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PAPER

APPLICATION OF ORC UNITS IN SAWMILLS. TECHNICAL-ECONOMIC CONSIDERATIONS

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Abstract

In the last years, Turboden[i] ORC modules have become more and more popular on the market thanks to the high efficiency, the high availability and the low operational costs in comparison with other technologies. Nowadays there are 78 plants in operation in different European countries. A survey of the main references in the wood industry and of the developments over the last years.

This article shows a typical application in sawmills with drying chambers based on a biomass combustion system and an ORC unit

This application of ORC units is particularly interesting because additional income can be obtained from electricity generated by the ORC unit without significant changes to the typical sawmill. Part of the electricity generated is used for the own consumption of the plant and the remaining part is sold to the grid, according to the market conditions about electricity value and possible subsidies (green certificates or feed-in tariffs) for renewable energy applied in the different countries. For this reason many of the new sawmill plants recently built or under construction are based on CHP solutions with ORC units.

A detailed costs/advantages analysis of the implementation in sawmill plants is performed. This study is based on a differential economic analysis between a CHP system based on ORC technology and a biomass boiler heating hot water for the same drying chambers. The financial results are calculated in terms of discounted Pay Back Time of the additional investment required by the cogenerative solution depending on a wide range of fuel and electricity values in full CHP mode.

[i] More information about Turboden in the Appendix

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1. A SHORT DESCRIPTION OF THE DRYING PROCESS IN SAWMILL PLANT

The drying of timber in a conventional sawmill is executed as a batch process in suitable drying chambers. The wood is dried in closed chambers where air is heated up in a controlled way usually by an external heat source (hot water, low pressure steam, gas boiler etc,). In most cases in order to avoid the strains of the wood, and maintain a high wood quality a relatively low air temperature is used inside the chamber. Usually the required air temperature is suitable for the use of hot water with 90-95 °C feeding temperature (75 – 80°C return) as heat source. Often the heat is produced by biomass boilers burning biomass residues available in the sawmill.

2. CHP PLANTS WITH ORC UNITS COUPLED TO DRYING CHAMBERS IN SAWMILLS

Depending on market boundary conditions, a biomass CHP solution within a drying chamber plant can be profitable. In the following part of this study a CHP solution based on biomass ORC units and drying chambers is shown.

A typical application in sawmills with drying chambers based on a biomass combustion system and an ORC unit does not lead to significant changes in conventional heat only solutions.

This means that retrofitting of already existing drying chambers plant based on a hot water boiler can easily be implemented as well, just replacing the hot water boiler (fed by natural gas or biomass) with a biomass boiler heating thermal oil in order to feed an ORC unit. Hot water will be available downstream the ORC condenser.

Figure 1 shows a block diagram of the process that occurs in a CHP biomass plant for sawmills based on drying chambers and an ORC unit.

Turboden has 22 references of CHP applications in sawmill plants and 17 references in pellet production.

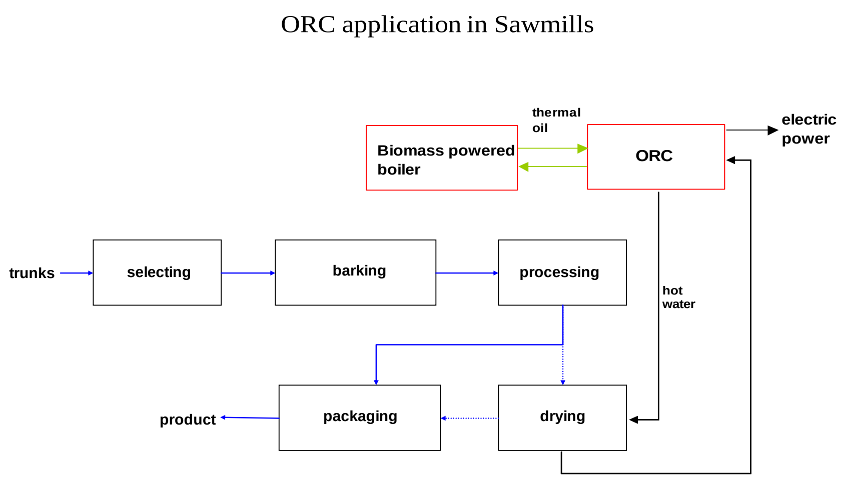

Figure 1 Schematic diagram of a CHP biomass plant for sawmills with drying chambers and an ORC unit.

3. DIFFERENTIAL ECONOMIC FEASIBILITY OF A CHP PLANT BASED ON ORC TECHNOLOGY

In this chapter a differential economic analysis between a CHP system based on ORC technology and a biomass boiler heating hot water for the same drying chambers is performed. In this economic analysis, only the additional "revenues" and "costs" (both capital and consumption/operating costs) that result from the addition of an ORC system for cogeneration (that is to say only the revenues and the costs which would not exist if a heat-only system was implemented) are taken into account.

In the following table (table 1) the technical features assumed for the 2 different plant configurations are underlined: one only with drying chambers and one with an ORC CHP plant configuration coupled to drying chambers. The table reports the assumed efficiencies for thermal oil boiler and for the hot water boiler and also the specific electric own consumptions for each configuration (thermal oil and hot water boiler).

It is considered that the product before the drying process in the drying chambers has a moisture percentage of 40% and leaves the drying process with a moisture percentage of 15%. In this study every ORC unit is assumed to supply drying chambers with hot water at a constant feed temperature of 90°C; a drying efficiency of 50% is considered (evaporation energy of the removed water content/thermal energy supplied to drying chamber).

The values shown in the table below are derived from our previous experiences and from bibliographic quotations.

PLANT TECHNICAL FEATURES	PLANT CONFIGURATION	
Combustion system	**Drying chamber**	**CHP**
Thermal oil boiler efficiency (including Split system)	-	90%
Hot water boiler efficiency (including water economizer)	90%	-
Thermal oil boiler own consumption [kWel/MWth]	-	25
Hot water boiler own consumption [kWel/MWth]	15	-
Drying chamber process	**Drying chamber**	**CHP**
Inlet wet product moisture	40%	40%
Outlet dry product moisture	15%	15%
Drying efficiency	50%	50%
Hot water temperature inlet drying chamber (about) [°C]	90	90

Table 1 Technical assumptions: Combustion system, Drying chamber process, Power generation system

Starting from these assumptions we can obtain a thermal energy requirement of 0.24 MWh/m^3 dried wood. Assuming a load factor of 6.500 full load operation hours per year every standard size of the ORC unit can be linked to a yearly dried wood production.

In table 2 the technical characteristics of every ORC unit are specified and the production capacity for all ORC sizes is resumed. The table shows:

- the thermal power input needed by every ORC unit coming from thermal oil;
- the outlet water temperature from the ORC at 90°C that will be used to feed the drying chambers;
- the thermal power output to the hot water feeding the drying chambers;

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- The ORC net electric power (ORC captive consumption, e.g ORC internal feed pump. Boiler own consumption is not considered, table 1 takes into account this technical feature);
- The ORC net electric efficiency (ratio between net electric power generated by ORC unit and thermal power inlet ORC from thermal oil)
- Full load operation hours (hr/year – time period where a plant which produces/uses power should work at full load to reach the yearly production/consumption)
- The thermal energy supplied to the drying chamber (MWh/year)
- The dried product (m^3/year)

	T200-CHP Split	**T500-CHP Split**	**T600-CHP Split**	**T800-CHP Split**	**T1100-CHP Split**	**T1500-CHP Split**	**T2000-CHP Split**
Thermal power input from thermal oil (kW)	1.340	3.240	3.910	5.140	6.715	9.790	12.020
Hot water temperature out from ORC (°C)	90	90	90	90	90	90	90
Thermal power output to hot water (kW)	1.108	2.637	3.191	4.148	5.426	7.920	9.700
ORC net electric power (kWel)	**205**	**538**	**641**	**889**	**1.155**	**1.674**	**2.079**
ORC net electric efficiency [ii]	15,3%	16,6%	16,4%	17,3%	17,2%	17,1%	17,3%
Full load operation hours (hr/year)	6.500	6.500	6.500	6.500	6.500	6.500	6.500
Thermal energy supplied to the drying chambers (MWh/year)	7.200	17.100	20.700	27.000	35.300	51.500	63.100
Dried production (m^3/year)	**30.000**	**71.400**	**86.400**	**112.300**	**147.000**	**215.000**	**263.000**

Table 2 Technical characteristics and the related production capacity (m3/year) for all ORC sizes

3.1 Discussion of main economic parameters and assumptions

The main economic parameters which influence the differential economic feasibility of a CHP plant are the following:

- Additional investment costs of CHP plant (shown in table 3)

In this study, the assumptions for the investment costs of all the components of the plant have been defined as a ratio between the cost of the various components of the plant and the cost of ORC units. This

[ii] Performance data according to Turboden standard Data sheets

means that the same scale effect of Turboden ORC units, is assumed for the investment costs of all components (table 3) .

The cost for the drying chambers wasn't taken into account because it is not relevant in this differential study given that it is identical for the CHP and heat only system.

ADDITIONAL INVESTMENT COSTS **CHP - Only drying chamber**	
Turboden ORC unit	1
Boiler	1,1
Civil work	0,5
Engineering	0,15
Overall (drying chamber excluded)	2,75

Table 3 Assumed investment costs for a CHP plant and a heat only plant as multiplier of ORC costs

In addition to the prices above an extra cost of 100.000 Euro due to the necessary equipment for the connection to the electric grid has been considered.

The actual additional investment costs assumed are reported in the table below for 3 different ORC sizes:

Turboden ORC unit	Overall Investment Cost [k€] CHP plant
T500	**(*) 2.800**
T1100	**3.300**
T2000	**5.400**

Table 4 Assumed investment costs for CHP plant and heat only plant

*(*) Example of calculation: 2.800k€ = 2,75 * 985k€ c.a. (investment cost of T500 ORC unit) + 100k€ (grid connection).*

- Value of electricity

One of the most significant parameters influencing the economic feasibility of a cogenerative plant is the value of the electric energy generated by the plant.

The economic value of this parameter strongly depends on the frame conditions and in particular on the specific type of regulation applied for green energy subsidy.

- Cost of biomass

The cost of biomass is another very significant parameter influencing the feasibility of a cogeneration plant in the sawmill industry.

The two different scenarios were considered, the first with a biomass cost of 10 €/MWh (equal to 25 €/ton, assuming a calorific value of 2,5 kWh/kg); the second with a biomass cost of 20 €/MWh (equal to 50 €/ton, assuming a calorific value of 2,5 kWh/kg).

- Yearly full load operation hours

The heat load curve of a single drying chamber has a small variation in seasonal load and is very variable during a single drying cycle (high load at the beginning of the cycle). To ensure a more constant heat load, operators usually try to distribute the peak loads of multiple drying chambers evenly. According to the experience of existing plants, a number of full load operation hours above 6.500 hours/year is reached.

In all the calculations of this study, a full load operation time of 6.500 hour/year has been assumed.

The sensitivity of the economic results depending on the variation of this parameter has not been investigated.

- Discount rate

In addition, the discount rate also influences financial results. In the present economic analysis a discount rate of 5% has been considered.

3.2 Influence of electricity value and plant size on the economic feasibility of a CHP unit (fuel cost 10 €/MWh)

The financial results are calculated in terms of discounted Pay Back Time of the additional investment required by the cogenerative solution. In this paragraph the sensitivity of the results to the variation in plant size and electricity value is investigated.

The following boundary conditions are assumed:

- constant fuel cost (biomass) :10 Euro/MWh;
- Average Electricity Value variable between 0,10 and 0,25 Euro/kWh_{el};
- ORC size: from T200 to T2000 (about 30.000 – 260.000 m^3/year dried production capacity);
- constant hot water feed temperature to drying chambers: 90°C.

The assumed biomass cost (10 Euro/MWh) can be considered as a moderate fuel cost which may be common for countries with low electricity value markets or for low quality fuel (for instance bark) in high electricity value markets.

The payback time is strongly influenced both by the Electricity Value and by the Size Effect, due to higher specific investment costs for small units.

The results show that plants with an installed power over 1500 kW_{el} have a good feasibility (discounted PBT about 6-7 years and IRR about 16% for 15 years) with an energy value of 0,1 Euro/kWh which can be considered realistic in medium term as cost for the own consumption of an industrial user in most European countries. Therefore starting from this sawmill size (equivalent to a yearly dried production of 215.000 m^3/year), biomass cogeneration is economically competitive in most European countries.

Plants with a smaller size need a higher electricity value in order to reach a good feasibility. For example,

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plants with an installed power of 800 kWel (dried timber production >100.000 m3/year), can be an economically interesting solution starting from an electricity value of about 0,13 – 0,14 Euro/kWh$_{el}$, In areas with electricity values above 0,16 Euro/kWh$_{el}$ also cogeneration plants with a power range of 600 kWel (dried production of ca. 85.000 m3/year) become feasible (discounted PBT under 7 years and IRR of 17% for 15 years).

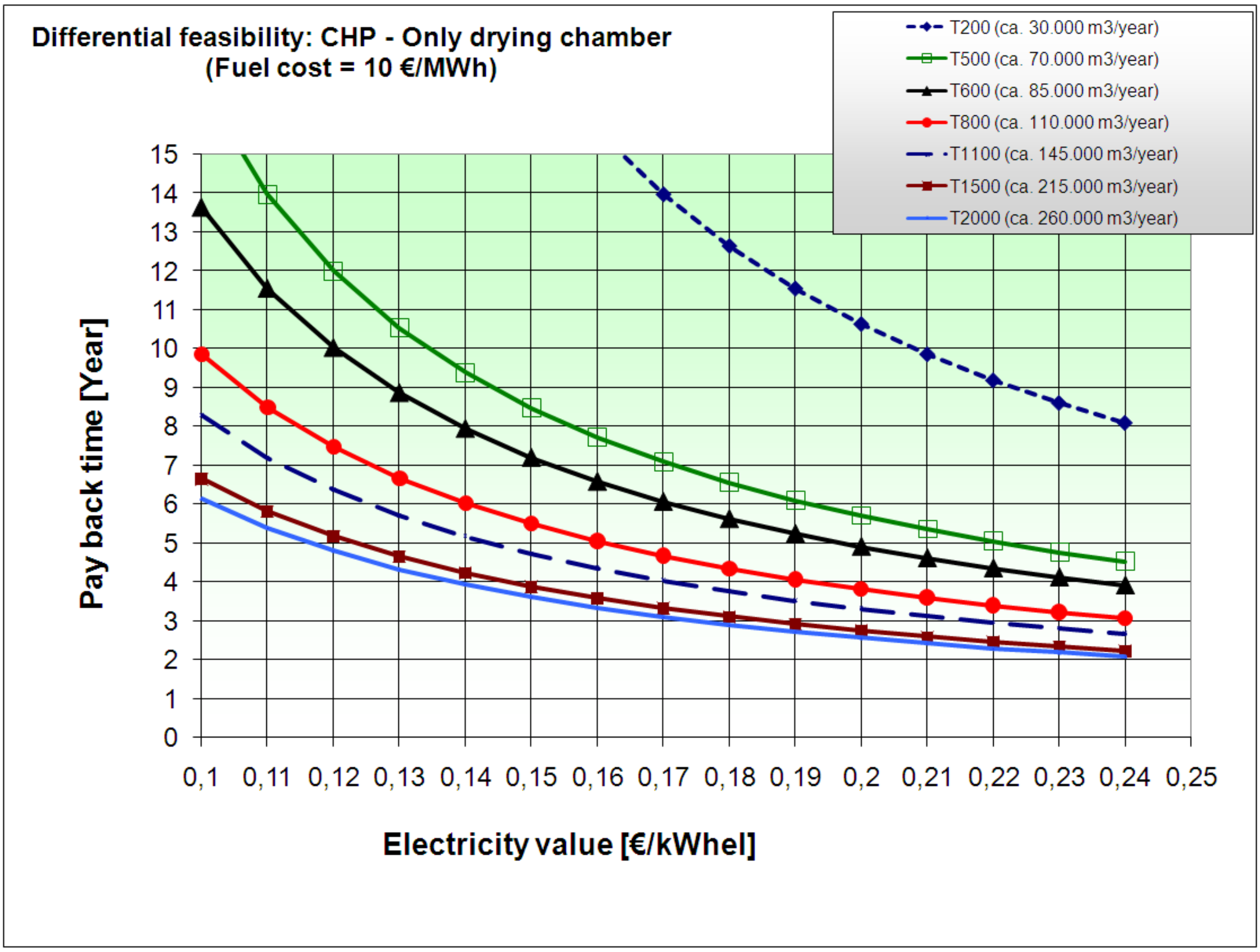

Figure 3 Discounted Pay Back Time of the additional investment cost of a cogeneration system compared with a only drying chamber plant employed in sawmill plants as a function of electricity value and plant size

The solution based on the Turboden T200 unit (about 200 kW$_{el}$ and dried production ca. 30.000 m^3/year) is not economically competitive under any realistic frame condition due to the relevant economy-of-scale-effect.

3.3 Influence of electricity value and plant size on the economic feasibility of a CHP unit (fuel cost 20 €/MWh)

In the countries where electricity value is high due to relevant support schemes for green electricity generated from biomass, fuel costs tend to become higher. For this reason, the previous analysis has been repeated with a high fuel cost (20 Euro/MWh).

The following boundary conditions are assumed:

- constant fuel cost (biomass): 20 Euro/MWh;
- Equivalent Electricity Value variable between 0,10 and 0,25 Euro/kWh$_{el}$;
- ORC size: from T200 to T2000 (about 30.000 – 260.000 m^3/year dried production capacity);
- constant hot water feed temperature to drying chambers: 90°C.

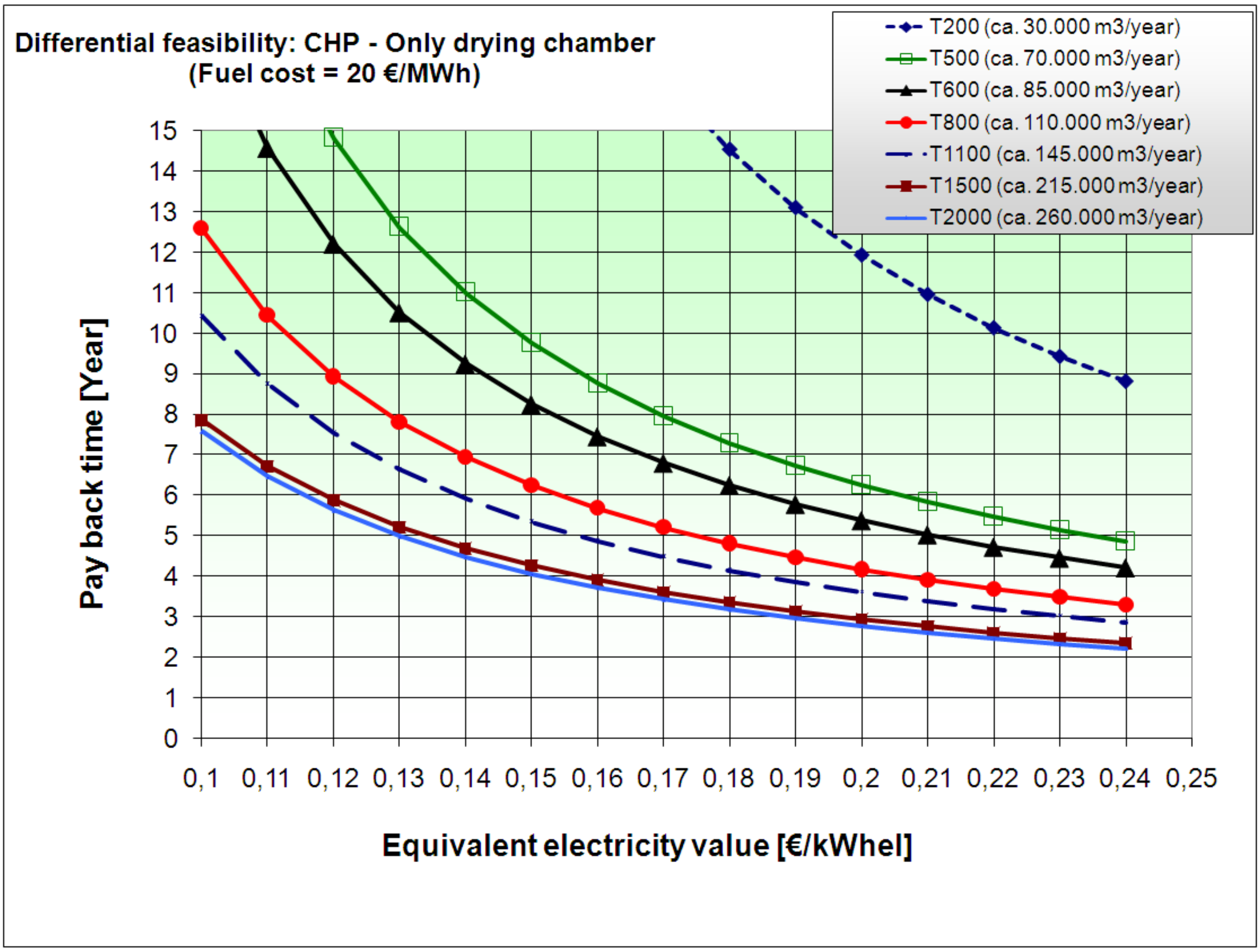

Figure 4 Discounted Pay Back Time of the additional investment cost of a cogeneration system compared with a only drying chamber plant employed in sawmill plants as a function of electricity value and plant size

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The results show that, also in a less favourable scenario, plants with an installed power over 1500 kW_{el} show an acceptable feasibility (discounted PBT about 7-8 years and IRR about 13% for 15 years) with an electricity value of 0,1 $Euro/kWh_{el.}$

Also for smaller plants the impact of an increase of 100% of the biomass cost from 10 Euro/ MWh to 20 Euro/MWh is limited. For example, the payback of the 800 kWel system at an electricity value of 0,14 $Euro/kWh_{el}$ increases by about 1 year from 6 to 7 years (IRR decreases from 19% for 15 years to 16% for 15 years).

Resuming biomass cogeneration in sawmills is economically competitive when the right boundary conditions exist. The most important parameters are the size of the plant and the value of electricity. Given the right frame conditions, the investment is safe, being only marginally influenced by biomass cost.

4. CONCLUSIONS

The economic analysis performed in this paper shows that the installation of cogeneration units based on thermal oil boilers and Turboden ORC units coupled with drying chambers as heat suppliers for sawmill plants is an economically interesting option under a broad range of frame conditions.

Plants starting from 110.000 m^3/year of dried production capacity can be economically competitive starting from an electricity value of 0,16 Euro/kWhel (see Figure 3). Even more important is the fact that, due to the additional incomes from electric energy generation, this solution reduces the risk connected with increased biomass costs, being able to generate positive cash flows at much higher fuel costs than the heat only solution. These frame conditions are actually present in many European countries where new sawmill plants are under construction (Germany, Austria, Italy, Belgium, and UK , etc).

For a dried production capacity of 250.000 m^3/year, a cogeneration plant may be a good solution for covering the own consumption of the sawmill plant also in countries where no support schemes for renewable energy production are implemented, especially if fuel at negligible cost can be used. In this case is shown an acceptable feasibility (discounted PBT up to 5 years) starting from electricity values in the range of 0,10 Euro/kWhel which can be considered a long term average buying rate for industrial customers in many countries in the world. In particular, this gives excellent medium term application opportunities for new plants in Eastern Europe, Russia and North America.

The frame conditions described above apply to a big share of the new production capacities planned worldwide both concerning economical conditions (electricity value and biomass cost) and plant size.

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APPENDIX

1) TURBODEN PROFILE

Since 1980, when it was founded by Prof. Gaia, Turboden has been wholly dedicated to development, design and supply of ORC (Organic Rankine Cycle) plants for distributed energy production.

This long experience, gained through several prototype units with increasing performance, has enabled since the 90's the production and commercialization of standard modules with high efficiency and reliability together with ease of operation and low running costs.

The fields of application of Turboden ORC units for distributed generation are mainly:

- Combined Heat & Power starting from renewable energy sources such as biomass,
- Heat Recovery from otherwise wasted hot flows (gaseous or liquid),
- Electric generation from low enthalpy geothermal energy sources and from sun power through solar collectors.

Currently, there are 75 Turboden ORC plants operating in Europe with further 45 plants under construction.

Turboden ORC units range between 200 kWel and 3.000 kWel.

The electrical efficiency of Turboden ORCs in typical CHP applications is about 18%.

Turboden usual clients for CHP applications are industries where the thermal power of hot water (up to 120°C) is valued, such as sawmills, pellet production plants, wood panel/fibre/particle board industries, waste to energy plants and local utilities providing district heating.

Typical clients for Heat Recovery applications are cement, glass, and metal industries. Turboden HR modules are also employed in small combined cycle for distributed generation as our turbo-generators can be used to recover heat and produce electric power from the exhaust gas of diesel/biodiesel, gas/biogas engines and gas turbines.

Turboden is world leader in biomass based ORC plants and number one supplier of ORC systems in Europe.

Since the year 2000 the company has been going through a strong organic growth process, increasing production capacity, widening the size range of ORC modules, extending applications, guaranteeing service and deepening R&D efforts.

In 2007 Turboden production was about 27 million Euros with 70 employees.

Since the end of the year Turboden has moved to a new building in Brescia with 2300 sq m shop for module assembly and tests and 1400 sq m offices.

The new headquarters in Brescia house most company staff (proposal, sales, design, engineering, planning, project management, administration) including the Service & Client Support with remote monitoring of plants in operation.

A separate office in Milano houses a group dedicated to Research & Development in fluid dynamics and modelling.

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2) ORC UNITS IN BIOMASS COGENERATION

Over the last 10 years the ORC technology has demonstrated to be a well proven industrial product for application in small decentralized biomass CHP plants (0,5 – 2 MWel).

Typical systems are based on the following main steps:

- biomass fuel is burned in a combustor made according to the well established techniques also in use for hot water boilers. These combustors with their set of accessories (filters, controls, automatic ash disposal and biomass feed mechanism etc.) are nowadays safe, reliable, clean and efficient;

- hot thermal oil is used as heat transfer medium, providing a number of advantages, including low pressure in boiler, large inertia and insensitivity to load changes, simple and safe control and operation. Moreover, the adopted temperature (about 315°C) for the hot side ensures a very long oil life. The utilization of a thermal oil boiler also allows operation without requiring the presence of licensed operators as for steam systems in many European countries;

- an Organic Rankine Cycle turbogenerator is used to convert the available heat to electricity. Thanks to the ORC, that is thanks to the use of a properly formulated working fluid and to the optimization of the machine design, both high efficiency and high reliability are obtained. The condensation heat of the turbogenerator is used to produce hot water at typically 80 – 120°C, a

temperature level suitable for district heating and other low temperature uses (i.e. wood drying and cooling through absorption chillers etc.).

The ORC unit is based on a closed Rankine cycle performed adopting a suitable organic fluid as working fluid. In the standard units for biomass cogeneration developed by Turboden silicon oil is used as working fluid. The first ORC adopting this fluid was tested in 1986 by Turboden.

The thermodynamic cycle and the relevant scheme of components are reported in Figure 5.

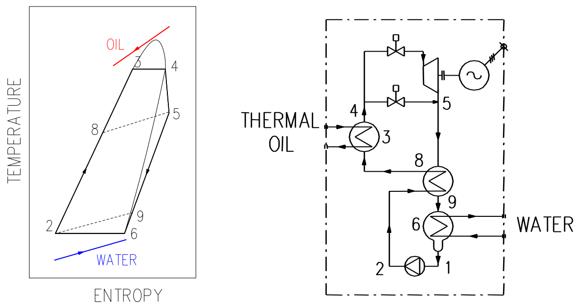

Figure 5 Thermodynamic cycle and components of an ORC unit

The turbogenerator uses the hot temperature thermal oil to pre-heat and vaporise a suitable organic working fluid in the evaporator (8➔3➔4).

The organic fluid vapour powers the turbine (4➔5), which directly drives the electric generator through flexible coupling.

The exhaust vapour flows through the regenerator (5➔9) where it heats the organic liquid (2➔8).

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Finally, the vapour is condensed in a water cooled condenser (9➔6➔1).

The organic fluid liquid is then pumped (1➔2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.

Compared to other competing technologies (i.e. steam turbines), the main advantages obtained from the ORC technology are the following :

- high cycle efficiency (especially if used in cogeneration plants);
- very high turbine efficiency (up to 85%);
- low mechanical stress of the turbine, thanks to the low peripheral speed;
- low RPM of the turbine allowing the direct drive of the electric generator without reduction gear;
- no erosion of the turbine blades, thanks to the absence of moisture in the vapour nozzles;
- very long operational life of the machine due to the characteristics of the working fluid that, unlike steam, is non eroding and non corroding for valve seats, tubing and turbine blades;
- no water treatment system as in steam plants is necessary.

There are also other relevant advantages, such as simple start-stop procedures, quiet operation, minimum maintenance requirements and good partial load performance. The main advantage of ORC technology is that no particular qualification or know how is required for the personnel operating the CHP plant. This means that also customers without any background in electricity generation can easily evaluate an investment in a CHP plant .

Due to these main reasons the standard range of ORC units developed, produced and marketed by Turboden Srl. Brescia is considered an optimal solution for small biomass cogeneration systems in the power range up to 2 MWel per unit . This is confirmed by more than 70 Turboden ORC plants in operation for a total installed power of more than 65 MWel that are showing very good results in terms of reliability (average availability of the ORC units > 98% over more than 1.000.000 hours of operation) and in terms of reduced operational and maintenance costs.