THE ROLE OF EXPLORATION IN INCREASING GEOTHERMAL DEPLOYMENT IN THE US DEPARTMENT OF ENERGY GEOVISION STUDY

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ABSTRACT

The objective of the GeoVision study of the US Department of Energy's Geothermal Technologies Office (GTO) is to characterize the current status of geothermal energy in the United States and identify future scenarios for potential geothermal growth for 2020, 2030 and 2050 across multiple market sectors, including electrical power generation, direct use, and other value streams. This study will also identify barriers to increased deployment, and explore transformative technologies, methodologies, and approaches that might accelerate the commercial deployment of geothermal resources. The project consists of the following task forces: 1) Exploration and confirmation; 2) Reservoir management and development; 3) "Potential to Penetration" economic analysis; 4) Social and environmental impacts; 5) Institutional market barriers; 6) Hybrid systems; and 7) Thermal applications. These task forces consist of scientists and engineers from the DOE national laboratories, and are being advised by a group of geothermal experts known as the Visionaries.

Our exploration team has focused on evaluating the current status of geothermal exploration activities (i.e., business as usual) and identifying new and improved methods and technologies that might be applied successfully by the geothermal industry. Reviews of existing methods and lessons learned from past exploration efforts (both successes and failures) can lead to improved approaches for exploration geared to specific geothermal play types and expansion of geothermal resource utilization from hydrothermal systems to the larger enhanced geothermal systems resource base. Technology transfer from related industries, such as oil and gas and mineral exploration, can also lead to improved methods for subsurface characterization and drilling. Inclusion of direct use applications and harnessing other attributes of geothermal fluids, such as mineral recovery, could also increase the impact of geothermal resources and enhance their utilization. Such innovations could impact geothermal deployment on a global scale.

1. INTRODUCTION

One of the main challenges facing the geothermal industry in the United States is how to transform geothermal from a niche regional energy producer with a low growth rate into a significant contributor to the national energy market. This low growth rate is in sharp contrast to other renewable energy sources such as PV solar and wind; these trends are mirrored around the world, where the annual growth rates between 1994 and 2014 of PV solar, wind and geothermal have been 46.2%, 24.3%, and 3.1%, respectively (IEA, 2016). The different growth trajectories for these renewable energy sources reflect differences in the cost of deployment, the risks associated with exploration and development, the time required from project initiation to generation, the availability of financing, and policy and regulatory impacts.

Wall and Dobson (2016) have conducted an evaluation of the current state of geothermal exploration efforts in the US; these results are summarized in Section 3. Improvements in geothermal exploration methods can result in lower costs, reduced risk, and improved economics for geothermal resource development. Such improvements can be applied to geothermal exploration efforts worldwide.

2. GEOTHERMAL RESOURCE TYPES IN THE US

The US Geological Survey conducted an extensive review of moderate (90 to 150°C) and high-temperature (> 150°C) geothermal resources in the United States (Williams et al., 2008a, b). This assessment is broken down into three main resource types: 1) Identified; 2) Undiscovered, and; 3) Enhanced Geothermal Systems (EGS). Identified systems are further categorized as producing, confirmed (via successful commercial flow tests), or potential (initial studies provide reliable estimates of temperature and volume for the reservoir but the area has not had a successful discovery well yet). The 2008 USGS assessment estimates that the electric power generation potential (mean values) from identified, undiscovered, and EGS resources in the US are 9, 30, and 518 GWe, respectively. These estimates suggest that if significant expansion of geothermal power production is to occur in the US, it will need to come from undiscovered and EGS geothermal resources, given that a third of the identified geothermal resource base has already been developed.

2.1 Undiscovered Systems

Undiscovered systems are most promising type of rapidly deployable geothermal resources in the US, given that they represent conventional hydrothermal systems, which already have been demonstrated to be commercially viable using present day technology. Most of the undiscovered systems in the US are likely to be considered hidden or blind systems, which have no active surface thermal features associated with them. Williams et al. (2009) used a series of statistical models that spatially correlate key geological factors associated with known geothermal systems, such as heat flow, Quaternary magmatism, Quaternary faulting, seismicity, and tectonic stress, to estimate the abundance and distribution of these resources. Many of the developed geothermal fields in the western US that were originally hidden systems were often discovered by happenstance (i.e., when drilling for water, oil and gas, or mineral resources). However, these resources share many of the same elements that are observed in conventional hydrothermal systems that have active surface thermal features (Dobson, 2016).

Exploration methods that have been successfully utilized in identifying and discovering hidden systems include water chemistry, temperature gradient wells and shallow heat flow surveys, gravity, magnetics, and electrical resistivity surveys, field mapping of structural and alteration features, development of conceptual models, and deep exploration drilling. Examples of hidden systems in the US that have been discovered and are currently producing geothermal fields include the Brawley, East Mesa and Heber geothermal fields in the Imperial Valley of California and the Desert Peak, Blue Mountain, McGinness Hills, Soda Lake, Stillwater, Raft River, Lightning Dock, and Wild Rose geothermal fields in the Basin and Range province of Nevada, Idaho, and New Mexico (Dobson, 2016).

One new geothermal exploration approach that has been encouraged by the US DOE GTO is the use of play fairway analysis (Garchar et al., 2016). This approach, which was originally developed by the oil and gas industry, consists of compiling and evaluating existing data for the region under evaluation, determining possible geothermal play types and their characteristics, constructing common risk segment maps, and developing an integrated geothermal favorability map. This methodology is predicated on using geoscience data to identify the presence of defining elements of geothermal systems, such as a heat source, permeable structures and a reservoir seal. The distribution of geothermal play types is controlled by the tectonic setting (e.g., Moeck, 2014).

Several of the teams funded by the DOE GTO noted that this approach did identify known hidden systems, and thus appeared to be a valid methodology for identifying prospective regions that might host similar hidden geothermal systems (e.g., Faulds and Hinz, 2015; Faulds et al., 2015; Lautze et al., 2016; Shervais et al., 2016; Wannamaker et al., 2016). This integrated approach should help reduce the risk associated with exploring for this type of geothermal resource. Exploration methods should be tailored to address the play type features and geologic setting.

2.1 Enhanced Geothermal Systems (EGS)

Enhanced geothermal systems represent the largest and most widely distributed geothermal resource in the US. The MIT report (MIT, 2007) suggested that 100 GWe of EGS resources could be commercially developed in the US by 2050 at depths between 3 and 10 km, provided that there are significant technological advances in drilling, reservoir creation and power conversion technologies (e.g., Ziagos et al., 2013). A more recent USGS geothermal resource assessment (USGS, 2008a) came up with a mean EGS resource estimate of over 500 GWe. These studies document that the US has extensive EGS resources, which have been confirmed by deep wells and heat flow studies; the challenge is whether or not the heat contained in these low permeability rocks can be extracted from the subsurface in a large-scale fashion that is commercially viable.

There have been a number of pilot EGS projects worldwide that have been launched to demonstrate and improve critical technologies associated with resource characterization, reservoir access (via drilling), reservoir creation (via well stimulation), and reservoir sustainability. Early R&D efforts in the US focused on the Fenton Hill site in New Mexico (e.g., Kelkar et al., 2016); more recent activities are briefly described in Section 4. A survey of EGS systems worldwide conducted by Grant (2016) noted that EGS reservoir thermal recovery factors (0.2 to 2.0) are typically an order of magnitude lower than those observed for conventional hydrothermal systems, and that the tracer swept volumes for these systems are more than two orders of magnitude lower than those found in conventional systems. These observations highlight one of the main technology challenges for EGS: that of creating widely distributed permeability within an EGS reservoir. The development of zonal isolation methods to permit multizonal stimulation of EGS wells could help address this challenge (e.g., Nordin et al., 2013; Cladouhos et al., 2016).

Two types of prospective EGS resources have been proposed for the first stages of development. One is developing the lower permeability margins of existing hydrothermal systems, such as at The Geysers, Raft River, Brady's, and Desert Peak (e.g., Garcia et al., 2016; Bradford et al., 2015; Benato et al., 2016). Many of the existing EGS "projects" have utilized previously drilled low permeability boreholes as "wells of opportunity" to test out well stimulation techniques and attempt to create EGS reservoirs that connect to existing hydrothermal systems. Another advantage of conducting EGS development in such areas is that they already have existing steam field and power plant infrastructure in place, greatly reducing the cost of development. A second region for early EGS development would be in areas with elevated heat flow (such as the Snake River Plain and the Cascades), where EGS resources could be accessed at shallower depths (Blackwell et al., 2013). Geothermal exploration for EGS would thus be initially focused in these two types of environments.

3. CURRENT EXPLORATION TRENDS IN THE US

The U.S. geothermal industry today consists primarily of three types of commercial projects for electricity generation, all of which are hydrothermal: repower/expansions, new greenfield projects in identified geothermal areas, and new greenfield projects in blind geothermal systems. Each of these three project types have differing degrees of exploration risk and require differing amounts of time to move from discovery to confirmation. Since financing is tied to both the time value of money and the likelihood of the return, it then follows these projects also require different costs of capital. Within the technoeconomic model constraints of the GeoVision Study, these factors translate to analyzing a project's exploration timeline, success rates, and costs of capital.

The timeline for geothermal project exploration is interwoven with the processes necessary to receive appropriate permits. Young et al. (2014) show that permits for exploration have taken 21-64 days on average between first paperwork and acceptance – but may be 10-25 months if NEPA EA or EIS documents are required. If no delays are experienced, a well-executed geothermal exploration program is expected to take 9 months from literature search to well siting (IFC, 2010). Thus, the timeline for a well-executed program is no less than 10 months' time when permitting is considered.

However, a project is not always successful in discovering a feasible resource. To determine the number of locations that must be evaluated to result in a single feasible power project, we developed an analysis of project success rates at different stages of the geothermal exploration process (Wall & Dobson, 2016). This work involved studying the progress of 137 geothermal exploration projects in development in Nevada from 2010-2016. For this subset of data, the success rate for a typical geothermal exploration process is approximately 16% to proceed beyond confirmation drilling, varying 11% to 43% for greenfield and nearfield or expansion projects, respectively. This analysis is in line with large commercial developers, who have estimated project portfolio success rates of approximately 20%. In essence, a single power project from a blind greenfield area could require 9 geochemical and geophysical field campaigns while on average a successful exploration project could require 6 field campaign locations.

The project's success rate, however, is not equivalent to the economic risk or return of the project. Financing rates, or costs of capital, reflect both the perceived risk of the project and the developer. As of 2009, a typical 35 MW geothermal project could require a 12% weighted average cost of capital at a ratio of 70% debt to 30% equity (Glacier Partners, 2009). Our ongoing work is to revisit these financial factors for different project types.

Within GETEM, the US DOE GeoVision Study's technoeconomic model, geothermal exploration costs for research and sampling a single location (i.e. the exploration phase of a project) are approximately 15% of the overall project capital costs. However, drilling costs for exploration wells are 87.5% of these costs. The team's ongoing work is to catalog studies of recent drilling costs.

4. FUTURE EXPLORATION SCENARIOS

Because future scenarios looking to break from the *status quo* are necessarily hypothetical, this research sets the groundwork for DOE to select visionary scenarios that can be justified. Within the geothermal industry, given the business as usual analysis, our team has identified that key challenges to deployment are how to reduce cost and risk, and how to shorten the exploration timeframe. Additionally, the team has been working to review research into macroeconomic and external industry trends that could influence change in the future geothermal industry.

To support and justify changes to future exploration scenarios, the team has been compiling business models, technologies, and processes that would appear to influence a project's exploration timeline or success rate. As one example, better data analytics (and the advent of real-time data analytics and cloud computing) have the potential to find better prospects faster. Wall (2016) proposes two possible future scenarios for exploration within the GeoVision Study. **Stability in size**, in which the geothermal industry competes for baseload energy by phased development of large plants in a world of long-term low energy prices, or **nimble in numbers**, in which the geothermal industry focuses on developing small localized energy solutions in a world of high energy prices.

Significant advances in technology could also have a major impact on the costs, risks, and rate of deployment of geothermal resources for power generation in the US. One example in a related industry is the development of unconventional oil and gas resources. Rapid improvements in multistage fracturing of horizontal wells in shale reservoirs have led to a boom in oil and gas production in the US (e.g., Sutton et al., 2010). This effort, initiated by smaller companies, was triggered by innovations and cost reductions in drilling, reservoir stimulation, and well completion.

Technology transfer from the oil and gas industry has provided benefits to the geothermal industry throughout its history, and will continue to serve as a primary source of new innovations. Shembekar and Turaga (2011) have suggested that technological and operational advances in drilling, well completion and reservoir stimulation could lead to significant cost reductions for development of commercial EGS resources. In particular, they note that new drilling technologies such as spallation and particle jet drilling could lead to significant increases in the rate of penetration for drilling deep EGS wells. The use of expandable tubulars could help reduce well completion costs while achieving larger bottom-hole diameters. Drilling optimization techniques, such as monitoring mechanical specific energy to guide drilling operations, have been successfully demonstrated as a way to increase rates of penetration and reduce well costs for conventional geothermal systems (e.g., Knudsen et al., 2014). Development of multiscale digital models to characterize the subsurface (such as BP's "Digital Rocks" system) could help improve well targeting of permeable zones and thus lower risks and costs associated with geothermal exploration (Fredrich et al., 2014).

The US DOE GTO has invested in a series of EGS field demonstration projects at sites associated with existing producing hydrothermal fields (e.g., Desert Peak, Brady's, Raft River, and The Geysers) as well as a greenfield site (Newberry). These projects have contributed to developing new approaches and insights into zonal isolation, reservoir characterization and monitoring, and reservoir stimulation methods (e.g., Bradford et al., 2015; Garcia et al., 2016; Rutqvist et al., 2016; Cladouhos et al., 2016; Benato et al., 2016). The DOE GTO is currently in the early stages of creating a dedicated EGS field site (Frontier Observatory for Research in Geothermal Energy – FORGE) to develop and test new technologies and methods to facilitate subsurface characterization, reservoir creation and monitoring, and developing and testing new tools to facilitate commercial development of EGS resources.

One other approach that could help make geothermal resource development more competitive with other renewable energy options is to consider a more holistic use of geothermal systems. Such an approach has been successfully applied in Iceland, where the concept of a geothermal "cluster" has been developed. A cluster is defined as a geographic concentration of companies and associated institutions in a particular field, linked by commonalities and complementarities (e.g., Gunnarsson and Þorgeirsdóttir, 2011; Iceland Geothermal, 2015). This concept has led to the development of the HS Orka Geothermal Resource Park on the Reykjanes Peninsula, which consists of the Svartsengi geothermal power plant (which generates electricity and provides brine for district heating, fish drying, fish farming), the Blue Lagoon spa, clinic and inn, a renewable methanol plant, a skin care manufacturing unit, and a molecular farming plant (Albertsson and Jonsson, 2010; Iceland Geothermal, 2015). In the US, incorporation of direct use applications into geothermal resource utilization plans would expand the geographic extent of viable geothermal resources as well as their commercial applications. Future exploration efforts will need to consider these applications.

5. CONCLUSIONS

The rate of geothermal energy deployment over the past 20 years currently lags behind the rapid development of solar and wind resources in the US. The US DOE GTO is conducting a GeoVision study to assess the current state of geothermal resource utilization in the US and identify potential scenarios that could result in increased deployment.

The exploration task force for the GeoVision study is examining current exploration methods and trends and assessing potential technology advances that could result in accelerated future geothermal deployment in the US. Over the short term, hydrothermal resources will be the primary targets for future exploration efforts. Research and development efforts for EGS resources supported by the US DOE GTO are aimed at lowering some of the key technology barriers (such as reservoir creation and access) that have made harnessing the extensive US EGS resource uncommercial. Many of the needed innovations may come from technology transfer from the oil and gas industry.

The exploration challenges that confront the US geothermal community (such as long lead times between exploration and development, elevated exploration risks, difficulties in identifying subsurface permeability, and high costs of drilling) are shared by the geothermal community worldwide. Collaboration on a global scale will benefit the geothermal industry around the world. Utilization of geothermal resources for power generation, direct use applications, and other value streams could help make geothermal development more viable.

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