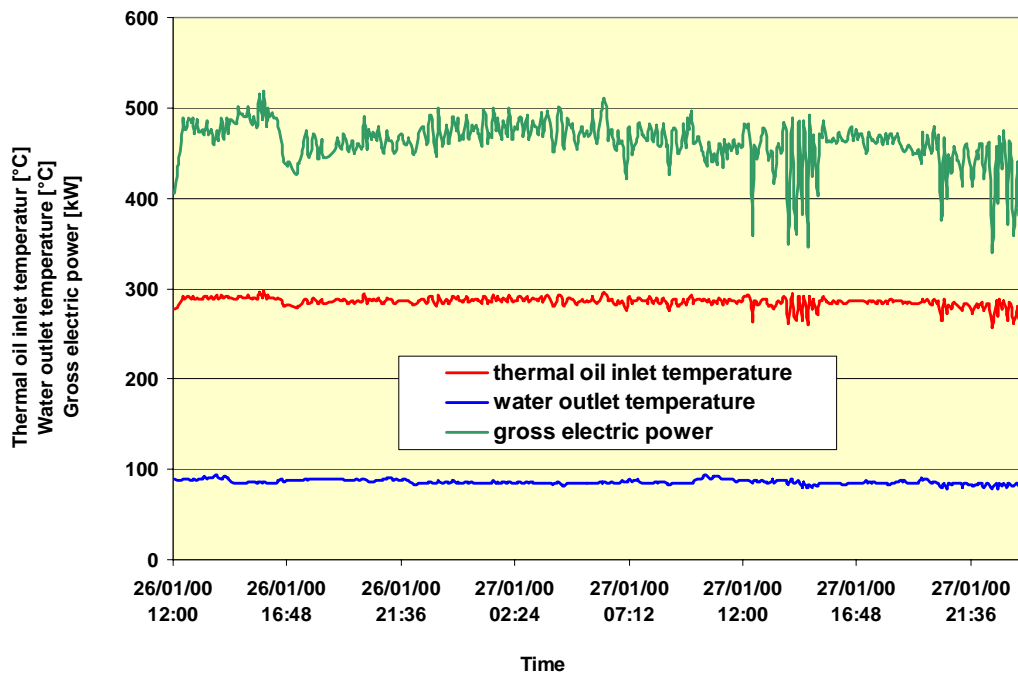
Thermal oil boiler: dust 24.8/21.0; CO 56.9/62.6; TOC 2.8/2.6; NO<sub>x</sub> 129.1/115.4;

Hot water boiler: dust 29.4/21.7; CO 89.2/93.4; TOC 2.2/2.1; NO<sub>x</sub> 98.6/101).

These emission values can be evaluated as very low and are considerably below the strict emission limits set up by of the local authorities for the plant.

### ORC plant:

The acceptance test and the following long-term operation have shown very promising results of the ORC performance. The nominal net electric power output of the ORC can even be achieved with thermal oil inlet temperatures below 300°C (300°C was the nominal value specified). The electric efficiency of the ORC (= net electric power output / power input with the thermal oil) at nominal load is about 18%, what is a quite high value for small-scale CHP plants. This high net electric efficiency can also be kept at partial load operation (between 50 and 100% load almost no deviations regarding electric efficiency occur), which is very important for CHP plants in heat controlled operation. The thermal efficiency of the ORC unit (= thermal power output / power input with the thermal oil) is about 80% and is slightly increasing at partial load operation. Following, the overall efficiency of the ORC plant is about 98% (thermal and electric losses amount to about 2%). Figure 5 shows the gross electric power production as well as the thermal oil and feed water temperatures for a typical operation mode of the ORC unit.



**Figure 5: Gross electric power, thermal oil and water outlet temperatures at a typical operation mode of the ORC**

The plant operation was very satisfactory, both in terms of performance and in terms of reliability. Due to the non-scaling and non-erosive characteristics of the adopted working fluid, the performance kept very constant over the whole first year of operation. Stops of the ORC unit during the whole monitoring period (more than 10,000 hours of operation in parallel to the grid) were limited to a few days in summer 2000 (when maintenance activities were performed) and to a small number of hours due to minor problems occurring (mainly related to wrong measurement values of the instrumentation).

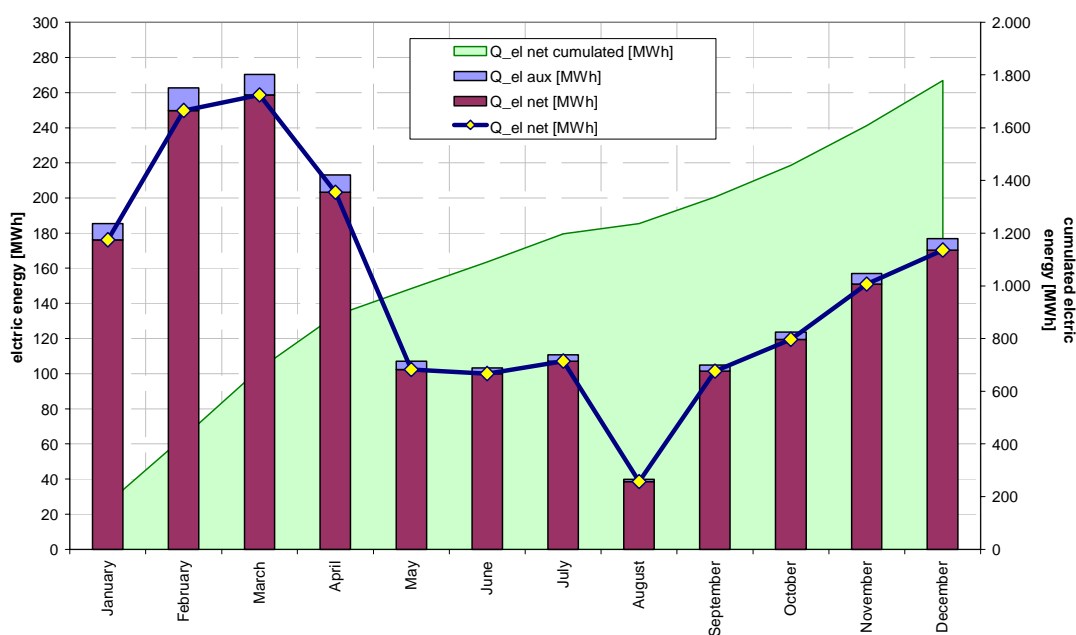
During the monitoring period a special control system was implemented which allows to optimise the electricity production of the ORC at partial load. By means of this control devise it is possible

to optimally adapt the ORC operation to the actual heat demand (especially important during the intermediate or summer season).

### Overall CHP plant:

Table 1 shows the energy balance for the biomass CHP plant based on an ORC (excluding the hot water boiler and the flue gas condensation unit) for the year 2000. It is expected that the amount of electricity produced will increase in the near future to values between 10-11% (related to the energy input by the fuel) as soon as the number of process heat consumers (drying chambers) connected to the heat distribution system has reached its targeted value, which will be the case from the year 2001 on most probably.

Figure 6 shows the annual electricity production of the ORC plant in Admont for the year 2000. Due to the fact that the plant is operated in heat controlled mode and that the process heat consumers connected to the heat distribution network have not yet reached the targeted capacity, the electricity production between winter and summer season differs considerably. Furthermore, in August STIA shuts down its production for two weeks (summer holidays), which explains the low electricity production in this month. In total the net electricity production of the ORC plant amounted to 1,778 MWh in the year 2000, which corresponds to 4,445 full load operation hours. For the year 2001 more than 6,000 full load operating hours should be achieved and in the year 2002 the targeted value of 7,200 full load operating hours seems realistic.



**Figure 6: Annual electricity production of the ORC in the year 2000**

Explanations: Q<sub>el aux</sub>....auxiliary electric energy (electricity consumption of the ORC) ; Q<sub>el net</sub>....net electricity produced (fed to the grid); Q<sub>el net accumulated</sub>....accumulated net electricity production over the year

**Table 1: Energy balance for the biomass CHP plant based on an ORC for the year 2000**

Explanations: hot water boiler and heat recovery in the flue gas condensation unit not included; average moisture content of the biomass fuel 15.0 wt.% (w.b.); kind of biomass fuel: sawdust and wood powder (production residues from STIA wood industry)

	Amount (tons)	Energy produced (MWh)	Energy (%)
Biomass fuel input (w.b.)	~ 5,000	24,116	100.0
Thermal oil boiler output		17,484	72.5
Thermal energy to hot presses		5,629	23.3
Thermal energy – ORC input		11,855	49.2
Net electricity produced		1,778	7.4
Thermal and electric losses - ORC		237	1.0
Thermal energy - ORC output		9,840	40.8

#### Rotational particle separator:

In winter 1998/99 the rotational particle separator was set into operation for the first time and, in the beginning, worked without remarkable problems. After some weeks of operation imbalances of the filter element were detected. As a consequence the filter element was removed and several balance trials were performed without success. Even a new filter element that was ordered in order to replace the old one showed the same problems again. Finally it turned out that the main problem of the RPS application in a larger scale is the internal stability of the rotating filter element (most probably an insufficient brazing quality). Finally it was decided to take no further technological and financial risks and to replace the RPS by a multi-cyclone.

#### Glue water injection:

The glue water injection was taken into operation together with the thermal oil boiler but operated with pure water at the beginning. After the operation with glue water started, it became obvious that some changes and improvements in the system had to be done in order to avoid pipe blockage (change of feed pump, modification of piping as well as of the control system) due to the unfavourable properties of the glue water (high amount of dust and sawdust particles in the glue water). After these modifications had been performed, the system operated for several weeks but caused problems periodically due to partly blocked pipes again. Due to the high efforts (man power needed) for cleaning the pipelines at regular intervals, the glue water injection system was finally taken out of operation at the end of November 2000. Because of the poor transport properties of the glue water it must be assumed, that even a further development and improvement of the injection system would not avoid the blocking of the pipes, and therefore, this kind of injection system, would not be appropriate for an automatic operation over longer periods of time. In future, the glue water will be sprayed directly on the fuel before entering the furnace (with the disadvantage that in this case the NO<sub>x</sub> reducing effect of the glue water due to its urea content cannot be utilised).

## **5. Economic Performance**

The investment costs for the biomass-fired CHP plant based on an ORC (excluding the hot water boiler system) in Admont amounted to about 3,200,000 EURO including monitoring and dissemination costs. The project was supported by national grants (“Austrian Kommunalkredit AG”) with 890,000 EURO and by the European community with 576,991 EURO. The rest of the project costs was financed by own capital and bank loans.

When the connection of process heat consumers to the heat distribution system will be completed (about year 2002), the following annual costs and incomes are expected:

The operating costs consists of the biomass fuel costs (256,000 EURO /a), personnel costs (34,000 EURO /a), maintenance costs (50,000 EURO/a), costs for auxiliary electricity demand (26,000 EURO /a) and other costs (administration, insurance,... 15,000 EURO /a). Summing up, the total operating costs will amount to 381,000 EURO /a. These numbers highlight one of the biggest advantages of the ORC technology, its low maintenance demand and man power needed. ORC plants can be operated fully automatically and require less than a day per week of manpower. These figures have been proven during the monitoring period.

The incomes consists of the heat sales to the wood processing department of STIA and to the monastery (in total 620,000 EURO /a) and of the electricity sales to the local utility (in total 210,000 EURO /a). Following, the overall annual incomes arise to 830,000 EURO.

According to these data the payback time of the project is about 7 years (based on a static calculation).

These economic figures stress the attractiveness of this CHP technology for decentralised biomass combustion systems in the wood manufacturing industry as well as in regional district heating systems.

## **6. Environmental impact**

The results of a global prediction of emissions show that the implementation of the biomass-fired combined heat and power production plant based on an ORC process in Admont represents an important contribution to environmental protection. The ORC process itself produces no emissions as it is designed as a closed cycle so that no losses of the working fluid are to be expected.

The CO<sub>2</sub>-reduction of 68% or 2,800 t/a caused by the project will be another step towards the achievement of the Toronto goal, which aims at a reduction of the CO<sub>2</sub> emissions to 80% of the level of 1988 until the year 2005. Furthermore, the reduction of other gaseous and particulate emissions of relevance achieved will improve the air quality in the entire region of Admont, which in its turn will increase the quality of life of the local population.

Due to the realisation of the new CHP-plant the following reductions of emissions are achieved (compared to the previous installation): SO<sub>2</sub> –86% (-15 t/a); NO<sub>x</sub> –48% (-11 t/a); TOC –44% (-4 t/a); CO –77% (-21 t/a); dust –75% (-10 t/a).

## **7. Degree of success, dissemination and outlook**

The results of the EU demonstration project Admont have become a new technical standard for biomass-fired combined heat and power production systems in the envisaged capacity range (0.3 to 1.2 MW<sub>el</sub>). This CHP technology should be of commercial value for at least three to four years, or even longer with sufficient potential for further development. The ORC technology should be of great interest especially for small- and medium-scale wood industries as well as for decentralised biomass district heating systems with an appropriate demand for process / district heat and the intention to produce electricity for in-house use or for grid supply. Hence, a considerable replication potential for this technology exists on a European level.

Furthermore, feed-in tariffs for electricity produced from renewable energies have been established in many European countries, which implies a great and valuable financial support for the dissemination of this technology.

The standardisation of the ORC technology used helps to decrease the investment costs for further installations and consequently renders thermal energy utilisation from biomass, especially combined heat and power production, more competitive with respect to fossil fuels.

A considerable number of visits has been organised at the CHP plant in Admont in order to disseminate the results. In particular, visitors from Austria, Switzerland, Germany, Denmark, Spain, France, United Kingdom and Italy came to the plant. These visitors consisted of engineering companies, potential future clients as well as energy authorities. By means of the demonstration of this technology, a strong interest in this kind of application has been developed. Following, the Admont plant is a very good reference for future projects.

In addition, as another important activity of dissemination, the new ORC technology has been presented at the 1<sup>st</sup> World Conference on Biomass in Seville 2000, at the Austrian Biomass Conference 2000 and will be presented at the international VDI Conference “Thermal Utilisation of Solid Biomass” in May 2001 in Salzburg in an oral presentation as well as by a field trip arranged to the Admont plant.

Moreover, the further development and upscaling of this technology to a nominal electric capacity of 1,000 kW has already started. This 2.5 times larger ORC unit will be demonstrated as a follow-up EU demonstration project in the end of the year 2001 in a new biomass district heating plant in Lienz (Austria).

In the meanwhile, four new biomass-fired CHP plants based on an ORC are in the design phase.

## 8. Project identifiers

**Project:** BM/120/98

**Owner:** STIA - Holzindustrie Ges.m.b.H.

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**Contractors:** STIA - Holzindustrie Ges.m.b.H. (coordinator)

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**Technology:** TURBODEN (ORC plant)

**KOHLBACH (combustion unit, flue gas condensation unit, rotational particle separator)**

**BIOS (engineering, monitoring)**

**Total Costs:** 3,200,000 ECU

**EC Support:** 576,991 ECU