EU – THERMIE PROJECT
BM 0333 / 95 / AT / DE

SUSTAINABLE BIOMASS HEATING PLANT TAMSWEG

FINAL REPORT

Co-ordinator

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Contractors

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SUMMARY

The project concentrated on several main objectives. The first aim was to increase the efficiency of the whole process of thermal energy utilization from biomass. This was achieved by improving the efficiency of combustion through energy recovery from the flue gas in a flue gas condensation unit, by reducing the electricity consumption of the whole process through well-designed pumps and fans and significantly reducing the heat losses in the network of pipes. The second aim of this project was to increase the sustainability of such systems. This point focused on the reduction of NO_X emissions and an environmentally compatible closed-cycle economy based on wood ash.

Therefore several innovative technologies were integrated:

- biomass fuel drying system,
- NO_X reduction based on the technology of air staging,
- technology of fractionated heavy metal separation,
- optimized design of the pipe network.

The biomass heating plant Tamsweg consists of 2 bark and wood chip fired combustion units with nominal boiler capacities of 5 MW_{th} and 3 MW_{th}, a flue gas condensation unit and an ash preparation system. On 31st August 1998 the length of the pipe network supplying more than 700 households with district heat was about 22,120 m.

During the first two years of operation it was demonstrated that the performance of all innovative components of the project was satisfactory. Due to the high acceptance of the district heating system in Tamsweg even more households than initially expected were connected to the pipe network and therefore, in comparison with initial calculations, the payback time of the installation was reduced by about 20%.

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1 PROJECT DETAILS

Project Number:	BM-0333-95
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2 PROJECT AIM AND GENERAL DESCRIPTION

2.1 Aim of the project

The project focused on the realization of certain innovative technologies in order to increase the energy efficiency of biomass district heating plants significantly, and to prove that sustainable energy production from biomass is possible.

The aim of increased energy efficiency was realized by a flue gas condensation unit, which allows almost 20% of the energy to be recovered (related to the NCV of the fuel). Furthermore, an optimized pipe network design reduces the heat losses to 70% of the values of conventional systems and in addition decreases the investment costs. Furthermore, the design of all electricity components of the biomass heating plant, such as air fans, flue gas fans and pumps, was optimized in order to reach a low electricity demand.

To obtain sustainable energy utilization of biomass, which was the second main aim of the project, it is not only necessary to close the CO_2-cycle, which can be achieved by sustainable forest management, but also to close the elementary cycles of nature (soil/nutrient - root/tree - combustion - ash/fertilizer - soil) by recycling the wood ash produced. This goal is achieved by a new combustion technology that facilitates fractionated heavy metal separation in the ash fractions produced (bottom ash, secondary bottom ash, cyclone fly-ash and condensation sludge). Using this technology, 90 to 95 % of the total ash produced can be recycled in forests or on agricultural fields in an environmentally compatible way. The ash stream which is enriched with heavy metals (condensation sludge) is separated from the ash cycle and allows the heavy metals to be recovered.

Another innovative part of the project was the implementation of the technology of air staging as a primary measure to reduce NO_x emissions. This can be achieved by a special design of the furnace accompanied by an appropriate process control system. This technology was for the first time applied to biomass combustion units in the capacity range of this project.

Furthermore, an optimized fuel storage system and layout of the daily fuel storage boxes allows the fuel to be dried with pre-heated air. In this way not only the quality of the fuel fired, but also the performance of the whole combustion unit is improved.

To sum up, the total efficiency of the biomass district heating plant Tamsweg was planned to be about 35% higher than that of present state-of-the-art plants, whereas the emissions, especially NO_x emissions, should be reduced significantly. Furthermore, the sustainability of the whole process should be increased by the technology of fractionated heavy metal separation.

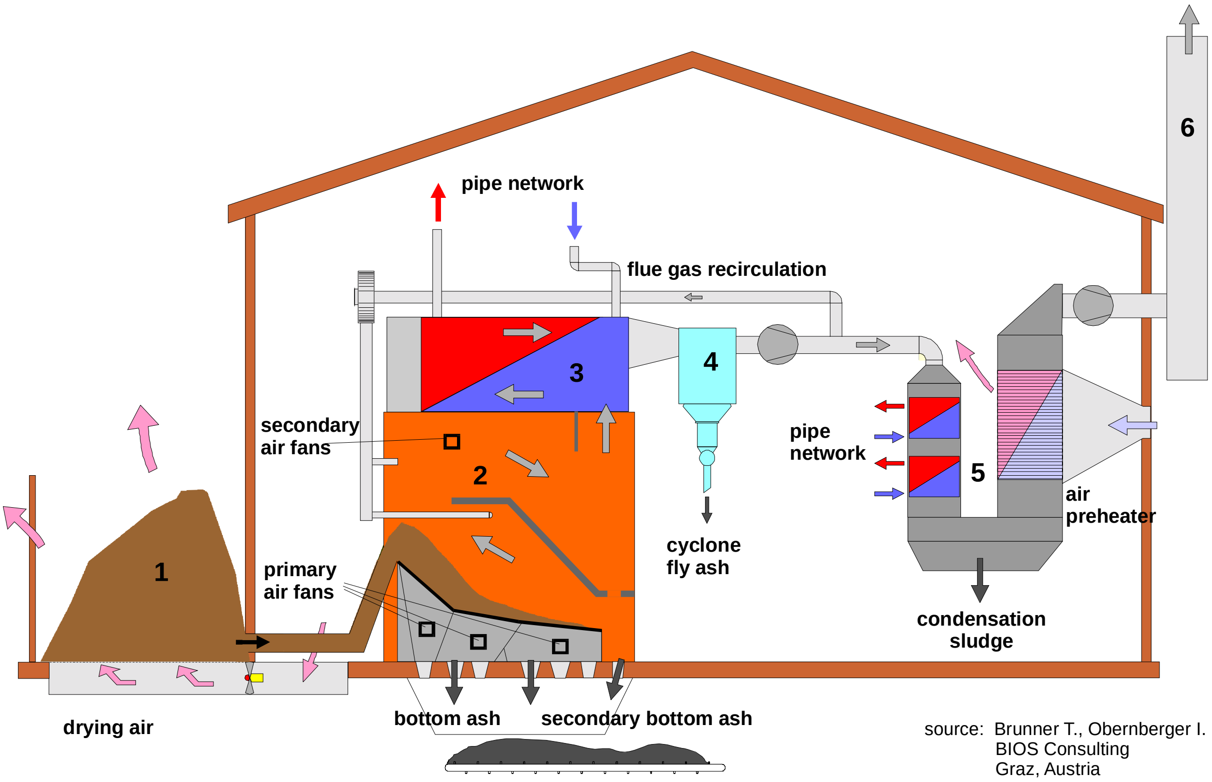
2.2 Description of the installation

A scheme of the biomass heating plant Tamsweg is shown in Figure 1. The plant consists of the following main components:

- the biomass storage and drying system,
- the combustion units,
- the boiler and the multi-cyclone,
- the flue gas condensation unit,
- the ash delivery and preparation unit,
- the condensation sludge preparation stage,
- the network of pipes including the heat exchanging units at the clients,
- the computer-aided control system for the plant and the network of pipes

2.2.1 Fuel

Only chemically untreated (natural) biomass is used as fuel and consequently the emissions caused by a well-working combustion unit are low and public acceptance high. The major part of the fuel is bark (80%), while the remaining part are shavings, sawdust and wood chips (20%). 70% of the fuel delivered to the biomass heating plant Tamsweg, are supplied from the surrounding Lungau region, while 30% are imported from the adjacent regions, Pongau and Tennengau. Anyway, the transport distances are short and the money spent for fuel remains in the region. During the last business period (September 1997 to August 1998) the fuel demand amounted to about 31,000 m³.



source: Brunner T., Obernberger I.
BIOS Consulting
Graz, Austria

Figure 1: Main components of the biomass heating plant Tamsweg

Explanations: 1: drying system; 2: furnace; 3: boiler; 4 multi-cyclone; 5: flue gas condensation unit; 6: chimney

2.2.2 Biomass storage and drying system

After delivery the biomass is first stored in an open-air storage area with a capacity of about 11,000 m³, which corresponds to the plant's fuel demand of 3 to 4 months. At the time of delivery the water content of the fuel amounts to 50 - 60 wt.% (w.b.) Depending on the ambient temperature and the energy demand of the clients, the daily fuel storage boxes of the biomass combustion units are filled once or twice a day using a wheel-loader. From there the fuel is delivered to the combustion units by sliding bar conveyors. The bottom plate of the daily storage box is perforated, which allows pre-heated air from the third stage of the flue gas condensation unit to be blown through the pile by an air fan (see Figure 1). In this way the fuel is dried to a water content of 40 – 50 wt.% (w.b.). Since the energy for the warming of the drying air is waste energy from the flue gas condensation unit, which remains unused in other combustion plants, the operating costs for the fuel drying system are reduced to the electricity demand of the air fan.

2.2.3 Combustion units

The plant consists of two combustion units with nominal boiler capacities of 5 MW_{th} and 3 MW_{th} based on identical technologies and design features. Therefore only combustion unit 1 (the one with the higher nominal capacity) is precisely described in this report and also shown in Figure 2.

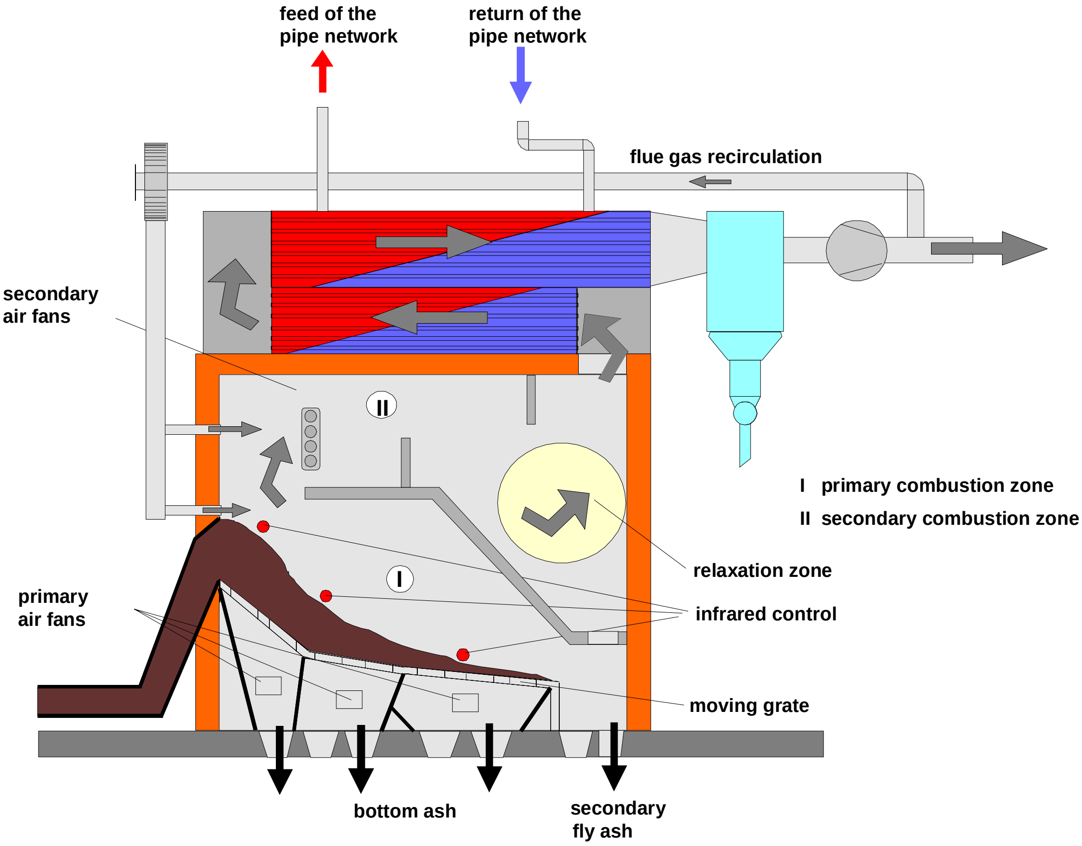


Figure 2: Scheme of the combustion unit including the boiler and the multi-cyclone

The furnace is designed as a moving-grate incinerator with three separate grate sections. The first grate section is rigid, while the second and third sections are individually movable. By continuously measuring the height of the bed of embers by means of light beams the distribution of the glow over the grate can be adjusted by controlling the motion of the grate sections. This guarantees even coverage of the grate, which is a basic requirement for low plant emissions.

The incinerator is specially designed to facilitate "air staging", which means that gasification of the biomass and combustion of the gases produced take place in different combustion chambers. In the so-called primary combustion chamber gasification of the fuel takes place under reducing conditions, while in the secondary combustion chamber the gases are burned in oxidizing atmosphere. To avoid back mixing of gases from the oxidizing atmosphere of the secondary combustion chamber to the reducing atmosphere of the primary combustion chamber, these two sections of the furnace are connected by a channel which is kept as small as possible. To guarantee optimum distribution of the combustion air, three frequency-controlled air fans are installed for the primary combustion zone and two for the secondary combustion zone. The exact air rates are calculated and optimized by the plant control system in order to keep the emissions and the electricity demand of the incinerator as low as possible.

Due to the reducing atmosphere and high temperatures in the primary combustion zones NO_x formation from the fuel nitrogen is reduced. Moreover, the formation of less volatile heavy metal oxides is avoided, and therefore the bottom ash can be kept almost free of heavy metals. Apart from the reducing atmosphere, the temperature, residence time and air ratio in the primary combustion zone also affect the success of air staging. Therefore these parameters were also optimized to reach optimum conditions:
primary air ratio: 0.6 to 0.8
temperature: 1,000 – 1,100 °C
residence time of the gases: >0.5 s

Complete combustion of the gases produced in the primary combustion chamber is achieved by designing the secondary combustion chamber large enough to reach a flue gas residence time of approximately one second and by additionally forcing intensive mixing of the secondary combustion air with the flue gas. Flue gas recirculation limits the temperature in the secondary combustion chamber to 1,100 °C in order to prevent the fly-ash particles from melting, which is of special importance for dry biomass with a water content of less than 45 wt.%. Relaxation zones and deflectors in the primary and secondary combustion chamber retain a great amount of dust particles and keep the amount of fly-ash entrained from the incinerator low. Due to the low heavy metal content of fly-ashes precipitated at high temperatures, this measure is of great importance for fractionated heavy metal separation.

2.2.4 The boiler and multi-cyclone

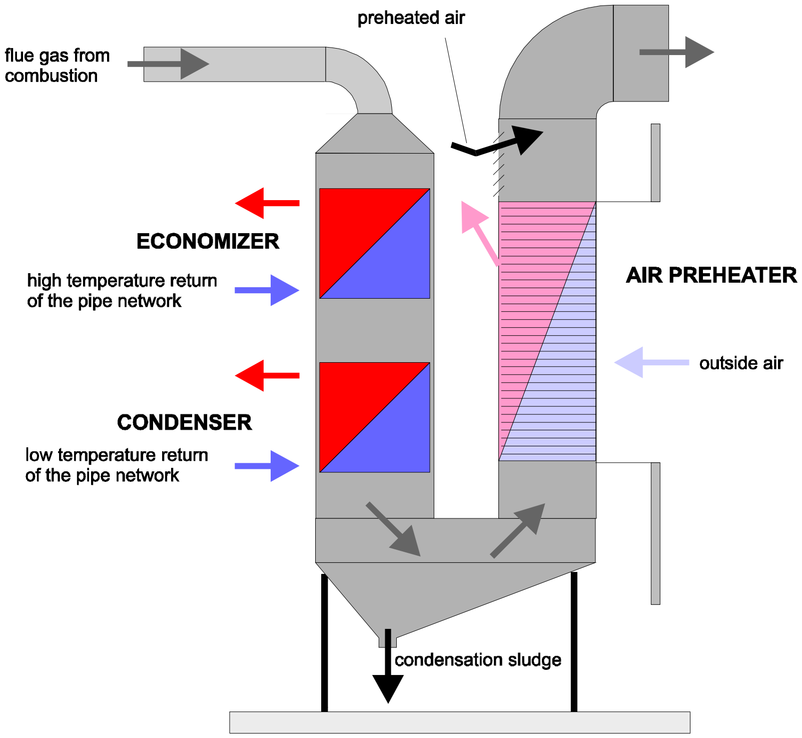
The boilers with nominal capacities of 5,000 kW_{th} and 3,000 kW_{th} are designed as tubular heat exchangers with two flues. They were additionally equipped with an automatic heat exchanger cleaning system which prevents particle depositions at the tube surfaces by injecting pressurized air at high velocities. This system has two advantages: firstly, the efficiency of the boiler is kept at a high level for longer periods than usual, and secondly, the effort for manual heat exchanger cleaning is significantly reduced. Moreover, fly ash depositions at the tube surfaces are reduced, thus impeding damage caused by low-temperature corrosion, which has proven to be a serious problem in numerous biomass combustion plants.

To separate coarse fly-ash particles from the flue gas, a multi-cyclone is placed downstream each boiler.

2.2.5 The flue gas condensation unit

As there are clients in Tamsweg whose heating systems are designed to utilize low temperature heat (45-55 °C), a great part of the heat obtained from the flue gas condensation unit can be recuperated. The flue gas condensation unit (Figure 3) consists of an economizer, a condenser, and an air pre-heater. In the economizer the flue gas is cooled down from 180 °C to about 70 °C. The next stage, the condenser, reduces the temperature of the flue gas to approximately 45 - 50°C. As the dew point of the flue gas is in the range of 52 to 58 °C, condensation and consequently recovery of latent heat starts at this stage. With the energy obtained from the economizer and the condenser, the return of the pipe network is preheated before entering the biomass boilers. In the third stage of the condensation unit, the air pre-heater, the flue gas is cooled down to about 35 - 45°C by warming up outside air which is sucked into the heating plant. At this stage, continuous flue gas condensation takes place. The pre-heated air is used energetically as combustion air and for the fuel drying system, and major part of it is mixed with the flue gas at the outlet of the condensation unit to avoid vapor steam condensation in the remaining parts of the plant. Additionally, this measure serves to avoid the formation of vapor clouds in the flue gas leaving the chimney.

In addition to the mentioned energetical advantages of the flue gas condensation unit, dust emissions are also reduced significantly. This is due to the fact that, as soon as the dew point of the flue gas is reached, dust particles serve as condensation nuclei for water droplet formation. About 60% - 70% of the dust load at the inlet of the flue gas condensation unit are precipitated with the condensate.



source: Brunner T., Obernberger I.
BIOS Consulting
Graz, Austria

Figure 3: Scheme of the flue gas condensation unit

To sum up, the advantages of the flue gas condensation unit lie in the significant increase in plant efficiency from about 85% to even more than 100% (related to the fuel NCV) and efficient dust separation, which reduces the particle emissions of the plant to a level < 50 mg/Nm³ (dry flue gas, related to 13 vol.% O_2). Last year about 10% of the total energy production were gained from the flue gas condensation unit, and consequently the fuel consumption of the heating plant was 10% less than in heating plants without energy recovery in flue gas condensation units.

2.2.6 Ash delivery and preparation unit

To increase the sustainability of the whole system, the reuse of the ashes in forests and on agricultural fields was stated as one major aim of the project. To make this attractive for the farmers, the ash has to fulfill a number of requirements. It should be free of slag and stones with particle sizes greater than 2.5 cm and free of iron particles. Furthermore, the ash should be easy to spread and handle. To fulfill these needs an ash-preparing unit was installed (Figure 4). In defined periods the useable ash, which is a mixture of bottom ash, secondary bottom ash and cyclone fly-ash, is transferred to the ash-preparing unit by conveyor belts. This unit consists of a sieve, a magnet and containers for the oversized material and the recyclable part of the ash. The whole ash-preparing system, including the conveyer belts from the furnaces to the sieve and to the containers, is encased and works under a light vacuum to avoid dust and noise emissions. The undersized particles (80 to 90% of the total ash sieved) are delivered to a storage room and filled into 50 lt. sacks. The sacks contain an ash mixture of the bottom ash, secondary bottom ash and cyclone fly-ash in the plant-specific production ratio with a guaranteed particle size diameter smaller than 1.5 cm. As a secondary raw material with fertilizing and liming effects this ash can be applied to forest or agricultural soils using conventional lime spreaders.

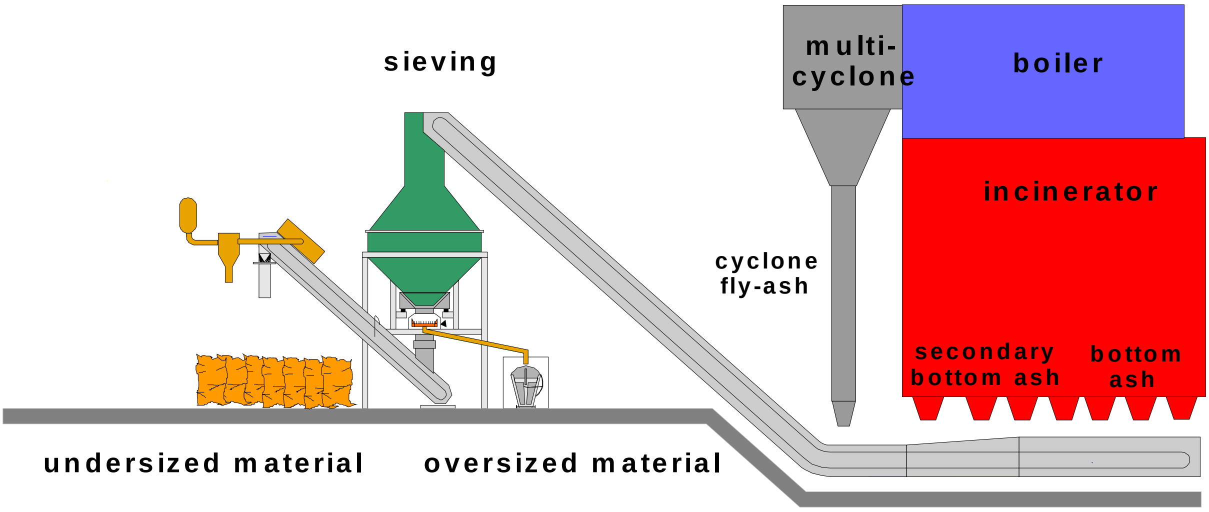


Figure 4: The ash preparing unit

2.2.7 Condensation sludge preparing stage

The fly-ash and condensate precipitated in the flue gas condensation unit form the condensation sludge. In defined periods the condensation sludge is removed from the bottom of the flue gas condensation unit by a screw conveyor and filled into a settling tank where the particles are separated from the water. As the solubility of heavy metals in water depends on the acidity of the system, the flue gas condensation unit is equipped with a pH-value control system which ensures a steady pH-value of about 7.5 to 8.0. This value guarantees almost complete fixation of the heavy metals in the sludge and consequently compliance with the respective limiting values, which is required for discharging the condensate into the local waste water purification plant.

2.2.8 Network of pipes including the heat exchanging units at the clients

One main aim of the project was to increase the energy efficiency of biomass district heating plants. Within this part of the project special emphasis was put on the optimization of the pipe network. The first step of this optimization was an exact calculation of the clients' energy demand for heating and warm water based on the annual fuel consumption of the previous three years and the average outside temperatures of the region over a year. Based on these data, taking into account different kinds of consumer behavior (detached houses, hotels, schools, hospitals, etc.), the heat exchanger units at the clients were designed. As a second step the optimal pipe network design and the pipe diameters were calculated. Depending on pressure and heat losses and the minimization of the total costs (including operating costs for pumps as well as investment costs for the pipe network), the optimal pipe diameters for each section of the pipe network had to be calculated. This was done with a computer program developed at the Institute of Chemical Engineering, Technical University Graz.

The temperature of the feed of the pipe network is controlled in dependence on the outside temperature and the daytime-dependent consumption behavior of the clients and amounts to about 90 to 100°C. Since some clients utilize low-temperature heat, two returns were provided. The high-temperature return (50 – 70°C), which can be compared with the return of conventional pipe networks without low-temperature utilization, is used as feed for low-temperature users. Therefore a second return, the low-temperature return (30 – 50°C), leads from these clients back to the heating plant. By the end of August 1998 the pipe network had reached a length of 22,120 m. 290 heat exchanging units supplied about 700 households, public and commercial buildings with district heat.

Last year the clients' heat demand amounted to 20,170,000 kWh. Due to the optimized layout of the pipe network the heat loss amounted to only about 19% (average value since the startup of the plant), which is about 5 - 9% less than that of conventional pipe networks. Another parameter influencing the economic efficiency of district heating networks is the nominal heat demand of the clients per meter network laid. A minimum guiding value for this parameter is 0.5 kW/m. With its energy demand of about 1 kW/m per meter of pipe network laid the district heating network in Tamsweg also keeps this requirement concerning the economic efficiency of the installation.

2.2.9 Computer-aided process and pipe network control system

The whole process of energy production and transport is controlled and optimized by a computer-aided control system, which ensures continuous plant operation, high efficiency and low emissions. Additionally, all relevant operating data, such as temperatures, flows, energy production etc., are processed, visualized on-line and recorded. In this way it is possible to analyze the performance of the plant permanently and thus facilitate optimization.

3 CONSTRUCTION, INSTALLATION AND COMMISSIONING

3.1 Suppliers of Equipment and Services

Kohlbach GmbH & Co
Grazer Straße 26-28, A - 9400 Wolfsberg, AUSTRIA

- Combustion units including boilers, multi-cyclones, flue gas ducts, air and flue gas fans.
- Flue gas condensation unit.
- Heat exchanger units at the clients.
- Control systems of the plant and the pipe network.

Klöckner - Moeller GmbH
Heinz Moeller Straße 7 – 11, D - 53115 Bonn, GERMANY

- Electrical installations.
- Hardware concerning the plants and the pipe networks control system.

Mannesmann Anlagenbau Austria AG
Schillerstraße 1, A - 5020 Salzburg, AUSTRIA

- Hydraulic piping.
- Laying of the pipe network.

Institute of Chemical Engineering, Technical University Graz
Inffeldgasse 25/II, A - 8010 Graz, AUSTRIA
in cooperation with
Consulting office BIOS – Bioenergy Systems
Sandgasse 47/13, A - 8010 Graz, AUSTRIA

- Design of the innovative components of the plant.
- Process data visualization and evaluation.
- Monitoring.

3.2 Project Management

The project was proposed and coordinated by Fernwärmeversorgungs- GmbH. & Co KG Tamsweg. The support of the State Government of Salzburg, which placed two engineers with great experience in the field of thermal biomass utilization and project management at the project's disposal, was of great importance for the success of the whole project. This management structure led to a fast and well-coordinated progress of the work and also guaranteed that lessons learned from the erection of other heating plants in Salzburg, were implemented in the work concerning the Tamsweg heating plant.

3.3 Technical Problems and Solutions

After publishing the intention of installing a biomass district heating plant in Tamsweg, the operators were faced with resistance of the people living next to the planned site of the plant. The most important argument against the heating plant was the fear of toxic emissions. The doubts were eliminated by providing comprehensive information about the environmental benefits of biomass district heating plants and organizing a visit to the biomass heating plant at Lofer (Salzburg/Austria). It must be mentioned that the increasing level of information about the project resulted in rapidly rising acceptance of the biomass heating plant among the population of Tamsweg.

Since the main part of the pipe network was laid in the inner city of Tamsweg, some shopkeepers protested because of traffic handicaps. Again, comprehensive information about the biomass district heating plant and the tight schedule concerning the trenching helped to eliminate the problems.

Apart from these social problems some technical problems occurred:

During the first months of operation several problems occurred concerning the optimization of the process control of combustion unit 1. These problems also had a negative impact on the performance of the flue gas condensation unit. Since the problems were solved through intensive efforts of the plant operators, an important lesson was lesson learned: collaboration of the plant operators and the manufacturers during the first months of operation would have helped to solve the problems more quickly and would have saved time and money.

As mentioned in section 2.2.2, the daily fuel storage boxes are equipped with perforated bottom plates which are an important part of the fuel drying system. Due to the rather large holes in the bottom plate (about 25 mm in diameter), smaller bark pieces fell through the holes into the room below the storage box. To remove these fuel pieces and feed them to the furnace an additional discharge device was installed.

3.4 Modifications and overruns

The progress of the work concerning biomass combustion unit 1, the flue gas condensation unit, the stand-by oil boiler and the buildings was according to schedule. Since the public acceptance of the district heating plant turned out to be very high, even more clients than initially expected signed energy supply contracts and were connected to the pipe network during the first year. Therefore the pipe network had to be expanded faster than scheduled, and biomass combustion unit 2, whose erection was originally planned for summer 1998, was already installed in April 1997. Since May 1997 all components of the biomass district heating plant Tamsweg have been in operation, and therefore, phase 3 (assembly, erection, installation) and phase 4 (commissioning) were completed one year earlier than initially scheduled (see also, Annex A, Table 5).

Since the main components of the biomass heating plant Tamsweg, i.e. the two biomass combustion units including the boilers and multi-cyclones, the flue gas condensation unit, the ash and the condensation sludge preparation systems and the pipe network, have worked without any noticeable problems since plant startup, no significant modifications were necessary.

4 OPERATION AND RESULTS

4.1 Operating History

In April and May 1996 work started on the pipe network and the building, respectively. In August and the beginning of September 1996 energy was supplied to the pipe network by the stand-by oil boiler. On 15th September 1996 biomass combustion unit 1, including the ash delivery and preparation system, and the flue gas condensation unit with the condensation sludge preparation unit were put into manual operation for the first time. Since October 1996 these units have run fully automatically. In June 1997 combustion unit 2 was put into operation. The heat demand of the predominant part of the clients depends on the ambient temperature. During the summer months the energy demand can be covered by combustion unit 2 and during autumn and spring by combustion unit 1. During the winter months (December – March) combustion unit 1 and 2 operate continuously.

4.2 Performance

Besides the latest data about energy production and efficiencies obtained from the evaluation of the operating data from September 1997 to August 1998 this section mainly focuses on the operation results concerning the innovative parts of the project and therefore, corresponding to the aims of the project mentioned in section 2.1, concentrates on the following topics:

- fuel drying system
- NO_x reduction by primary measures
- fractionated heavy metal separation
- energy efficiency of the plant

The Institute of Chemical Engineering, Technical University Graz, was responsible for the evaluation of plant performance and plant monitoring. Besides special measurements focusing on the innovative tools, operating data obtained from the plant’s process control system were evaluated.

4.2.1 The fuel drying system

In the period from January to April 1998 test runs focusing on the evaluation of the drying effect of the fuel drying system were carried out. In addition to the plant's process data visualization and storage system, several parameters, including drying air flow, drying air humidity, pressure drops over the stored fuel and water content of the fuel, were observed.

In Figure 5 a typical progress of the drying process is shown. At 18:00 the daily fuel storage box was filled up and the drying air fan was set into operation. During the test run described in Figure 5, the drying air flow was between 18,000 and 22,000 m³/h at 38 – 40 °C. The pressure drop over the pile was measured continuously and at certain times, in order to determine the water content of the fuel, two fuel samples were taken immediately before the combustion unit. In some cases the variance of these paired measurements was high due to the inhomogeneity of the fuel. The initial water content of the fuel amounted to 54.1 wt.% (w.b.). Since at the beginning parts from the top of the pile, which contain a higher amount of water, and not the fuel layers at the bottom, which are dried first, were removed and burned, no significant drying effect occurred during the first hours. Because of the low heat demand during nighttime hours, less fuel was needed, and in the morning, when the plant is supposed to operate at full load, fuel with low water content (about 44 wt.% w.b.) was available. Since the height of the pile is reduced by feeding fuel to the combustion unit, the pressure drop over the pile is also reduced. The actual fuel consumption of the combustion unit at any given time can be estimated from the gradient of the differential pressure curve.

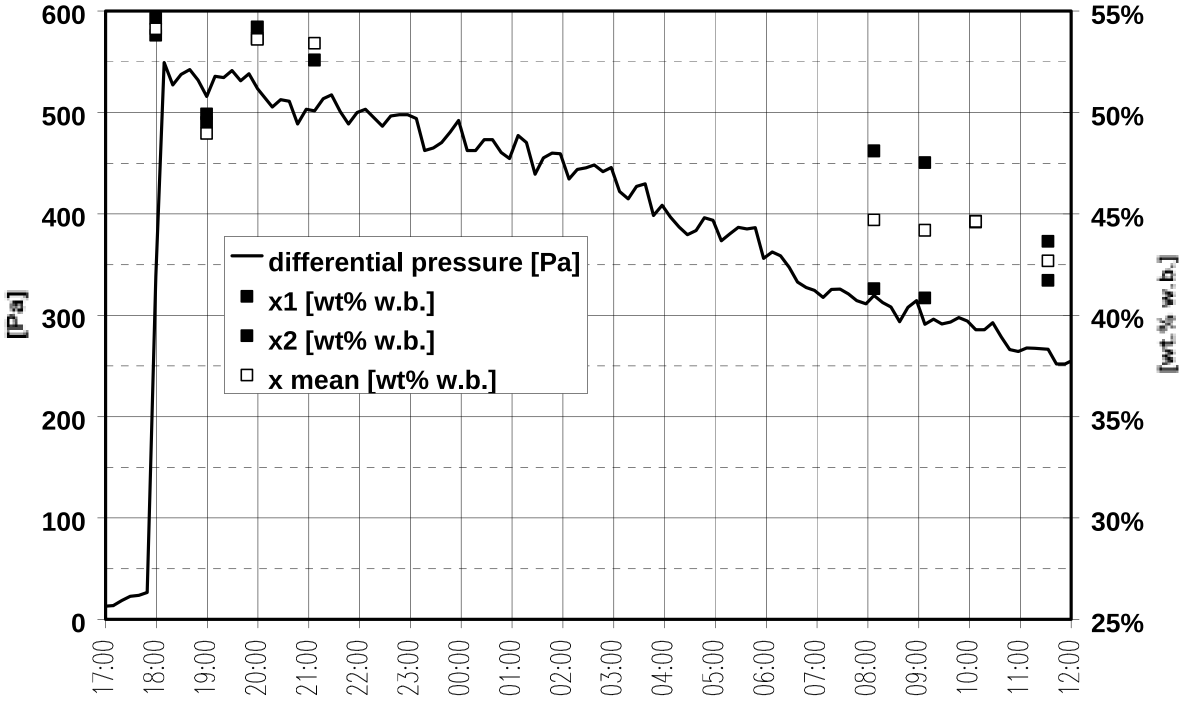


Figure 5: Change of the moisture content and the pressure drop of the fuel during drying

4.2.2 NO_x reduction by primary measures

Comprehensive test runs including continuous emission measurements were carried out to determine the NO_x reduction potential of the air staging technology implemented.

First flue gas measurements carried out in January 1997 showed that the technology implemented led to a reduction in NO_x emissions to 140 – 180 mg/Nm³ (related to NO_2 and dry flue gas, 13 vol.% O_2, ½ hour mean values). Emissions of Austrian bark-fired plants that are not equipped with air staging amount to 200 and 300 mg/Nm³ (related to NO_2 and dry flue gas,13 vol% O_2).

Within the scope of test runs (3 to 5 days) performed from February to April 1998 continuous NO_x measurements were carried out. Since the results of the test runs were very similar, one 4-day period representing typical NO_x data is described in the following:

Constraints:

Temperature in the primary combustion zone:	900 – 1,050 °C
Excess air ratio in the primary combustion zone:	0.6 – 0.9
Nitrogen content of the fuel on average:	0.4 wt.% d.b.

As shown in Figure 6, 97.8% of the NO_x emissions were <200 mg/Nm³, 75% < 172 mg/Nm³ and 50% < 160 mg/Nm³. During the test runs mean CO emissions of about 134 mg/Nm³ (related to NO_2 and dry flue gas, 13 vol.% O_2) were measured. Concerning the mean values and the upper and lower limits of the NO_x distribution the results of the remaining weeks are comparable with those shown in Figure 6.

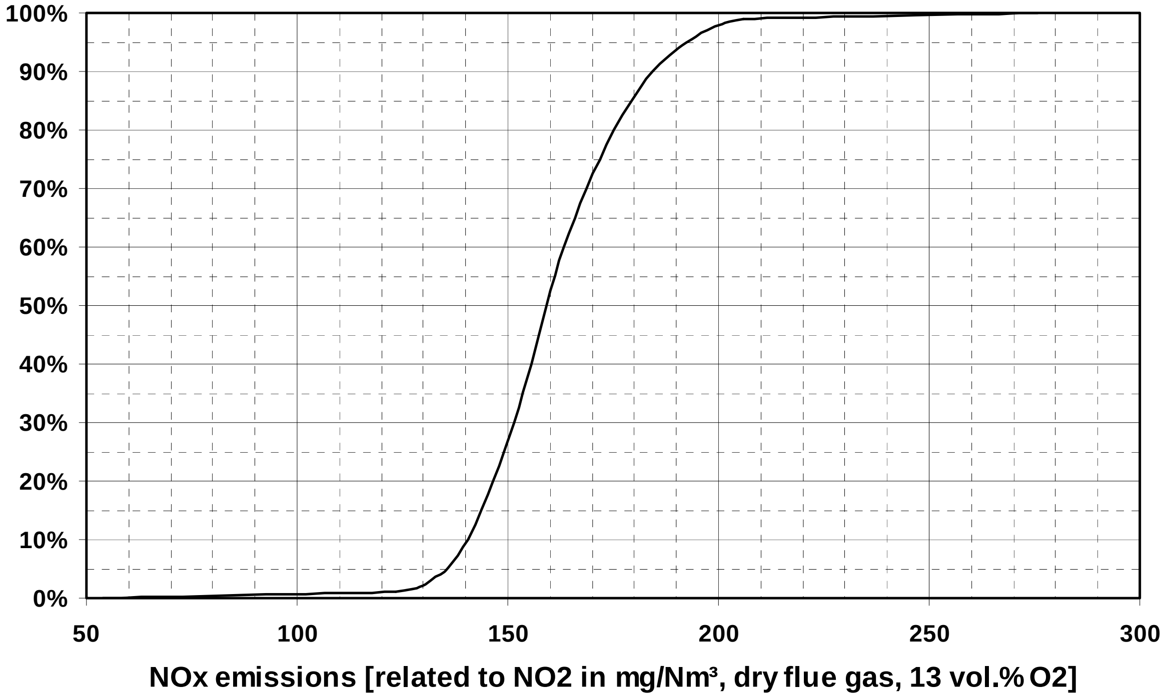


Figure 6: Distribution of NO_x emissions during 1 week.
Explanation: Continuous measurement during one week, scan rate: 10 s

4.2.3 Fractionated heavy metal separation

As mentioned in section 2.1, one aim of the project was to keep the major part of the ashes produced, the so-called useable ash (mixture of bottom ash, secondary bottom ash and cyclone fly ash) almost free of heavy metals and concentrate the environmentally harmful heavy metals (mainly Cd and Zn) in a small sidestream, the condensation sludge. This can be achieved by the technology of fractionated heavy metal separation, which is based on the heavy metal fractionation potential of a reducing atmosphere on and around the grate and the separation of a maximum amount of fly-ash at high furnace temperatures. As mentioned in section 2.2.3, the furnace in Tamsweg was designed according to these requirements.

To evaluate the effects of fractionated heavy metal separation on the composition of the ash fractions, 4 test runs of 48 hours each were carried out. Besides the evaluation of relevant process data and flue gas emission measurements (CO, CO_2, O_2, NO_x) the following samples were taken:

- fuel samples,
- samples from the bottom ash, secondary bottom ash and cyclone fly ash,
- fly-ash samples upstream and downstream the flue gas condensation unit.

Furthermore the amounts of ashes produced were determined for each testing period. Subsequently the ash and fuel samples were subjected to wet chemical analyses, which provided input data for energy and mass balances focusing on the composition of the ash fractions and the distribution of the heavy metals.

Figure 7 and Figure 8, for instance, show the Cd and Zn contents of different ash fractions. As expected, the bottom ash is nearly Cd-free. Higher amounts of Zn but again low amounts of Cd are found in the secondary bottom ash, while the highest Cd and Zn amounts within the useable ashes were found in the cyclone fly-ash. The absolutely highest Cd and Zn concentrations occurred in the fly ash fraction leaving the multi-cyclone. About 60-70% of this fraction were precipitated in the flue gas condensation unit while the remaining particles were exhausted with the flue gas. The mass distribution of the ashes produced is shown in Figure 9. Since almost 80% of the ashes produced are precipitated as bottom ash and secondary bottom ash, the measures designed to force fly ash particle separation in the incinerator and therefore reduce the ash fraction separated in the multi-cyclone and the flue gas condensation unit, worked well. Therefore, the heavy metal concentrations of the useable ash (mixture of bottom ash, secondary bottom ash and cyclone fly ash) are low, which is due to the low amount of cyclone fly ash, which contains the highest heavy metal concentrations of the useable ashes.

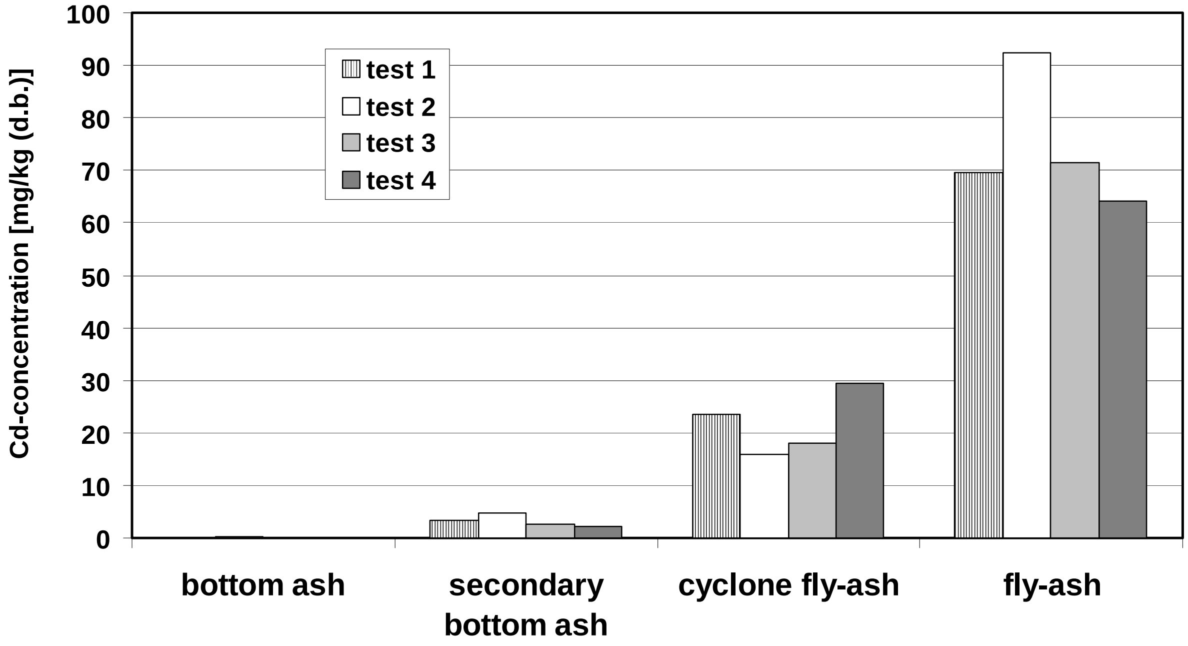


Figure 7: Cd concentration in the different ash fractions

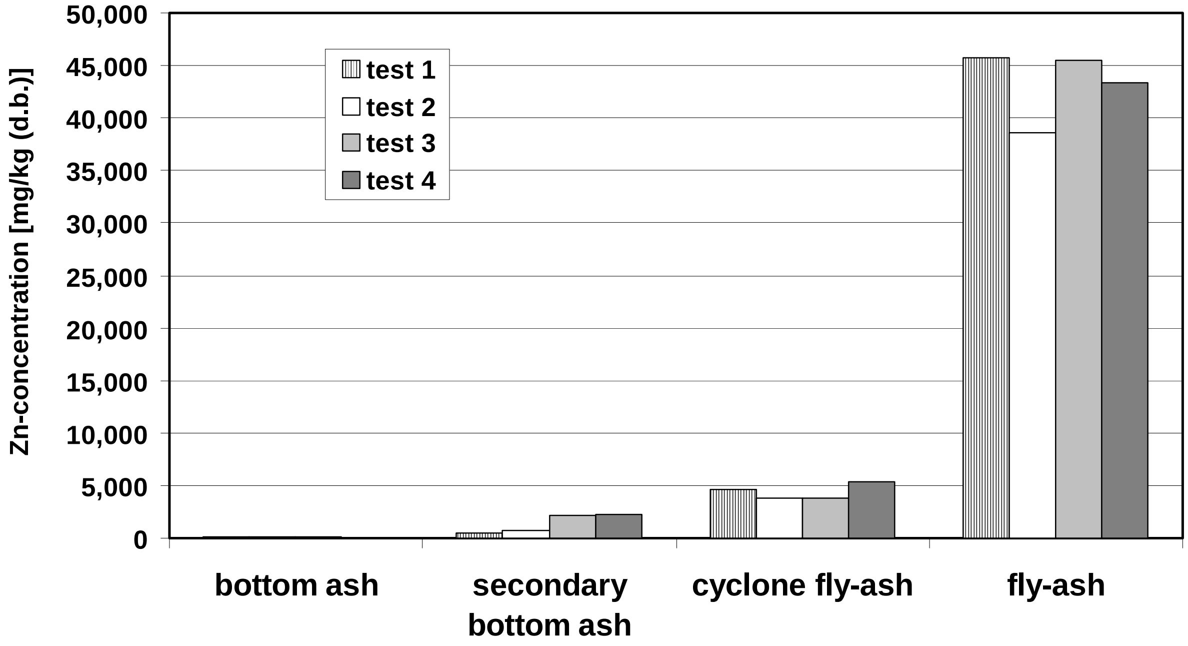


Figure 8: Zn concentration in the different ash fractions

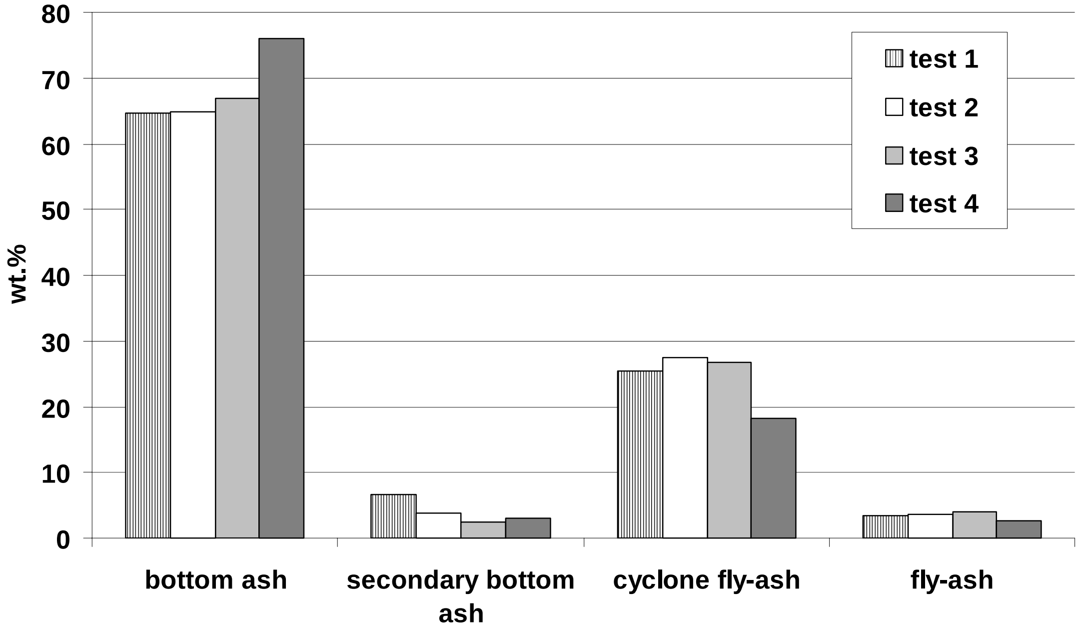


Figure 9: Mass distribution of the ash fractions produced

4.2.4 Energy production and efficiencies

One major aim of the project was to raise the overall efficiency of a biomass heating plant. To achieve this the flue gas condensation unit was implemented and the layout of the components was optimized in order to reduce the electricity consumption of the heating plant. Furthermore, a carefully designed pipe network should also help to save investment and operating costs.

In Table 1 the efficiencies of the biomass heating plant Tamsweg, which were evaluated during the monitoring phase of the project, are compared with the efficiencies achieved in conventional heating plants and the predictions stated at the beginning of the project.

	Conventional biomass heating plant	Predicted value	Results of the monitoring phase
Efficiency of combustion (related to NCV)	83%	103%	99.4%
Efficiency of electricity consumption	< 2%	1 – 1.5%	1 – 1.5%
Efficiency of the pipe network	72%	80-84%	about 80%
Total efficiency	56%	76%	72%

Table 1: Efficiencies of the biomass heating plant Tamsweg

Explanations: efficiency of combustion: energy produced / net calorific value of the fuel * 100; efficiency of electricity consumption: electrical energy demand / energy produced; efficiency of the pipe network: energy consumed by the clients / energy produced

4.3 Success of the project

Taking into account that during the last period of operation the most important low-temperature energy user, the indoor swimming pool of Tamsweg, was out of order due to revision work, the efficiency of combustion as well as the efficiency of the energy supply are expected to increase as soon as this client is supplied with district heat. Therefore, all efficiencies mentioned in Table 1 will probably meet the forecasts even better than during the operating period 1997/1998.

As mentioned in section 4.2.1, the water content of the fuel was reduced from 50 - 60 wt.% (w.b.) to 40 - 50 wt.% (w.b.) by the fuel drying system. Based on the observations during continuous operation of the fuel drying system and the results of the test runs the following conclusions can be drawn concerning this innovative part of the project:

1. An advantage of the new drying technology is that the usual work cycle of the fuel supply can be retained (long-term storage area near the heating plant and daily refilling of the storage box). Furthermore, it was noticeable that at ambient temperatures <0°C fuel agglomeration at the storage box walls by icing disturbed the operation of firing unit 2, which is not equipped with a drying system, and had to be removed manually. Due to the warm drying air such problems did not occur at the combustion unit equipped with the drying system.
2. Due to the use of waste heat in the flue gas condensation unit for the warming of the drying air, no additional operating costs are incurred, except for the electrical power supply of the drying air fan. On the other hand, the energy demand of the flue gas fan is reduced due to the fact that the amount of flue gas decreases with the water content of the fuel. Since the use of dry fuel also reduces the dew point of the flue gas, less air is required to avoid vapor clouds in the flue gas leaving the chimney, and consequently the electricity demand of the fan downstream the flue gas condensation unit also decreases. Since the operating costs of the drying air fan and the energy savings concerning the flue gas fans balance each other, the operating costs of the biomass heating plant Tamsweg did not increase due to the drying system. Optimization of the amount of air mixed with the flue gas in order to prevent vapor condensation at the top of the chimney could even lower the operating costs of the plant. An appropriate control device will be developed within another project and installed in Tamsweg as soon as possible.
3. The flue gas temperatures in the combustion zones of the incinerator increased in the range of 50 – 100°C when the drying system was in operation, which is important concerning NO_x reduction and heavy metal separation by primary measures.
4. Odor emissions caused by the fuel drying unit occurred very rarely, usually when burning fuel that had been stored for several months.
5. The rate of drying (from initially 50 – 60 wt% (w.b.) to 40 – 45 wt% (w.b.)) corresponds with the results achieved by calculating the drying process with a computer program specially developed for the drying system in Tamsweg. As

mentioned in section 4.2.1, the drying system operated at an air flow of about 20,000 m³/h. The pressure drop after filling up the daily storage box amounted to 500 – 600 Pa. As mathematical simulations have shown, a higher drying efficiency could be achieved by increasing the drying air flow rate, but consequently the pressure drop would also rise due to the higher air velocities. Since the pressure drop increases with the square of the velocity, the operating costs of the drying system would also rise significantly and the efficiency of the whole process would decrease.

To evaluate the success of NO_x reduction by primary measures, the data shown in section 4.2 must be compared with Figure 10, which shows the relation between the nitrogen content of the fuel and the emissions caused by different combustion technologies. The comparison of these data (white box in Figure 10) clearly shows that the emissions in Tamsweg are in the range in which combustion units equipped with air staging normally operate. Compared with conventional biomass combustion plants a NO_x reduction of about 30% is reached.

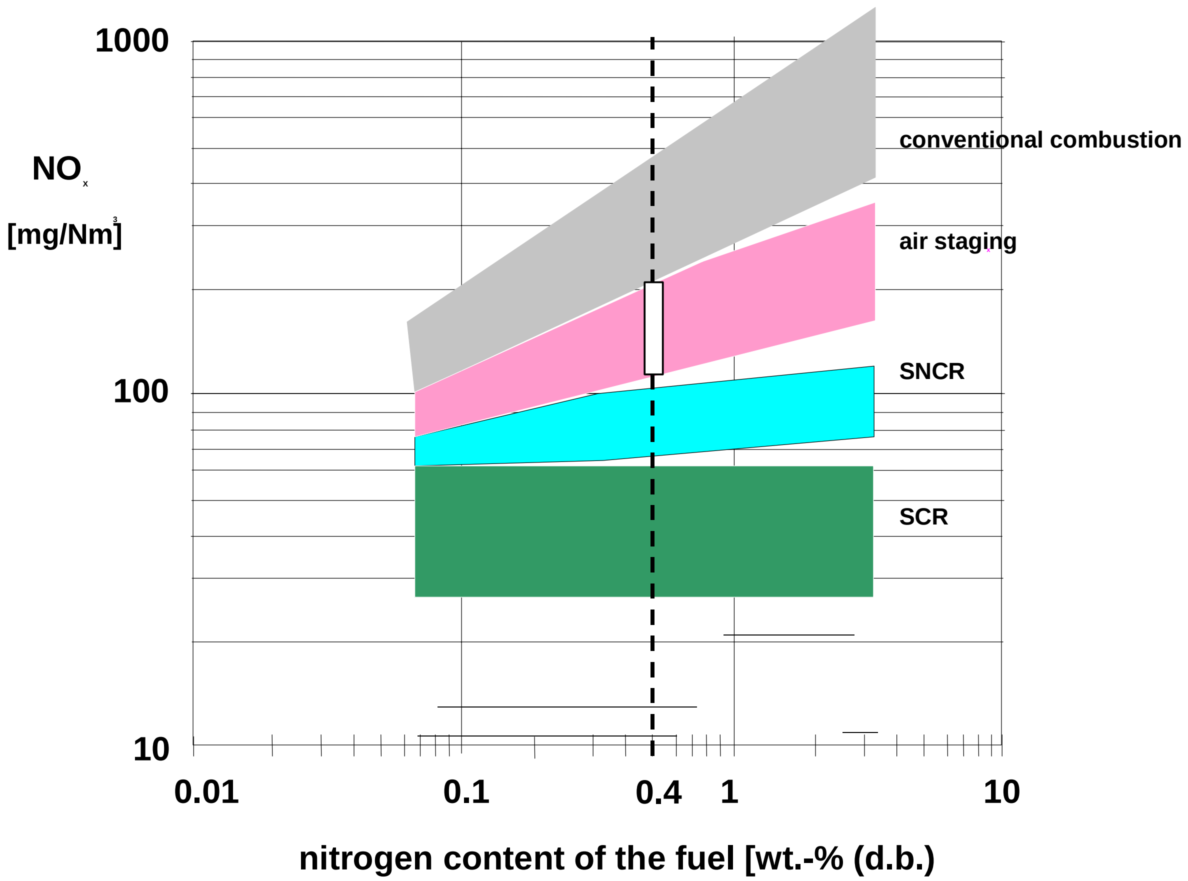


Figure 10: NO_x emissions of several combustion technologies with relation to the fuel nitrogen content

As shown in Figure 7, Figure 8 and Figure 9, the special design of the furnace, supporting fractionated heavy metal separation, also proved successful. During all test runs the heavy metal concentration in the useable ashes was clearly below the limiting values stated in guidelines regulating the use of biomass ashes in forests and on agricultural fields [1, 2].

	test 1 mg/kg (d.b.)	test 2 mg/kg (d.b.)	test 3 mg/kg (d.b.)	test 4 mg/kg (d.b.)	mean mg/kg (d.b.)	limiting value mg/kg (d.b.)
Cu	110.0	100.0	100.0	120.0	107.5	250.0
Zn	1,433.6	1,304.2	1,169.0	1,111.3	1,254.5	1,500.0
Ni	83.4	71.4	81.1	92.3	82.1	100.0
Pb	20.7	11.0	11.3	17.0	15.0	100.0
Cd	6.3	4.7	5.1	5.6	5.4	8.0

Table 2: Heavy metal content of useable ash fraction in mg/kg d.b.

In conclusion, it is noticeable that all components concerning the innovative parts of the project are working as expected. The drying rate and the NO_x-reduction potential of the air staging technology as well as the heavy metal fractionation potential are in the range of the results of theoretical pre-evaluations. Due to the further extension of the pipe network and the expected increase of low-temperature energy users, the efficiencies of heat production and distribution as well as the efficiency of the electric power supply of the plant will further increase within the next year. However, even during the last two years plant efficiencies were significantly better than for conventional (state of the art) biomass district heating plants.

Besides the success of the technologies implemented in the biomass district heating plant of Tamsweg, the social acceptance constantly increased since the launching of the project.

4.4 Operating costs

The annual operating costs (exclusive of VAT), based on the period from 1st September 1997 to 31st August 1998, are listed in Table 3. In contrast to the first year of operation (1996/1997), which also included the start-up phase, the 1997/1998 costs are typical values, which should remain constant in the following years.

Fuel costs	2,418,000 ATS
Electricity for pumps and fans	609,000 ATS
Personnel costs	1,057,000 ATS
Maintenance, repair	1,426,000 ATS
Insurance	78,000 ATS
Telephone	47,000 ATS
Taxes	11,000 ATS
Water conditioning	58,000 ATS
Charges	113,000 ATS
Tax consultant	238,000 ATS
Disposal	50,000 ATS
Other costs	377,000 ATS
Total	6,485,000 ATS

Table 3: Operating costs of the biomass heating plant Tamsweg

4.5 Future of the installation

Within the next years a further increase in energy production is intended by raising the number of clients connected to the pipe network. Modifications of the heating plant itself are not planned.

4.6 Economic viability

In comparison with the working hypotheses stated in the project proposal, the payback time of the installation was reduced significantly (see Table 4). This is mainly due to the high public acceptance of the biomass district heating plant of Tamsweg, which had a positive effect on the number of clients connected to the pipe network. Within the supply area of the pipe network about 85 - 90% of the overall heat demand is now covered by the district heating plant.

	year	1	2	3	4	5	10	15	
Investment costs	proposal	86,373	86,373	106,102	106,102	106,102	106,102	106,102	[1000 ATS]
	actual	92,355	110,672	110,672	110,672	110,672	110,672	110,672	[1000 ATS]
Operating costs	proposal	3,620	3,947	4,112	4,703	4,728	4,855	4,989	[1000 ATS]
	actual	5,424	6,759	6,570	6,592	6,615	6,732	6,855	[1000 ATS]
Annual monetary money	proposal	4,930	6,090	6,670	8,767	8,854	9,306	9,781	[1000 ATS]
	actual	4,930	11,525	11,640	11,757	11,874	12,480	13,117	[1000 ATS]
Payback time	proposal	66	40	41	26	26	24	22	[a]
	actual		23	22	21	21	19	18	[a]

Table 4: Economic viability of the Tamsweg plant

5 PUBLICITY, COMMERCIALIZATION AND OTHER DEVELOPMENTS

5.1 Publicity

Due to the efforts of the project partners and the city of Tamsweg, the EC-THERMIE project “Sustainable biomass heating plant Tamsweg” became well known in Austria and other European countries. Therefore considerable national and international interest in the plant and the innovative technologies realized within this project was achieved. Until August 1998 63 groups consisting of private persons interested in thermal biomass utilization, schools, operators of other heating plants as well as national and international politicians and scientists visited the biomass district heating plant of Tamsweg. To provide them with comprehensive information, a brochure about the history, technology and financing of the project was printed and distributed.

In the past two years the biomass heating plant Tamsweg was the subject of 20 reports in local newspapers, 5 reports in national and international magazines, several radio reports and one program of the German TV station ARD.

Apart from this public relations aspect, the technology, specially the innovative parts of the project, were presented at national and international technology conferences [3, 4, 5], e.g. at the VDI-conference “Thermische Biomassenutzung – Technik und Realisierung”, April 1997, Salzburg. A technical visit at the biomass district heating plant Tamsweg was also part of this conference.

5.2 Outlook

As mentioned in sections 4.2, 4.3 and 4.5, the main components of the biomass heating plant Tamsweg, specially the innovative tools, have proven to work continuously within the expected range of performance. Therefore, only further improvements are intended, e.g. optimized process control concerning the amount of air mixed with the flue gas in order to prevent vapor clouds at the top of the chimney.

The innovative parts of the project have already become standard in the products distributed by the co-signatories of the project. Since all these items, except the fuel drying system, are mainly further improvements and additional features of existing successful products, the demonstrated technology is by now produced in series. Replications in other plants have already taken place. National and international interest in the technologies demonstrated in Tamsweg also helped the participating companies to strengthen their position in the European market.

5.3 Lessons learned / conclusions

The planned erection of a combustion plant, irrespective of the type of fuel used, is always preceded by discussions about emissions. In order to increase public acceptance of the project, people must be provided with comprehensive information about the combustion technology used and the expected decrease of pollution achieved by replacing old heating systems by a new state-of-the-art district heating plant.

One major aim of the project was to increase the energy efficiency of biomass district heating plants. As mentioned in section 2.2.8, special emphasis was put on the optimization of the pipe network and the heat exchanger units at the clients. The result of these efforts is clearly shown in the efficiency of heat distribution, which is about 8% higher than in common district heating systems. Therefore, this design step which has to stand at the very beginning of the project is one of the most important factors influencing the economic viability of the whole project.

Summing up the experiences gathered during the erection of the district heating plant Tamsweg, the most important lesson learned was that close collaboration of the coordinator and the companies supplying the major plant components helps to save time and money and also leads to the quick solution of technical and administrative problems, which occur during the realization of such a large-size project.

5.4 Patent Activity

Concerning the technology of fractionated heavy metal separation patent activities have already been initiated.

5.5 Commercialization

The technologies used to realize the project represent the latest state of the art concerning biomass combustion plants and district heat pipe networks. Since the components used were not totally new developments but innovative improvements of successful products, these innovative features are already being implemented in other projects. For instance, the air-staging technology which has been successfully realized and demonstrated within this project, has become a typical feature of furnaces produced by the project partner Kohlbach GmbH & Co KG. The same applies to the technology of fractionated heavy metal separation. The other co-signatories of the project also took advantage of the possibility of demonstrating their latest technologies and innovations in the framework of an internationally well-known project, thus setting a new standard for biomass heating plants in the capacity range between 1 and 10 MW_{th}. Therefore, the technologies that were new and innovative in Tamsweg are now available as standard tools.

Due to the high international interest in the biomass heating plant Tamsweg, the technologies featured within this project will also be exported to other European countries (mainly Germany, Italy, eastern European Countries).

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ANNEX A

YEAR	1995				1996												1997												1998											
PHASES	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1. DESIGN		■	■	■																																				
		▨	▨	▨																																				
2. MANUFACTURE					■	■	■	■	■	■	■	■																												
					▨	▨	▨	▨	▨	▨	▨	▨																												
3. ASSEMBLY/ INSTALLATION/ ERECTION									■	■	■	■	■	■	■	■	■	■	■	■	■													■	■	■	■	■	■	
									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨																			
4. COMISSIONING												■	■	■	■	■	■	■	■	■	■																			
												▨	▨						▨																					
5. MONITORING																■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
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■ PLANNED

▨ ACTUAL

Table 5: Comparison of planned and actual project schedules

Non-publishable ANNEX

3.3 Technical problems and solutions

In addition to the problems mentioned in section 3.3 of the publishable report several other technical problems occurred:

Initially it was planned to discharge the condensate of the flue gas condensation unit into the municipal sewerage system. However, first chemical analyses of the condensate have shown that the nitrite content by far exceeded the respective limiting value. Therefore, the condensate has to be supplied to the sewage treatment plant Tamsweg.

To reduce the CO emissions a special vorticity device made of the same material as the refractory coatings was installed in the secondary combustion zones of the biomass combustion units. In this way, the mixing of the flue gas with the secondary combustion air is reinforced and therefore the CO emissions can be kept low. In December 1997 this equipment was partly eroded due to high flue gas velocities and temperatures. In March 1998 nearly the whole device was destroyed and therefore the CO emissions of the combustion unit sometimes exceeded the limiting value of 250 mg/Nm³ (dry flue gas, 13 vol.% O_2). During a repair period in summer 1998 a new reinforced vorticity device was installed, which caused the emissions to decrease again.

In November 1997 a valve controlling the water flow through the economizer stage of the flue gas condensation unit was damaged, thereby reducing the water flow through the economizer. As a negative effect the energy efficiency of the flue gas condensation unit, especially the economizer, was reduced. Since it would have been necessary to set the whole pipe network out of operation to replace the valve, which is not possible during the winter months, the repair work was carried out in summer 1998. A lesson learned from that accident was that a hydraulic facility for separating the flue gas condensation unit from the pipe network would have helped to carry out the repair considerably earlier and should be considered for future installations.

Another problem concerning the pipe network was that in several cases the control units of the heat exchangers at the clients did not work correctly. The reason for the malfunction was found in the EPROMs of the control units and most of the EPROMs had to be replaced.

4.2 Performance

Concerning the technology of fractionated heavy metal separation the following additional information about the measurement data must be mentioned:

The actual load of district heating plants always depends on the ambient temperature and the heat demand behavior of the clients. To examine the effects of the technology of heavy metal separation, ash samples of all fractions are taken and the mass flows of all ash fractions produced during the testing period (48 hours) are determined. Due to the sampling technique and the borders of the energy and mass balances, such test runs can only be performed with combustion unit 1 running. During the test runs demand peaks occurred in the morning hours, and due to the fact, that the second combustion unit was out operation because of the reasons mentioned above, unit 1 was operating at 20-25% overload for about one hour. When operating at overload, the flue gas velocities are higher than usual, and therefore, the fly-ash separation effect of the relaxation zones in the furnace is reduced and more particles than usual are entrained. Consequently the amount of cyclone fly-ash is higher than during operation at nominal load. Following the theoretical background of the fractionated heavy metal separation technology, due to the separation at low temperatures (200°C), the heavy metal content of the cyclone fly-ash is higher than that of the bottom and secondary bottom ash. Since the amount of cyclone fly-ash increased from normally 15-20% up to 20-30% of the whole ashes produced during the mentioned overload phases, the heavy metal content of the useable ashes, which are a mixture of the bottom ash, secondary bottom ash and cyclone fly ash, also was higher than usual. It must be emphasized that during operation with both combustion units overload conditions are not usual and consequently the heavy metal content of the useable ashes (mainly Zn and Cd) remains far below the limiting values. Nevertheless, even under these unfavorable operating conditions the limiting values were not exceeded.

4.6 Economic viability

To make the calculation of the payback time mentioned in section 4.6 repeatable, all data needed are stated in the following.

Annual monetary money	year	1	2	3	4	5	10	15	
Length of the pipe network	proposal	11,101	11,101	11,101	15,831	15,990	16,805	17,663	[m]
	actuel	11,101	22,120	22,120	22,120	22,120	22,120	22,120	[m]
Number of connected objects	proposal	145	145	145	215	217	228	240	[-]
	actuel	145	290	293	296	299	314	330	[-]
Full working time of the plant	proposal	1,500	1,500	1,500	1,500	1,500	1,500	1,500	[h/a]
	actuel	1,500	1,802	1,802	1,802	1,802	1,802	1,802	[h/a]
Connected heating power	proposal	5,667	7,000	7,667	10,077	10,177	10,697	11,242	[kW]
	actuel	5,667	11,194	11,306	11,419	11,534	12,122	12,740	[kW]
Heat consumption of the clients	proposal	8,500	10,500	11,500	15,115	15,266	16,045	16,863	[MWh]
	actuel	8,500	20,172	20,374	20,577	20,783	21,843	22,958	[MWh]
Average price for thermal energy	proposal	0.58	0.58	0.58	0.58	0.58	0.58	0.58	[ATS/kWh]
	actuel	0.58	0.57	0.57	0.57	0.57	0.57	0.57	[ATS/kWh]
Annual monetary money E	proposal	4,930	6,090	6,670	8,767	8,854	9,306	9,781	[1000 ATS]
	actuel	4,930	11,525	11,640	11,757	11,874	12,480	13,117	[1000 ATS]

Fuel costs	year	1	2	3	4	5	10	15	
Heat consumption of the clients	proposal	8,500	10,500	11,500	15,115	15,266	16,045	16,863	[MWh]
	actuel	8,500	20,172	20,374	20,577	20,783	21,843	22,958	[MWh]
Heat loss (pipenet)	proposal	2,125	2,625	2,875	3,779	3,817	4,011	4,216	[MWh]
	actuel	2,125	5,084	5,084	5,084	5,084	5,084	5,084	[MWh]
Heat produced in the boiler	proposal	10,625	13,125	14,375	18,894	19,083	20,056	21,079	[MWh]
	actuel	10,625	25,256	25,458	25,661	25,867	26,927	28,042	[MWh]
Energy input by fuel (without cond. unit)	proposal	12,129	14,983	16,410	21,569	21,784	22,895	24,063	[MWh]
	actuel	11,806	28,062	28,286	28,513	28,741	29,919	31,157	[MWh]
Heat recovered in the flue gas conden.	proposal	1,594	1,969	2,156	2,834	2,862	3,008	3,162	[MWh]
	actuel	1,535	4,911	4,974	5,039	5,105	5,445	5,808	[MWh]
Net energy input (fuel)	proposal	10,535	13,014	14,254	18,734	18,922	19,887	20,901	[MWh]
	actuel	10,535	22,636	22,792	22,949	23,108	23,924	24,776	[MWh]
Specific fuel costs	proposal	104	104	104	104	104	104	104	[S/MWh]
	actuel	141	96	96	96	96	96	96	[S/MWh]
Annual costs for fuel:	proposal	1,106	1,366	1,497	1,967	1,987	2,088	2,195	[1000 ATS]
	actuel	1,502	2,418	2,437	2,457	2,477	2,578	2,685	[1000 ATS]

Specific electricity consumption	proposal	20	kWh/MW$_{\text{thermal energy consumed}}$			
	actuel	16	kWh/MWh$_{\text{thermal energy consumed}}$			
Price for electricity	proposal	1.68	S/kWh	=	0.125	Ecu/kWh
	actuel	1.50	S/kWh	=	0.111	Ecu/kWh

Annual operating costs	year	1	2	3	4	5	10	15	
Electricity:	proposal	286	353	386	508	513	539	567	[1000 ATS]
	actuel	301	609	612	615	618	634	650	[1000 ATS]
Personnel:	proposal	476	476	476	476	476	476	476	[1000 ATS]
	actuel	1,021	1,021	1,021	1,021	1,021	1,021	1,021	[1000 ATS]
Maintenance, repair:	proposal	1,267	1,267	1,268	1,267	1,267	1,267	1,267	[1000 ATS]
	actuel	574	829	1,412	1,412	1,412	1,412	1,412	[1000 ATS]
Insurance:	proposal	85	85	85	85	85	85	85	[1000 ATS]
	actuel	97	78	78	78	78	78	78	[1000 ATS]
Telephone:	proposal	35	35	35	35	35	35	35	[1000 ATS]
	actuel	60	50	50	50	50	50	50	[1000 ATS]
Tax:	proposal	70	70	70	70	70	70	70	[1000 ATS]
	actuel	180	133	133	133	133	133	133	[1000 ATS]
Water processing:	proposal	5	5	5	5	5	5	5	[1000 ATS]
	actuel	16	25	25	25	25	25	25	[1000 ATS]
Charge:	proposal	70	70	70	70	70	70	70	[1000 ATS]
	actuel	25	36	36	36	36	36	36	[1000 ATS]
Tax adviser:	proposal	80	80	80	80	80	80	80	[1000 ATS]
	actuel	283	257	257	257	257	257	257	[1000 ATS]
Other costs:	proposal	90	90	90	90	90	90	90	[1000 ATS]
	actuel	1,344	1,282	488	488	488	488	488	[1000 ATS]
Waste disposal:	proposal	50	50	50	50	50	50	50	[1000 ATS]
	actuel	20	20	20	20	20	20	20	[1000 ATS]
Sum of annual operating costs	proposal	2,514	2,581	2,615	2,736	2,741	2,767	2,795	[1000 ATS]
	actuel	3,922	4,341	4,132	4,135	4,139	4,154	4,170	[1000 ATS]
Annual operating and	proposal	3,620	3,947	4,112	4,703	4,728	4,855	4,989	[1000 ATS]
	actuel	5,424	6,759	6,570	6,592	6,615	6,732	6,855	[1000 ATS]

Economic profitability

Investment costs	year	1	2	3	4	5	10	15	
Concept design	proposal	350	350	350	350	350	350	350	[1000 ATS]
	actuel	113	113	113	113	113	113	113	[1000 ATS]
Engineering	proposal	1,112	1,112	1,112	1,112	1,112	1,112	1,112	[1000 ATS]
	actuel	1,587	1,587	1,587	1,587	1,587	1,587	1,587	[1000 ATS]
Combustion unit 1	proposal	8,700	8,700	8,700	8,700	8,700	8,700	8,700	[1000 ATS]
	actuel	8,739	9,155	9,155	9,155	9,155	9,155	9,155	[1000 ATS]
Combustion unit 2	proposal			5,220	5,220	5,220	5,220	5,220	[1000 ATS]
	actuel	4,777	5,011	5,011	5,011	5,011	5,011	5,011	[1000 ATS]
Condensation unit	proposal	6,500	6,500	6,500	6,500	6,500	6,500	6,500	[1000 ATS]
	actuel	4,132	4,959	4,959	4,959	4,959	4,959	4,959	[1000 ATS]
Ash delivering and preparing system	proposal	616	616	616	616	616	616	616	[1000 ATS]
	actuel			0	0	0	0	0	[1000 ATS]
Steel construction	proposal	650	650	650	650	650	650	650	[1000 ATS]
	actuel			0	0	0	0	0	[1000 ATS]
Pipes and pumps (plant)	proposal	3,600	3,600	3,600	3,600	3,600	3,600	3,600	[1000 ATS]
	actuel	3,004	4,720	4,720	4,720	4,720	4,720	4,720	[1000 ATS]
Flue gas channels	proposal	770	770	770	770	770	770	770	[1000 ATS]
	actuel			0	0	0	0	0	[1000 ATS]
Pipe net	proposal	34,214	34,214	48,723	48,723	48,723	48,723	48,723	[1000 ATS]
	actuel	35,471	49,193	49,193	49,193	49,193	49,193	49,193	[1000 ATS]
Control system	proposal	16,601	16,601	16,601	16,601	16,601	16,601	16,601	[1000 ATS]
(combustion and pipenet)	actuel	18,197	19,480	19,480	19,480	19,480	19,480	19,480	[1000 ATS]
Building	proposal	11,160	11,160	11,160	11,160	11,160	11,160	11,160	[1000 ATS]
	actuel	13,718	13,835	13,835	13,835	13,835	13,835	13,835	[1000 ATS]
Wheel loader	proposal	900	900	900	900	900	900	900	[1000 ATS]
	actuel	1,304	1,304	1,304	1,304	1,304	1,304	1,304	[1000 ATS]
Oil heating unit	proposal	1,200	1,200	1,200	1,200	1,200	1,200	1,200	[1000 ATS]
	actuel	1,315	1,315	1,315	1,315	1,315	1,315	1,315	[1000 ATS]
Monitoring	proposal	2,547	2,547	2,547	2,547	2,547	2,547	2,547	[1000 ATS]
	actuel	1,896	1,896	1,896	1,896	1,896	1,896	1,896	[1000 ATS]
Total costs	proposal	88,920	88,920	108,649	108,649	108,649	108,649	108,649	[1000 ATS]
	actuel	94,251	112,568	112,568	112,568	112,568	112,568	112,568	[1000 ATS]

Investment	proposal	86,373	86,373	106,102	106,102	106,102	106,102	106,102	[1000 ATS]
(Total costs-Phase 5)	actuel	92,355	110,672	110,672	110,672	110,672	110,672	110,672	[1000 ATS]

Payback time for	proposal	66	40	41	26	26	24	22	[a]
investment t	actuel		23	22	21	21	19	18	[a]

Life time of the installation	proposal	31	31	30	31	31	31	31	[a]
	actuel	28	28	28	28	28	28	28	[a]