The Possibility of Large-Scale Geothermal Power Plants

By Fathali Ghahremani

Abstract

It is conceptually possible to extract one thousand megawatts of thermal power from a single geothermal site. This paper presents a new model to extract such energy by concentrating on heat mining without the requirement of using *in situ* (in-place) or injected fluids, thereby avoiding the problems inherent in the current paradigms.

Most current geothermal power plants are water/vapor driven and dependent on subterranean fluid reservoirs. These reservoirs are characterized by subterranean rock formations with enough fluid volume and pressure, adequate porosity and permeability, and sufficient temperature to allow viable energy extraction. These unalterable geologic conditions (heat, fluid content, pressure, porosity and permeability) seldom occur simultaneously, thereby restricting both the size and location of power plants. Enhanced Geothermal Systems (EGS) are a slight modification of these requirements. The permeability of the rock is increased by hydraulically fracturing – that is, shattering – the subterranean rock formation, thereby facilitating the flow of fluid through it. This allows for heat mining by circulating fluid between the surface and the hot dry rock (HDR). Similar to other vapor-driven systems, this method depends on direct fluid to rock contact. However, the EGS system does not require *in situ* fluids. The plant supplies the fluid necessary for heat transport.

A new model is proposed that is independent of the flow characteristics of the subterranean lithology. It concentrates on energy extraction, requiring only a high-temperature conductive rock formation. The technique does not need direct fluid to rock contact, thus avoiding the problems associated with hydraulic fracturing or chemical alteration of the formations. Since HDR formations are readily accessible and widely distributed, this method would allow the development of high megawatt geothermal plants.

Introduction

Energy consumption has been a determinant of human development and, in fact, may be the best measure of human activity.[1] It is a force multiplier that gives humans the tools necessary for modifying their environment, building their massive infrastructures and communicating over global distances. Its availability is the one requirement, *sine qua non,* without which all human civilization, as it is known today, would cease to exist.

The use of energy in ever-increasing amounts is no longer a luxury for the elite. It is an essential component for the continued development of the human population. This rapid population growth necessitates efficient utilization of existing sources and development of new ones.[2] The availability of concentrated and transportable forms of energy is required to assure the advancement of our technology-based society.

The basic sources of energy in the world are twofold: the radiant energy from the sun, solar; and the latent energy trapped in the earth, geothermal. The preponderance of our current paradigm is based on fossilized energy from the sun – solar energy that was trapped by photosynthesis in the earth's flora. Upon their death, plants formed the strata of coal,[3] while the bodies of animals that fed on them formed the reservoirs of petroleum. In today's world, 86 percent of available energy is from fossilized biological sources (coal, petroleum and natural gas).[4]

The biologically stored solar energy can only be released by combustion. Carbon dioxide (CO_2) molecules, transform into carbon products by photosynthesis and/or geological activity, and revert back to CO_2 when burned. Thus, the inevitable byproduct of biological energy sources, fossil or current, is CO_2, which is now considered a greenhouse gas.

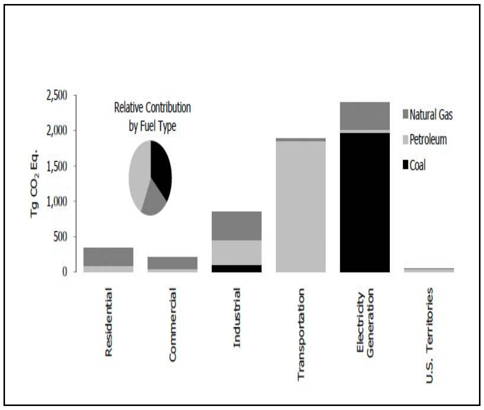
Other low CO_2-emitting sources are hydro, tide, wind, etc. The driving force of these natural phenomena is the sun; hence, they are solar based. However, they may pose other environmental problems – for example, a large geographic footprint, since they need large tracts of real estate to be effective.

The only non-solar-based sources of energy are nuclear and geothermal. These sources are part of the makeup of the planet and do not depend on inputs from the sun. It is interesting that, similar to fossil fuels, the most polluting of these sources, nuclear, is also the most developed. While non-polluting solar sources such as wind, photovoltaic, tide, etc. are developing rapidly, geothermal, also a non-polluting energy source, has attracted little interest.

Concept Background

The Energy Information Administration (EIA) reported total electric production to be just over four quadrillion watt-hours from fossil and all non-fossil sources in the United States.[5] Of this, about 72 percent – some three quadrillion watt-hours (2.98 billion megawatt hours) – was from fossil sources, i.e., coal, oil and natural gas. By comparison, only about 2.5 percent, about 0.1 quadrillion watt-hours, was from “other renewable” non-polluting electric generation, i.e., wind, solar, geothermal, biomass, etc. The balance, about one quadrillion watt-hours, was from nuclear and hydroelectric. It should be noted that as the U.S. moves toward a fleet consisting of hybrid and/or electric vehicles, recharging batteries would impose additional load on electric power generation facilities.

Figure 1[6]



2007 US CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Note: Electricity generation also includes emissions of less than 0.5 Tg CO_2 Eq. from geothermal-based electricity generation.

Tg (teragram) = 1,000,000,000 kilograms

An adverse consequence of this massive use of fossil fuels (Figure 1) is the release of 7.15 billion metric tons of CO_2 into the atmosphere annually.[7] The speed with which this enormous volume of pollutants is dumped into the atmosphere is beyond nature’s ability to act as a sink, accelerating the rate of global warming.

The general public is increasingly sensitive to energy usage and has become aware of the relation between fossil energy and pollution. Consequently, there is an increasing demand for non-fossil, less environmentally destructive energy sources. The demand for non-polluting energy requires a major shift in production and consumption of various fuels. It belittles the scope of the problem to assume that replacing fossil fuels will be easy. It is critical not to endanger the future of society by presenting the public with the false hope of a rapid, painless, and cheap move to new energy regimes.

Engineers and scientists have considered various energy schemes such as wind, solar (both solar thermal and photovoltaic), tide, etc. The question, however, remains: Can such “renewable sources” easily, cost-effectively, and rapidly replace fossil fuels? Engineers, when asked this question, consider the energy of the future to most probably be “wind, solar and other renewable energy” (Figure 2). Most engineers, apparently, did not consider geothermal energy a serious “renewable resource.”

Yet of all the renewable energy sources, geothermal has the highest capacity factor, is the most reliable, has the least environmental impact, and is the best source for electric generation (Table 1). The lack of interest on the part of a majority of engineers may be a reflection of the perception that geothermal sources are small or un-exploitable. In addition, it is known that most geothermal plants in the world are relatively small (in the range of tens rather than the hundreds of megawatts).[8]

Concept

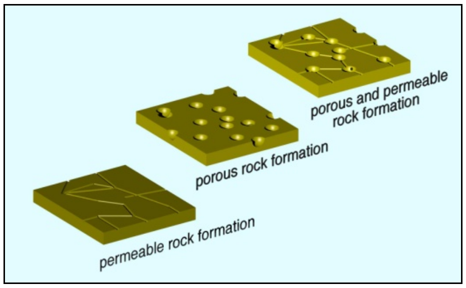
The miniscule role of geothermal generation in the overall national power paradigm can be attributed to its dependence on specific geological structures. The characteristics of these geologic structures can be summarized as follows:

1. A subterranean heat source at an accessible depth

2. A lithology above the heat source that has sufficient porosity and permeability (Figure 3) to allow fluid accumulation and flow

3. A rock structure with enough volume, pressure and temperature to force the useful fluids to the surface.[9]

Figure 3



The simultaneous occurrence of these geologic events is rare. Most of these sources are incapable of providing the energy to power large power plants, thus restricting the average size to 30 megawatts. Even the Geysers in California, the largest facility in the world with a rated output of about 1500 megawatts, is composed of 25 power plants, the largest being 113 and the smallest 20 megawatts.[10] These plants are distributed over an area of about 30 square miles.[11]

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Previously, geothermal reservoirs were identified with hot water sources. This is no longer the case since technology provides access to more varied sources. Geothermal systems are now classified into five basic categories:

1. vapor dominated
2. hot water
3. hot dry rock (HDR)
4. geo-pressured
5. magma[12]

Historically, "geo-pressured" and "magma" geothermal energy have been marginally exploited due to their complexity, geologically and technically. Geo-pressure systems pose the question of how and at what cost the reservoir pressure can be maintained. Magma sources because of its volcanic flows have major corrosion and stress problems.[13]

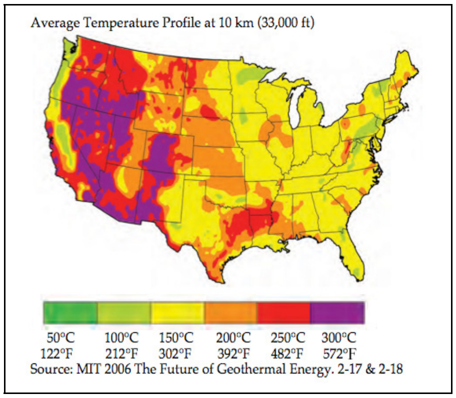
Current geothermal energy production has been centered on hydrothermal systems, i.e., "vapor-dominated" and "hot water."[14] These sources are the easiest to exploit, even if the confluence of previously mentioned geologic parameters are rare and limited in productivity.

A limit to hydrothermal systems is the need to re-inject fluid into the reservoir for volume and pressure maintenance. Generally, hydrothermal systems need one well to extract hot fluid – a production well – and another well (or wells) to re-inject the cold fluid – an injection well. This system of fluid circulation avoids the necessity for additional "make-up" fluids, but the injected fluid can cause chemical and physical damage to the reservoir. Such damage can reduce the effective life of geothermal wells.[15]

This dependence on the productivity of subterranean reservoirs has limited the size of geothermal plants. To date, only two large-scale geothermal plants exist: one in Larderello, Italy – approximately 900 megawatts – and the second at Geysers, California – about 1,000 megawatts.[16] Even these facilities are made up of multiple small plants, each less than 110 megawatts, spread out over a large area.

The third model, "hot-dry-rock" (HDR), is the most geologically extensive. HDR, as the name implies, is a hot dry formation, that is, no in situ fluid. These sources were defined as: "a completely impermeable homogeneous crystalline rock at a temperature that can provide useful amounts of energy" by the 1993 Congressional Report 93-377.[17] HDR formations (300°C - 572°F), at accessible depths of up to 35,000 feet, cover most of the Western United States (Figure 4).

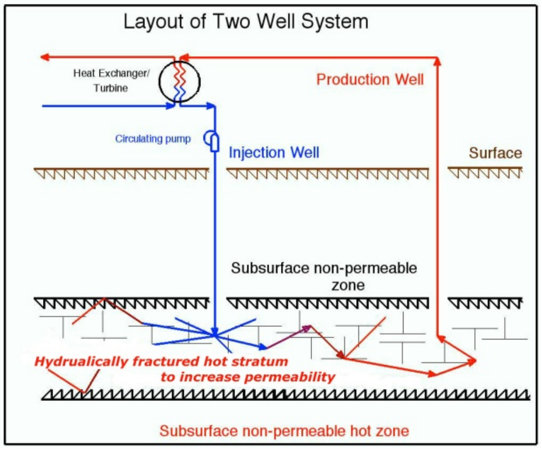
Figure 4[18]



Source: MIT 2006 The Future of Geothermal Energy. 2-17 & 2-18

These HDR strata are the targets of the Enhanced Geothermal System, EGS (also called Engineered Geothermal System) for energy extraction.[19] Most of these rock formations are considered "tight," i.e., impervious to fluid flow, and must be "enhanced" by hydraulically fracturing to increase their permeability (Figure 5).[20] Once the formation is shattered with hydraulic pressure, fluid can flow through the interconnected fractures, allowing heat extraction.

Figure 5

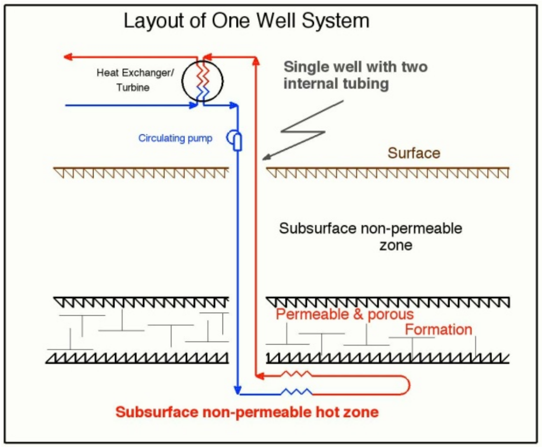


Hydraulic fracturing *can* cause earthquakes. The possibility of earthquakes is controversial. It was considered in Congressional Report 93-377, but the MIT report on EGS systems discounted the matter.[21] Subsequent reports suggest that heavy fracturing may cause local earthquakes. Earthquakes, supposedly induced by hydraulic fracturing, have raised concerns about two EGS projects (one in Basel, Switzerland[22] and another in Landau in der Pzalz, Germany[23]).

The need for "clean" energy means that geothermal resources, in spite of the technical difficulties, cannot be ignored. A possible new model that avoids some of the previously mentioned problems is shown in Figure 6. Here, heat extraction is independent of heat reservoir's lithology, fluid content, permeability, or porosity. In this scenario, high-pressure fluid is circulated between the surface and the HDR through a totally closed tube. The fluid, sealed from all direct contact, would acquire heat by conducting it from the hot sub-subterranean rock and releasing it to a working medium on the surface. Such a geothermal facility could produce 1,000 megawatts of thermal power plant and would have a physical footprint similar to an equivalent fossil fuel plant.

"The need for 'clean' energy means that geothermal resources, in spite of the technical difficulties, cannot be ignored."

Figure 6



Similar models have been presented; for example, Warren and Whitelaw in 1975 suggested a heat extraction method that was similar but required depths of 50,000 feet.[24] Also, Schulman and Whitelaw (Patent Numbers 5,515,679 dated 1996 and 6,247,313 dated 2001) presented a two-well system of heat mining, where the injection and the production wells were linked by an underground pipe.

The availability of shallow HDR is important for this model of heat mining. There are many sources available at depths of 6-8,000 ft at 300°C (572°F),[25] and even sources at the depth of 33,000 ft are highly accessible. This makes it unnecessary to drill to the depth of 50,000 feet suggested by Warren to obtain reasonable energy sources.

Furthermore, drilling technology, both directional and straight, has advanced considerably. Presently, the deepest well in the world is on the Kola Peninsula in Russia (40,233 ft deep).[26] The longest oil well is in Qatar (40,320 ft in length including a 35,770 ft horizontal section).[27] Thus, the technology for creating a single well with sufficient subsurface area for high volume heat extraction is available. However, it should be noted that the subterranean interconnection of two wells (as required by Schulman) has yet to be implemented.

Test program considerations

Once the test site has been selected, the availability of technical resources must be considered. Primary technical issues involve the drilling and completing the geothermal well and can be summarized below:

Drilling

1. The target rock formation need not have any *in situ* liquid but fluids may be encountered. High-density and non-permeable formations have better coefficients of heat transfer and are well suited to this model. Formation fluids that are encountered could pose significant problems for the drilling fluid, both in terms of dilution and potential toxic components.

2. Extended drilling in a hot zone will be required. The cooling of tens of megawatts of thermal energy will pose significant problems for the drilling rig and its operations. The equipment and drilling protocols must be modified for temperatures of 600°F. Drill bits and cooling systems capable of working in these conditions must be designed.

3. Drilling equipment must be modified to drill large diameter holes in hard rock formations. Such large holes will be necessary to provide the required surface area and flow rates.

4. Sealing the well casing into the formation will pose special problems. This is normally done with cement; however, most cement will fail at high temperatures. In order to assure adhesion to the formation, current cements must be modified for high temperature applications.

Completion

1. The conceptual design calls for a totally enclosed fluid circulation at high temperatures, pressures and flow rates. The well piping must be designed for the maximum physical and temperature stresses expected under these conditions.

2. Thermal expansion and contraction will impose stresses on the pipe that must be resolved with high pressure, high temperature expansion joints.

3. Tubing insulation in the bore-hole to minimize heat loss is critical. Insulation systems must be robust enough to withstand the abuse of being installed and removed from the casing. The stress imposed on the suspended insulation must be considered. Development of new types of insulation could be required.

This is a short list of issues that must be addressed. Others will arise during the testing. It is not foreseen that technical issues will be “game changers,” but the rewards for achieving a breakthrough in major geothermal energy production are significant.

Conclusion

The lack of development of geothermal resources has much to do with the two-well energy extraction model. This model consists of production and injection wells fluid linked by a subterranean rock formation. It is ill-suited for extracting large volumes of heat because of its dependence on subterranean lithology. The fluid flow between the injection and production well is totally dependent of the flow characteristics of subterranean rock formations. This limits the availability of sources as well as potential energy available for extraction.

While fracturing may enhance the permeability of the underground rock formations, there is no guarantee that these fractures will actually increase the flow between injection and production wells. Furthermore, there is a possibility that such fracturing could result in detrimental local earthquakes.

Furthermore, the intimate contact between the fluid and rock can cause problems. The contact inevitably results in the absorption of minerals, pollutants and particulate matter by the fluid complicating its treatment. The movement of dissolved material throughout the formation adversely affects the reservoir, reducing the functional life of the production and injection wells.

An alternate one-well system is proposed. In this paradigm, a fluid is circulated between the surface and the hot zone in a closed loop. The fluid, volume and pressure are entirely controlled from the surface thus assuring optimal heat recovery. Simple energy calculations indicate that there is high likelihood that up to 1,000 megawatts can be extracted with this method. Furthermore, unlike the two-well model, the fluid in this paradigm never makes contact with the formation, thereby avoiding any potential contamination.

This method depends on the development of equipment and techniques for high-temperature drilling – an engineering challenge. Yet, the viability of safely extracting large megawatts of thermal power from a high-temperature geothermal zone independent of the rock permeability and porosity makes this an attractive prospect. The earth’s energy is a 24/7, large-volume, pollution-free, zero-carbon-footprint energy source. It has the potential to replace fossil fuels for electricity generation in the United States and throughout the world.

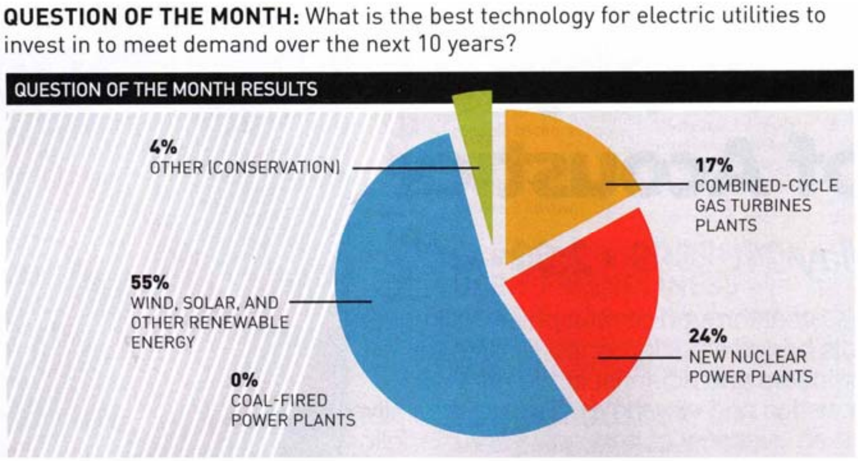
Fathali Ghahremani-Ghadjar holds a Bachelor's of Science in fluid mechanics from the University of Cincinnati. In addition he holds a Master's of Business Administration from the Iran Center for Management Studies. He is currently the president of Neurodynamics, Inc where he holds 10 patents and two patents pending. Fathali has also co-authored numerous articles for medical technically journals. Recently, Fathali has had an interest in renewable energy and wrote a Master's thesis on recovering geothermal energy.

Table 1[28]

Renewable Energy Sources	***Capacity Factor (%)***	***Reliability of Supply***	***Environmental Impact***	***Main Application***
Geothermal	85-95	Continuous & reliable	Minimal land usage	Electricity generation
Bio-mass	83	Reliable	Minimal (non-combustible material handling)	Transportation, heating
Hydro	30-35	Intermittent dependent on weather	Impacts due to dam construction	Electricity generation
Wind	25-40		Unsightly for large-scale generation	Electricity generation (limited)
Solar	24-33			

Note: Capacity Factor = Total Energy Produced/ Energy Produced at Full Capacity
Source: Geothermal Energy Organization

Figure 2[29]



QUESTION OF THE MONTH: What is the best technology for electric utilities to invest in to meet demand over the next 10 years?

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