Experiences of ENDESA Group in generation of electricity with biomass

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Abstract. ENDESA’s activities in renewable energy are carried out by Endesa Cogeneración y Renovables, SAU (ECYR), a 100% participated company. Besides its experience with industrial cogeneration, wind farms, waste-to-energy plants and minihydraulic plants, ECYR has a large experience with electricity generation with different types of biomass. This paper reviews ECYR participated plants and future projects, using residual biomass from agriculture and forestry (“orujillo”, “alperujo” and residual wood), energy crops and biogas, from landfill and from sewage plants. A brief description of the plants is given, as well as a more detailed description of the newest and most outstanding plants (“orujillo” plants of ENEMASA and La Loma, as well as landfill biogas plant in Garraf).

Key words
Biomass, biogas, “orujillo”, landfill, energy recovery.

1. Introduction
Endesa Cogeneración y Renovables SAU (ECYR) is a company belonging to ENDESA group, which is the responsible within Endesa Group for developing small-scale electricity generation, including:

- Cogeneration of heat and power in industrial plants (714 MW in 84 plants)
- Waste – to – energy plants (about 63 MWe and 900,000 t/year MSW in 3 plants)
- Renewable energy plants.

In this last item, ECYR is specially involved in projects of:

- Mini-hydraulic power plants (68 MW in 19 plants)
- Wind farms (822 MW in 42 sites)
- Biomass – to – energy plants.

In this paper the activities related to biomass plants are described.

A. Biomass from agricultural residues
Agricultural residues are an increasingly interesting source of renewable energy, since such residues are widely available in Spain. As the most important plants in this sector, we can mention:

- ENEMANSA (Energía de la Mancha, SA): this is a plant fired exclusively on “orujillo”, a dry residue of olive processing, which is grinded to a size of about 1 mm and fired in suspension in a Foster Wheeler steam generator, which produces 65.8 t/h of steam at 60 bar and 450 °C for a 16 MW turbine. The boiler burns the “orujillo” in suspension, although it has a small bottom grate to reburn the coarse particles. The plant uses around 100,000 t/year of orujillo with a LHV of 15.5 MJ/kg and a water content around 10%. The plant is owned by ECYR in partnership with AGECAM and Aceites Pina, and was commissioned on March 2002. The plant is located in the province of Ciudad Real, close to the big olive-processing factory of Aceites Pina, which supplies all the fuel for the plant.

This plant is described in detail in the following sections.

- La Loma: this is a twin-plant of ENEMANSA, located in the province of Jaén and burning also some 100,000 t/year of “orujillo”, but coming from a large number of small suppliers. The plant produces also 16 MW of electric output, and was commissioned on March 2002.

- Vetejar: this is a plant located in the province of Málaga using “alperujo” as a fuel in a bubbling fluidised bed. “Alperujo” is a very wet residue from
olive processing, with around 70% water content. The fluidised bed boiler produces steam at 84 bar and 515°C for a steam turbine with an electrical output of 12.4 MW. The plant was commissioned in 1994. The plant is owned by ECYR in partnership with Oleicola El Tejar and Abengoa.

Fig. 1: The plant of Vetejar

- Allarluz: this is a 2.35 MW plant located in Allariz, in the province of Ourense, using forest residuals, clean residual wood, sawdust and different types of residual wood. The plant consists of a Vulcano boiler with a vibrating grate and induced draft, which raises 11.0 t/h of steam at 40 bar 400°C for a condensation turbine.

B Energy crops

Energy crops appear as an interesting developing area for the future. A large number of old agriculture fields are presently out of exploitation, so large surfaces could be used for quick-growing agricultural species (Cynara Cardunculus and others) which would be used as fuel for small scale power plants.

ECYR has developed a project for a plant of 10 MW electrical output, based on vibrating grate firing and steam turbine, which would use a mix of energy crops and residual straw.

The development of this project, however, is limited by the economics of the plants, which in present conditions is positive only if a significant sponsoring quantity is available.

C Biogas

Biogas is also an area of interest for ECYR, which is involved in the following plants:

- Aguas de Jerez: a sewage treatment plant located in Jerez de la Frontera (Cádiz), using the biogas produced in the anaerobic digestion of sewage sludge. The biogas is fed to a 477 kW engine. The plant was commissioned in January 2001. The plant is owned 100% by ECYR.

- Ecoenergía de Can Mata: a plant of 1 MW using landfill biogas, located in Hostalets de Pierola (Barcelona). The biogas is suck from the landfill by a booster and fed into a cleaning system previous to the Jenbacher engine. The plant was commissioned in 2001. The plant is owned by ECYR in partnership with CESPA

- Biogás Garraf: this is one of the biggest plants using landfill biogas in Europe. It is located in the landfill of Garraf (Barcelona), and consists of 12 engines of 1048 kW each. This plant was commissioned in March 2003 and ECYR's share is 50%, in partnership with CLP Envirogas.

The plant of Garraf is also described in detail in section 3 of this paper.

2. Case study: Electric biomass from olive residues. The experience of Enemansa (Villarta de San Juan) and La Loma (Villanueva del Arzobispo)

A Definition of the plants

The electricity generation plant of Enemansa is located in Villarta de San Juan, in the province of Ciudad Real. This is a thermal power plant of 16 MW, where the fuel is the “orujillo”, a dry residual from olive processing, coming from the extraction plant of Aceites Pina located near the thermal power plant.

The plant is owned by the society Energia de la Mancha S.A. (ENEMANSA), having the following shareholders:

- Endesa Cogeneración y Renovables 52%
- Aceites Pina S.A. 24%
- AGECAM 24%

From the technical point of view, except in its biomass handling and pretreatment, it is similar to a small coal fired power plant. It requires all the safety systems, as well as controls, actuators and auxiliaries as a thermal power plant of this kind, but with an output 20 times lower and without worldwide experience with this fuel and without the economy of scale.
Simultaneously to the plant in ENEMANSA, Endesa Cogeneración y Renovables (ECYR) has also built another twin plant in Villanueva del Arzobispo (province of Jaén), which is already in operation as well as ENEMANSA. The only remarkable difference is, in Jaen plant it was necessary to build a fuel storage area for 80.000 tons of biomass, since the orujillo comes from several olive processing plants having no biomass storage facilities.

B Project preliminars

First contacts to carry out the project began on mid 1997. During the first year, different types of analysis and tests on the biomass were done, and in parallel the arrangements of the society and the biomass supply contract were discussed. In May 1999 the society was founded, with an agreement for orujillo supply and buying the ground where the new installations had to be built.

ECYR considered absolutely essential that the future biomass supplier was involved in the society, since the project viability depends on the guarantee of fuel supply of an adequate quality for a time period longer than 15 years. Uncertainties about investment recovery in the future are limited by sharing the plant operation risks with the fuel supplier, rather than having him merely as a supplier of a fuel with no alternative market and in which the plant can’t change the supplier.

C Project development

At the beginning of 1998 started the conceptual and technical design of the plant, and purchase specifications for the different equipments were prepared. Different options for fuel handling, combustion and storage were considered, as well as the possibilities of using the fly ash. Finally, after two years of common specific R+D for both projects, the main construction contract of the plant was signed in May 2002. The contract was awarded to a joint venture of Ghesa and Foster Wheeler. This was a turnkey contract for the complete plant, excluding the electrical line, substations at the plant outlet and at the grid interconnection, and effluent evacuation line.

R+D did not finished at that time. By the contrary, since a worldwide completely new project was developed, one might estimate the equipments performance, but there was in fact no real field experience. The goal of the project was not only to achieve high combustion efficiency and a high electrical efficiency of the whole plant, but also to achieve a high availability that allows paying back the investment over a long period of operation. It became necessary to study different alternatives already available in the market and to choose the most suitable technology to be adapted to this specific case. Foster Wheeler, as the boiler supplier, as well as Ghesa, as engineering company, had a very active participation in this research, working closely together with ECYR’s technicians.

All the technicians involved in the project were aware that the plant would suffer some “children illnesses” since it is a new and not tested technology, in the same way as all the power plants of mid 20th century suffered them when the technology was developed. But in present conditions, the problem is that the application of the know-how gained in new installations is not immediate, and thus R+D costs must be assumed by the projects (which, on the other hand, are economically quite adjusted) and can’t be transferred to other future projects.

Total investment of the project amounts 21 million €.

D Plant description

The plant works on a classical Rankine cycle, which ensures a high availability, with steam generation in a biomass fired boiler, steam turbine, steam extraction for deaerator and air condensation.

The boiler raises superheated steam at 60 bar and 450°C. Live steam is fed to the turbine, where it expands and moves the generator to produce electricity. The exhaust steam of the turbine is led to an air condenser. The plant has all the necessary auxiliaries for operation: water treatment plant, effluent water plant, flue gas cleaning system, and electric and control systems.

The orujillo comes from the plant of Aceites Pina in Villarta de San Juan (as already mentioned, Aceites Pina is a shareholder of Enemansa). From Aceites Pina, the orujillo is carried by large tonnage trucks to the fuel storage of the thermal power plant, which has a capacity of about 10 – 15 days of full load.

At a first stage, the orujillo is sieved to separate the finest fraction, which is led directly to the burner feeding silo and does not go through the biomass grinding system.

The coarse fraction is fed to the hammer mills, and its size is reduced to about 1 mm. At the mills outlet, grinded biomass is sent to another sieve and the coarse particles are recirculated to the mills.

Fig. 3 General view of the plant.
Due to the granular structure of the orujillo and its low humidity, together with the high requirements about efficiency, unburnt fraction and pollutants, suspension firing was selected as the best option. To allow this suspension burning, the orujillo must be pretreated in the described way.

The boiler type is water tube and natural circulation, and consists of a superheater, evaporator bank and economizer. At the furnace outlet, some water tube baffles have been arranged to cool down the flue gases below ash melting temperature, to avoid slagging.

The boiler has a pilot burner for start-up and an auxiliary burner, injecting light oil in the burner. The total amount of light oil is only 2% of the main fuel (orujillo) used in the boiler.

The boiler has a forced draft fan and an induced draft fan. Flue gases go through a fabric filter before being released to the atmosphere through the stack. There are also transport blowers to carry pneumatically the grinded orujillo to the burners. A turbulence air blower introduces air at different levels of the furnace to produce a high turbulence to ensure a complete combustion and to control NOx emissions.

Flue gas is cleaned before being released to the atmosphere up to emission values well below local and European regulations. The gas cleaning system consists of an anti-spark cyclone and a fabric filter supplied by AAF. The cyclone avoids that any burning particle reaches the fabric filter and damages it. Fabric filter separates the fly ash from the flue gas; fly ash is removed and stored in a specific silo.

There is no water available on site, and therefore it was necessary to build a high capacity air condenser. This means higher investment costs as well as a reduction in electrical efficiency compared to other condensation systems operating with water, but it represents an important environmental improvement because no water resource is used and also avoids uncertainties about possible outages during dry periods. The system consists of all the necessary equipments to condensate the turbine exhaust steam using air as coolant.

Turbine and air condenser were selected in order to maximize the electricity generation all the year round, once live steam conditions and the requirement of air condensation (because no permit to use well water was obtained) were known.

A condensation turbine Thermodyn model 6.8 MC8 was selected, horizontal multistage, based on action technology, as well as an air condenser Balcke – Dürr of four modules, each one with an electrical driven fan with two speed.

The main components of the steam turbine are:

- Turbine type 6-8MC8 multistage horizontal. The shell consists of two blocks horizontally bound.
- Control and shut off steam valves are on the upper side, as well as a flange for steam extraction for the deaerator.
- Generator of 20.000 kVA, 11.000 V ± 5%
- Gearbox supplied by BHS, 5690 / 1500 rpm.

The plant requires also other equipments and systems as electrical system, emergency genset, control system, water treatment system, liquid effluents plant, and in general all ancillary systems used in modern electrical power plants.

**E Plant operation and social benefits**

Permanently, a staff of 24 persons is working directly in the plant, and a remarkable amount of indirect working places is also induced by the plant activity. About 400 people in several periods during 2 years were involved in the erection of the plant. We should also remember that this is a rural area objective 1 in the European Union.

The plant of Enemansa in Villarta de San Juan has a capacity of 100.000 t/year of orujillo.

It is foreseen that the plant will be in continuous operation 24 h a day and an availability of 90% will be achieved, what means 7884 operating hours per year and 113,2 GWh of electricity sent to the grid. This is enough to supply 30.000 people with electricity, and also a remarkable reduction of CO2 released to the atmosphere is obtained.

**F Future market potential**

About 1.500.000 tons / year of orujillo are produced in Spain. This means that, using our plant of Enemansa in Villarta de San Juan as an average, about 12 similar projects in Spain could be developed.

But when the feasibility of those projects is closely considered, one notices that there are important limitations. For these projects to be feasible, it is necessary that the fuel is obtained at low cost and with a high supply reliability. This is only possible in areas where large olive processing factories are installed, because transportation costs increase the total fuel cost and increase risks in future fuel availability.

Regarding to an international application of the experience gained in Enemansa and La Loma, taking into account the olive production, the countries of the Mediterranean basin as Turkey, Greece, Morocco, Italy, Algeria and Tunis, for example, are potentially interesting for this projects of energy valorization. However, there are important limitation in geographical dispersion of the olive processing factories as well as in regulations, and at this moment the possibilities seem quite remote.

**G Main problems associated with the plant**

- Technological problems.-
As already mentioned, there was no previous experience of orujillo firing in suspension neither in prototypes nor at industrial scale. In consequence, there was also no previous experience of grinding and sieving orujillo. When putting these two completely new systems together, problems arise continuously, requiring an important investment in time of experts in different technologies and also in money to improve the systems or merely to keep the plant running.

These problems are even harder due to the biomass nature. This fuel is very heterogeneous, depending on different factors as: origin, weather during harvest, weather during storage, weather when fed to the boiler, ... It is necessary to balance versatility and efficiency, what is always difficult to find. Moreover, cash-flow structure in biomass projects poses important limitations on investments, so it is necessary to seek versatility – efficiency – economy, an equation quite difficult to solve.

- Economical.-

As mentioned, economical ratios of these projects are low, depending mainly on:

- Long construction periods: high intercalary interests.
- Long pay back period: higher risk price
- Biomass is not considered as a residue. It has a selling price for its energetic valorization, instead of a treatment fee as a contaminant residue.
- High specific investments, because the plants are technically sophisticated, with the same environmental regulations as conventional power plants but with a smaller relative size.

- Administrative.-

In licensing the systems associated to these plants, there is no specific advantage compared to other industrial activities without the environmental characteristics of these plants. There are situations where the licenses are the same as, for example, a ceramic industry, a cement factory or an oil refining plant, but the plants are completely different in concept as well as in social effects.

Besides, electricity generation plants in special regime are no included in those exempt of Hydrocarbons Tax. This is a different situation compared to ordinary electricity generation plants or to cogenerations, which are exempt of this tax. That means an additional cost for the cash-flow due to the conventional fuel used for start-up and flame support. In any case, we are expecting that this tax exemption for biomass plants in general will be included in the legislation of the present year.

3. Case study: landfill biogas plant of Garraf

The site of Garraf is the biggest landfill in Spain. Since its opening in 1974, over 22 million tones of MSW have been tipped in it, and it is foreseen that it will contain more than 25 million at the end of its life. The landfill has a total surface of 64 Ha.

The landfill authority is the Entitat Metropolitana de Serveis Hidràulics I Tractament de Residus (EMSHTR) of the metropolitan area of Barcelona. The EMSHTR called for bids on may 2001 for the degasification and energy recovery of the landfill.

The project was awarded on July 2001 to a joint venture of ECYR and CLP ENVIROGAS S.L., which has to project, build and operate the plant up to June 2013.

A. Generation of biogas

Since 2000, a small installation of biogas collection and valorization is operating in the landfill, consisting of 14 wells and an engine of 477 kW. This plant supplies electric energy to the leachate treatment plant of the landfill.

The experience of this engine, as well as further analyses carried out in the biogas, have shown that the methane content of the biogas is over 50% and the H2S content is very low, what is very favourable for biogas direct use in reciprocating engines.

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy of collected biogas (GWh/year)</th>
<th>Number of engines in operation</th>
<th>Load factor of the engines (%)</th>
<th>Electricity sent to the grid (GWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>409,50</td>
<td>12</td>
<td>100,0%</td>
<td>73,37 (2)</td>
</tr>
<tr>
<td>2004</td>
<td>399,79</td>
<td>12</td>
<td>100,0%</td>
<td>97,83</td>
</tr>
<tr>
<td>2005</td>
<td>390,09</td>
<td>12</td>
<td>100,0%</td>
<td>97,83</td>
</tr>
<tr>
<td>2006</td>
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<td>12</td>
<td>100,0%</td>
<td>97,83</td>
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<td>2007</td>
<td>342,16</td>
<td>12</td>
<td>100,0%</td>
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</tr>
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<td>99,2%</td>
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<tr>
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<td>217,01</td>
<td>9</td>
<td>92,4%</td>
<td>67,79</td>
</tr>
</tbody>
</table>

(1) Not included the power that the existing engine of 477 kWe will supply to the leachate plant
(2) Commissioning in March 2003
The forecast for biogas generation, as well as electricity generation, based on theoretical models, are shown in table I.

According to the estimated profile of biogas generation, a set of 12 engines of 1048 kWe each (12.576 kWe in total) has been installed. The engines are arranged into standard 40 ft containers in modular configuration, allowing a future expansion of the set if necessary.

According to this biogas profile, the twelve engines will be operated at full load for at least seven years; from this moment, the number of engines in operation would decrease following the available biogas, and at the end of the concession time (June 2003) nine engines would be still in operation.

B. Description of the plant

Figure 4 shows a basic schema of the plant.

On the landfill surface (1) more than 200 biogas extraction wells (2) have been drilled, with a ratio of about 4 wells per Ha. Their average depth is 20 m, although the depth of the wells near the landfill borders has been limited allowing a security distance up to the bottom of the landfill. The total length of biogas pipes is more than 10 km.

The biogas leaves the wells saturated with moisture. When it cools down in the pipes, the moisture condensates, and this condensate must be drained to avoid water blocking on the pipes.

The landfill has a remarkable slope (height difference between highest and lowest points is more than 200 m). There are some intermediate draining points in the pipes connecting to the individual wells, but most of the condensate flushes down through the main biogas pipes and is collected in two knock-out pots with electrical pumps, located at the lowest point of these main pipes (5). Condensate is sent to the leachate plant of the landfill, where it is conveniently treated.

All the gas field is maintained at negative pressure, so avoiding biogas leaks to the atmosphere and thus biogas smell. The negative pressure is adjusted to avoid air intrusion in the wells. For biogas transport, there are 3 biogas boosters of 3000 Nm³/h each, with a frequency drive. The boosters increase the biogas pressure up to a suitable value for engines.

Downstream the boosters there is a high temperature flare (>1000°C), designed for 3000 Nm³/h (7). This flare will burn the excess biogas which can not be used by the engines, due to excess in biogas generation or to engines outages.

The twelve groups engine – generator (8) are identical, supplied by G.A.S. Energietechnologie GmbH based on Jenbacher JMS 320 engines, 1048 kW each, and an electrical efficiency of 37,1%. The gensets are located into individual standard containers, each with all ancillary equipment: silencer, water coolers, control, etc.

To reduce environmental impact, the containers have been built with an increased noise reduction, designed for 60 dBA at 1 m. The arrangement in containers allows a reduction of the total height of the set, and the visual impact of the plant is minimum.

Generators output voltage is 6,3 kV. All MT switches, auxiliary 6,3 / 0,4 kV transformer and the control room are located in an electrical building.

Some 100 m away from the control building a new substation has been built (9). The elevator transformer 6,3 / 66 kV has an output of 18 MVA, thus allowing an additional engine in the future.

A remarkable fact affecting this project is that in 1987 the Natural Park of Garraf was established, and the landfill is inside the Park area. This means that the plant has to meet very strict conditions regarding visual impact, noise, revegetation of soil, etc. In particular, the electrical overhead line was designed to seek the least environmental impact and to be compatible with the Park standards and criteria.
The electricity was supplied to the landfill and other consumers through an overhead line of 25 kV. This line crossed below an existing transport line of 66 kV, belonging to Endesa.

To reduce the visual impact and to avoid any new electrical line over new trace, the existing line of 25 kV was dismantled from its crossing with the line of 66 kV up to the landfill. On the same trace a new line was built, consisting of 3 circuits: 2 circuits of 66 kV in the upper side of it, to build the input/output loop of the new substation, and a circuit of 25 kV in the lower part, to replace the old line supplying the local consumers.

The supports have been mimetized on the site, by selecting an appropriate colour for them. Besides, adequate devices have been installed to protect birdlife.

According to its size, electrical output and energy generation, this is one of the biggest plants of landfill biogas in Europe.

C. Environmental aspects

Landfill degasification avoids the uncontrolled emission of biogas to the atmosphere, which has two positive environmental effects:

- Locally: biogas is properly treated, and the components causing bad smell of landfills are completely destroyed.
- Globally, the biogas contains about 50 % CH4. Methane has an effect on global warming of about 20 times that of the same amount of CO2.

The combustion of methane produces CO2. However, since methane comes from residual organic matter (not fossil), its contribution to global CO2 balance is zero. Around 50 x 10^6 m^3/year of CH4 will be used in engines, equivalent to a reduction of about 600,000 t/year of CO2 in terms of global warming.

From an energetic point of view, the plant produces about 100 GWh/year of electricity, thus saving an equivalent amount of electricity produced in fossil–fired power plants. This means a saving of CO2 emissions of 50,000 to 110,000 t/year, depending of the type of fuel saved (natural gas or coal).

Both effects of CO2 reduction lead to a saving of 650,000 to 700,000 t/year. In forest terms, it is equivalent to 17,000 hectares of new growing forest. As a comparison, the Natural Park of Garraf has a total extension of 12,820 hectares.

The total electricity transferred to the grid (100 GWh/year) is enough to supply all public street light system of the city of Barcelona.