Geothermal Power Plant Repowering by Means of Biomass Combustion

Maurizio Fedeli, Matteo Moscariello and Fabio Sabatelli

Enel Green Power, Via Andrea Pisano 120 – 56124 Pisa (Italy)

D +39 050 6185356 M +39 320749962 E-mail matteo.moscariello@enel.com

Keywords: Biomass Steam Superheating Repowering.

ABSTRACT

The idea of increasing both the power output and the thermal efficiency of geothermal steam cycles by means of steam superheating has a long history. However, most (if not all) evaluations carried out so far, including a previous Enel study, dealt with fossil fuel superheat; moreover, no hybrid power plant of this kind is known to exist in operation.

Enel Green Power is dedicated to the development of generation from renewable energy sources only; therefore, the idea to use biomass combustion to repower an existing geothermal power plant appeared very interesting. This scheme proved to be technically feasible by the fact that the fleet of geothermal power plants in operation in Italy is largely made up of standardized units with an installed capacity of 20 MW_e, adaptable to steam inlet pressures from 5 to 20 bar. Of course, these units feature a power output much lower than 20 MW when the reservoir characteristics dictates a steam pressure near to the lower limit. In this case, all the equipment has the capability to increase the power output by means of steam superheating within the temperature limit of the existing turbine, after the necessary modifications to the turbine to accommodate for the new operating conditions (higher volumetric flow).

This paper describes the history of the Cornia 2 project (from the name of the existing 20 MW_e power plant, located in the Southern part of Larderello field), from the feasibility study of the biomass superheat, analyzing the different schemes envisaged, to the detailed engineering phase. The main technical issues that arose during the process are dealt with, as well as the main findings and solutions developed for this first-of-a-kind biomass-geothermal hybrid power plant.

1. INTRODUCTION

Hybrid fossil-geothermal power systems have been studied, mainly from a thermodynamics point of view, since long ago: a thorough description can be found in the first comprehensive treaty on geothermal energy, (J. Kestin et al., 1980) recently re-published (R. DiPippo, 2007).

Geothermal energy may be used as preheat in a fossil-fired power plant, or fossil fuels may be used to superheat geothermal steam cycles. The first possibility is hindered by the fact that geothermal energy is generally not available in the sites of fossil-fired power plants; the second one is in principle easier to accomplish, but did not find any practical application, so that as of today no hybrid power plant of this kind is known to exist in operation.

Enel started to evaluate the possibility of steam superheating in some operating power plants in order to increase both the power output and the thermal efficiency of geothermal cycles. A first study was carried out in the mid-1990s with the support of Perugia University and focused on small scale natural gas turbines (about 5 MW_e size), whose flue gas could be used for steam superheating (A. Baldacci et al. 1997). The idea was abandoned, as environmental concerns related to the use of natural gas prevailed.

The idea of steam superheating by means of biomass combustion followed at the turn of the century, as it allowed the advantages of hybrid cycles combining two renewable energy sources. However, the legislative framework of renewables was not favorable enough at that time to make the initiative profitable in Italy, so that studies were abandoned at the prefeasibility stage.

In Italy, electricity generation from biomass was awarded higher contributions since 2008; studies were thus resumed and finalized.

2. TECHNICAL FRAMEWORK

Enel Green Power is the company of Enel Group dedicated to the development of generation from renewable energy sources; therefore, the idea to use biomass combustion to repower existing geothermal power plants appeared very interesting.

In Italy, Enel Green Power owns and operates 32 geothermal power plants (34 units) with a total gross generating capacity of 722 MW. 25 out of 34 units are 20 MW size, with 23 of them belonging to the so-called “standardized geothermal unit” solution, although different generations of machinery exist.

The main feature of these units is the capability to accommodate different inlet pressures, in the range from 5 to 20 bar, while maintaining the same flow

(110 to 130 t/h of geothermal steam), thanks to the possibility to adjust the nozzle area upstream from the first stage (G. Allegrini et al., 1985). The choice of the inlet pressure is made according to the reservoir characteristics, in order to allow its optimum exploitation.

As a consequence, the units fed with steam falling in the lower range of pressure have the capability to increase even significantly their power output (up to 5-6 MW), should the steam be superheated. From a technical standpoint, although the turbines were designed for a maximum temperature of 280°C, minor adjustments allow operation up to 400°C; of course, major modifications are required to the inlet stages in order to accommodate for the much higher volumetric flow of superheated steam at such temperature (and low pressure).

It has to be noted that from a thermodynamic point of view or, in other words, for a better overall efficiency, it would be more advantageous to superheat higher pressure steam (20 bar or the like). However, this is not feasible within the limits of the existing equipment, both mechanical and electrical.

Among the 20 MW units working at low pressure, the most suitable were selected keeping into account the location (availability of terrain for the new biomass equipment, ease of biomass transportation, etc.) and any environmental constraint.

The most promising power plants are Cornia and Nuova Larderello, with the former being less penalized by the loss of generation linked to the modifications to the main machinery and the steam piping. Cornia was thus selected as the first power plant to be hybridized with biomass.

3. HISTORY OF THE CORNIA 2 PROJECT

3.1 Cornia 2 Geothermal Power Plant

Cornia 2 geothermal power plant is a dry steam power plant, of the condensing type, in operation since 1994, located in the territory of Castelnuovo Val di Cecina (PI), south of Larderello. Due to the chloride content of the steam, a caustic scrubbing is carried out upstream from the turbine, so that the inlet steam is in the saturated state, featuring a non-condensable gas content (NCG) of 2% by weight, mainly constituted (over 95% v/v) by carbon dioxide (CO_2), with around 1% v/v of hydrogen sulfide (H_2S).

The composition of the steam condensate is reported in Table 1.

Table 1: Steam condensate composition.

Na		1 ÷ 3
Cl		1 ÷ 2
H_3BO_3		50 ÷ 150
NH_4		20 ÷ 50
pH		5 ÷ 5.5
Other trace elements are present (As, Sb, Fe, etc.)		

The inlet steam flow is around 110 t/h at an absolute pressure of 5.2 bar and 153°C (the pressure is limited by the reservoir characteristics). In this conditions, the electrical gross power is near 14 MW, with a net power delivered to the grid slightly over 13 MW.

A simplified scheme of a power plant of this type was described in Baldacci et al. 2005.

Not far from Cornia 2 is located the dismissed Cornia power plant (Figure 1). The area of this plant can be used to install the steam superheating equipment, while the existing powerhouse can be transformed into a biomass storage with an automatic feeding system for the boiler.



Figure 1: Cornia and Cornia 2 power plants aerial view.

3.1 Cornia 2 Hybridization with biomass

The choice of Cornia 2 as the most suitable for a possible hybridization with biomass derives from the following considerations:

1) Cornia 2 is presently working at 65% of its theoretical maximum power output, due to the poor inlet steam conditions (low pressure and temperature, as previously described)
2) Availability of a nearby area where the steam superheating equipment can be installed (the site of the former Cornia power plant, dismissed since many years)
3) The machinery can accommodate, with limited modifications, steam at temperatures higher than initial design conditions
4) Availability of biomass in the surrounding area (woods, possibility of dedicated crops).

As far as the main machinery is concerned, the Franco Tosi turbine installed in Cornia 2 power plant has an impulse control stage and subsequent reaction stages, with a design temperature of 280°C. The manufacturer was involved in order to verify the feasibility of steam superheating and the maximum temperature allowable.

After a dedicated study, the answer was that no mechanical or structural problems are to be expected

up to a maximum temperature of 380°C. The modifications to be made to the turbine include:

1) Removal of the first reaction stage of turbine fixed and mobile blades
2) Substitution of the nozzles of the control stage with new ones featuring higher area and of the mobile impulse blades of the same stage

A preliminary calculation of the power output increase deriving from the steam superheating was made, using the present operating conditions of the power plant, 370°C as the reference temperature of the superheated steam and assuming an overall pressure drop of 0.5 bar through the process.

The turbine efficiency was recalculated, starting from the present one, on the base of the new outlet humidity using the empirical Baumann rule.

The thermal input required to reach the desired temperature of the steam amounts to 14 MW thermal, and an electrical net power output increase of around 5 MW can be obtained, with an overall efficiency (not considering the biomass combustion efficiency) over 35%.

The advantages deriving from the possible hybridization of Cornia 2 with biomass are:

1) Use of an existing industrial area and road, with no additional soil occupation and natural habitat modification
2) Minimum landscape impact
3) Use of an existing electrical connection with the grid (no need of new lines)

Lower CapEx and OpEx and higher efficiency with respect to a stand-alone biomass power plant of the same size as the power output increase deriving from the hybridization, with the latter coming from the improvement of the existing steam cycle (lower humidity at turbine outlet).

4. FEASIBILTY STUDY OF THE STEAM SUPERHEATING WITH BIOMASS

In order to accomplish steam superheating with biomass, a plant must be designed and built with the following main parts:

1. Biomass long-term storage
2. Biomass short-term storage and automatic feeding system to the boiler
3. Biomass combustion
4. Heat transfer to the geothermal steam
5. Flue gas treatment
6. Steam connections with the existing power plant

Moreover, connections must be provided for saturated steam from the geothermal power plant to the superheating system and vice-versa for the superheated steam.

Apart from the superheating of the geothermal steam, the remaining equipment is quite standard for biomass power plants and will not be dealt with in this paper.

Biomass power plants use “standard” steam boilers; in the case of the Cornia plant, steam already exists and must only be superheated; moreover, the steam pressure is much lower than typical values of biomass steam boilers. Therefore, the boiler can not be standard and must be specifically designed for this application, also taking into account the characteristics (corrosivity and fouling) of geothermal steam.

Two possible solutions were envisaged:

- Direct heat exchange between flue gas and steam
- Mixed heat recovery (using both flue gas and diathermal oil)

In the former solution, the main issue is the low heat exchange rate of steam with respect to water in a traditional boiler. As the flue gas temperature at the combustion chamber outlet is in the range of 1,000°C, a very high wall temperature might be reached, requiring special materials to withstand creep phenomena. To overcome this problem, low flue gas velocities are required, so as to decrease the heat transfer rate from the flue gas and to maintain the wall temperature closer to the steam temperature. At the same time, the steam tubes must be made larger than the tubes in a standard boiler, in order to minimize the pressure drop of the low-pressure steam.

Both solutions increase the dimensions and the cost of the boiler with respect to a standard one of the same thermal capacity.

In the latter solution, diathermal oil (which has a good heat transfer rate) is used for the first cooling of the flue gas; dedicated heat exchangers are used between the oil and the steam outside the boiler. Due to the temperature limits of the available diathermal oils, the final superheating of the steam has to be carried out within the boiler, after the initial cooling of the flue gas by the diathermal oil.

4.1 Direct heat exchange

As previously outlined, in this solution the flue gas (at the outlet of an adiabatic chamber) are cooled from 900-1,000°C down to 200-250°C with direct heat exchange with geothermal steam, which is heated from 150°C up to 370°C.

Flue gas are further cooled down to 150°C by heat recovery to preheat combustion air up to 120°C. Flue gas velocity will be kept in the 5 – 7 m/s range, both to avoid excessive wall temperature of the tubes and to prevent ash fouling of the tubes.

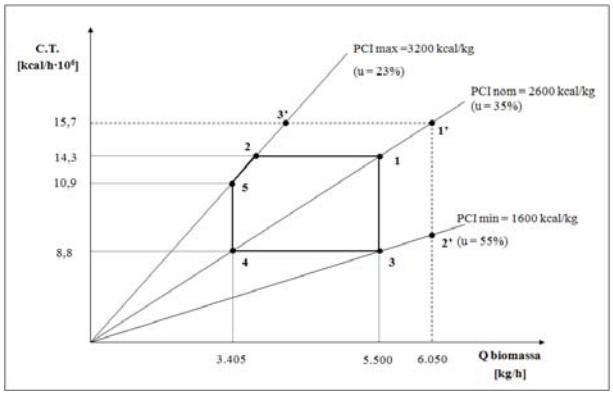

Figure 2: Direct heat exchange boiler combustion diagram.

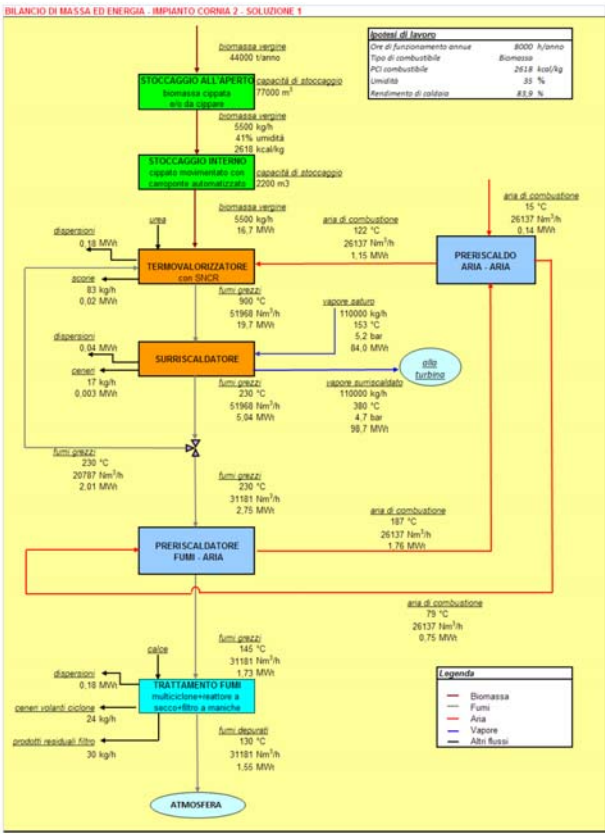

Figure 3: Direct heat exchange heat & mass balance.

4.2 Mixed heat exchange

With this approach, the steam superheating occurs in a series of heat exchanges, using also diathermal oil as the intermediate fluid for heat exchange. Flue gas are cooled from 1,000°C down to 770°C by radiant heat exchange with diathermal oil tubes, where the oil is heated from 260°C up to 300°C. The oil is used to heat the steam from 200°C up to 300°C in a dedicated heat exchangers located outside the boiler.Flue gas are further cooled down to 430°C by a first direct heat exchange with the steam (which is heated from 300°C to 370°C) and down to 250°C by a second direct heat exchange with steam (which is heated from 152°C to 200°C); both these exchangers are located inside the boiler.

Flue gas are then used for preheating purposes.

This solution is more standardized, as it uses proven solutions; however, a higher complexity is entailed by the diathermal oil circuit with all the required safety requirements and redundancies. Also from an O&M perspective, the higher complexity of this solution makes it less attractive.

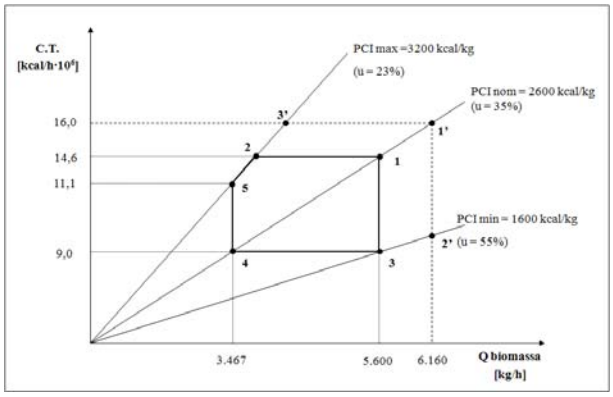

Figure 4: Mixed heat exchange boiler combustion diagram

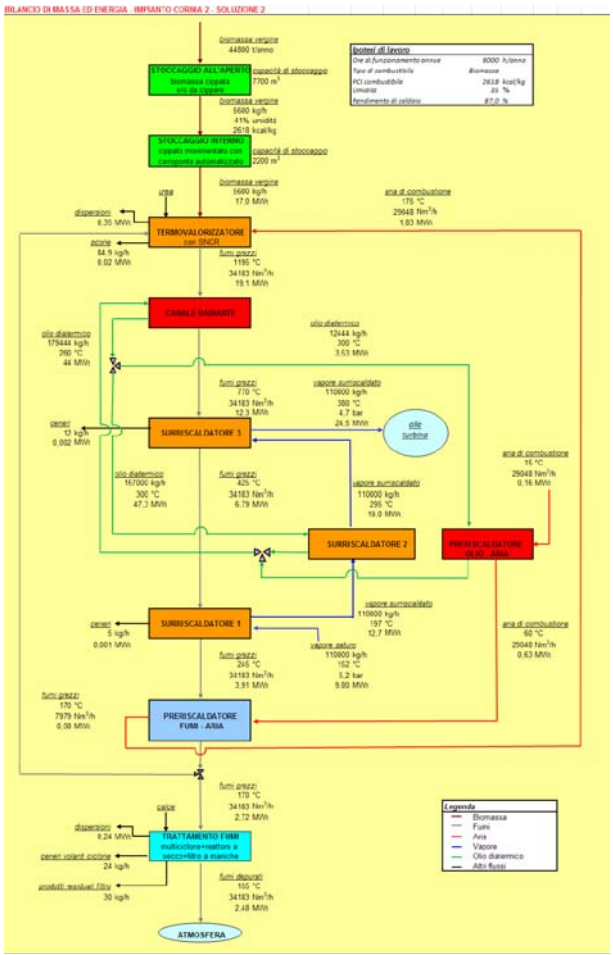

Figure 5: Mixed heat exchange mass and energy balance

4.3 Final choice

A tender was launched open to boiler manufacturers; the solution initially chosen was the one with diathermal oil, as it seemed more reliable from a technical standpoint. However, during the tender process technical and economical evaluations demonstrated that the direct steam superheating was sound and cheaper also from the CapEx standpoint, so that it was eventually selected.

5 MODIFICATIONS TO THE POWER PLANT

In order to allow the steam to be superheated, a by-pass must be realized, as schematically shown in Figure X. The steam has to be sent to the superheating after the scrubbing described in para. 3.1, so as to prevent possible corrosion by acid chlorides.

At the same time, the by-pass must be upstream from the vent where steam is sent during the power plant outages, to avoid interruptions of the steam flow to the superheating system.

When the superheating system has to be put in operation, the by-pass is closed and the steam is sent to the superheating system and flows back to the turbine in the superheated condition; should the superheating system be unavailable due to maintenance, the by-pass is opened and the steam feeds the turbine in the saturated condition.

Of course all the existing steam piping (downstream from the superheating) must be modified to comply with the new temperature, higher than the previous design figure.

As as the turbine is concerned, the present configuration for operation at around 5 bar (absolute) entails a first impulse control stage and 10 reaction stages (vs. 17 stages for operation at 16 to 20 bar).

The manufacturer's proposal foresees the complete removal of the first reaction stage for operation with superheated steam at a flow rate within 100 to 110 t/h, with the possibility to remove an additional stage in order to reach a flow rate of 120 t/h (not considered to be feasible due to reservoir constraints).

Moreover, the first action control stage blades and nozzles must be changed so as to accept the higher volumetric flow of the superheated steam; a set of self-actuated valves will be installed to reduce the nozzle area and maintain an adequate inlet pressure when the steam is in the saturated condition.

Interestingly enough, the power output increase calculated by the manufacturer is in very good agreement with the estimates of the feasibility study: the expected increase of the turbine mechanical power is nearly 6 MW with steam at 370°C with respect to steam at 160°C, although with an inlet pressure reduction of 0.3 bar only (at least 0.5 bar are expected, as the boiler only, according to the supplier's data, has a pressure drop of 0.4 bar).

6 CONCLUSIONS

Technical discussions with suppliers confirmed the feasibility of the plant and of the solutions envisaged.

Although the superheating plant was completed from an engineering standpoint and some tenders launched for the main components (boiler, biomass automatic feeding system), a stand-by situation is presently hindering its construction.

The main reason lies in the low feed-in tariff deriving from the most recent regulations rewarding RES in Italy (government decree of July 2012 and regulations for its application by the GSE, the Italian authority for electricity management).

According to these documents, the additional energy generated in the geothermal power plant by means of the steam superheating would be rewarded with the incentivation of biomass generation, but related to the total power of the plant (geothermal plus biomass, i.e. over 5 MW) rather than to the power deriving from the biomass only (up to 5 MW), using a coefficient of 0.8 (power increase of an existing plant) and without any other additional incentivation applying to biomass power plants (biomass from short range, reduced atmospheric emissions).

These unforeseen penalization has a strong impact on the business plan of the initiative, since CapEx and OpEx are lower, but not very different from those of a stand-alone biomass power plant, highly reducing its profitability and financial attractiveness.

REFERENCES

J Kestin, R. DiPippo, H. E. Khalifa, D. J. Ryley: Sourcebook on the Production of Electricity from Geothermal Energy, *Brown University*, Providence - Rhode Island, (1980).

R. DiPippo: Geothermal Power Plant, Principles, Applications, Case Studies and Environmental Impact, Butterworth-Heinemann.

A. Baldacci, R. Papale, F. Sabatelli, G. Bidini: Efficiency Increase and Environmental Benefits of Using a Gas Turbine Hybrid Cycle in Mount Amiata Geothermal Area, Proceedings of Geothermal Resources Council 1977, Annual Meeting, Burlingame, CA, USA (October 12-15, 1997), Vol. 21, 481-487.

G. Allegrini, G. Giordano, G Moscatelli, A. Palamà, G. G. Pollastri, G. P. Tosi: New Trends in Designing and Constructing Geothermal Power Plants in Italy, Proceedings of International Symposium on Geothermal Energy, Kailua-Kona, HI,(1985), 279-288.

A. Baldacci, M. Mannari, F. Sansone: Greening of Geothermal Power: An Innovative Technology of Abatement of Hydrogen Sulphide and Mercury Emission, Proceedings of World Geothermal Congress 2005, Antalya, TK, (April 24-29, 2005), paper 0215.