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Geothermal Power Plant Production Boosting by Biomass Combustion: Cornia 2 Case Study

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ABSTRACT

Enel Green Power is dedicated to electric energy generation from renewable energy sources. Although development plans are mostly based on mature technologies, such as onshore wind and photovoltaic solar plants, project portfolio includes innovative hybrid plant configurations, i.e. plants combining more renewable energy sources.

Among them, the idea to boost an existing geothermal power plant using biomass combustion has been studied and recently applied. The scheme used for Cornia 2 project (Cornia 2 is an existing 20 MW_e power plant, located in the Southern part of Larderello field) proved to be both technically feasible and economically viable. Before the project, the existing Cornia geothermal power plant, designed according to the standardized geothermal unit configuration with an installed capacity of 20 MW_e, showed a production quite lower than the nominal capacity. The standardized units used in the Italian geothermal fleet of Enel Green Power are adaptable to steam inlet pressures from 5 to 20 bar but of course feature different power output when the reservoir makes available a steam pressure near to the lower limit. In this case, the enthalpy of the steam and, in turn, the power output, can be significantly increased by means of steam superheating within the design temperature limits of equipment and systems.

This paper describes the case history of the successful Cornia 2 project, from the initial feasibility studies to the end of the project execution, and highlights the good results of such a configuration in terms of plant efficiency and cost of energy, thanks to the synergy of the two renewable sources in this first-of-a-kind biomass-geothermal hybrid power plant.

1. INTRODUCTION

Hybrid renewable energy power plants have been studied in the last ten years and research is still going on; among them, hybrid solutions involving geothermal source have been evaluated combining it with solar and biomass resources, in order to gain efficiency compared with separate generation systems.

Recently, DiPippo and Thain (DiPippo, Thain 2015) evaluated various design solutions for geothermal-biomass hybrid plants and the MIT energy group (Manente et al, 2011) proposed several conceptual studies for solar-geothermal designs.

Applications of this kind of solutions in operation are the geothermal-biomass plant in Honey Lake, California USA (Geothermal Hot Line, 1988) and the geothermal-solar plant at Stillwater, Nevada USA (ENEL, 2011). In the first one, geothermal hot brine is used to preheat combustion air and to dry wood chips, while in the second one a hot fluid circulating in parabolic solar collectors is used to increase the operating temperature of the geothermal brine feeding the Organic Rankine Cycle geothermal plant.

Both studies and applications demonstrated that, among different solutions and configurations, every one of them could be the most suitable for a specific project, depending on source, geographic area and ambient and economic conditions.

Cornia 2 project is an operating power plant where biomass is used to boost energy production of an existing geothermal power plant with a superheater, increasing geothermal steam temperature from 150°C to 370°C and adding 6 MWe of electric power.

2. TECHNICAL, ECONOMICAL AND AMBIENTAL FRAMEWORK OF CORNIA 2

In Italy, Enel Green Power owns and operates a significant number of geothermal power plants. Despite different steam inlet conditions, many turbo generator sets are of the so-called “standardized geothermal unit” of 20 MW size, having the capability to accommodate different inlet pressures with the same flow rate (110 t/h). So, some power plants don’t reach maximum power production due to the poor pressure inlet conditions of steam.

Table 1 – Cornia 2 steam conditions at turbine inlet

	Values
Pressure, bar	5
Temperature, °C	153
Flow rate, ton/h	110
Non condensable gas content, NCG	2 %

Cornia 2, fed with steam at 5 bar abs and 150°C, was one of the power plants not having the maximum production capacity and was selected among other candidates as the first unit in the world boosted with biomass, by means of a steam superheater with biomass combustion, resulting in a first-of-a-kind hybrid solution.

The main reasons that enabled the technical feasibility and profitability of the project were:

1) An existing geothermal power plant not working at its theoretical maximum, capable of higher power output (+ 6 MW) with superheated steam at 370°C, with limited modifications on existing equipment

2) Availability of a nearby dismissed industrial area to build the steam superheating equipment and its auxiliaries, with no need of new roads, soil occupation and electrical connection

3) Availability of biomass in the surroundings, from local suppliers

4) A dedicated feed-in tariff and an incentive won through a tender from Tuscany government for innovation in renewable energy

The conceptual design of the plant is shown in figure 1.

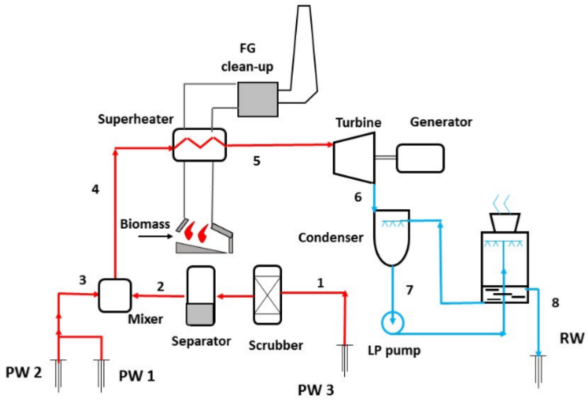

Figure 1 –Conceptual design of Cornia 2 hybrid power plant

Apart from small modifications in turbine and valves equipment, the geothermal section was not changed and main activities were on new pipelines and biomass equipment as handling system, flue gas clean-up line and the superheater, the most challenging to design, because it was a novel one.

Regarding biomass equipment, the short term storage was designed in order to withstand an autonomy of more than forty hours, with automatic feeding of biomass to the combustion chamber.
Flue gas line was selected for high depuration efficiencies, searching for the best technologies available.

3. ENGINEERING CHALLENGES AND SOLUTIONS IN EXECUTION PHASE

The development of such a unique design for the first time generated some challenges not faced in other projects, which need to be carefully evaluated for the success of the investment. So, during the first phase of execution, some solutions where found in order to guarantee high efficiency, reliability and ease of operation.

The idea of a direct exchange between flue combustion gas and geothermal steam instead of an intermediate fluid like a diathermic oil was synonymous of higher efficiency and simplicity but carried a lot of questions about possible corrosion and salt deposition inside the tube coils. To overcome these issues, a gathering system with a scrubber for wells with high chlorides content and a mixer between superheated and low chloride content steam from another well was realized, as shown in figure 2, resulting in a superheated steam at biomass heat exchanger coils inlet with low chlorine content.

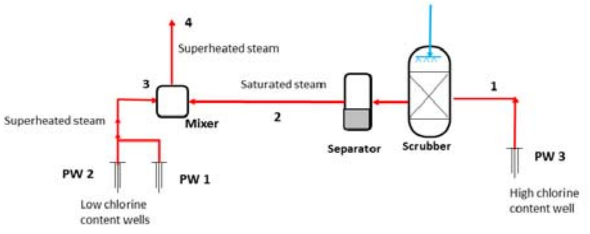

Figure 2 –New gathering scheme for biomass superheater of geothermal fluid

The biomass superheater itself was a unique design, because of the sour fluid, the unconventional low pressure for this kind of equipment (typically in the range 70-90 bar), high metal temperature and for the temperatures required to reach high heat exchange efficiency.

A countercurrent solution was realized with high tubes diameters and low gas velocities and minimum tube temperature, to reduce pressure loss and stress corrosion cracking issues.

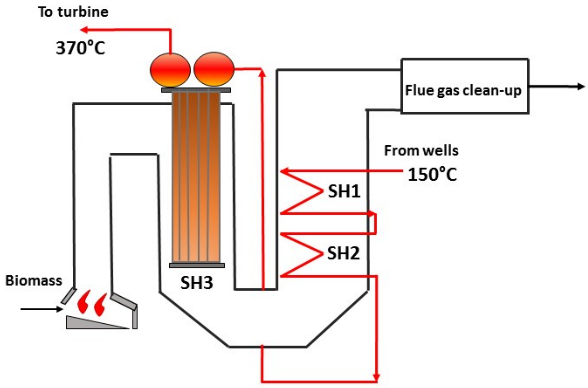

Figure 3 – Biomass superheater scheme

The existing geothermal turbine was modified for new thermodynamic conditions of steam, with the removal of three reaction stages, substitution of control stage with new ones with a bigger area and substitution of the two sets of inlet valves.

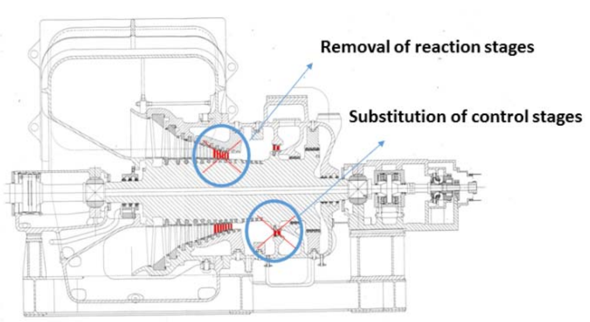

Figure 4 – Modifications to the existing turbine for new inlet conditions

For operation and maintenance aspects, a by-pass line and a control of the inlet stage section of the turbine were developed in order to have the possibility to work and produce electricity both with superheated steam and with saturated steam at 150°C if the biomass plant faces an outage, resulting in higher availability.
Besides, operational aspects were studied in order to try to adapt this hybrid solution to the philosophy of the geothermal power plants in the Larderello area, which are managed from remote without personnel in site. While conventional biomass power plants have presence of personnel 24/7, a special automation and control system was implemented and actually the personnel is in site only in the day, while in the night the power plant is managed from remote.

Finally, to comply with emission limits imposed by the law and to access to an economic bonus for emissions below law limits (Ministry decree 06/07/2012, or DM 06/07/12), a careful combustion control system and a flue gas depuration line with cyclones, fabric filters, lime injection reactor and NOx reduction system was implemented.

First months of operations demonstrated the compliance of the plant to law limits and to the values for the bonus, as registered by the continuous monitoring emission system.

Table 2 – Emission and measured limits

	CONCENTRATIONS (mg/Nm3) @ 11 % O2 dry gas		
POLLUTANT	LIMITS		REGISTERED VALUES (mean)
	AUTHORIZATIONS	DM 06/07/2012	
Dust	10	10	0,05
Total Organic Carbon (COT)	30	20	0,81
Carbon Monoxide (CO)	120	150	40
Sulphur Dioxide (SO2)	140	150	2
NOx (as NO2)	200	150	130
Ammonia (NH3)	15	5	0,8

Besides installed equipment, biomass itself is the first guarantee of low emissions for the reduced content of chemical species like sulphur and nitrogen.

4. PERFORMANCE AND EFFICIENCY ANALYSIS

The temperature-entropy diagram shown below summarizes the thermodynamic conditions of the scheme proposed in fig. 1.

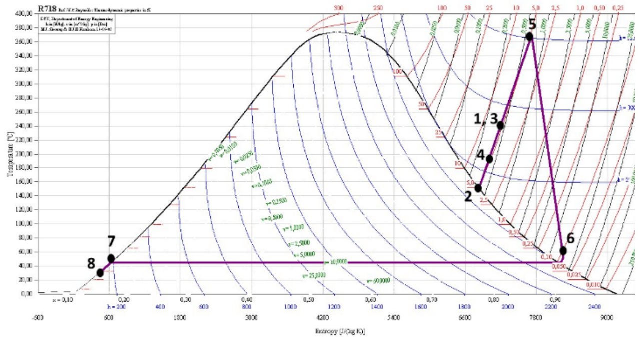

Figure 5 – Temperature entropy diagram with reference points of Cornia 2 scheme in fig. 1

Biomass furnace superheater increases enthalpy and temperature of geothermal steam from 155°C to 370°C, thus resulting in a power plant output increase of 6 MW gross, with the same flow rate compared to the power output before hybridization.
Heat input to the geothermal fluid is given by 5,5 t/h of wood chips burned with a lower heating value of 10,46 MJ/kg (or 2500 kcal/kg), considering an efficiency of the superheater of 85%.

The following table reports the main data of the hybrid solution, compared with the basic geothermal plant before repowering and with a standard biomass plant with the same heat input.

Table 3 – Power outputs and thermal efficiencies

	Cornia 2 basic geothermal plant	Standard 5 MW biomass plant	Cornia 2 hybrid
P gross, MW	12	4	18
P net, MW	11	3	16,5
Heat input, MWth		15,7	15,7
Superheater efficiency			33 %
Thermal efficiency	13 %	20%	16,8 %

The thermal efficiency is the ratio of total net power output to the rate of heat input from geothermal fluid and biomass source, when foreseen.
With reference to the hybrid case of Cornia 2, the superheater efficiency η_{sh} is defined as the extra power output due to biomass superheating divided by the biomass heat input.
The main outcomes of this analysis reveals a superheater efficiency of 33 %, quite higher than standard biomass design. This is due to the high input temperature of steam inside the first heat exchanger, resulting in higher power output at geothermal turbine with the same energy input. The gain in terms of net power of this hybrid solution compared to two conventional separate generating units is of 2,5 MW (16,5 MW versus 11 + 3 MW), or a + 18 % in general terms.
Auxiliaries consumption of two separated systems are higher than the hybrid one, because in the first case two separate unites cannot share the cooling tower fan consumptions of hybrid case where, moreover, there's no need to take into account pump consumption for water closed cycle of a standard biomass cycle, as well.

Considering thermal efficiency, a preliminary analysis indicates an increase after repowering from 13 % to 16,8 %, or in relative values a 30 % increase. As the main heat input is the geothermal source (82 MW geo vs 15,7 MW bio), the efficiency gain is impressive.
On the other side, there is a better use of biomass resource thanks to high efficiency of superheater, resulting in a lower consumption of wood chips.

5. CONCLUDING REMARKS

The Cornia 2 project demonstrated that, starting from a conceptual design of a hybrid solution where site specific conditions have been taken into account and positively used, a detailed solution that matched profitability and financial appeal to start the construction was found and developed.
During project path many engineering challenges were faced and solved with innovative solutions, always keeping in mind the long-time experience in geothermal activities of the company.

The result is a power plant that optimizes the synergies of two different renewable resources, with high efficiency and minimum impact on local environment, giving also an economic impulse to the local activities with the reactivation of forestry management companies.

The plant was put in operation in September 2015 and first months of production demonstrated high reliability and ease of operation, not always guaranteed for innovative and new configurations.

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