WHAT DOES THE FUTURE HOLD FOR GEOTHERMAL ENERGY?

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ABSTRACT

The past five years have brought considerable changes to geothermal development. Historically high oil prices since 2005 have focused attention on renewable energy, supported by a global ambition to address greenhouse gas reduction. Geothermal developments have accelerated in many parts of the world, both in countries (such as New Zealand, Indonesia and the US) that have a traditional interest in "conventional" geothermal resources, as well as countries without a historical interest in geothermal energy (such as Australia and Germany). Some new developments have followed well-worn paths using conventional hydrothermal resources in volcanic regions, while others have struck out in new directions in Enhanced Geothermal System (EGS) projects in nonvolcanic regions. Technology has allowed for developments of conventional resources with lower temperature, restricted water access, and constrained surface utilization. EGS projects have launched in a variety of different directions and places (the US currently has six active EGS developments).

In this context, the future expansion of geothermal developments depends on exploring for new fields and overcoming technical challenges in known but not-yet-exploited fields. Two issues that are currently being addressed by the world geothermal community are: (1) the "productivity gap" in the exploitation of fields that are too hot for downhole pumps, but too cool for flash production, (2) the development of reliable EGS development procedures that can ensure sustainable flow rates and assure the public that induced seismicity will not be a problem.

1. INTRODUCTION

The past five years have represented a boom time for geothermal energy development in the world, with substantial interest and activity in many countries. As an example, the resurgence of interest in geothermal energy is evident in Figure 1, from the Geothermal Energy Association (GEA) April 2011 Annual U.S. Geothermal Power Production and Development Report. Although slowed somewhat by the financial crisis of 2008-2009, installed capacity in the USA rose steadily during this period.

Furthermore, it is clear that this new development was not merely "sweeping up the crumbs" – projects that had been set aside for later years before – as Figure 2 shows, there is a large number of projects under development in areas that are classified as "unproduced". These are defined by GEA (2011) as:

> *"Conventional Hydrothermal (Un-produced Resource): the development of a geothermal resource where levels of geothermal reservoir temperature and reservoir flow capacity are naturally sufficient to produce electricity and where development of the geothermal reservoir has not previously occurred to the extent that it supported the operation of geothermal power plant(s)."*

So the 111 projects in conventional/unproduced resources represent exploration and development in new areas not currently under production.

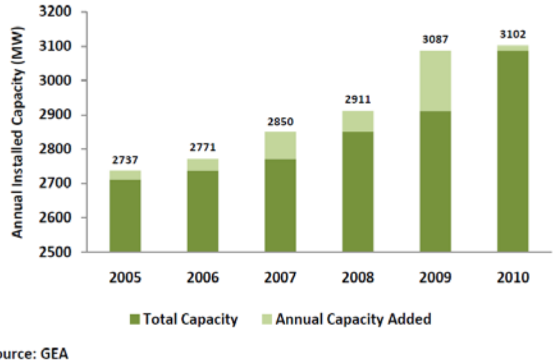

Figure 1: Installed capacity in the USA, 2005-2010, from GEA, April 2011.

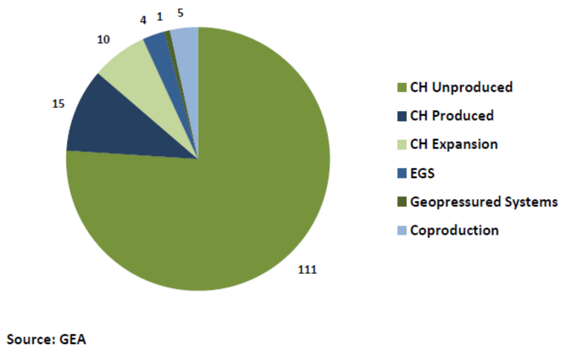

Figure 2: A total of 146 projects under development in the USA, and their category (CH = conventional hydrothermal), from GEA, April 2011.

Similar expansions have been seen in many other countries, with a total increase of installed capacity worldwide of 1782 MWe (from 8933 to 10,715 MWe) between 2005 and 2010 (Bertani, 2010). Figure 3, from Bertani (2010), shows the increase in installed capacity and produced electricity from 1950 to 2010, with a projection to 2015. Although the 2015 figure of 18,500 MWe is a projection only, the number of projects under development (as shown for example in Figure 2) leads credence to the number. It should also be noted that historically high oil prices in the early 1980s also stimulated a substantial expansion of geothermal capacity.

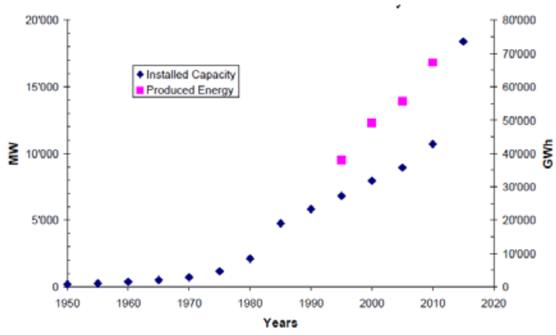

Figure 3: World geothermal electricity, installed capacity (MW) and produced electricity (GWh), 2005-2010, from Bertani (2010).

This renewed interest is the result world economic and political forces (mainly increased oil price and moral preference for renewable energy) combined with advances in technology that make geothermal energy more accessible (for example, power plant efficiency increases and utilization of lower temperature fluids).

Innovations in utilization technologies have included:

1. Increasing use of innovative power plants, often by marrying flash plants with binary bottoming cycles. The result is an increased recovery of the thermal energy in the resource.

2. Use of fluids of lower temperature, with refined binary cycle power plants. The result is a wider availability of producible resources. A noteworthy example is the 250 kW organic Rankine cycle plant in Chena Hot Springs, Alaska, which produces electricity from a very low temperature (74°C) geothermal resource (Lund et al., 2010).

3. Reservoir enhancement techniques. The world has seen the first commercial Enhanced Geothermal System (EGS) plant at Landau, Germany, started in 2008 (Schellschmidt et al., 2010). Multiple EGS projects are now under development in the world, including six in the US alone.

This paper will discuss these three issues, as a path to understanding where they may take the geothermal energy industry in the future.

2. INNOVATIVE PLANTS

For many years, geothermal power plants had a degree of uniformity based on the adoption of strategies that had worked in the small number of flash plants in early developments. Based on experience at The Geysers, in the US the 55 MW plant came to be accepted as "normal" in size. Apparently this was often found to be a comfortably sized unit in many other parts of the world too. Based on reservoir temperatures common at the time, turbine inlet pressures tended to be in the vicinity of 600 kPa.

However in the more recent past, considerably wider variation in the design strategy of the plant has been seen. A good example is the combined cycle plant at Rotokawa in New Zealand (Figure 4), which was one of the first developments built with a binary bottoming cycles supplied from the exhaust of a steam flash plant. This plant combines a back pressure steam turbine with a very high inlet pressure (2550 kPa) with three binary plants into which the exit steam is sent (Legmann and Sullivan, 2003). This combined cycle unit has a steam consumption of around 5 kg/kWhr, which is very favorable compared to steam consumption at The Geysers of about 8 kg/kWhr (computed from data shown in Sanyal and Enedy, 2011) or around 9 kg/kWhr at Ahuachapán, El Salvador (Handal et al., 2007).

Combinations of binary and flash plants are now found in several other projects too.

Figure 4: Rotokawa geothermal plant, a combined cycle flash-steam/binary station (photo: Mighty River Power).

The innovation already extends beyond the combination of different geothermal generation technologies. The past few years has seen an interest in the combination of geothermal generation with other sources, for example the combined geothermal-solar operation at Ahuachapán, El Salvador (Handal et al., 2007, and Alvarenga et al., 2008), and one announced in August 2011 by ENEL Green Power for the Stillwater project in Nevada (see also Greenhut et al., 2010). The combination of geothermal with solar thermal energy provides an opportunity to raise source fluid temperatures and even out the intermittency in insolation.

In the future, energy combinations, such as the electricity and hot water supply projects common in Iceland, will certainly continue the innovation.

3. LOWER RESOURCE TEMPERATURES

The increasingly common use of binary power plants has expanded the range of geothermal resource temperatures from which electricity can be generated usefully. Although not yet common, there are specific examples of isolated electrical loads such as at Chena Hot Springs, Alaska, shown in Figure 5, which produces electricity from a very low temperature (74°C) geothermal resource (Lund et al., 2010). Chena Hot Springs is more than 100 km from the closest electrical transmission line, so would otherwise be dependent on diesel-fuelled generation. In fact, there are many off-grid communities in the state of Alaska that could benefit from geothermal electricity generation in place of diesel fuel that is supplied at extremely high cost due to their remoteness. Similar advantages are to be gained in island communities such as in the Caribbean (Huttrer, 2010). Figure 6 shows an active drilling program at Akutan Island in the Aleutian chain of Alaska (Kolker and Mann, 2011).

Figure 5: Binary power plant at Chena Hot Springs, Alaska. Photo: Roland Horne, 2007.

Figure 6: Drilling at Akutan, Alaska, from Kolker and Mann (2011). Photo: Amanda Kolker, 2010.

As electricity production from lower temperatures becomes more feasible, another intriguing possibility is the recovery of geothermal energy from coproduced fluids, for example those brought to the surface with oilfield water. Pilot projects are already in operation in Wyoming (Johnson and Walker, 2010) and Huabei, China (Gong et al., 2011). Figure 7, from Johnson and Walker (2010) shows the organic Rankine cycle plant in Wyoming, which has been in operation since September 2008. The worldwide oil industry produces as much as 300 million barrels of water per day (540,000 kg/sec) and in many places the temperatures are within the range of operational geothermal power plants. Oil field operations are often also substantial consumers of electrical power, so the generation of electricity local to the operation is of particular benefit.

Figure 7: Binary plant recovering heat from coproduced oilfield water at Rocky Mountain Oilfield Testing Center RMOTC in Wyoming, Johnson and Walker (2010).

The importance of resource temperature is somewhat more complex than appears at first glance. Although in simple terms it is true that hotter is better, there remains a "hole" in resource accessibility, due to the fact that self-flowing wells drop substantially in productivity at temperatures below a certain range, while downhole pumps are only effective up to a specific temperature range. This was described very succinctly by Sanyal et al., (2007), who illustrate the "hole" in a figure repeated here as Figure 8. As shown in the figure, there is a gap that lies roughly between 190 and 220°C, within which neither pumped nor self-flowing wells are completely effective.

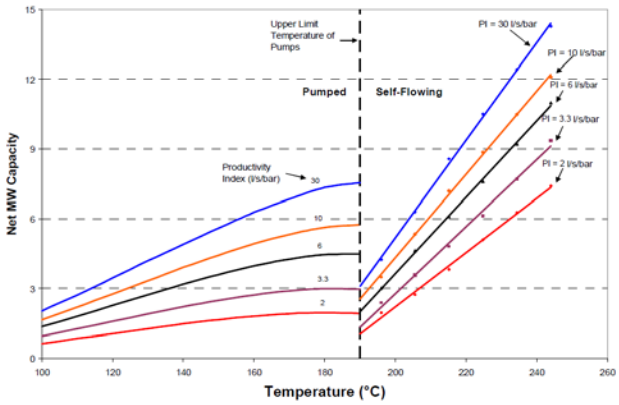

Figure 8: Net MW capacity of a geothermal well as a function of temperature, from Sanyal et al. (2007).

This resource temperature gap represents a technological challenge that is in the process of being addressed by the geothermal industry.

4. ENHANCED GEOTHERMAL SYSTEMS

Although new conventional geothermal reservoirs are being both discovered and exploited, the fact remains that the likelihood of major conventional resource discoveries is diminished. The world is not likely to find another resource like The Geysers. So the prospect for major expansion of geothermal development lies in Enhanced Geothermal Systems (EGS).

The "MIT Report" of Tester et al. (2007) undertook an extensive study of the promise of EGS for the USA, and this document proved very influential in swaying political and investment favor towards EGS. In the four years that have followed, at least six EGS projects have been initiated in the US, as well as several in other countries. Although some may choose to argue about the definition of EGS, by the definition of many the first commercial EGS development has been in operation at Landau in Germany since 2008 (Schellschmidt et al., 2010).

The successful stimulation of hot rock has been achieved in many "research" EGS projects dating back to the Fenton Hill, New Mexico, project in the 1970s. However it is only as the number of projects has grown that a more routine understanding of their creation and management has expanded.

In August 2011, Doone Wyborne presented a summary of experiences in EGS stimulations, providing a very useful side-by-side comparison of EGS projects in different environments. Some of Wyborne's tables are reproduced here, with permission.

Table 1 reproduces Wyborne's summary of projects that reported both successful stimulation and production. Table 2 reproduces his summary of stimulation projects that did not have production (or which did not report having production).

Table 1: EGS projects with successful stimulation and production, from Doone Wyborne (August 2011).

Project	Years	Rock type	Depth (m)	Production Temperature (°C)	Production (l/s)
Fenton Hill, New Mexico	72-96	granodiorite	3,600	191	13
Rosemanowes UK	78-91	granite	2,200	70	16
Le Mayet, France	84-94	granite	800	22	5.2
Hijiori, Japan	85-02	tonalite	2,200	180	12.8
Soultz, France	87-95	granite	3,800	135	21
Soultz	96-present	granite	5,000	155	25
Landau, Germany	05 - present	granite/faults	2,600	160	76
Habanero, South Aust	03-present	granite	4,250	212	30

Table 2: EGS projects with successful stimulation (no production reported), from Doone Wyborne (August 2011).

Project	Years	Rock type	Depth	Temperature of reservoir
Falkenberg Germany	78-85	granite	250	13
Hachimantai, Japan	83-88	granodiorite	400	60
Fjalbacka, Sweden	84-89	granite	500	15
Ogachi, Japan	89-01	tonalite	1000	250
Basel, Switzerland		Granite	4500	180
Bad Urach, Germany	06-08	Granite gneiss	4500	180
Jolokia 1	09-10	granite	4500	265

Doone Wyborn also compared projects in granite to projects in other kinds of rocks (generally either sandstone or volcanics). In general the experiences of granite EGS stimulations (which have been the most common) differ from fracture stimulation in sandstones and volcanic tuffs.

The stimulation at Groß Schönebeck in Germany, reported by Zimmermann et al. (2008) was an especially interesting one in that the fracturing involved distinct and independent injections into one formation that was sandstone and another that was volcanic. In this case the stimulation treatment was a propped fracture, presumably tensile, unlike the unpropped, slip fractures generally created in granite. Zimmermann et al. (2010) summarized the results, including that of a subsequent acidization treatment. Well productivity index was increased from 2.4 m^3/(hr.MPa) before stimulation to 10.1 m^3/(hr.MPa) by hydraulic fracturing, and to around 15 m^3/(hr.MPa) by acidization (Zimmermann et al., 2010, quote this later number as tentative). Following the stimulation, the flow rate was around 16 kg/sec.

A hydraulic stimulation at Berlin, El Salvador, was into volcanic rocks (not granite) and has been described by Rivas and Torres (2003). Injectivity was improved only modestly, from 0.67 to 0.84 kg/(sec.bar) (0.24 to 0.30 m^3/(hr.MPa)). Microseismicity was observed, but was not major..

Doone Wyborn associated permeability enhancement with the generation of microseismic events due to slipping fractures in granite. Overall, the collective experience he described suggests that microseismic activity has been an indicator of successful stimulation.

Although EGS developments continue to show promise, there remain several technological advances to be made. The MIT Report (Tester et al., 2007) made projections of EGS penetration into the US energy mix, based among other things on a flow rate per well of around 80 kg/sec (l/s). An examination of Table 1 shows that only one EGS project (Landau) has achieved such a flow rate. Improvement of well production rates will be dependent of making more connections in the reservoir, by better control of the fracturing process, for example by use of diverting agents to produce multiple fractures (Petty et al., 2011).. Such efforts are ongoing.

CONCLUSION

Geothermal energy has undergone a renaissance over the past ten years, as many new technologies and new countries have joined the industry. The use of innovative hybrid plants, lower resource temperatures and enhanced reservoir stimulation has made geothermal energy accessible in a much wider variety of places.

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