Prospect of Enhanced Geothermal System in Baseload Power Generation

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***Abstract*—Given the strength of commodity prices in recent years, concerns over energy security and widening adoption of carbon emission pricing, renewables are well positioned to play growing role in global energy mix. Geothermal energy is on the face of it. By harnessing the heat of the earth, geothermal power plants tap into a virtually inexhaustible and continuous source of energy, using a small footprint facility to provide baseload electricity that is virtually CO2 and waste free. Geothermal projects today center on the exploitation of hydrothermal resources- reservoirs of naturally occurring water. This could change with Enhanced Geothermal System (EGS), a new form of geothermal exploitation being tested in areas that are not hydrothermal. This paper discusses the prospect of Enhanced (or Engineered) Geothermal System as a means to the baseload power generation. It also focuses on the technology behind creating engineered reservoirs, drilling costs and also the economics involved. It also reviews the environmental impacts as well as the areas for possible developments.**

Keywords- EGS; geothermal; baseload power

I. INTRODUCTION

Geothermal energy is the thermal energy stored in the earth's crust. Thermal energy in the earth's reservoir is stored between the constituent host rock and the natural fluid that is contained in its fractures and pores at temperatures above ambient levels. These are mostly water with varying amounts of salts and minerals dissolved in it. The traditional geothermal approach of energy production relies on finding these naturally occurring reservoirs of superheated steam and hot water. Local and regional geologic and tectonic phenomena play a major role in determining the location and quality of a particular traditional geothermal resource. These characteristics of the conventional geothermal approach have limited its use within specific regions where natural reservoirs are available. Enhanced Geothermal Systems (EGS) expands the potential of geothermal energy by orders of magnitude. EGS is also known as Engineered Geothermal Systems (EGS), Hot Dry Rock (HDR) etc. EGS technology does not depend upon naturally occurring reservoirs; in fact the reservoirs in this technology are enhanced or engineered. That is why it can be adapted in more locations than the conventional geothermal system.

II. THE EGS CONCEPT

The EGS concept is to extract heat by creating a subsurface fracture system in the hot constituent rock to which water can be added through injection wells. Rocks are permeable due to minute fractures and pore spaces between mineral grains. EGS are reservoirs created to improve the economics of resources without adequate water and permeability. A production-injection well is drilled into hot basement rock that has limited permeability and fluid content. Water is injected at sufficient pressure to ensure fracturing or open existing fractures within the developing reservoir and hot basement rock. Pumping of water is continued to extend these fractures to some distance from the injection well bore and throughout the developing reservoir and hot basement rock. A second production well is drilled with the intent to intersect the stimulated fracture system created in the previous step and circulate water to extract the heat from the previously dry rock mass. Additional production-injection wells are drilled to extract heat from large volumes of rock mass to meet power generation requirement. Since the only prerequisite of EGS is heat, it can theoretically be deployed anywhere there is rock hot enough to produce power. Additionally, since permeability is created by design, EGS systems can be developed in a modular fashion [1].

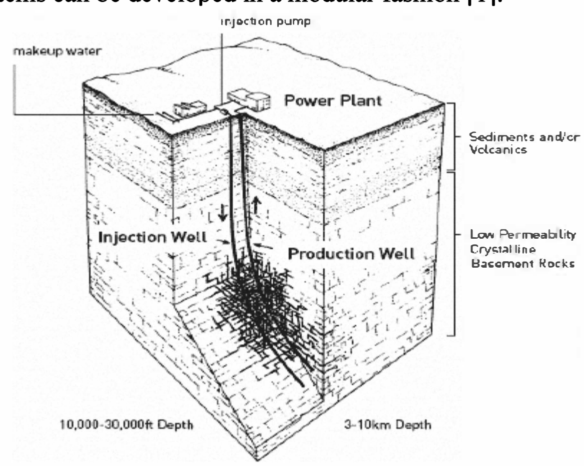

Figure 1. EGS Schematic Diagram.

III. EGS RESOURCE BASE

Geothermal energy is one of the few renewable energy sources which can be employed as baseload power generating source. The quality of a geothermal resource varies as a function of temperature with depth along with the natural porosity, permeability and/or connectivity of the rock that comprises it. Good locations are over deep granite covered by a thick (3-5 km) layer of insulating sediments

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which slow down the heat loss. A recent survey result from German energy Agency has shown that approximately 99.9% of the earth temperature is greater than 100ºC. A 2006 report by MIT on Enhanced Geothermal Systems (EGS) concluded that it would be affordable to generate 100 GW (Gigawatts of electricity) or more by 2050, just in the United States. The MIT report calculated the world's total EGS resources to be over 13 YJ(13,000 ZJ), of which over 200 ZJ would be extractable, with the potential to increase this to over 2 YJ with technology improvements - sufficient to provide all the world's energy needs for several millennia. The report further found that the "recoverable" resource (that accessible with today's technology) to be between 1.2–12.2 TW for the conservative and moderate recovery scenarios respectively [1] - [2].

IV. Energy Conversion Technology

Electric power is generated by using steam or a secondary working vapor to turn a turbine-generator set to produce electricity. A vapor dominated (dry steam) resource can be used directly, whereas a hot water resource needs to be flashed by reducing the pressure to produce steam. In the case of a low temperature resource, generally below 150°C, the use of a secondary low boiling point fluid (such as hydrocarbon or water-ammonia mixture) is required to generate the vapor. A total of 24 countries now generate electricity from geothermal resources; almost all of them employing the conventional hydrothermal resources. Total electric energy production is nearly 57,000 gigawatt-hours (GWh); with the introduction of EGS these figures are expected to rise by many folds. Experts estimate that up to 72 GWe world-wide could be produced with current (i.e. conventional geothermal) technology at known hydrothermal sites. With enhanced technology, these estimates increase to 138 GWe worldwide, which is a very much realistic possibility [2] - [3].

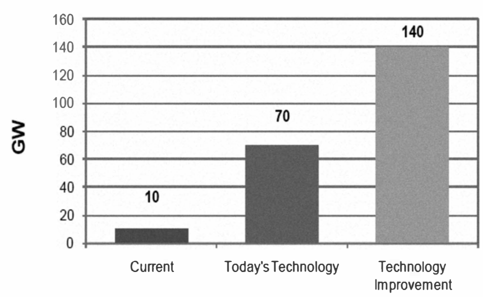

Figure 2. Energy extraction from geothermal reservoirs.

Conventional geothermal power plant techniques are available to cope with changing properties of the fluids derived from EGS reservoirs. If a mass flow rate of 20 kg/s can be sustained from a 200°C EGS reservoir, approximately 1 MW of power can be produced; the same power can be achieved from a 250°C EGS reservoir, with only about 8.5 kg/s. If supercritical fluids from an EGS reservoir can be used in a triple-expansion power plant, about 15 kg/s will yield about 10 MW of power with fluids at 400°C and pressures in the range of 25-27 MPa. Supercritical fluids from an EGS reservoir at very high pressures up to 35 MPa and 400°C can be used in a single-expansion power plant to generate 10 MW of power from flow rates of 21-30 kg/s, depending on the fluid pressure [3].

V. Drilling Technology And Costs

Enhanced geothermal system (EGS) reservoir performance is controlled by the interplay of a complex set of parameters: reservoir, geologic, drilling, well completion, plant design, and operation. To extract thermal energy, it is required to drill to depths where the rock temperatures are sufficiently high to justify investment in the heat-mining project. For generating electricity, this will normally mean drilling to rock temperatures in excess of 150°C to 400°C; for many space or process heating applications, much lower temperatures would be acceptable, such as 100°C to 150°C. Well costs occupy a significant portion of any geothermal project. Depending on the parameters like- well diameters and depths, drill-site specifics, bit life, penetration rate, casing design, geological conditions, stimulation approaches the cost vary for different cases. Using current drilling technology it is possible to pump from surface up to 3 km3 of fractured volume and extend fractures out over 800 m to circulate at more than 25 kg/s flow rates. In the year of 2006 MIT published "Future of geothermal energy", this used 'Wellcost Lite Model' for estimating statistically meaningful well costs at particular depths and also compared with the costs of similar wells in gas and oil industry. Wells in the depth ranges from 1,500 m (4,920ft) to 10,000 m (32,800 ft) were modeled in three categories: shallow wells (1,500-3,000 m), midrange wells (4,000-5,000 m), and deep wells (6,000-10,000 m). Well costs were estimated for depths from 1,500 m (4,900 ft) to 10,000 m (32,800ft). The drilling costs estimated by the "Wellcost Lite Model" are given in Table 1 [1] [5]. Emerging technologies like- changes in well design, drilling with casing, increase in rate of penetration (ROP), expanding the lifetime of drill bits can significantly reduce the cost associated with the drilling specially for depths more than 4000 meters (4 Km). The reduction can be as much as $2.5 million to $3 million per well. So the geothermal wells are more likely to be graced by the evolution of technologies more than the oil and gas wells. This indicates the competitiveness of geothermal resources with conventional baseload power resources.

TABLE I. Comparison of cost between EGS and Oil & Gas wells of various DEPTHS (in accordance with "Wellcost Lite Model" and previously drilled wells data)[1][2][4].

Well Depth m(ft)	Well Category	Estimated Cost EGS ($ millions)	Estimated Cost Oil & Gas Average ($ millions)
1500(4921)	Shallow well	2.303	0.9
2500(8202)		3.372	1.81
3000(9842)		4.022	2.55
4000(13123)	Mid range well	5.223	5.1
5000(16404)		6.740	6.45
6000(19685)	Deep well	9.172	8.92
7500(24606)		14.645	13.83

10000(32808)		19.731	Not available

VI. Economics And Sustainability

Renewable energy resources are increasingly gaining interest because it can help achieve the major societal goals of energy independence, greenhouse gas emission reduction, and meeting an ever increasing electrical load growth. Amongst all the renewable energy sources geothermal has got some distinct advantages over the other. Geothermal energy is one of the most reliable renewable baseload power sources. EGS plants have got high capacity factor, availability factor and leaves a smaller surface footprint. Thus have the potential to be sited closer to population centers, reducing the transmission and infrastructure costs. The significant cost associated with an EGS project are drilling cost (exploration drilling, development drilling, confirmation drilling), reservoir stimulation, power plant, transmission and other regulatory costs. Despite having significant amount of capital cost, EGS is receiving attention in the world stage because of its lower operation and maintenance cost, environmental cleanliness and relatively lower cost of the energy produced and in some cases it proves to be very competitive with other sources of energy.

The sustainability of a particular EGS resource is dependent upon the production rate, characteristics of the reservoir (size, temperature, depth etc.). Any "balanced" fluid/heat production (i.e. production does not exceed natural recharge) by a geothermal utilization scheme can be considered "fully" sustainable. A new and sustainable equilibrium condition can be established through "dynamic recovery", where natural recharge rate is increased by the pressure and temperature sinks created by production. But, production rates that exceed long-term recharge rate will eventually lead to reservoir depletion. Practical replenishment (e.g. 95% recovery) will be reached generally on a time-scale of the same order as the lifetime of geothermal production systems. The longevity of a certain EGS resource can be improved by having moderate production rates and having multiple wells [4] - [5].

Electric Power Research Institute review and comparison report of recent studies in various sectors of energy source reveals the true potential of enhanced geothermal system as a baseload power potential. Table 2 summarizes the reliability, cost and some of the constraints of some of most popular energy sources. For an energy source to be considered as a potential candidate for baseload power reliability is the most import issue. From table 2 it is vivid that most of the renewable energy sources don't have high reliability to be considered as a baseload power generating source. Although Biomass and Tidal energy have got high enough reliability but the cost of the production of electricity is quite high as compared to conventional fossil fuel sources and geothermal sources. Moreover the geothermal power generation requires minimal of operation and maintenance cost which makes it more attractive despite having high initial costs. It is very much evident from the table that the cost/MWh2 associated with conventional geothermal and enhanced geothermal (Hot Dry Rock) energies are comparable with the cost/MWh2 of the most popular fossil fuel and nuclear sources and in the case of conventional geothermal it far cheaper than the fossil fuels and nuclear energy [6]. Extensive R&D activities are ongoing all over the world to establish the EGS technology as one of the most popular, effective and clean baseload power source around the world.

TABLE II. Review and Comparison of Electricity Generating Sources [6]

Renewable type	Reliability	Cost $/MWh^2	Constraints
Biomass	High	80	CO_2 emissions. Distributed waste sources. Possible impact on food production.
Wind	Low, intermittent	70	Intermittency.
Photovoltaic	Medium-high, intermittent	180-220	High capital cost. Currently best suited to remote installations. Requires large land area.
Solar thermal concentration	Medium-high, intermittent	135-185	Potential large-scale energy source including hydrogen generation. Requires large land area.
Solar tower	Medium-high, intermittent		Very early stage of development. Probably resource and capital-intensive. Requires large land area.
Wave	Medium-high	50	Require relatively deep water close to shore. Desalination potential is a bonus.
Tidal	High, intermittent	410	Extreme tides are required. High capital cost & long time to build. Environmental impact. Potential for hydrogen generation.
Geothermal hot dry rock	High	50-60	Early stage of development. Technical (drilling) challenges. Potentially very large-scale energy source including hydrogen generation.
Geothermal aquifer	High	1.40-1.70	Exploration of sites, initial cost associated.
Coal	High	28-40	Severe environmental impacts due to green house gas emissions.
Clean coal (with carbon capture)	High	52-105	Potentially clean, high capital costs.
Gas	High	37-54	Large-scale energy source, although cheap but limited. Environmental impacts due to green house gas emissions
Gas (with carbon capture)	High	52-94	Potentially clean large-scale energy source but capital cost is high.

Nuclear	High	40-65	Potentially very large-scale energy source but can be hazardous if the radioactive wastes are not disposed properly.

VII. Environmental Impacts

The overall impact of EGS plants on environment is remarkably lower than other conventional fossil fuel-fired and nuclear power plants. In addition, EGS plants may have lower impacts in comparison with other renewable energy sources such as solar, biomass and solar photovoltaic on an equivalent energy-output basis. This is primarily because a geothermal energy source is contained underground and need not to be exposed in the atmosphere and the surface energy conversion equipment is relatively compact, making the overall footprint of the entire system small. EGS power plants also provide environmental benefits by having minimal greenhouse gas and other emissions. Unlike the conventional fossil fuels, there are minimal discharges of carbon dioxide (CO_2), nitrogen or sulphur oxides or particulate matter resulting from its use, and there is no need to dispose radioactive materials. Conventional coal-powered plants have the highest greenhouse gas emissions of all power generation technologies which compares emissions on a life-cycle basis. Worldwide, coal generates about twice the CO_2 emissions of gas, despite having a similar share in the world energy supply. World average emissions are 919 and 389 grams per kWh of electricity and heat production from coal and gas, respectively. 'Clean coal' technologies promise to substantially decrease the level of greenhouse gas emissions, but resultant levels would still be about 10 to 100 times higher than for renewable sources[8] - [9]. Figure 3 shows a comparison of greenhouse gas emissions from fossil fuel and renewable energy sources. The emissions from renewable energy power generation depend on the source of energy used in its production and operation [9] – [11]. However, still there are impacts that must be considered and managed if enhanced geothermal energy resource is to be developed as part of a more environmentally sound, sustainable energy portfolio for the future. The major environmental issues for EGS are associated with ground-water use and contamination, with related concerns about induced seismicity or subsidence as a result of water injection and production. Issues of noise, safety and land use associated with drilling and production operations are also important but fully manageable.

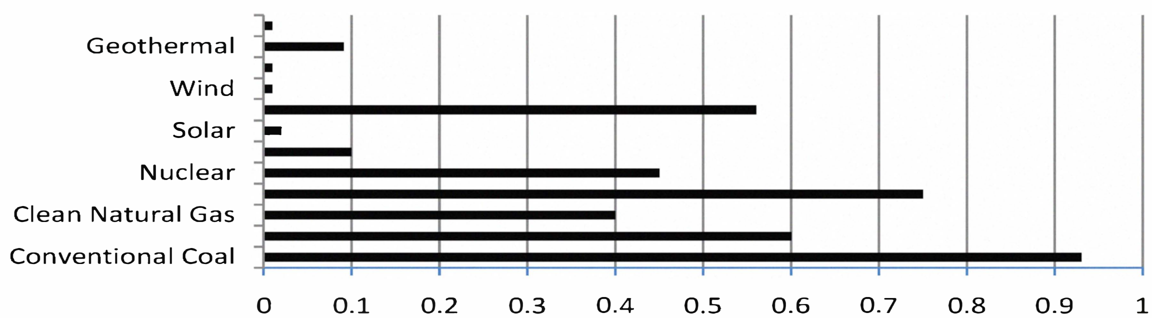

Figure 3. Greenhouse gas emissions from various energy sources [8] [12] [13].

VIII. Barriers To Overcome

- Development of drilling technology that would yield low cost of drilling wells. Hence the capital cost for EGS plants would reduce.
- Develop high temperature instrumentation to better evaluate fractures prior to stimulation (discriminate between open and sealed fractures).
- The main technical barriers to EGS are increasing flow rates and sustaining high heat flows within the engineered reservoir for sustained periods of time.

IX. Projects Around The World

There are around 24 countries using geothermal energy to produce electricity. Prominent names are USA, Philippines, Mexico, Indonesia, Italy, Japan, New Zealand, Iceland, Costa Rica, Kenya, El Salvador, Nicaragua, Guatemala, Turkey and France. Among them USA has the highest production of 17917 GWh/year [12]. Countries like Philippines with 18.8%, Iceland 17.5% and El Salvador 22% having the most prominent percentage of geothermal power in their total energy production. This clearly demonstrates how significant the role of geothermal energy can be in the electricity production. There are EGS systems currently being developed and tested in France, Australia, Japan, Germany, USA and Switzerland. There are several EGS projects that are already or will soon produce power. Some of them are for commercial purpose and some are just for research and development. Table 3 summarizes some of the EGS projects around the world with their capacity, type well depth, plant type, location and purpose of the project.

X. Conclusion

Geothermal energy offers compelling prospect of baseload power generation that operates continuously regardless of weather conditions, negligible fuel costs and greenhouse gas emissions. Considering the reliability and sustainability issues, geothermal energy is preferable over other forms of renewable energy and as it is cleaner, it has also got an edge over the conventional fossil fuel fired power generating technologies. It has the potential to help insulate energy consumers from future rises in the fossil fuel prices and provide energy security in the future. With the impending commercialization of Enhanced Geothermal System (EGS), geothermal energy could be harnessed everywhere in the world and no longer be limited to a few selected areas. Works to overcome both technical and non-technical barriers associated with EGS are being conducted all over the world with USA, Australia and some of the European countries (France, Germany,) are in the forefront. If it is possible to maintain the cost of the energy produced from EGS within a certain level, it can be a viable means for baseload power generation for the years to come.

TABLE III. Projects around the world based on enhanced geothermal system [10] [11]

Project	Type	Country	Capacity (MW)	Plant Type	Depth (km)
Soultz (EU)	R&D	France	1.5	Binary	4.2
Desert Peak	R&D	United States	11–50	Binary	(Unknown)
Landau	Commercial	Germany(EU)	3	Binary	3.3
Paralana (Phase 1)	Commercial	Australia	7–30	Binary	4.1
Cooper Basin	Commercial	Australia	250–500	Kalina	4.3
The Geysers	Demonstration	United States	(Unknown)	Flash	3.5 – 3.8
Ogachi	R&D	Japan	(Unknown)	Flash	1.0 – 1.1
United Downs, Redruth	Commercial	United Kingdom	10 MW	Binary	4.5
Eden Project	Commercial	United Kingdom	3 MW	Binary	3–4

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