The Future of Geothermal Energy: The Shale Gas Analogy
Significant Electrical EGS Resource Areas in the US

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ABSTRACT

The geothermal industry has been referred to as “mature” because of the length of time the industry has been producing electricity and the level of technology involved in projects. The same could have been stated about the oil and gas industry in the early 2000’s. Yet both industries are continuously trying to advance through research involving resource understanding, technology advances, and technique development. The shale gas play is an outcome of this advancement by the oil and gas industry, taking approximately 20 years to reach the current level of intensive and successful development characterized by using uniform techniques and standards applied to broad areas of similar resource types. In the geothermal industry Enhanced Geothermal Systems (EGS) have been conceptualized for over 40 years and are now starting the initial development phase in a few sites worldwide. Geothermal Energy could follow a track analogous to the oil and gas industry and reach large scale development in 20 years if it learns from the shale play process and addresses the key factors that will enable it to succeed on a large scale. The factors are related to identifying and characterizing the large-scale thermal resources in the upper 3 to 4 km and developing the ability to access the heat-in-place. Accessing the heat in place includes a grid to transport the energy to market and a supply of water. For near-term successful research and development these crucial factors must be maximized. This paper addresses the locations where EGS research and development activities might be optimal over the near term to facilitate development over the longer term.

Introduction

Until there is government/industry policy that recognizes the need to prioritize areas of research and development based on the key factors, development of EGS will lag behind expectations. Therefore this paper is an effort to focus discussion on the optimization of EGS development.

The fundamental keys to the success of large-scale geothermal development are simple, lower the cost of power and maximize the resource accessibility. Enhanced Geothermal Systems (EGS) have the possibility of incorporating both of these keys to success. However, thus far implementation of appropriate research and technology enhancements has been difficult to achieve. To become viable, EGS development must operate on a large scale.

Figure 1. Well locations and tracks in the Barnett Shale development area north and west of Cleburne, Texas (outlined by highway 67). From Texas Railroad Commission website 2010. A well pad is a pentagon and a well terminus is a small blue circle or a red star.
analagous to the shale gas revolution of the oil and gas industry. In the case of shale gas, the two factors that have led to the large-scale development are reproducibility and access. More specifically, the key factors include: areas of basin wide development, uniformity of resource characteristics, development of technology (horizontal drilling and stage fracturing), and pipelines. Currently, in the horizontal tight/shale gas and oil plays, the development is on the order of 50% or more of the subsurface area, but utilizes a much smaller percentage of the surface area (Figure 1). In the case of geothermal resources capable of EGS development, the key factors are similar. The projects need large areas with uniformity in accessible heat, favorable geology (rock type, structure, stress), and water supply. Like the pipelines for shale gas, geothermal projects need access to transmission lines to electrical use areas. As the shale gas plays exponentially expand into favorable areas across the county, it is time for the geothermal industry to learn from their success.

Initially EGS development will be confined to areas of high temperature (about 200+°C at 3 to 4 km) in areas with water, and with access to transmission. Geology and/or stress regime may or may not be major factors. By focusing on a set of areas that satisfy these conditions research can be concentrated into the most productive directions for rapid deployment. This discussion focuses on areas with enough deep well temperature data (at least 2 km or more) to document the existence of high temperature in the depth range of 3 to 4 km. The areas to be discussed are outlined on Figure 2. The remainder of the areas on the map in Figure 2 are either cooler or do not have sufficient data to prove high temperature at what might presently be considered drillable depths. The set of regional (large) areas that satisfy these criteria on the basis of present data are the Cascade Range of the Pacific Northwest, the Snake River Plain in Idaho, and the Northern Louisiana area. Smaller but regional areas (such as the Raton Basin in Colorado), and individual basins in the Basin and Range Province (e.g. Allis et al., 2012) are also areas to be considered. This paper will briefly discuss these areas emphasizing their favorability characteristics for large scale nontraditional geothermal development. The Gulf Coast Geopressure zone is shown but not discussed. Large scale development is also possible with geopressed geothermal systems, but they are not the topic of this paper as the price of gas and thus the reduced wholesale price of electrical power is the primary limitation on geopressure development at the present time.

Excluded from discussion are small areas such as the periphery of hydrothermal systems. Although research so far has focused on these types of areas their potential for large scale development is not significant and there are structural problems with their development such as water limits in the arid Great Basin and the lack of interest by the Nevada utility to purchase geothermal electricity in the near term.

**Figure 2.** Heat flow for the central and western US. Regional areas of the conterminous US favorable for near term large scale EGS electrical production are outlined and identified.

**Figure 3.** Oregon Cascade Range Thermal Anomaly and thermal data sites. Stratovolcanoes are shown by asterisks (MH is Hood, MJ is Jefferson, NS and SS are Sisters and CL is Crater Lake). Area discussed in the text is outlined by the blue box. Contours are measured heat flow values in mW/m² (after Blackwell et al., 1990; based on USDOE support of ODOGAMI). Area in red has heat flow greater than 100 mWm².
Regional Descriptions

Cascade Range

The Cascade Range in the Pacific Northwest is probably the premier EGS resource in the conterminous US (Figures 3 and 4). There are several reasons for this prime position. The first reason is that the required drilling depths to reach 200°C temperatures are modest and apparently quite uniform (2.5 to 3.5 km on a regional basis and even less in some places such as on the western flank of the Newberry Volcano). The second factor is accessibility because much of the area is private land or areas in national forests that have been heavily logged, so road access is relatively good and cultural difficulties a minimum. A third advantage to developing the geothermal potential of the Cascade Range is that the curtailment of hydropower from the NW region to California means that geothermal power generated in the Cascades can be transmitted throughout a large part of the western US via existing power line capacity. Finally, the availability of water is less of a critical factor than in most of the other regions of the US.

A heat flow map of the northern Oregon portion of the Western and High Cascade Range is shown in Figure 3 and a cross section is shown in Figure 4 (after Blackwell et al., 1982, 1990a). The prospective area of the Oregon Cascade Range is shown in red. This area has a minimum heat flow of 90 mW/m² and a minimum shallow gradient of about 60 °C/km (Figure 4) due to the presence of a regional heat source at a depth of 10 km and about 60 km wide centered on the axis of the High Cascade Range (Figure 5). As a result minimum projected regional temperatures or about 190°C at 3 km over this large area. The western side of the high heat flow and the geographic boundary with the Western Cascade Range are defined by thermal gradient wells, and intermediate and deep drilling. Availability of subsurface data is sparse in the central part of the High Cascades (much of which is classified as federal Wilderness areas) and along the eastern side except for Newberry Volcano where major hydrothermal and EGS projects are taking place (Waibel et al., 2012; Cladouhos et al., 2011). A well drilled east of Crater Lake National Park had a temperature of over 100°C at ~500 m. So, based on the limited data and the presence of similar to more favorable geological conditions all of the area outlined in red has very high temperatures (175 to 300°C) at a depth of 3 to 3.5 km.

Within the area outlined by the blue box in Figure 3, a well documented thermal area of about 12,000 km² is available for development that is not in designated wilderness areas. The distribution of land ownership in the area of high temperature is about 50% National Forest, 30% private, and 20% National Forest-Wilderness. So overall, the potential accessibility to the high grade resource area is about 80%. The total area encompassed in the northern ½ of the Oregon Cascades is about 15,000 km². If 40% of the area outlined could be developed at 25 MW/km² (Tester et al., 2006, Beardsmore et al., 2010) then the electrical power potential could be on the order of 150 GW in northern Oregon alone. Note that this estimate is for development of only 40% of the area of the thermal anomaly and does not include the Wilderness areas (so the estimate does not include any of the immediate proximity to the stratovolcanoes).

The Southern Oregon and Northern California Cascade Range segments are not included in this calculation for lack of data, although conditions there are probably very similar in thermal characteristics to the northern Oregon Cascade Range. A similar power estimate for the remainder of the Cascade Range in Oregon and northern California would more than double that estimated for the northern ½ of Oregon because of the increase in available area.

The northern Cascades in Washington are also not included in the potential estimate because the thermal pattern there is somewhat different, the gradients are not as high, and high heat flow seems to be more concentrated around the volcanoes where access is not generally possible (Blackwell et al., 1990b). Still local areas there could well be possible EGS targets.

Characteristics of the Cascade Resource Area

There has been extensive drilling of the northwestern side of the northern Oregon Cascades. This information allows for a fairly precise description of the characteristics of the regional...
geothermal resource (Blackwell et al., 1982; 1990). Most of the resource assessment drilling has been concentrated along the western Cascades/High Cascades boundary and into the west edge of the High Cascades. There are limited data from the High Cascades proper and the eastern edge next to the Blue Mountains and the Oregon Basin and Range. Temperature depth curves for several of the deepest wells are shown in Figure 6.

At the present time an active EGS project is ongoing on the east side of the Cascades in the Deschutes National Forest within the prime accessible area of Newberry Volcano by Altarock on leases held by Davenport Energy. In this area temperatures in wells are over 300 °C at 3 km over an area of at least 11 km$^2$ within the permitted exploration area. Estimated geothermal power potential for the area under geothermal lease is 2,000 to 3,000 MW.

**Snake River Plain**

The Snake River Plain (SRP, Figure 2 has been documented as an EGS resource area for many years (Arney et al., 1980; Blackwell, 1989). Recent drilling has confirmed average thermal gradients of over 50°C/km over all of the Snake River Plain (Shervais et al., 2012). The heat flow is highest in the Eastern Snake River Plain, but a combination of high heat flow and low thermal conductivity rocks results in temperatures that are generally higher in the western ½ of the SRP. Several wells in the WSRP have measured temperatures of 200+ °C at 3 km (Figure 7). The geological section at development depths consists of volcanics and sediments in the west and granitic rocks in the east. So the geological setting is more complex than the Cascade Range from an EGS point of view. Water might be available and the infrastructure is present to distribute power. The area of potential development within the WSRP is at least 5,000 km$^2$ and may extend to 10,000 km$^2$ so the potential of development of 40% of the area at 25 MW/km$^2$ would be on the order of 50 to 100 GW. The land is all owned by BLM or private entities so in general land access is practical.

**Sedimentary Basins in the Great Basin**

The potential for developing large areas of high temperature in the deeper Cenozoic sedimentary basins in the Basin and Range Province has been pointed out. The details of this thermal resource are discussed in detail by Allis et al (2912) and therefore not covered here. There are two reasons that this resource type may not be of prime importance. The first is that geothermal energy already contributes significantly to electrical production in the Basin and Range and additional needed capacity is small. Secondly, water availability in this desert region is a major problem if these resources have to be developed as EGS systems.

**Other Areas**

**Raton Basin**

An example of a smaller area that could be a major geothermal production area is the Raton Basin in south central Colorado (Morgan, 2009). This area is a small sedimentary basin at the east edge of the Southern Rocky Mountains (Figure 2). The basin has

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*Figure 6. Temperature-depth curves from the Cascade Range. The deep point for the Sun Breitenbush well is a BHT and is a minimum temperature (Blackwell and Baker, 1988). The Old Maid Flat well is at the western foot of Mt Hood and the High Cascade well is between The Sisters and Mt Jefferson stratovolcanoes (Blackwell and Steele, 1987).*

*Figure 7. Temperature depth curves for the Snake River Plains, southern Idaho. Red curves are from the Eastern Snake River Plain, blue and green curves are from the Western Snake River Plain. Thermal data from Blackwell (1989; Ore-Ilda-1, Bostic 1A, , INEL GT 1, INEL WO-2, MT Home AFB), and Shervais et al. (2012; Kimama and Mt. Home AFB(2012)). The Ore-Ilda well is 3064 m deep and probably over 200°C at TD.*

*Figure 8. Raton Basin corrected BHT data (Morgan, 2009).*
temperatures of ~200 °C at 3 km in basement granite and so it may be a classic EGS geothermal resource (Figure 8, see Morgan, 2009). Morgan (2009) has estimated that an area of 50 km² in the sedimentary section that has temperatures over 200 °C. This area has high potential because of accessibility and relatively shallow high temperature in the subsurface. Although this area is mountainous it is extensively developed for coal gas and there is an extensive network of roads, well sites, and pipeline right of ways to use for geothermal development.

**Haynesville Shale Area**

East of the Rocky Mountains there are generally relatively small areas with temperatures approaching 200 °C at 3 to 4 km. One large area, the Haynesville Shale, is in northern Louisiana and northeast Texas (Blackwell and Steele, 1988; Blackwell et al., 1993; Negru et al., 2008, see temperature depth curves in Figure 9) and covers an area of over 50,000 km². This area is being extensively developed for shale gas at depths on the order of 3 km. While the temperatures at depth are a little lower than west of the Rockies, the extensive drilling for development of the Haynesville shale means that costs could be relatively low and that an infrastructure is already developed. The rock types are low porosity sandstones at the bottom of the sedimentary section and, based on the high heat flow, probably granite rocks in the basement. In addition there is the possibility of using abandoned or failed shale gas or conventional oil or gas wells to test concepts of EGS development in sedimentary rocks and to develop scale models of reservoir behavior in horizontal wells.

**Figure 9.** Temperatures in the Northeastern Texas/Northern Louisiana area (Blackwell et al., 2007). The Mosely and Haynes wells are close together in northern Louisiana and Well #1 is in northeastern Texas about 50 km to the west.

**Conclusion**

Areas not discussed here include the Imperial Valley in southern California and the Geysers area in northern California. The access and the supply of water constrain development outside the presently developed area of the Geysers, but there are significant thermal reserves outside the presently developed geothermal system as discussed by Burns and Potter (1998). Physical and water access are problems. Water, if available, is likely to be used to sustain the development in The Geysers geothermal field which is water short at the present time.

Investment in geothermal research must emulate the shale gas development model if geothermal energy is to be relevant to the US in the next 20 years. On the basis of present data the prime areas for initial development have been discussed. Failure to focus on these areas, or develop deep temperature data to prove other areas in the near term will result in failure of geothermal energy to reach significant development in the time frame envisioned by the Future of Geothermal Energy report (Tester et al., 2006) and perhaps relegate geothermal energy to a back seat in US energy policy.

**References**


