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LOW ENTHALPY SYSTEMS IN GEOTHERMAL ENERGY

NIZKO ENTALPIJSKI SISTEMI V GEOTERMALNI ENERGIJI

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Abstract

Geothermal energy is the most available form of energy and is also weather independent (unlike other types of renewable energy). Furthermore, geothermal energy is present almost everywhere, and it is expected that this energy would have a more important role in the near future. However, not all areas in the world have appropriate geothermal resources, so new technologies are being developed using geothermal resources for generating heat and electricity at low temperatures or enthalpy.

Povzetek

Geotermalna energija je energija, ki je človeštvu najbolj dostopna ter vremensko neodvisna kot druge vrste energije iz družine OVE. Prav tako je količinsko neomejena in pričakovanja so, da se bo ta energija med vsemi najbolj intenzivno širila. Pa vendar niso vsi kraji enako obdarovani z ustreznimi viri geotermalne energije. Zaradi tega se razvijajo nove tehnologije, ki lahko izkoriščajo geotermalne vire za pridobivanje toplote in električne energije z nižjimi temperaturami oz. nižjo entalpijsko vrednostjo.

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1 INTRODUCTION

Geothermal energy is a renewable energy source that has sparked a great deal of interest, for the production of both electricity and heating, because it is not dependent on the weather. However, geothermal energy is not available to all regions in the world because temperatures in different geothermal resources are not equal, and the possibilities for utilization of them are not the same. The eastern part of our Slovenia is part of the Pannonia region (Pannonia Basin), where geothermal energy can be found more easily than elsewhere; it has thus attracted the attention of scientists, especially from the field of energy technology; they have produced many written expert studies and articles. The central question or problem is almost always the same: is it feasible to build a geothermal power plant for generating electricity? The second question is how to utilize geothermal resources with low temperatures (ca. 40–80° C) for heating and generating electricity.

2 GEOTHERMAL ENERGY

Geothermal energy is defined as energy coming from the centre of Earth. Fig. 1 shows temperatures in the Earth.

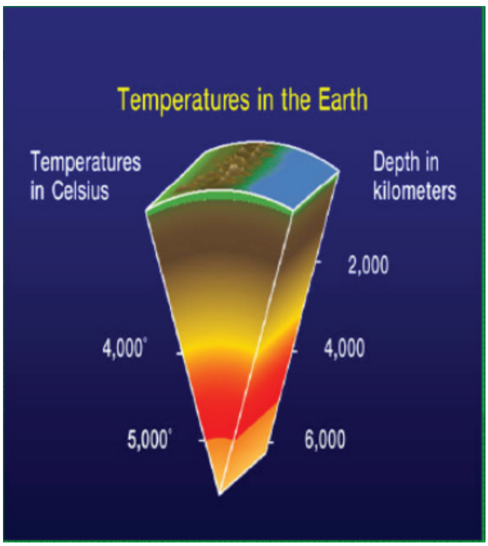

Figure 1: *Temperature in the Earth*

The total flow of heat from the Earth is estimated at 42×10^{12} W (conduction, convection and radiation). Of this figure, 8×10^{12} W come from the crust, which represents only 2% of the total volume of the Earth but is rich in radioactive isotopes; 32.3×10^{12} W comes from the mantle, which represents 82% of the total volume of the Earth, and 1.7×10^{12} W comes from the core, which accounts for 16% of the total volume and contains no radioactive isotopes, [1].

The most important value is the temperature and the quantity of the geothermal resource. On this basis, the kind of geothermal source to be used shall be determined, as can clearly be seen in Lindal diagram (Fig. 2).

Table 1 shows that several types of classification are used; all are based the temperature, and they are distinct according to different geographic areas that provide different conditions for the utilization of geothermal energy. New types of classifications shall be developed according to the latest technologies, all of which have the same goal of obtaining useful heat energy from much lower geothermal resources.

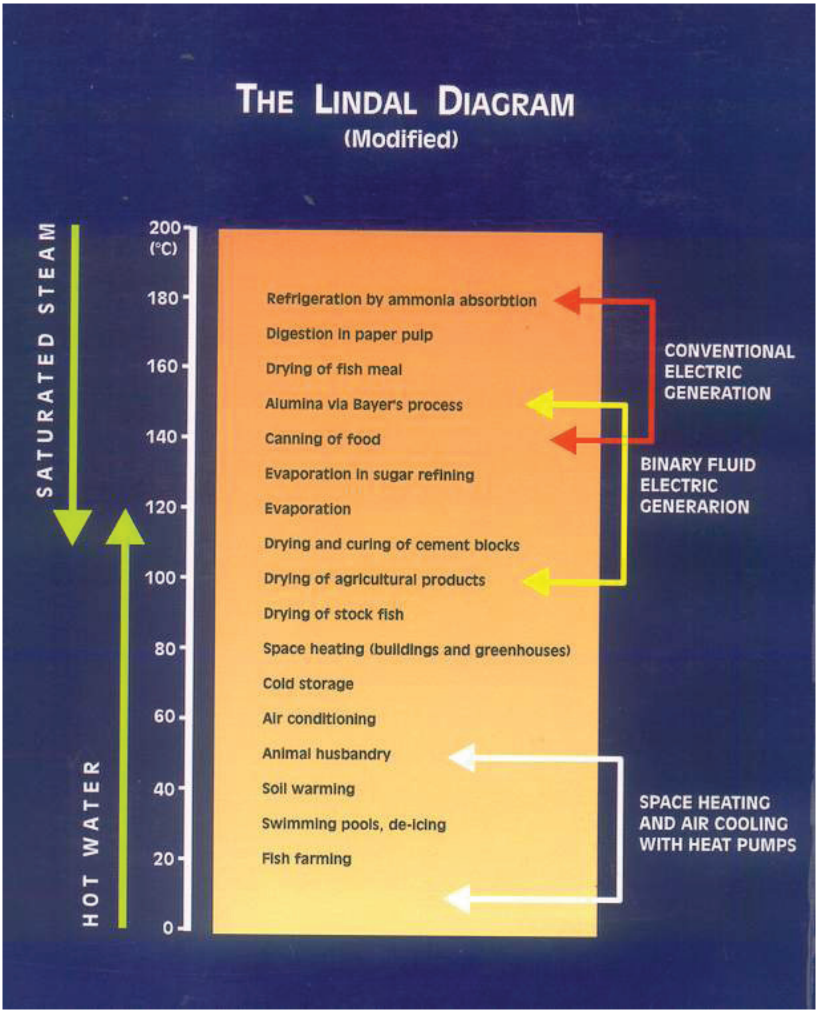

Figure 2: *The Lindal diagram*

***Table 1:** Different classifications of geothermal resources [1]*

	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	< 90	<125	<100	≤150	≤190
Intermediate enthalpy resources	90-150	125–225	100–200	-	-
High enthalpy resources	>150	>225	>200	>150	>190

Table 1, source: (a) Muffler and Cataldi (1978), (b) Hochstein (1990), (c) Benderitter and Cormy (1990), (d) Nicholson (1993), (e) Axelsson and Gunnlaugsson (2000).

2.1 Geothermal energy in Slovenia

Slovenia has suitable conditions for the utilization of geothermal energy. Low temperature resources of geothermal energy dominate (geologically younger structures from the tertiary and quaternary periods); the greatest potential is in the south-eastern part of Slovenia. More than 20 geothermal resources have a constant temperature 20° C. Termal II is the only high temperature aquifer in Slovenia (110°C) at a depth of 2000m. The geologic and tectonic structures of the entire nation are highly complex, and divided into several geothermal regions: the Pannonia reservoir (Banovci spa, Murska sobota and others), the Rogaška-Celje-Šoštanj region (Topolščica, Zreče, Dobrna), the Krško-Brežice region (Šmarješke toplice, Čateške toplice, Bušeća vas), the Planinsko-Laško-Zagorje region (Medijske toplice, Laško, Rimske toplice, Podčetrtek), the Ljubljana basin (Ljubljana moor, Podpeč, Vrhnika, temperature about 18-30 °C) [2].

In Slovenia, geothermal water is divided according to:

- Temperatures under 25° C: convenient for heat pumps, which can utilize such energy
- Temperatures between 25–90° C: convenient for direct utilization. The biggest aquifer is Termal I in Murska Sobota. Around 400 GWh heat energy is available.
- Temperatures greater than 90°C; The Termal II aquifer is the only one, and it is suitable for generating heat and electricity
- As can be seen in Fig. 3, low temperature geothermal resources dominate in Slovenia. These resources that are interesting from the perspective of energy production.

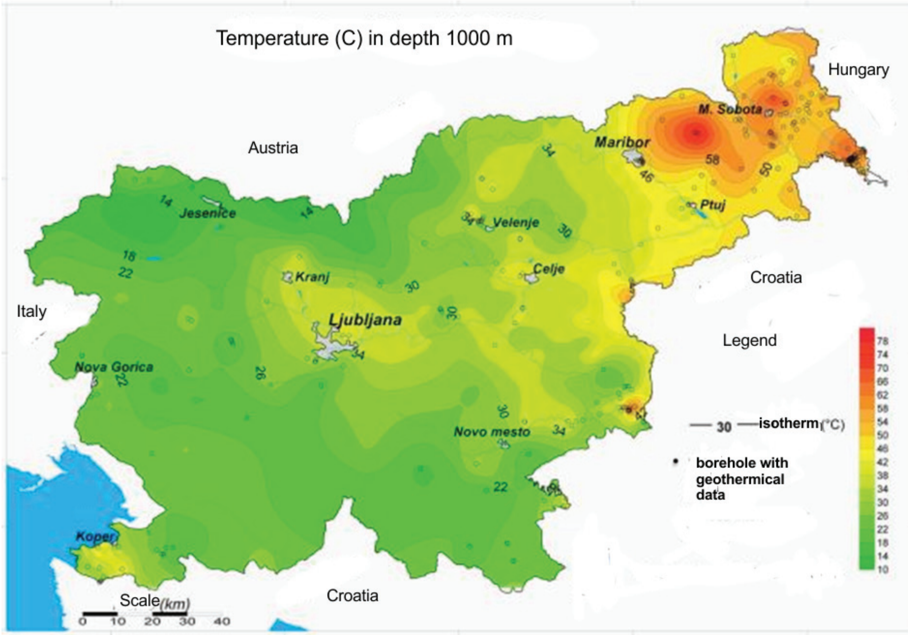

Figure 3: *Temperatures of geothermal resources in Slovenia*

A typical geothermal resource is Mostec near Čatež, [3], classified as a low temperature or low enthalpy resource, with a temperature of 61 °C, a flow of 40 l/s and maximum available power of 7.8 MW_t. This resource has been repeatedly studied and all have reached the same conclusion that the resource is under-utilized and inappropriately maintained. A quick calculation shows that for 60 houses in the village of Mostec a mere 1.8 MW is needed. Energy experts are alarmed by this situation; the owner of Mostec resource is the state. Furthermore, it was determined that a nearby health spa where still hot once-used water with temperatures of 30-35° C runs into the sewer system, [2].

Figure 4: *Abandoned geothermal resource in Mostec*

At the same time, Slovenia states in its documents renewable energy sources (AN OVE 2012-2020) [4] that there will be no electricity generated from geothermal power plants. Nevertheless, significant progress has been made in ground (geothermal) source heat power or GSHP. To the middle of 2010, almost 4,410 GSHP units had been installed. It may be expected that up to 1,000 units shall be installed annually in the next five years.

From a technical point of view, the obvious question is what else can low temperature geothermal sources teach other non-technical people about suitable utilization of available resources. Low temperature geothermal resources are appropriate for generating heat and electricity with so -called binary systems or cycles, which are well known in the energy production field, but less so by the general public.

2.2 Systems for generating electricity

Classification of all geothermal systems that can generate electricity:

- high-temperature resource (more than 150° C) – dry steam

- middle-temperature resource (between 90 and 150° C) – flash steam

- low-temperature resource (T under 90° C) – binary cycle

C

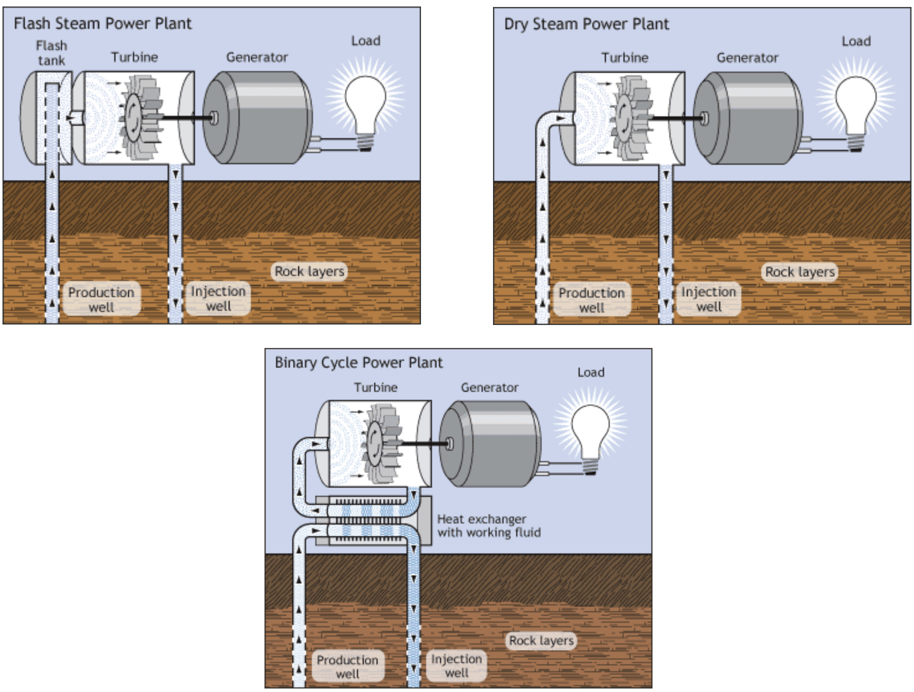

Figure 5: *Systems for generating electricity*

The latest technology is called EGS (Enhanced geothermal system).

2.3 Systems for generating heat and electricity from low enthalpy resources

Very recently major technological progress has been made and the possibility of generating heat and electricity from low enthalpy resources has now become a reality. In Fig. 6, it is shown that appropriate systems for using low enthalpy resources are the ORC and Kalina processes. Furthermore, some good results have been brought about with a new Stirling engine concept especially designed for geothermal resources.

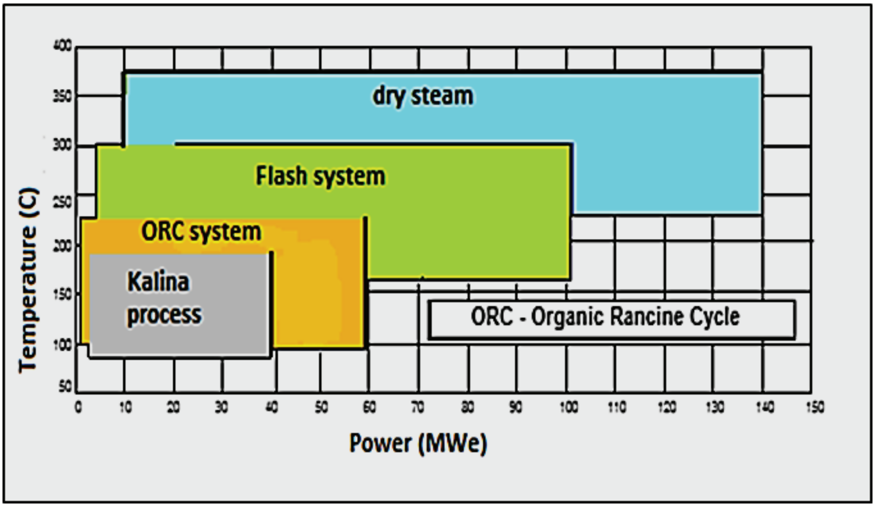

Figure 6: *Using of geothermal energy according to the temperature of geothermal resource, [5]*

2.3.1 Binary plants – ORC cycle

Generating electricity from low-to-medium temperature geothermal fluids and from the waste hot water coming from the separators in water-dominated geothermal fields has made considerable progress since improvements have been made in binary fluid technology. The *binary plants* utilize a secondary working fluid, usually an organic fluid (typically n-pentane) that has a low boiling point and high vapour pressure at low temperatures in comparison to steam. The secondary fluid (Freon, Isobutene, Isopentane, R-115, R-717, R-22, R 114, etc.) is operated through a conventional Rankine cycle (ORC), [1]; the geothermal fluid yields heat to the secondary fluid through heat exchangers, in which this fluid is heated and vaporises; the vapour produced drives a standard axial flow turbine, is then cooled and condensed, and the cycle begins again (Fig. 7). According to the latest research, binary plants can function even with temperature sources at 57°C (the temperature of the Mostec resource).

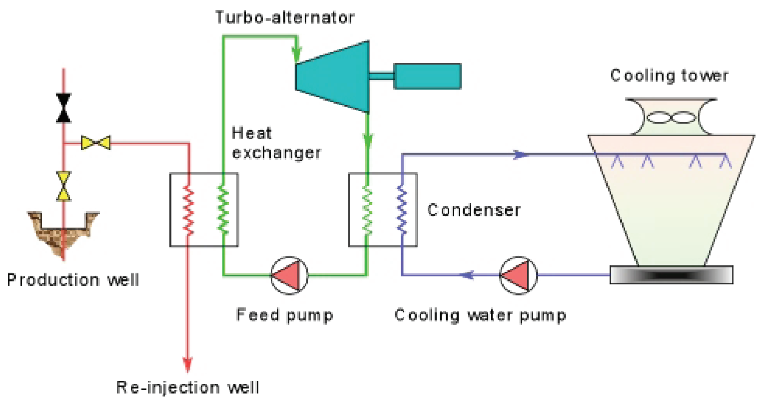

Figure 7: *Binary system, [1]*

Binary plants are usually constructed in small modular units of a few hundred kW_e to a few MW_e capacity. These units can then be linked up to create power-plants of a few tens of megawatts. Their cost depends on a number of factors, but particularly on the temperature of the geothermal fluid produced, which influences the size of the turbine, heat exchangers, and cooling system. The total size of the plant has little effect on the exact cost, as a series of standard modular units is joined together to obtain larger capacities.

2.3.2 Kalina process

A new binary system, the Kalina cycle, which utilizes a water-ammonia mixture as working fluid, was developed in the 1990s. The working fluid is expanded, in super-heated conditions, through the high-pressure turbine and then re-heated before entering the low-pressure turbine. After the second expansion, the saturated vapour moves through a recuperative boiler before being condensed in a water-cooled condenser. The Kalina cycle (Fig.8) is more efficient than existing geothermal ORC binary power plants, but is of a more complex design, [1].

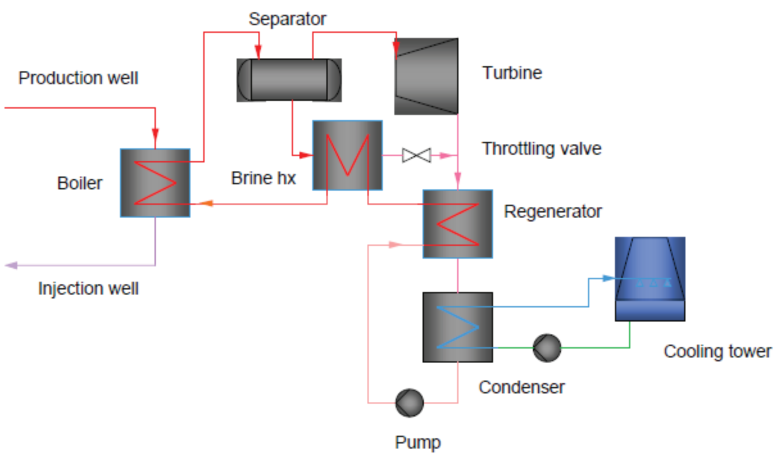

Figure 8: *Kalina process*

Small mobile plants, conventional or not, can not only reduce the risk inherent to drilling new wells, but, more importantly, they can help in meeting the energy requirements of isolated areas. The standard of living of many communities could be considerably improved were they able to draw on local sources of energy. Electricity could facilitate many apparently ordinary, but critical operations, such as pumping water for irrigation, freezing fruit and vegetables for longer conservation, etc.

Such ORC, including Kalina processes, still need temperatures of geothermal resources near the bowling point of water; at this moment, energy cannot be generated from lower temperatures of geothermal resources.

2.3.3 Stirling engine in geothermal energy

The low temperature potential of some geothermal reservoirs is their major disadvantage when it comes to power generation, since the abovementioned processes require reheated steam for their operation. Therefore, the Stirling cycle seems to be a better and more practical solution resulting in considerably higher efficiency, because it is thermodynamically equivalent to the optimum Carnot's cycle. The development of a Stirling engine with flat plate heat exchangers (Stirling-Kolin engine) has shown that the low temperature geothermal reservoirs may also be successfully used for the conversion of heat into mechanical work or electric energy. Hot water from the well circulates through a number of flat boxes connected with a crankshaft driven by a generator. After its heat is transferred to the plant, the cooled water is returned into the reservoir using an injection pump. Additionally, the geothermal plant using the Stirling cycle has considerable technical and economic advantages in comparison to the classic Clausius-Rankine process because there is no evaporator, condenser, feed water pump or numerous other associated elements [6].

All the thermodynamic processes for the conversion of heat into mechanical work, and in particular for the low temperature resources, are dependent upon the ambient temperature. Each heat engine works better during the winter than during the summer time.

The key feature of this engine design that would make it attractive to potential buyers is its ability to run on a variety of low grade heat sources that are potentially free; however, for it to be successful in the marketplace, it must be very cost competitive as an outright purchase. If a small version (1-4 kW output) was able to be produced cheap enough, then it could potentially find its way into applications such as off-grid domestic power generation [7].

3 CONCLUSIONS

Energy is becoming very expensive and also strategic, for each family budget, for each state, and for our currently united Europe. Its institutions and chambers have prescribed very detailed plans with actions due to energy saving and energy efficiency in all economic fields. According to the new regulations, buildings must have efficient heat envelopes, which is basic for using low-power generator. For this reason, a strong trend for the utilization of such generators has begun. An action plan called “Each J counts” has begun.

In an expert articlewritten by geologists, [8], it is was again concluded that theoretical possibilities for geothermal power plants in Slovenia exist but in order to start serious and detailed discussion about such plants, more research has to be done. Areas with geothermal energy have been very well researched, so new geothermal resources are not expected to be found.

For the research of geothermal resources, grants should be given to the laboratories, institutes, universes for the basic task of developing the above-described systems.

Organizing and demonstrating the latest technologies and experiences in using of low enthalpy geothermal resources is the next step forward. It should be followed by different types of ubsidies to increase the number of investors using small geothermal power plants. These plants in the first phase still have to be developed and tested and then placed into operation.

The Mostec geothermal resource is to be used for generating electricity. From the technical point of view, there is no problem, but economic questions regarding such a solution remain. How much the cost of electricity from such a resource would be cannot be exactly determined in advance. Naturally, the cost of electricity would be a key factor in any economic analysis and decisions for investment. Currently, Slovenia lacks investors for such an investment.

The progress of binary systems shall continue by developing new material and working fluids. The temperature of geothermal resources needed for first phase (i.e. for thermal water from for heating and vaporizing of secondary working fluid) would be lower. It could be expected that the possibilities for generating heat and electricity would be better, with temperatures from 80° C to 40° C or even less.

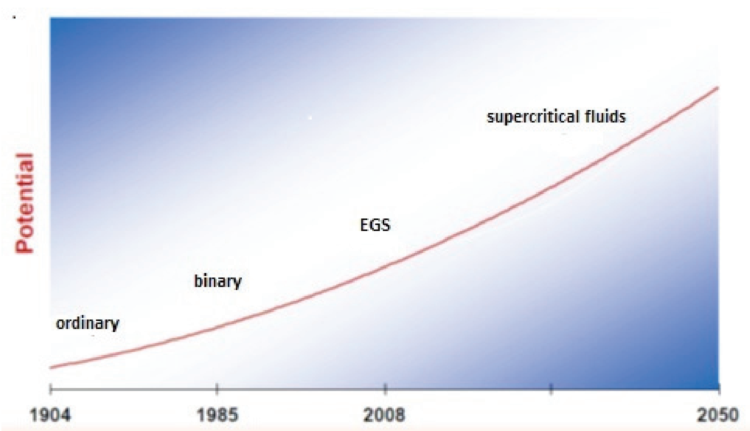

Figure 9: *Potential of geothermal energy*

The transformation of geothermal heat into mechanical or electrical work is generally discussed mostly for the relatively large scale of several thousands of kW. In contrast, the small range of power of a few kW is often neglected in the case of geothermal resources. Nevertheless, only one kW power could be quite sufficient to drive a circulation pump for a very large quantity of geothermal water in very different applications. Practical examples could be space heating, various technological processes using moderate temperatures, and other similar systems.

All these examples require a significant amount of heat, but relatively small pumps to circulate hot geothermal water. For the time being, low temperature difference Stirling motors, driven by hot water, are not available in large power units. However, due to the promising contemporary development of geothermal Stirling engines, ever-growing power units will most likely soon be available to cover increasing energy needs as well.

However, a new concept of Stirling motor is being developed that is able to use low temperature geothermal resources; it is currently entering production.

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