# Medium-enthalpy geothermal energy systems: new opportunities of renewable energy in China.

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# MEDIUM-ENTHALPY GEOTHERMAL ENERGY SYSTEMS: NEW OPPORTUNITIES OF RENEWABLE ENERGY IN CHINA

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**ABSTRACT** High enthalpy geothermal fields (>150°C) are present in western China (eg. Yangbajing field in Tibet) and are exploited through steam- or "flash"-type thermoelectric power plants. Many other areas in China show lower, but interesting geothermal gradients, likely due of medium-enthalpy (90° -150° C) fluids at depth that could be exploited through binary cycle, 200 kW to over 30 MW power plants (e.g. in USA, Turkey, Iceland). These use a heat exchanger where the geothermal fluid yields heat to a low-boiling "working fluid" (i.e. Kalina or ORC systems) that operates within a sealed circuit feeding turbines in a saturated steam Rankine or a superheated steam Hirn cycle. Binary cycles systems, based on the total reinjection of all geothermal liquid and non-condensable gases at depth, eliminate any possible environmental pollution. CIRPS Florence Section proposes the evaluation of medium-enthalpy geothermal resources in the Chinese territory and their exploitation by binary cycle thermoelectric plants.

**Keywords**: Geothermal Energy, China, Geothermal potential, Middle Enthalpy Systems, Binary cycle geothermoelectric plants

## 1. INTRODUCTION

On a global scale and particularly in some countries (Iceland, Italy, USA, Philippines, Indonesia, Mexico, Japan, New Zealand, etc.), geothermal energy is an important resource leading to the national energy supply [1,2]. In any case, geothermal energy has a prominent role to develop a fully renewable energy in the future.

The great geothermal vocation of large part of China is well known and multipurpose use of this resource (e.g. spas, fish farming, district heating, heat pumps, geothermoelectric production of high enthalpy systems) belongs to its long history. In the last decades, the geothermal researches have been developed not only for finding "classical" high-enthalpy geothermal systems(with fluid temperatures above 150° C), but also to the more widespread medium-enthalpy systems (90°-150°C) whose exploitation is made through binary-type geothermoelectric power plants.

These are characterized by a great modularity (from 200 kW to more than30 MW power plants), but, more important, also for their practically nil environmental impact because of the complete re-injection of geothermal fluids (including gases) in the subsoil and the small size of the plants.

In China, geothermal systems with high enthalpy fluids for geothermoelectric energy production (e.g. Yangbajing field in Tibet) and the low-enthalpy systems for direct use (district heating, geothermal heat pumps, etc.) are in exploitation, but researches and applications on medium-enthalpy systems through binary cycle power plants are still lacking particularly in those thermal anomalous areas like some of the most populated and industrial regions of the country.

The members of the CIRPS Florence Section have a long experience for the geothermal research and applications in medium and high enthalpy systems and scientific collaborations with national and international public institutions (e.g. CNR-Italian National Research Council) and private companies (e.g. leading companies for geothermoelectric power generation).

The purpose of this paper is to focus on the presence and the potential of the medium-enthalpy geothermal systems in China, and their applicability in the geological-environmental and social-economic context of the Country.

## 2. GEOTHERMAL SYSTEMS

Compared to other renewable energy sources (e.g. solar, wind, biomass), geothermal energy is directly linked to the endogenous heat of the Earth [2,3,4]. In particular the total flow of heat from inside to the outside of the Earth is 30-42 TW.

Proceeding from the surface towards the interior of the Earth, the temperature of the subsoil grows (3 ° C per 100 meters on the average in the crust). This temperature increase is known as "geothermal gradient". Due to the rise towards the surface of the magmatic masses (originated in the lithosphere by geodynamic-tectonic activity), the geothermal gradient is very high (more than ten times) in some areas of the world causing the heating of the rocks and of the circulating groundwater, and producing geothermal fields.

In particular, the existence of a geothermal field in a certain area is substantially linked to four factors (see Fig. 1): 1) the presence of a heating body at depth (e.g. a magma chamber) hosted in impervious rocks (e.g. metamorphic rocks), 2) an overlying "reservoir" characterized by porous and permeable rocks (e.g.

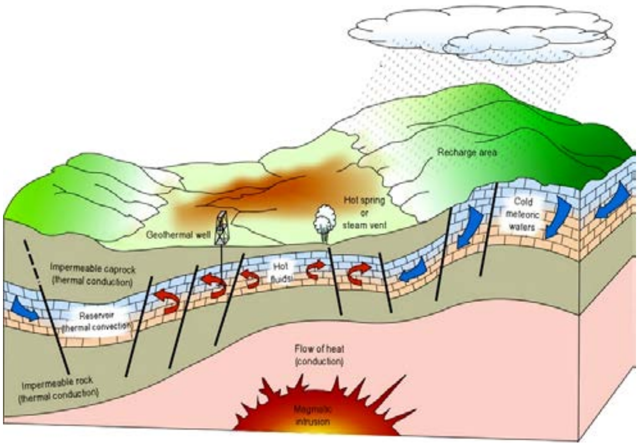


Fig. 1 – Sketch of a “hydrothermal”-type geothermal system (after [2])

fractured limestones), 3) impermeable "cover" rocks, constituting the “lid” of the geothermal "pot", 4) an hydrological system that would allow rainwater to infiltrate at depth and recharge the geothermal "reservoir". When these heated fluids spontaneously go back to the surface (e.g. through faults and fractures), they will lead to natural vents such as hot springs, geysers, fumaroles. This is the so-called hydrothermal-type geothermal system. The hot and high pressure geothermal fluids can be also artificially intercepted at depth by drillings. In 1904 at Larderello (Italy), high pressure geothermal fluids of the local hydrothermal system, until then exploited only for direct uses and for chemical industry (extraction of boron from geothermal brines since 1790), were first used for the production of geothermoelectric energy [5].

The hydrothermal systems that contain a geothermal resource are divided on the basis of physical-chemical features and enthalpy of the fluids present within [1,2,3, 6]:

1) steam dominated systems. These dry or "wet "steam systems have a higher energy content, but are rare all over the world (e.g. Larderello in Italy, Geyser in the USA). They represent the most simple and advantageous system for the conversion of the contained geothermal energy in electricity.
2) water-dominated systems. They constitute nearly all of the geothermal fields (e.g. the Monte Amiata field in Italy, Yangbajing geothermal field in China) and contain hot water or a biphasic mixture of prevalent water and steam.

Moreover, on the basis of the temperature of the hydrothermal fluid, the following systems can be defined: a) high enthalpy systems (T> 150° C, or 150-350° C), b) medium enthalpy systems (T = 90-150°C), c) low enthalpy systems (T <90°C).

Unlike the fluids at high and medium enthalpy that are used for the production of electricity, low enthalpy fluids are used directly to extract heat for many purposes (e.g. heating of buildings and greenhouses, agribusiness like agricultural, animal husbandry and acquaculture, industrial applications like drying and dehydration, seawater desalination).

The research of geothermal energy is also open to other possibilities still in the testing phase: 1) HDR (hot dry rocks) or EGS (enhanced or engineered geothermal systems) where heat extraction is made directly from the rocks developing an developing an artificial geothermal field by rock fracturing, injection of water and recover of the heated fluids), 2) geopressurized systems (from deep and high pressure reservoirs), 3) supercritical fluids or UGS (unconventional geothermal system) where fluids derive in large part from magmatic bodies with temperatures exceeding 400°C.

If the geothermal resource is exploited in order to guarantee its renewability (e.g. the amount of the fluid extract should not exceed the natural recharge of the system, development of an appropriate reinjection program for the of extracted geothermal fluids), geothermal energy is certainly one of the best available energy source because, even if concentrated only in certain areas of the planet, it is characterized by a continuous availability in time.

Geothermal energy contained in the Earth amounts to 13000 Zetta Joule, but the technologies currently available allow the use of only 2000 ZJ; therefore, with a 0.5 ZJ / year of world energy needs and using only the sustainable use of geothermal energy, we already produce each year the amount of energy needed to the global demand for 4000 years!

The geothermal fluid are essentially composed of water, either in liquid or vapor state, and by a lesser amount of non-condensable gases and of dissolved salts which varies because of the nature of the leached rocks that host the geothermal system.

The non-condensable gases consisting mainly of carbon dioxide and, to a lesser extent, of methane, while the most common pollutants in order of importance are: hydrogen sulfide, boric acid, nitrogen, hydrogen, ammonia, arsenic, mercury, chlorine, antimony and other elements, both stable and radioactive, in traces.

## 3. GEOTHERMICS IN CHINA

The China territory, which includes more than 3000 thermomineral vents and more than 1600 spas, has a great geothermal vocation [7,8]. Actually, the Chinese people have used for centuries hot spring water for therapeutic, recreational and agricultural purposes. Today, China, together with USA, is at the top in the world for the direct use of low enthalpy geothermal fluids (i.e. spas, district heating and geothermal heat pumps in small and big towns as Xianyang, Beijing, Tianjin and Shenyang, etc.)[8,9,10], given also its interest for environmental problems such as the reducing of pollution of the conventional fossil fuel power plants, heaters and boilers. In addition, China falls within the top 20 countries for the production of electric power from high enthalpy energy geothermal fluids (i.e. the geothermal fields in Tibet and Yunnan [11,12]). To date more than 250high-temperature geothermal systems have been found on mainland China, with an estimated electric generation potential of at least 1,740 MW up to 6,744 MW (in 2010 the installed electric power capacity was about 25 MW) [11,13,14,15,16]. Over than 3200 areas characterized by thermal anomalies are present in China (Fig. 2). The areas with the highest heat flow (> 80 mW/m$^2$up to 150 mW/m$^2$, but locally about 300mW/m$^2$), are the Himalayan belt (Tibet, Yunnan and western Sichuan), as well as those of the Pacific coast; other thermally anomalous areas are also present in other inland areas of China (e.g. Shando, Henan, Quinghai, Shanndu)[17,18,19](Fig. 2). The distribution of hot springs, geothermal fields and heat flow anomalies are controlled by still active geological structures resulting from plate tectonics [20,21]. In particular, they are the Himalayan orogenic belt, derived from the collision of India plate with the Asiatic plate, and the Pacific "active" continental margin, linked to the subduction of the Pacific and Phillippine Plates below the Asia continent [22,23,24].

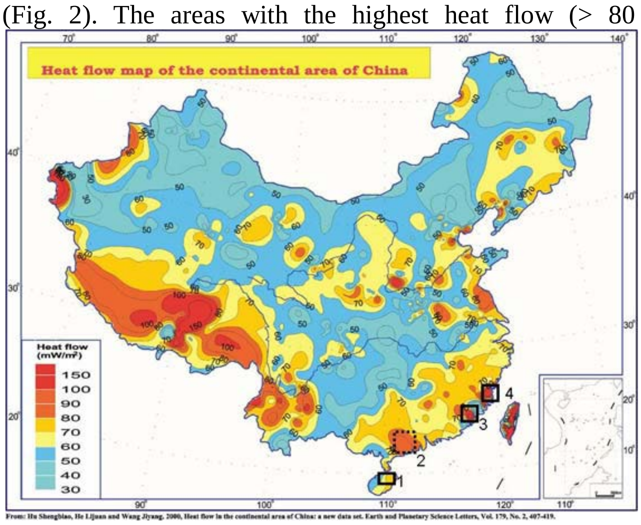


Fig. 2 – Heat flow map of China (after [17]).

In these areas (Himalayan and Pacific belts in Fig. 2) are concentrated the most significant thermal anomalies due to the presence of quiescent or in cooling magmatic systems at depth and local volcanic activity of Neogene-Quaternary age, but it should be noted that intraplate volcanism is also present in other parts of China (e.g. Wudalianchi and Changbai volcanoes in north-east China; Datong volcano in Shanxi Province, west of Beijing; Honggeertu volcano in Inner Mongolia Province) [23,25]. In the last tens years, EGS projects were also developed in the Pacific geothermal belt (see Fig. 2) and the estimation of heat energy contained in the HDR between 3.5-7.5km at 150-250°C in Mainland China is 6.3 x 1024 J [17,18,19].

## 4. EXPLOITATION OF THE GEOTHERMAL RESOURCES FOR ELECTRIC POWER GENERATION

Due to the presence of gas and other pollutants in the geothermal fluids, geothermal power plants have a very different configuration from those of the thermoelectric plants fed by fossil fuels in which the produced steam is made up, practically, of distilled water [6].

In particular, as regards the geothermoelectric plants, you can have different types of power plants according to the chemical-physical features of the geothermal fluid [3,6]:

a) vapor-dominated systems, different types of steam cycle plants as "back-pressure"-, "condensation"- and "combined"- or "integrated"-types ("condensation" plants including a final binary cycle dedicated to the recovery of enthalpies contained in the waste fluid coming out from the steam cycle) can be used. Because of their high environmental impact, the "back-pressure" plants are in disuse all over the world and have been replaced with "condensation"-type plants. These latter, in spite of their continuous emission of incondensable greenhouse gases (such as methane and carbon dioxide)into the atmosphere, use filters and other devices to control the emissions of other pollutants (e.g. AMIS filter for removal of mercury and hydrogen sulfide, demister metal grids able to break down the "drift" of water containing boric acid). In any case, the efficiency of the system is also improved by the reinjection of geothermal exhausted fluids at depth into the reservoir rocks.

b) water-dominated systems, single or multi-stage "flash cycle" (which allows to produce steam through the depressurization of hot water), "binary cycle" "(ORC- or Kalina-type) or "combined" or "integrated" flash cycles(characterized by a final binary cycle). The applicability and convenience of one system over the others depends on the thermodynamic conditions of the geothermal source. In particular, a flash-type is convenient for high pressures fluids, while binary cycle is more suitable for fluids with smaller pressures and enthalpies (medium enthalpy). In fact, using a flash cycle, the further lowering in pressure of the middle enthalpy fluid to produce the required flow rate steam caused that the specific power of the turbine would drop to levels so low as to become disadvantageous.

In particular, "binary cycle" plants (developed to recover the residual enthalpies arising from the application of other thermodynamic cycles), exploit the transfer of heat contained in a geothermal fluid to a low-boiling (or working) fluid circulating in a sealed circuit through a heat

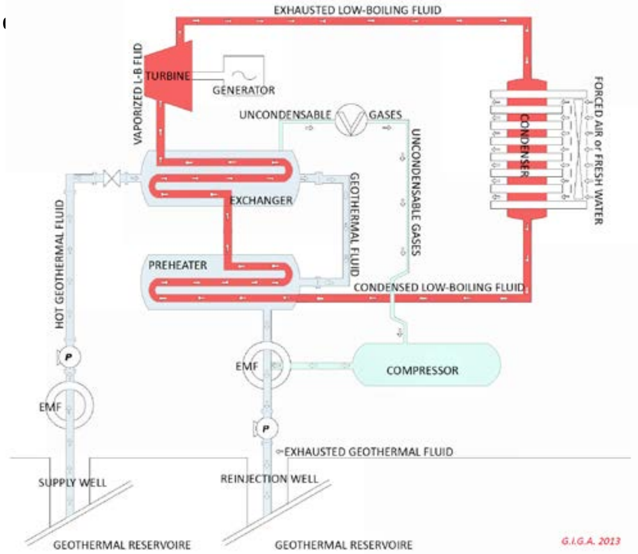


Fig. 3 – Sketch of a binary cycle-type geothermoelectric plant

environmental compatibility, as all the geothermal fluid and gases contained in it are returned to the original aquifer, resulting in the absence of dispersion of pollutants in the environment.

The "working fluid" of binary cycles is characterized by a boiling temperature, at a constant pressure, much lower than that of water. The low-boiling working fluids are constituted by a mixture of water-ammonia in the Kalina-type systems and hydrocarbons, chloro-fluoro-carbons, or siloxanes or metalorganic fluids in the ORC-type systems. Once this fluid has acquired the necessary amount of heat (well below the boiling temperature of water) through the heat exchanger, its vaporization will occur, making it usable in a saturated steam Rankine cycle or in a superheated steam Hirn cycle.

The heat exchange system consists of two stages: the preheater and the vaporizer. In the preheater, fed from geothermal fluid that exits from the vaporizer, the working fluid reaches a temperature close to boiling point (auto-recovery of waste heat). Finally, in the vaporizer, supplied directly by geothermal fluid coming from the well, the low-boiling fluid evaporates and is overheated to reach the inlet temperature of the turbine. The working fluid, which came in the turbine at the required pressure and temperature, expands and produces mechanical energy which, through an alternator, is converted into electrical energy.

The working fluid, once it has completed its expansion and left the turbine, passes through a capacitor (surface condenser) where, yields much of its residual enthalpy and returns to the liquid state ready to start a new cycle. The heat produced by the capacitor will be disposed into the environment through a system of extraction e.g. forced air or, in the area where there is a good availability of surface water, by means of a water exchanger.

The efficiency of a binary cycle plants is lower (around 10%) than that of traditional steam and flash plants(around 40%), but it can be improved in some ways for example by the use of new working fluids, that are still under study, seems to double if not to triple the performance of the plants. Moreover, in the design of a binary system, it is necessary to identify exactly the minimum temperature that can reach the geothermal fluid in output from the cycle in order to avoid corrosion and damage to system components due the precipitation of dissolved salts in the geothermal fluid.

The binary cycle power plants, which therefore represent the best cleaner system for the conversion of geothermal energy into electrical energy, generally have sizes ranging from hundreds of kW and 5 MW, but more than 30MW plants are also in activity all over the world. Finally, the size and the landscape impact of a binary cycle plant is much more limited than the traditional plants; in fact, a 5 MW binary system occupies an area of 100-200 $m^2$ (approximately 1/25 of that of a traditional plant) and it is also to underline that most part of it can be buried.

## 5. CONCLUSIONS

As shown in the previous paragraphs, a wide parts of China, beyond of the presence of high enthalpy geothermal fields in Tibet and in Yunnan, are characterized by lower, but relevant thermal anomalies that could be exploited not only for traditional direct uses (e.g. district heating), but also for the production of geothermal power plants through binary type plants. It should be underlined that the present geothermal fields in exploitation (e.g. Tibet) are far from industrial and populated areas of China. It is therefore important to assess the presence of medium-enthalpy geothermal systems possibly present not only along the Pacific coast, but also in other populated areas in the Chinese hinterland.

The high modularity and no-environmental impact of the binary cycle power plants allows their application in different social and territorial contexts. In fact, the modularity of those plants (from 200 kW to 40 MW), allows their application in different situations depending on the characteristics of geothermal fluids and the uses in small (groups of buildings) or in wide utilizations (towns). Moreover, the system can be easily integrated with other sources of renewable energy (solar, wind, biomass), thereby making users virtually independent of the national electric circuit. In this view, the integrated use of multiple sources can also be used to raise the temperature of geothermal fluids in cases that are close to the limit of use in binary cycles.

In any case, the possibility of a "cascade"-type use of exhausted geothermal fluid for direct uses as thermal wellness centers, food industry and heating, raises the overall performance of the middle-enthalpy system. There are well-known examples in different parts of the world (Austria, Iceland, etc.) of spas that produces electricity for their own use from hot mineral springs, and the exhausted fluid are then used for heating, bathing and spa therapies. In this way the development of geothermal tourism and spas resorts can be significantly improved.

As for the environmental impact, it is obvious that the geothermal fluids that circulate in the ground, can leach at depth and carry up to the surface elements and compounds that, at times, can be dangerous to humans and ecosystems (e.g. ammonia, boric acid, arsenic, mercury). This risk factor, of course, becomes much more significant when the geothermal fluids are artificially brought to the surface and, after removing their heat (e.g. for the production of electricity in conventional steam- or flash-type power plants) are released in the environment, both in the form of atmospheric emissions of gases and vapors (e.g. through chimneys and cooling tower) or, even worse, of liquid discharges.

All this makes evident the importance, both from the social and environmental point of view, of the binary cycle power plants that are characterized by a complete re-injection of geothermal fluid, including non-condensable in the subsurface reservoir rocks, and this is especially true in the surroundings of urban areas. The small size of the binary cycle plants also make modest even the landscape impact also in important social-cultural and natural localities.

Therefore, the research and exploitation of medium-enthalpy geothermal systems offers to many countries, such as China, a great opportunity for the energy supply, particularly where there is a greater demand, while preserving the environment and public health. In this case we can say that the geothermal energy is not only a "renewable", but also "sustainable" resource for the present and future communities.

The development and production of innovative binary plants could be an excellent opportunity for the Chinese industry, taking also into account the great demand, particularly in Asian countries (Philippines, Thailand, etc.), of Chinese technology because of its great technical-commercial competitiveness.

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