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Project LOW-BIN "Efficient Low Temperature Geothermal Binary Power"

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ABSTRACT

The aim of the LOW-BIN project, "Efficient Low Temperature Geothermal Binary Power", is to improve cost-effectiveness, competitiveness and market penetration of geothermal electricity generation schemes, target both hydrothermal resources for immediate market penetration and future enhanced geothermal systems. The main objective, after studying and recommending optimal Rankine cycles, is to develop and demonstrate two geothermal binary power machines. The first one should be able to generate electricity from low temperature geothermal resources, with profitable operation down to 65°C. The second one should be able to cogenerate both heat and power by heat recovery from the cooling water circuit, corresponding to geothermal fluids of 120-150ºC and cooling water supplying a district heating system at 60/80ºC.

1. INTRODUCTION

Present use of geothermal energy is limited to the exploitation of hydrothermal systems, which correspond to water bearing formations at elevated temperatures at depths up to 3 km. Applications include direct heat uses, usually at lower temperatures up to 110°C and electricity generation for higher temperatures, usually higher than 100°C. When the temperature exceeds 180°C and the plant capacity is high (10-300 MWe), the technology used is almost exclusively flash plants, where the geothermal fluid is flashed at 180°C or more and the separated steam drives a wet steam turbine and generates electricity.

In lower temperature the technology used for geothermal power generation, almost exclusively corresponds to Rankine cycle (binary) power plants. In these plants, the geothermal fluid transfers its heat to a closed loop of a working fluid, which can be either an organic fluid, usually a hydrocarbon (usually isobutane or isopentane) or a (hydro)fluorocarbon (Organic Rankine Cycle – ORC), the vapour of which drives a turbine for electricity generation. The working fluid condenses within a second heat exchanger cooled either by water (natural or through a cooling tower) or by air. Then the liquid fluid is pumped through the geothermal heat exchanger, where it evaporates, and the cycle continues.

Present geothermal binary plants can accommodate heat supply of a variety of temperature range, including temperatures higher than 180ºC. Geothermal binary plants have a high degree of computer based automation, including self starting. They are capable of 100% unattended operation, with remote monitoring and control through a telephone or satellite link, or alternatively they can be operated by semi skilled labour on part time basis. They can handle both base and peek loads, fluctuating loads including low instantaneous loads ranging from 0 to 25% of installed capacity. Conversion efficiency of such plants depends on the supply temperature and on the load, varying from 7% at 90ºC to 12% at 120ºC and to 15% for 150ºC supply temperature, with the bulk of energy losses occurring at the cooling heat exchanger.

By selecting the appropriate secondary fluid, binary systems can be designed to operate with inlet temperature as low as 90°C. These units have higher costs per unit of installed capacity by comparison with conventional condensing geothermal power plants, but in many cases they are the most suitable alternative for geothermal development. Life cycle costs for binary power generation amount at 5,7 Eurocents per kWh (2004) with highest values around 7,7 Eurocents per kWh. Binary plant capital costs amount at 850-1400 Euro/kW for large units (1-5 MWe) and up to 1800 Euro/kW for smaller units (400-500 kWe).

Today, more than 530 MWe of geothermal binary plants are installed around the globe, including binary plants installed as bottoming units in combined cycle geothermal power plants in high enthalpy geothermal fields. Of these, only 32 MWe are located in EU, Romania and Iceland. The annual market growth for geothermal binary plants has been estimated at around 5,6% or approximately 30 MWe of new plants every year.

In order to reduce capital costs and improve overall energy efficiency, geothermal direct heat applications are attached to binary units, either in parallel, or in cascade (series) to the power plant geothermal outlet line. Examples of such cases are the geothermal fields of Svartsengi and Husavic in Iceland, Neustadt Glewe in Germany, Altheim and Bad Blumau in Austria and others. The parallel systems provide limited cost or energy efficiency benefits to the binary plant, while the cascade systems result in significant reduction in energy production costs as more power is generated from the same amount of geothermal fluid.

2. LOW-BIN PROJECT

The LOW-BIN project aims in improving cost-effectiveness, competitiveness and market penetration of geothermal electricity generation schemes, targeting both hydrothermal resources for immediate market penetration and future enhanced geothermal systems, by:

1. Widening market perspectives of geothermal Rankine Cycle power generation by developing a unit that can generate electricity from low temperature geothermal resources, with temperature ***threshold for profitable operation down to 65°C***, compared with 90-100°C of existing units.
2. Developing a Rankine Cycle machine for cogeneration of heat and power by heat recovery from the cooling water circuit. This will lead to

cogeneration of heat and power from Rankine Cycle units in present and future geothermal district heating schemes with ***overall energy efficiency of 98-99%***, compared with 7-15% for existing units producing only electricity and for 35-60% of existing geothermal cogeneration schemes.

2.1 The LOW-BIN objectives

Project LOW-BIN addresses short-to-medium term research and aims in accelerating market penetration of geothermal power generation technologies by improving Rankine Cycle geothermal power plants in terms of (a) market opportunities due to broader range of geothermal supply temperature, and (b) improved overall energy efficiency and costs.

The objectives of the project are:

Develop water cooled Rankine Cycle units able to generate power from low enthalpy geothermal resources, with lower temperature threshold for profitable operation down to 65ºC (rather than 90ºC of present technology): In order to reduce costs, the machine will be tailor made for low temperature operation, namely for geothermal fluid supply temperature of 65-90ºC. This will allow Rankine Cycle geothermal power plants to target the market segment of hot groundwater, which is widespread beneath the European Continent at economic depths less than 2 km.

Develop geothermal water cooled Rankine Cycle units for heat and power cogeneration with overall energy efficiency of around 99% by heat recovery from the cooling water circuit: The units will be able to utilize geothermal fluids of 120-150ºC (compared to biomass units operating at ~300ºC), and will use as cooling media the water supplying a district heating system (at 60/80 ºC). The proposed technological solution for the geothermal combined heat and power generation allows large energy efficiency and cost improvements in geothermal power and district heating schemes, facilitating immediate market penetration of geothermal energy utilizing hydrothermal resources of temperature higher than 120ºC (e.g. Iceland, Italy, France, Greece, Portugal, Romania and elsewhere) and paving the way for the future exploitation of the vast resources of enhanced geothermal systems, which abound at depths 3-5 km.

Evaluation of the developed units: in terms of technological, economic and market aspects. The LOW-BIN project apart from technological risks also addresses market and cost issues; the developed prototypes will be manufactured and demonstrated only if all technological, market and cost prospects are positive, as determined by the technology research and market feasibility analysis performed.

Manufacturing of prototypes. If successful, two prototypes will be manufactured, one low temperature (1st prototype) at source temperature range of 65-90°C, and one for true cogeneration of heat and power (2nd prototype) at source temperature range of 120-150°C.

Demonstration, on-site monitoring and technology validation of prototypes as follows: a)65-90ºC geothermal binary plant for power generation only, b)120-150ºC geothermal binary plant, for power generation and district heating with 60/80ºC cooling water. The LOW-BIN project will demonstrate, on the one hand costs reductions associated with low temperature geothermal electricity (both prototypes), and on the other, how the integration, under full-scale operating conditions, of innovative technological solutions on geothermal cogeneration of heat and power (2nd prototype), can lead to improving both energy efficiency and costs. The demonstration sites are located in the geothermal fields of Simbach-Braunau in Austria and Bors in Romania.

Dissemination of project results. The corresponding activities include: (a) Market study, (b) Technology testing and validation, (c) Intellectual property protection according to EU and national legal codes and (d) Various dissemination activities such as the project web site, the project brochure, announcements in geothermal conferences, scientific publications, press releases, etc.

2.2 The LOW-BIN concept

In the frame of the EU THERMIE, the first European 1300 kW Rankine Cycle unit was designed and built. Its operation started in July 1992. The unit was tested at Castelnuovo V.C. near Larderello, in the vicinity of an ENEL geothermal power plant. It was tested by variable conditions of input hot water, with a temperature range 90ºC - 115ºC. When fed by 90ºC geothermal water it generated 800 kW of electric power.

The LOW-BIN project intends to complement and advance this project by developing two binary units, the first one for power generation at lower temperatures (65-90ºC) and the second one for true heat and power cogeneration at higher temperatures (120-150º) with drastically improved overall energy efficiency. Excluding a few early experimental units constructed in Russia and China, the majority of the geothermal binary plants operate with supply temperature above 100°C.

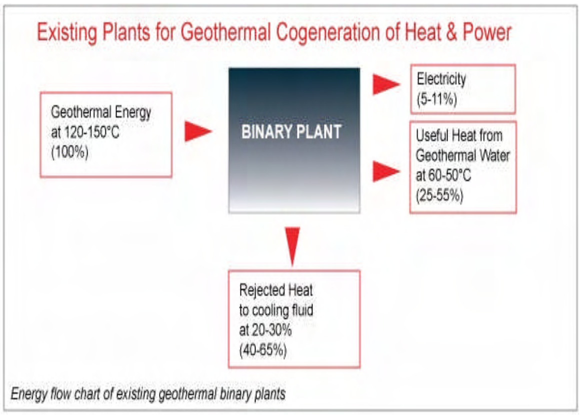

Figure 1: Existing plants for geothermal cogeneration of heat and power.

The **first LOW-BIN prototype** intends to widen the application of commercially binary power technology to geothermal fields of even lower temperature, without any significant impact to costs and conversion efficiency. Existing plants are designed for higher temperatures and include expensive corrosion and temperature resistant materials. In lower temperature applications, materials of less cost can be used in order to reduce capital costs.

The first prototype that will be developed for the LOW-BIN project will be tailor-made for low temperature geothermal environment, which allows the selection of alternative low cost materials and hence considerable costs reduction. In addition, the whole machine will be reengineered in order to identify recoverable energy losses and improve overall conversion efficiency.

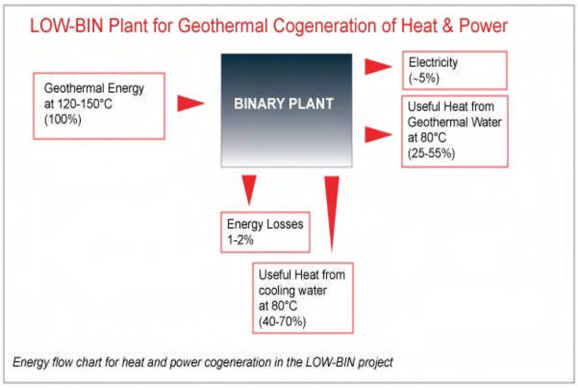

Figure 2: LOW-BIN plant for geothermal cogeneration of heat and power.

This will include reengineering the turbine design (improving the turbine efficiency from 80% to 90% would result in overall increase of conversion efficiency by 1%, e.g. from 6% to 7%), as well as selection of the working fluid that gives the best thermodynamic match to the geothermal temperature (65-90ºC). In any case, the theoretical design will be accompanied by a market-feasibility study that will determine whether commercialising this prototype is worth while in terms of energy costs and market profits, and the project will proceed to manufacturing and demonstration only in case of positive results.

Existing geothermal cogeneration of heat and power plants, although resulting in significant reduction in energy production costs and improving overall energy efficiency from 11-15% to 35-60%, still have large amounts of wasted energy released to the environment through the cooling fluid circuit (figure 1). This occurs because they do not provide true cogeneration, but they are essentially power generation and direct heat uses in cascade.

The **second LOW-BIN prototype** intends to tap this energy, by raising the temperature of the cooling water from 10-25°C to 60-80°C, which allows the heat content of the cooling water to supply a district heating system. The energy flows in the second LOW-BIN prototype are presented schematically in figure 2. In terms of geothermal energy utilization, this configuration allows drastic improvements in overall energy efficiency of geothermal cogeneration schemes, to approach 98-99%, with corresponding reduction in overall power generation costs, especially when the machine is integrated into an existing *district heating* system. In order to further reduce the contribution of capital costs to the life cycle costs of the machine, the machine will be able to operate in both CHP and electricity-only generation modes (for the time period of the year that the district heating system has no or low heating load).

2.3 The demonstration sites

The demonstration sites are located in the geothermal fields of Simbach-Braunau in Austria and Bors in Romania. The Simbach Braunau demonstration site is located within the Upper Austrian Molasse Basin, approximately 15 km west of Geinberg. The injection and production wells reach a final depth of 1850m and 1970m respectively. Production temperature amounts at 80ºC approximately, and the corresponding flow rate is 35 lt/s artesian and 75 lt/s by pumping. Local district heating scheme has a total length of 30 km and serves more than 600 consumers. Installed power amounts at 35 MW, 9,3 MW of which correspond to geothermal heat delivered at 80 ºC and reinjected at 50 ºC.

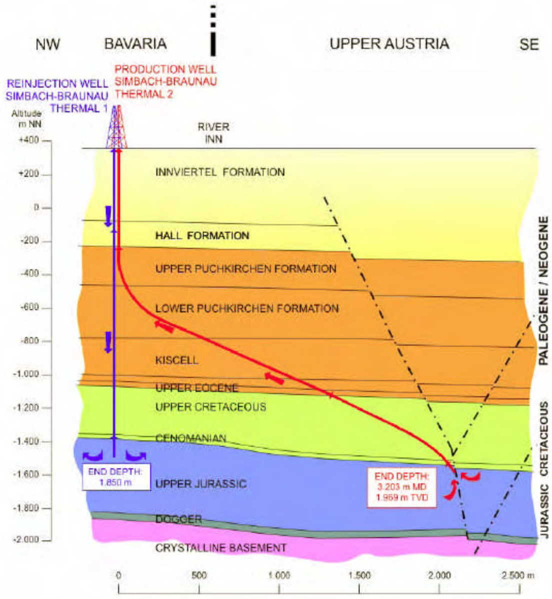

Figure 3: The demonstration site in the geothermal fields of Simbach-Braunau in Austria.

The Bors demonstration site is situated about 6 km northwest to Oradea. The geothermal reservoir is completely different from the Oradea reservoir, although both are located in fissured carbonate formations. The Bors reservoir is a tectonically closed aquifer, with a small surface area of 12 km^2. The geothermal water has about 13 g/l TDS, 5 Nm^3/m^3 GWR and a high scaling potential. The dissolved gasses are 70% CO_2 and 30% CH_4. The reservoir temperature is higher than 130°C at the average depth of 2.500 m, and the wellhead temperature is about 120°C. There are 5 wells drilled in the Bors reservoir, of which 3 were used to produce a total flow rate of up to 30 l/s, and the other 2 for reinjection, at a pressure that did not exceed 6 bars. The artesian production of the wells can only be maintained by reinjecting the whole amount of extracted geothermal water, plus additional cold water from a couple of shallower wells. The geothermal water was used about 10 years for heating 12 ha of greenhouses located in the vicinity. The dissolved gasses were partially separated at 7 bars, which was the operating pressure, and then the fluid was passed through heat exchangers before being reinjected. Downhole anti-scaling chemical inhibition in the production wells was still needed to prevent calcite scaling, even if most of the CO_2 was kept in solution.

The currently artesian production could be increased to 30 l/sec/well with pumping. The geothermal energy can be used to supply heat to a nearby hotel, the Bors Customs and to two villages (Bors and Santion), or to the newly retrofitted greenhouses in the vicinity. An industrial park is also planned to be developed in the area.

3. LOW-BIN BENEFITS

The LOW-BIN project has the following benefits:

Reduction of greenhouse gases and pollutants emissions (Kyoto): Geothermal binary power generation is a pollution free technology leading in reducing effectively greenhouse gases emissions to the atmosphere resulting from power generation by fossil fuels. According to our estimation, the short-term emissions reductions resulting from the LOW-BIN project amounts at around 3,6 million tons of CO_2. Long term CO_2 emissions reduction is expected to be considerably larger, due to:

- the large energy potential of ***low temperature hydrothermal resources*** of Europe, which exceeds the amount of 10.000 MWe.
- the cost reductions to the geothermal heat and power cogeneration schemes arising from the second prototype, which will facilitate the exploitation of the vast resources of ***enhanced geothermal systems***, estimated that can cover 70% of energy use in EU.

Improving overall energy efficiency: Energy conversion efficiency to electricity from geothermal heat is increased from 7-15% of existing electricity generating geothermal plants, or from 35-60% of existing geothermal cogeneration schemes to around 98-99% for the second LOW-BIN prototype. That way geothermal resources are exploited with the highest possible efficiency, when combined with a ***district heating scheme***. In addition, both LOW-BIN prototypes can be used in ***industrial waste heat recovery systems***, resulting in additional power to be generated from waste heat, especially in electricity intensive industries (which need electricity and not heat), further improving energy efficiency in the European Union.

Increasing the use of renewable energy: The LOW-BIN project will result in increasing effectively the use of geothermal energy, a renewable energy form, by the addition of more than 10.000 MWe to low temperature geothermal electricity resource base, and by dramatic cost reductions to geothermal cogeneration (short term) and hot dry rock (long term) exploitation schemes. These cost reductions will result in accelerating the utilization of over 20.000 MWth European geothermal resource base of 120-150ºC, for cogeneration of heat and power. Moreover, the low temperature LOW-BIN machine will find new applications in ***solar thermal electricity conversion***, where hot water of temperature 80-90ºC is delivered by standard solar water heaters, which will further increase the share of renewable energy in the European energy market.

Enhancing the competitiveness of European industry: The competitiveness of European industry will be effectively increased by the LOW-BIN project as:

- European industry of geothermal electricity generation machines will obtain a competitive advantage (low temperature geothermal electricity generation and low cost geothermal cogeneration) effectively assisting its efforts to enter the geothermal binary power market.
- European industry will be able to benefit from a new technology which can generate additional electricity or provide cogeneration of heat and power from waste heat recovery systems, reducing energy costs and improving competitiveness, especially of electricity intensive industries.
- European industry of solar water heaters can also benefit from the developed technology due to the creation of a new potential market of electricity generation from hot water.

Introduction of innovative and cost competitive renewable and energy efficiency technologies into the market: The main innovation of the *first LOW-BIN prototype* is attributed to commercial electricity generation from lower than 90ºC geothermal resources with competitive costs. The competitive costs will result from the use of low cost materials compared with the ones needed in higher temperature machines. The conversion efficiency will be optimised from the ability of the machine to operate at a variable temperature and flow rate range. The main innovation of the *second LOW-BIN prototype* arises from the use of high temperature cooling water (60-80ºC) coupled with relatively low temperature of energy supply (120-150ºC), compared with existing biomass machines, where the energy supply is at 300ºC. This machine allows increasing energy utilisation efficiency of geothermal cogeneration by a factor of 2-4, up to the value of 99%. *Both machines*, after the demonstration period of the prototypes, where the final operation tuning and technology improvements will be made, will be available to the market.

4. LOW-BIN RESULTS

The research that has been done until now was directed towards the study and the recommendation of optimal Rankine cycles using Isobutane (R600a) and R134a as working fluids for the two geothermal binary power machines [1]. The main Rankine Cycle parameters (the cooling heat exchanger, the geothermal heat exchanger, the turbine and the pump) are modelled.

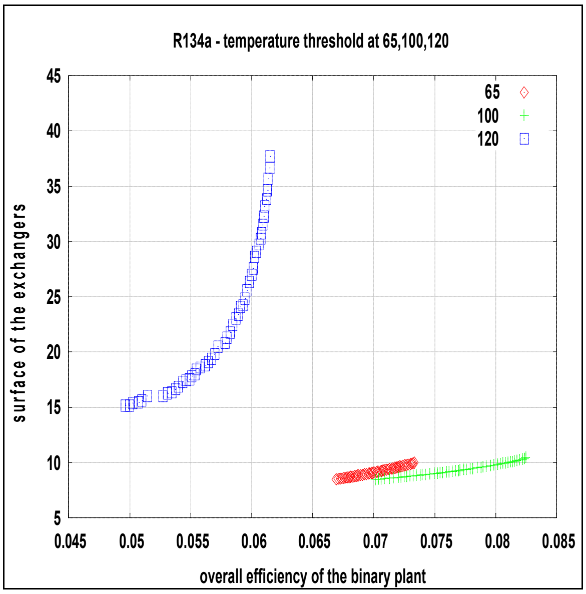

Figure 4: Rankine cycle optimization - Temperature threshold at 65°C, 100°C, 120°C - optimal solutions for R134a.

The optimization tool used is code EASY (Evolutionary Algorithm System by the Parallel CFD and Optimization Unit of the Laboratory of Thermal Turbomachines, National Technical University of Athens) [2]. The objectives of the optimization are maximizing overall net conversion efficiency and minimizing the cost of the plant (minimization of the surface of the heat exchanger and the condenser since they constitute a major part of the plant cost). The pressure of the liquid working fluid at the pump outlet, the hot ground water mass flow rate, the mass flow rate of the working fluid, the temperature difference of the ground water in the heat exchanger, the temperature difference of the cooling water in the condenser constitute the variables of the optimization. The electrical power of the plant is at $200kW_e$ and it is defined as a constraint in this optimization.

The results of the optimization are plotted in figure 4 and figure 5.

Each point of the above Pareto charts stands for an optimal solution represented by two numbers constituting the optimization objectives resulting from different combination of optimization variables and corresponds to an optimal Rankine cycle. In Figure 5 the surface of the heat exchangers needed for R134a is less than the one for Isobutane when the plant's efficiency is around 7% in both cases. On the other hand however, a comparison of the key variables corresponding to an optimal solution shows that the geothermal water flow rate, the working fluid mass flow rate and necessary auxiliary pumping power are higher in the case of R134a than in R600a. By comparing the optimum Rankine cycles of 65°C to standard binary machines of 100°C, Figure 4, the efficiency of the 65°C binary cycle is a little less than this of the 100°C binary cycle, which is predictable since the temperature of the geothermal water is lower. As a result, as far as it concerns the cost, there is no significant difference which shows that the Rankine cycles of 65°C do not contribute to the increase of the cost. Comparing water and air cooling options we conclude that water cooling yields higher efficiency and lower costs, but requires local availability of water resources for this purpose. By comparing Rankine cycles of 120°C to standard binary machines optimized for 100°C geothermal fluid supply, we see that the conversion efficiency of the 120°C binary cycle is less than the one of the 100°C binary cycle which indicates that the Rankine cycles of 120°C contribute to a remarkable increase of the plant's cost but the gain of the cogeneration of heat and power of 120°C geothermal water should be taken into account, as it allows significant cost reduction in system infrastructure since the same production wells, reinjection wells and geothermal fluid piping are utilized for both power generation and heat supply, while overall system efficiency approaches 100%.

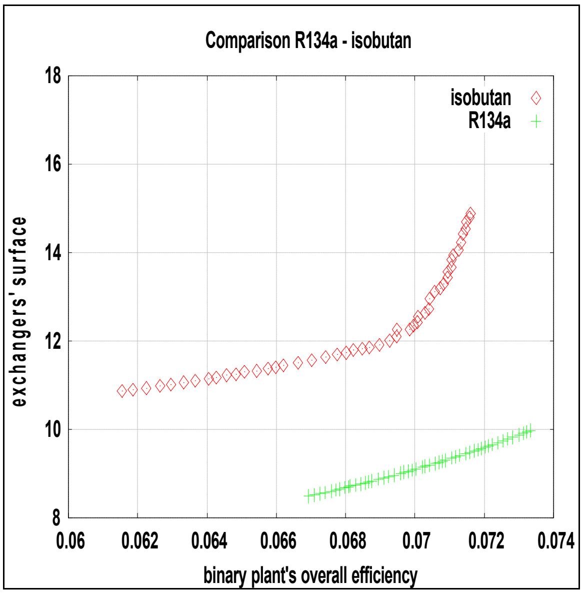

Figure 5: Rankine cycle optimization - Temperature threshold at 65°C – Comparison between optimal solutions for R134a and Isobutane

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http://velos0.ltt.mech.ntua.gr/EASY [2]