The Manageable Risks of Conventional Hydrothermal Geothermal Power Systems:

A Factbook on Geothermal Power's Risks and Methods to Mitigate Them

GEOTHERMAL
ENERGY
ASSOCIATION

The Geothermal Energy Association (GEA) has prepared this document for policy makers and the interested public to understand more about geothermal power's unique risks and about past and current policy and market approaches to address them. This report is intended to be a companion to a report published in October of 2013, "The Values of Geothermal Energy." That report outlined the positive values of geothermal energy, including supplying both firm and flexible grid operation support, creating jobs, having a small land footprint, and producing near-zero emissions.

For an investor or developer, geothermal projects have significant benefits, as detailed in "The Values of Geothermal Energy," but they also encounter unique risks. Many of the unique risks relate to finding, developing and producing from the geothermal resource. This report outlines the risks involved in exploration, drilling, development and operation of a geothermal project, and describes past and ongoing effort by the U.S. and global policies to address those risks.

This analysis should underscore that policies aimed at incentivizing renewable power for taking a "one size fits all" approach may miss the mark with geothermal investments due to the unique nature of their risk profile.

Geothermal power has an important part to play in the energy systems of the western United States and many other regions of the world. With increased understanding of its unique benefits and risks, key decision makers will be better equipped to support and promote the geothermal industry, leading to an expansion of geothermal power in the coming decades.

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GEOTHERMAL ENERGY ASSOCIATION
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Cover Page

Pictures Courtesy of Sam Abraham
(Top Left) Rainbow: Puna, Big Island, Hawaii
(Top Right) Lava flow: Kalapana, Big Island, Hawaii
(Bottom Left) Hot spring (foliage and steam): Wotten Waven, Dominica

Pictures Courtesy of Terra-Gen
(Bottom Right) Beowawe Power Plant, Nevada

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Section 1: The Geothermal Power Development Process

1.1 Introduction

This paper provides a brief description of the risks associated with primarily conventional hydrothermal geothermal power projects (not primarily Enhanced Geothermal Systems or EGS) and describes shared policy and market approaches intended to address them. Geothermal power projects have very unique development timelines that are substantially different from most, if not all, other energy technologies. In the first section, a brief discussion of geothermal power plant economics is followed by a list of the problematic risks that hinder or raise costs of geothermal power, and the second section lists a selection of past and ongoing programs to reduce risk. Finding effective and economical ways to reduce these risks is considered to be the number one way to expand the use of geothermal power globally.

1.2 Different Economics, Different Risks

Geothermal power projects have very unique development timelines that are substantially different from most, if not all, other energy technologies. A greenfield project typically starts with several years of exploration and drilling, followed by a brief construction period, and then several decades of operation. This timeline creates unique risks and challenges for the geothermal industry. The “one size fits all” policy approach, which attempts to levelize the playing field for renewable energy technologies, often misses the mark when it comes to geothermal power, leaving a valuable renewable power source lacking proper support. A few of the distinguishing factors of geothermal power that differentiate it from other energy technologies are listed below:

- Even with high upfront capital costs, geothermal power is a competitive renewable energy source. The absence of fuel costs and other variable costs over the long 50+ year project life span give geothermal power the lowest levelized cost ($89.6/MWh) of any renewable energy technology with the exception of wind power (at $86.6/MWh; 3% less). The data in Table 1 on the next page are from EIA’s Annual Energy Outlook 2013.

- Geothermal power plant construction involves high expenditures and capital costs at the beginning of the project. This upfront capital is especially necessary for the drilling and exploration phases where most of the project risk is undertaken.

- Wind, solar, and fossil fuels are less limited by location than traditional geothermal power systems. Geothermal plants must be placed near or above the resource.

- Having no reliance upon intermittent energy sources such as wind and sunlight, geothermal facilities can produce electricity 24 hours a day, 7 days a week. As a result, geothermal power plants have a high capacity factor, demonstrating a level of consistency and reliability not found in other renewable technologies. The EIA lists geothermal power as having the highest capacity factor (92%) of all the energy sources discussed (see Table 1), higher than coal (85%), natural gas (87%), and biomass (83%). Many geothermal power plants enjoy capacity factors of more than 96%. For comparison, the capacity factors of wind, solar thermal, and solar PV are listed as 34%, 20%, and 25%, respectively.[1]

Table 1: U.S. Estimated Average Levelized Cost for Plants Entering Service in 2018 [$/MWh]

Plant type	Capacity factor (%)	Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system levelized cost
Coal						
Conventional Coal	85	65.7	4.1	29.2	1.2	**100.1**
Advanced Coal	85	84.4	6.8	30.7	1.2	**123**
Advanced Coal with CCS	85	88.4	8.8	37.2	1.2	**135.5**
Natural Gas						
Conventional Combined Cycle	87	15.8	1.7	48.4	1.2	**67.1**
Advanced Combined Cycle	87	17.4	2	45	1.2	**65.6**
Advanced CC with CCS	87	34	4.1	54.1	1.2	**93.4**
Conventional Combustion Turbine	30	44.2	2.7	80	3.4	**130.3**
Advanced Combustion Turbine	30	30.4	2.6	68.2	3.4	**104.6**
Other Technologies						
Advanced Nuclear	90	83.4	11.6	12.3	1.1	**108.4**
Geothermal	92	76.2	12	0	1.4	**89.6**
Biomass	83	53.2	14.3	42.3	1.2	**111**
Non-Dispatchable Technologies						
Wind	34	70.3	13.1	0	3.2	**86.6**
Wind-Offshore	37	193.4	22.4	0	5.7	**221.5**
Solar PV	25	130.4	9.9	0	4	**144.3**
Solar Thermal	20	214.2	41.4	0	5.9	**261.5**
Hydro	52	78.1	4.1	6.1	2	**90.3**

Source: U.S. EIA 2013

There is a spectrum of development strategies used to avoid the risks associated with initial exploration and drilling. In some countries, the government serves as the resource and power plant developer, essentially taking all the risk. Elsewhere, governments fund the initial geothermal exploration and then lease already-discovered resources to private developers or government entities to build plants. Another common variant is for government and the private sector to share the costs and risks of early exploration and drilling, typically with a requirement that some or all data from the cost-shared wells will enter the public domain. In another model, companies share the risks of the initial exploration by forming equity partnerships, joint ventures or other business agreements to share the cost and risks of searching for and discovering a geothermal resource. Yet another approach is for a country to issue a long-term concession based on private companies completing all exploration, development, and operation in exchange for a fixed sales agreement and other financial incentives. Lastly, sometimes a country might support advancements in drilling technology.

More information about various publicly, privately or jointly funded exploration projects is included in GEA's International Project List (published September 2013), and some of the

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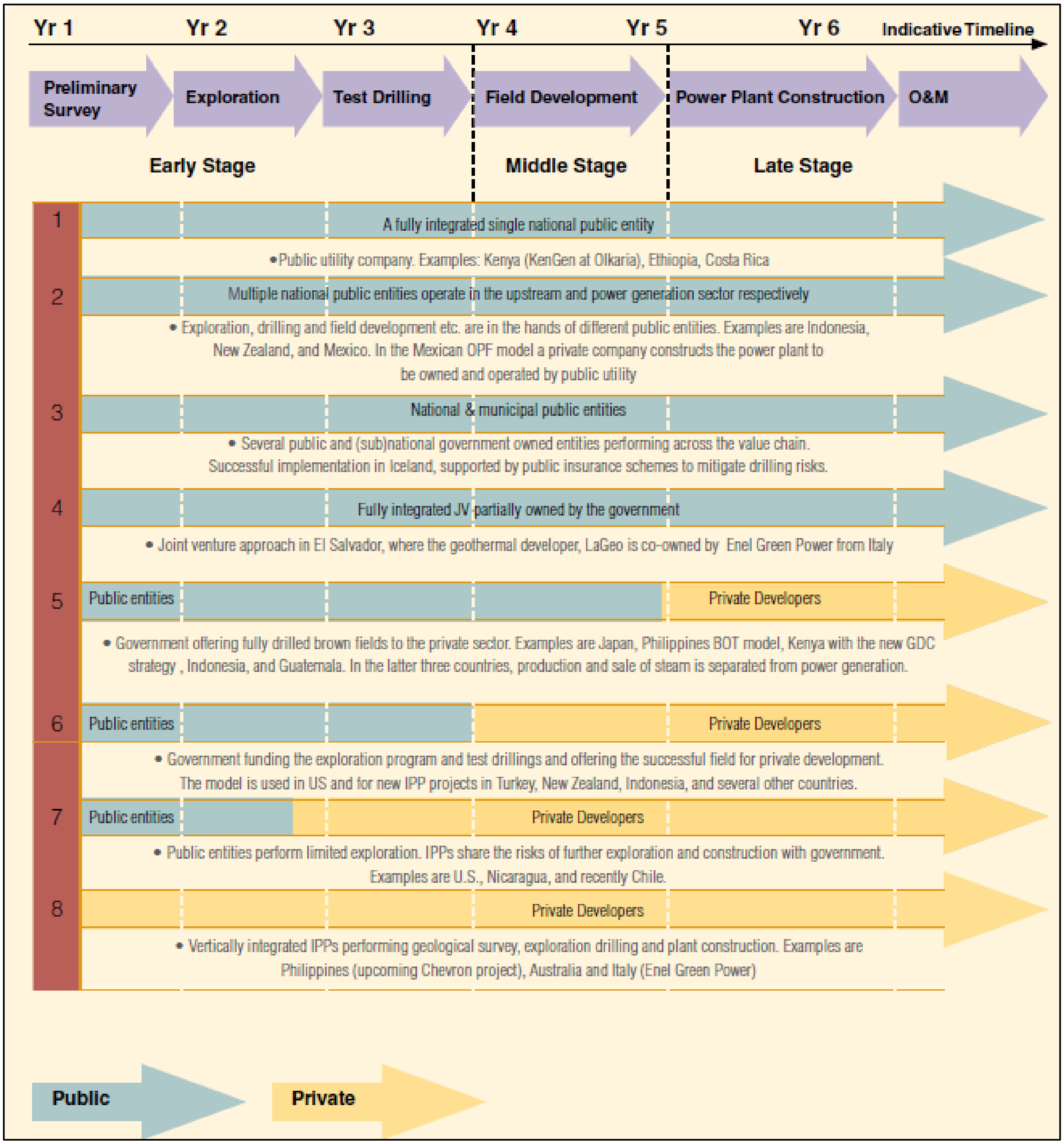
[1] U.S. EIA 2013

different models in the geothermal risk-sharing spectrum are illustrated in Figure 1 below from ESMAP, 2012: "Geothermal Handbook: Planning and Financing Power Generation."

Figure 1: Figure 1: Models of Geothermal Power Development in International Practice



1. A fully integrated single national public entity
   - Public utility company. Examples: Kenya (KenGen at Olkaria), Ethiopia, Costa Rica
2. Multiple national public entities operate in the upstream and power generation sector respectively
   - Exploration, drilling and field development etc. are in the hands of different public entities. Examples are Indonesia, New Zealand, and Mexico. In the Mexican OPF model a private company constructs the power plant to be owned and operated by public utility
3. National & municipal public entities
   - Several public and (sub)national government owned entities performing across the value chain. Successful implementation in Iceland, supported by public insurance schemes to mitigate drilling risks.
4. Fully integrated JV partially owned by the government
   - Joint venture approach in El Salvador, where the geothermal developer, LaGeo is co-owned by Enel Green Power from Italy
5. Public entities / Private Developers
   - Government offering fully drilled brown fields to the private sector. Examples are Japan, Philippines BOT model, Kenya with the new GDC strategy , Indonesia, and Guatemala. In the latter three countries, production and sale of steam is separated from power generation.
6. Public entities / Private Developers
   - Government funding the exploration program and test drillings and offering the successful field for private development. The model is used in US and for new IPP projects in Turkey, New Zealand, Indonesia, and several other countries.
7. Public entities / Private Developers
   - Public entities perform limited exploration. IPPs share the risks of further exploration and construction with government. Examples are U.S., Nicaragua, and recently Chile.
8. Private Developers
   - Vertically integrated IPPs performing geological survey, exploration drilling and plant construction. Examples are Philippines (upcoming Chevron project), Australia and Italy (Enel Green Power)

Source: Gehringer et al. 2012 *Note: Additional vertically integrated private developers include Ormat Technologies.*

Overview

In the public forum, geothermal power is often grouped in with the other major types of renewable energy, and as a result is frequently misconstrued as having similar economics. For example, the wind and (particularly) solar industry costs are driven by the economics of producing manufactured products for sale (PV cells, wind turbines). Biomass economics are closer to fossil fuel economics because a fuel is still involved, so although the capital costs are lower than geothermal plants, biomass power plants are still subject to fuel cost volatility. Similarly, it is important to note that, economically, the geothermal power business more closely resembles the oil or gas industries than other renewables, since geothermal resources need to be discovered, drilled for, and extracted.

Like oil and gas, geothermal power is a resource that requires exploration. But once oil or gas is discovered, it may be immediately produced and sold. On the other hand, even after discovery and drilling, a geothermal resource cannot generate a return on investment until a suitable power plant is constructed and connected to the electrical grid, presenting a significant delay before any revenue can be realized.

Economical Geothermal Resources

An integral part of geothermal power economics is choosing the most economically viable resource from which to extract geothermal fluids and generate power. Figure 2 schematically illustrates the relationships between geothermal power technologies, depth, temperature and economic feasibility. In most areas of the world today, projects rarely drill wells deeper than 4 km. Drilling costs increase exponentially with depth, and therefore, the optimum combination of temperature and permeability is sought within this depth range. A study by GeothermEx in 2004 found that the variation in resource depth accounts for more than 56% of the variance in drilling costs based on numerous geothermal wells in California.[2,3]

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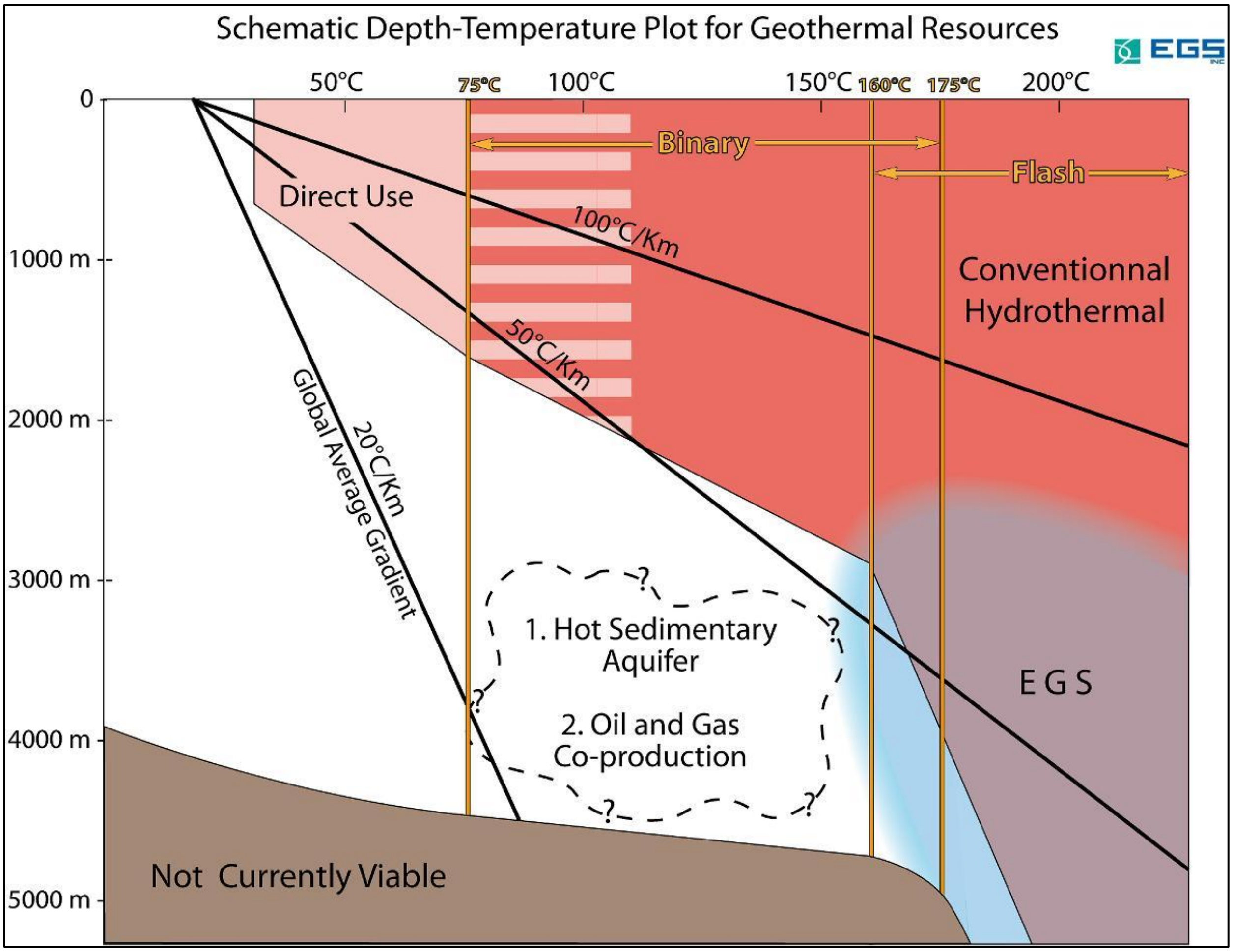
[2] Lovekin et al. 2004

[3] Because of proprietary concerns and the relatively small amount of geothermal drilling data within the United States at the time of the study, data from representative geothermal wells completed between 1997 and 2000 in Central America and the Azores were also incorporated to determine the variance in drilling costs.

Figure 2: Depth-Temperature Plot for Geothermal Resources

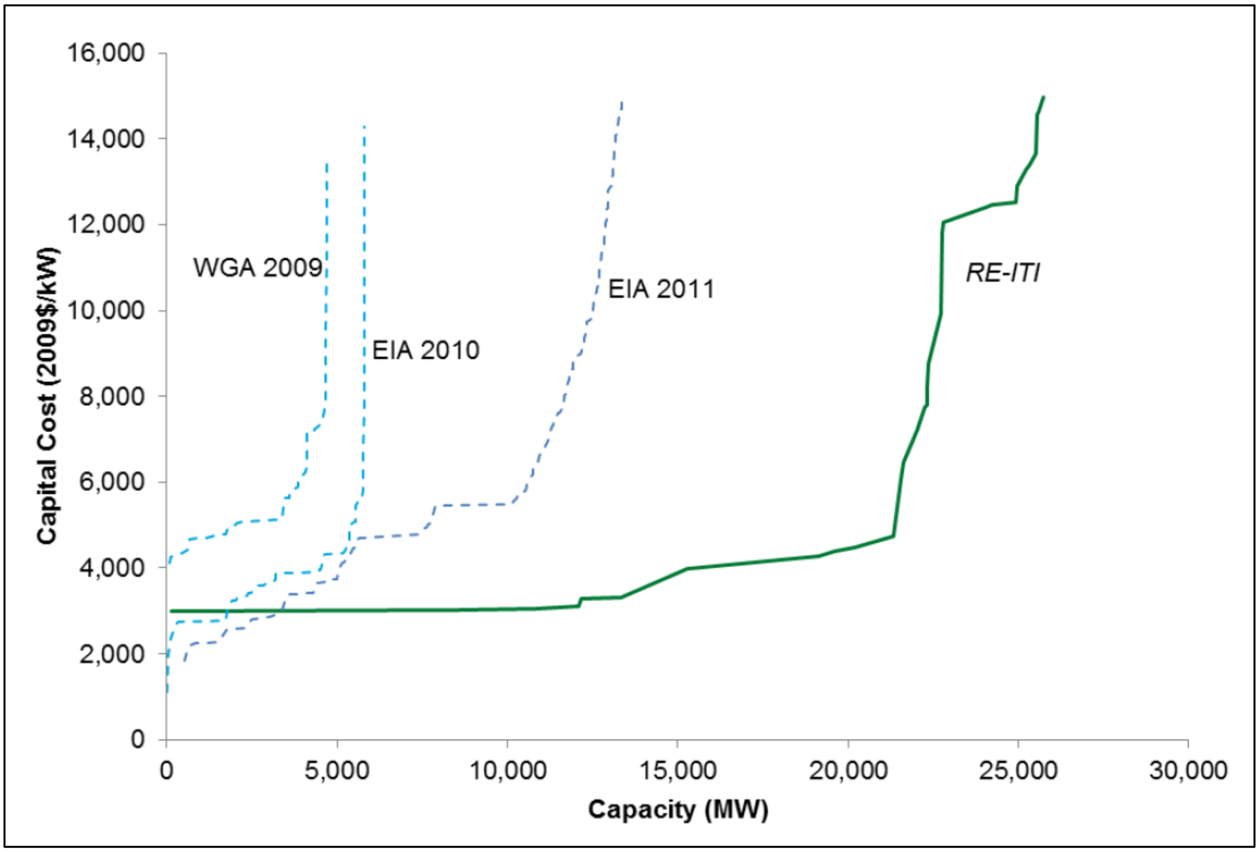


Source: EGS, Inc. *Note: New technologies have allowed for some scenarios where the "Not Currently Viable" portion of Figure 2 and the "EGS" portion at depths of 3000m - 5000m and temperatures of 100 - 150°C to become economical geothermal projects.*

Because of the relationship between well depths and drilling costs, the geothermal well field exploration accounts for up to 40% of the total projects costs. Often geothermal developers spend a substantial amount of time gathering as much information as possible about subsurface conditions in order to reduce risk. This information increases drilling success and decreases geothermal project risk.

Figure 3 is the most recent geothermal supply curve from NREL's "Renewable Electricty Futures Study" showing that as the capital cost of electricity increases, the amount of economical MW for development also increases. In other words, more geothermal resources become attractive when more money is available to bring a project online to operable status. The positive correlation of cost and potential generation is similar across the spectrum of energy technologies, but different technological advancements, discoveries, or policy initiatives can shift the geothermal supply curve over time. For example, advancements in drilling technology or capital loaned or granted from multilateral development banks can decrease the risk of a project, shifting the curve down and increasing the economic attractiveness of more geothermal resources.

Figure 3: U.S. Supply Curve for Geothermal (Hydrothermal) Energy Technologies Note: In general, the reason for the larger resource potential estimated in RE-ITI compared to the other estimates is the exclusion of undiscovered resource in the other estimates.



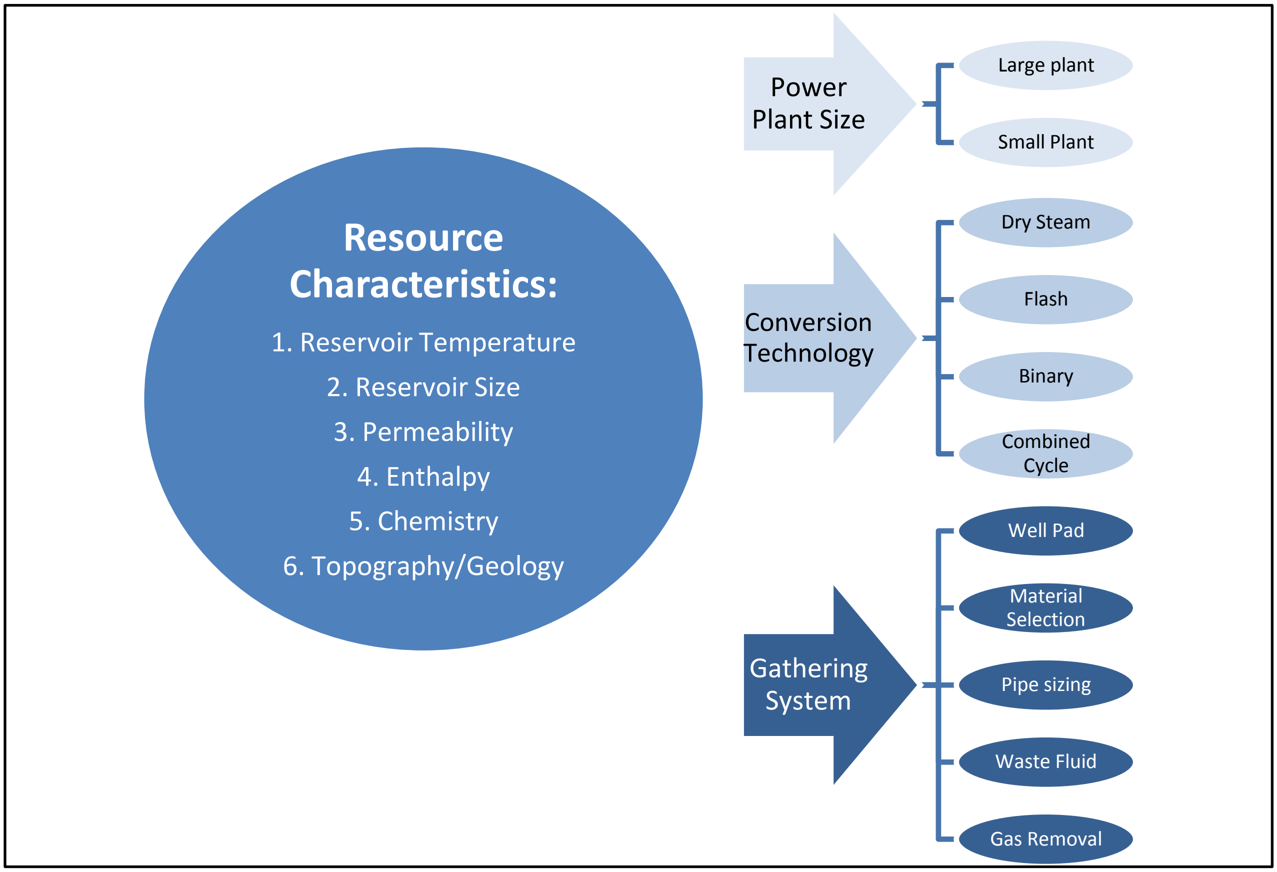
Source: Augustine et al. 2012

1.3 Geothermal Power's Risks to Project Development

1.3.1 Resource Risk

A major uncertainty in geothermal power project development concerns the size and quality of the geothermal fluids that can be extracted from the underground resource. As shown in Figure 4, this uncertainty affects the design parameters of the power plant downstream. Unlike a fossil fuel plant where burning X amount of coal may produce Y amount of power, in geothermal it is the resource quality and quantity that determine the power plant size, technology, and other engineering aspects. Therefore, the quantity and accuracy of resource information at the early stages of a project will lead to more accurate reservoir models, thus lowering the risk and uncertainty associated with the geothermal power project. A strategy to reduce resource risk starts with an understanding of the geological setting and an accurate assessment of the type and distribution of surface thermal manifestation (hot springs, fumaroles, etc.). Geophysical methods are used to improve the understanding of the controls on permeability and subsurface fluid flow. To lower resource risk uncertainty, the amount of data collected is less important than the type and quality of the data acquired.[4] However, resource uncertainty and risk will remain high until there are deep wells that actually penetrate the geothermal reservoir.

Figure 4: Resource Characteristics Governing Downstream Development



Source: Hadi et al. 2010

The six resource characteristics listed below and shown in Figure 4 significantly affect the type of geothermal power plant that is appropriate to build on a given field.

1. Reservoir Temperature

In general, the fluids that are withdrawn from the reservoir should have temperatures of at least 120°C and preferably about 150°C to generate electricity reasonably efficiently and at economical cost. However, some new technologies are experimenting with using geothermal waters with temperatures as low as about 90°C to generate electricity.

2. Reservoir Size

Reservoir size or volume is one of the most sensitive parameters of a geothermal resource, and it is usually estimated based on the available "container" (*i.e.*, reservoir area and thickness of the reservoir) and the "filler" (*i.e.*, reservoir porosity). These characteristics are estimated in advance of drilling by combining the results of different kinds of geophysical survey information

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[4] Hadi et al. 2010

data, particularly shallow heat flow, and various potential field surveys. Drilling the first few wells in a project tests the theories about the geometry and characteristics of the resource and provides proof that a commercially exploitable geothermal system exists.

3. Permeability

Reservoir permeability is a measure of how easily geothermal fluids can move through the system. Permeability can be found in “competent” rock units that can sustain brittle fractures, particularly around fault zones. Before drilling is undertaken, exploration data are integrated and evaluated by experts to identify permeable formations or structures that are likely to make good resources. Drilling is the only way available to quantify permeability; the presence of insufficient permeability is a significant obstacle in many geothermal power projects and is one of the greatest risks to determining the size and operating characteristics of geothermal power plants.

4. Enthalpy

Fluid enthalpy describes the amount of thermal energy per unit mass contained in the reservoir fluid and is governed by temperature, pressure, and the fluid’s chemical composition. Enthalpy has a major impact on power plant technology selection, engineering design cost, and the number of wells. Enthalpy can be estimated using chemical geothermometry, but direct measurements of *in situ* fluids are needed to accurately quantify this important parameter.

5. Geochemistry

Geochemical data helps to understand the size and temperature of the geothermal reservoir and thus its suitability for electricity generation. In addition, geochemical studies focus on understanding the geothermal fluid sources and flow paths and on assessing potential operational issues that could come with further development or even, when conditions are optimal, a fully operational power plant. The factors that are considered include, but are not limited to, wellbore scaling, corrosion, and concentrations of non-condensable gases.[5]

Other inferences and conclusions that can be drawn from geochemical data may include parameters such as:

- Estimated resource temperature at depth;
- The genesis or origin of the resource;
- The locations of different aquifers or reservoirs in two and three dimensions;
- Mixing between aquifers;
- Sources of recharge to the geothermal system;
- Pathways of discharge from the geothermal system; and
- The potential for corrosion and/or scaling of the geothermal fluids

In addition, active geothermal features at the Earth’s surface suggest the presence of an underlying subsurface geothermal system. Often the first step in field exploration is to locate and characterize all existing natural geothermal features in the project area’s neighborhood.[6]

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[5] Finger & Blankenship 2010

[6] *Ibid.*

Active geothermal features include any or all of the following:

- Hot/warm springs and seeps (hot ≥ 50°C, warm ≥ 25°C)
- Mineral springs (with conductivity exceeding one standard deviation or more above the background)
- Fumaroles and Solfataras
- Hot/warm wells, including geothermal or groundwater wells
- Gas seeps

Examples do exist where there are no obvious surface manifestations that indicate geothermal resources. These "blind" geothermal systems are typically discovered by drilling, either as part of an exploratory geothermal drilling campaign or when drilling groundwater wells.

6. Topography and Geology

Topography first and foremost controls the location where hot springs develop. As a result, topography can affect how and where a geo power plant developer can drill and how the developer lays out the production and injection wells.

Geology often affects drilling conditions. For example, certain geologic conditions can increase the speed of drilling, the incidence of drilling problems, and/or a power plant's engineering aspects.

1.3.2 Geothermal Drilling Risks

Drilling costs are estimated to account for between 35% and 40% of the total capital costs of an average geothermal power project. A single well may cost between $1 million and $7 million[7] depending on the geographic location, well depth and diameter, and local geology. As a result, a significant financial commitment needs to be made before the characteristics of the resource can be fully known.

As noted previously, there are several ways in which to mitigate drilling risk. A historically popular method is cost-shared drilling, with a government agency and a developer sharing the costs and risks. This approach served as a catalyst for geothermal development in Japan and the United States. Absent such a program, a private sector developer would either self-finance or would enter into an equity partnership to share the drilling risk.[8]

In a few countries, resource risk insurance has been available for geothermal wells, and interest in this geothermal risk mitigation approach is growing. However, since there is little information available for actuarial calculations at the initial exploration drilling stage, this approach is considered to be better suited to later drilling stages, after the resource has been discovered and confirmed.

Geothermal formations exhibit highly disparate and diverse characteristics from field to field and within the same field. To better understand these characteristics, geothermal developers

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[7] IFC 2013

[8] *Ibid.*

typically spend several million dollars on pre-drilling activities, recognizing that this provides information that can significantly improve the odds of success in initial exploratory wells.[9] Pre-drilling activities typically include:

- Detailed geological analyses to postulate the locations and characteristics of permeable formations;
- Additional geochemical work to assess the temperature, pressure and chemical compositions of reservoir fluids and the use of fluid mixing models to postulate fluid flow paths;
- Conceptual modeling to describe the geothermal system as completely as possible, including developing concepts about flow patterns such as “upflow” from the geothermal fluid source, lateral and vertical flow through the system, and discharge to hot springs or sub-surface aquifers; and
- Geophysics to test one or more theories about the controls on geothermal fluid flow and to make appropriate adjustments to the conceptual model.

These detailed analyses can significantly affect the rate of success during the initial drilling campaign. Even when a first well is not successful, the conceptual modeling process provides a basis for understanding the reason for failure, thus improving the odds of success on the second well. The funds required for such detailed analyses can be well spent, because they can be significantly less than those required for drilling even a single, deep, full-diameter well.

The International Finance Corporation funded a study to analyze the risks associated with geothermal drilling. In this analysis, IFC noted that “Of the 52 fields analyzed, the poorest-performing field achieved a success rate[10] of only 35 percent. **However, two thirds of all fields surveyed recorded success rates in excess of 60 percent**. This demonstrates that the probability of success varies widely across fields—a finding which further emphasizes the unique characteristics of individual geothermal fields.”[11]

In addition, IFC found that “In 63 percent of fields, more than 50 percent of wells proved successful in the Exploration Phase,” confirming the high risks of initial drilling. The good news is that the success rate for wells drilled during the Exploration Phase has steadily improved in recent decades.[12]

Lastly, the IFC found that “A success rate of between 60 and 70 percent was found to be the most common outcome for wells drilled during the Development Phase (the median success rate for wells drilled during the Development Phase is 72 percent). In 76 percent of all fields

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[9] *Ibid.*

[10] In the IFC report a well was deemed “unsuccessful” if it met any of the following criteria: (1) unexpected mechanical problems, leaving the well bridged by drill cutting and/or with a collapsed casing; (2) inadequate temperature; (3) too low a static pressure to enable flow at a commercially acceptable wellhead pressure; (4) encountering a reservoir that is too “tight” (*i.e.*, the well has a low Productivity Index); or (5) unacceptable chemical problems (such as gassy, corrosive, or scaling-prone fluids).

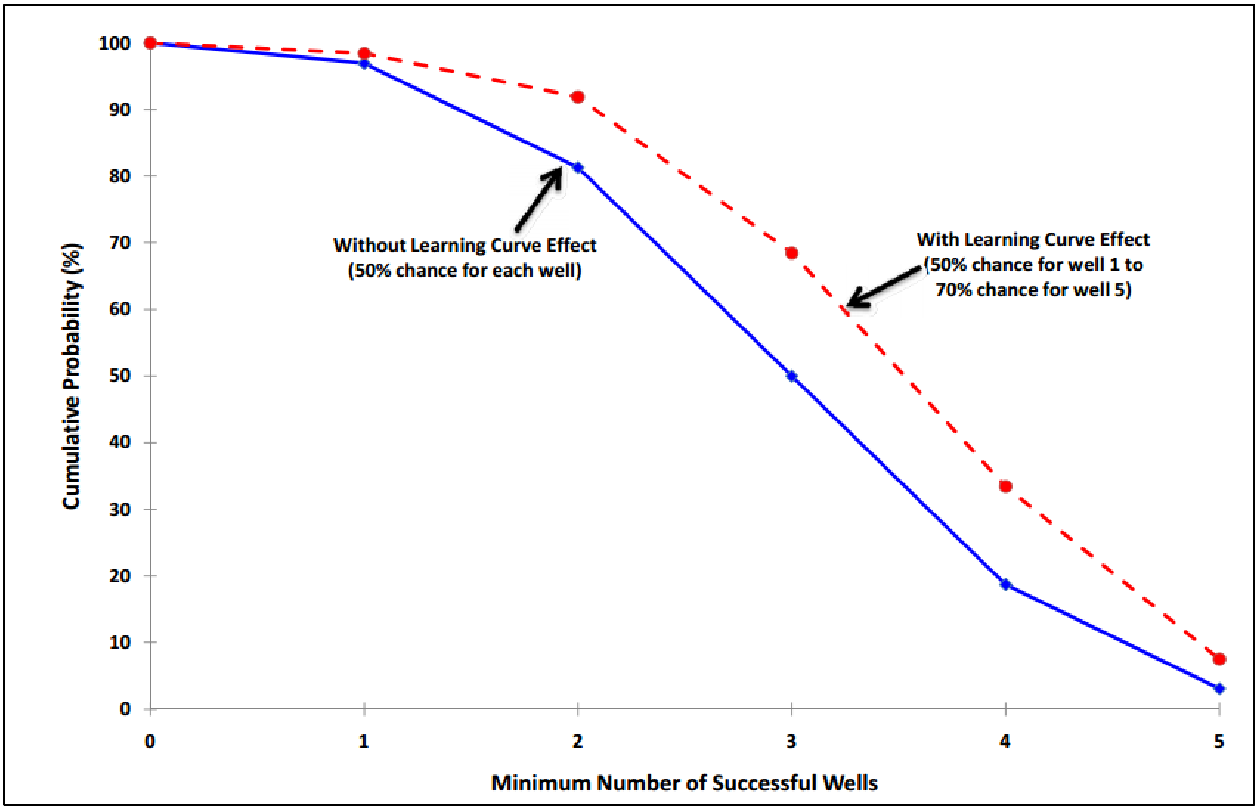
[11] IFC 2013

[12] *Ibid.*

surveyed more than 60 percent of wells drilled during the Development Phase were deemed to be successful."

Figure 5 below is taken from a paper published by GeothermEx that attempts to quantify geothermal resource risk. It shows how the learning-curve effect can improve the probability of success in the confirmation-drilling phase in a hypothetical field. When developers are able to learn from previous information gathered from each well, they can increase their probability of success. For example, Figure 5 indicates that for a five-well drilling program, the cumulative probability of getting at least two successful wells is 81% if there is no learning-curve effect. However, that probability increases to 92% with the benefit of the learning-curve effect.[13]

Figure 5: Hypothetical Example of the Geothermal Learning Curve of a Five Well Exploration



Source: Sanyal & Morrow 2010.

1.3.3 Project Financing Risk

As reflected by EIA's LCOE information in Table 1, geothermal power on a $/MWh basis is less expensive than competing energy technologies. Unfortunately, geothermal power has higher up-front capital costs because of the need to drill wells. These "extra" up-front capital costs essentially represent the advance purchase of the project's lifetime of "fuel" for electricity production.

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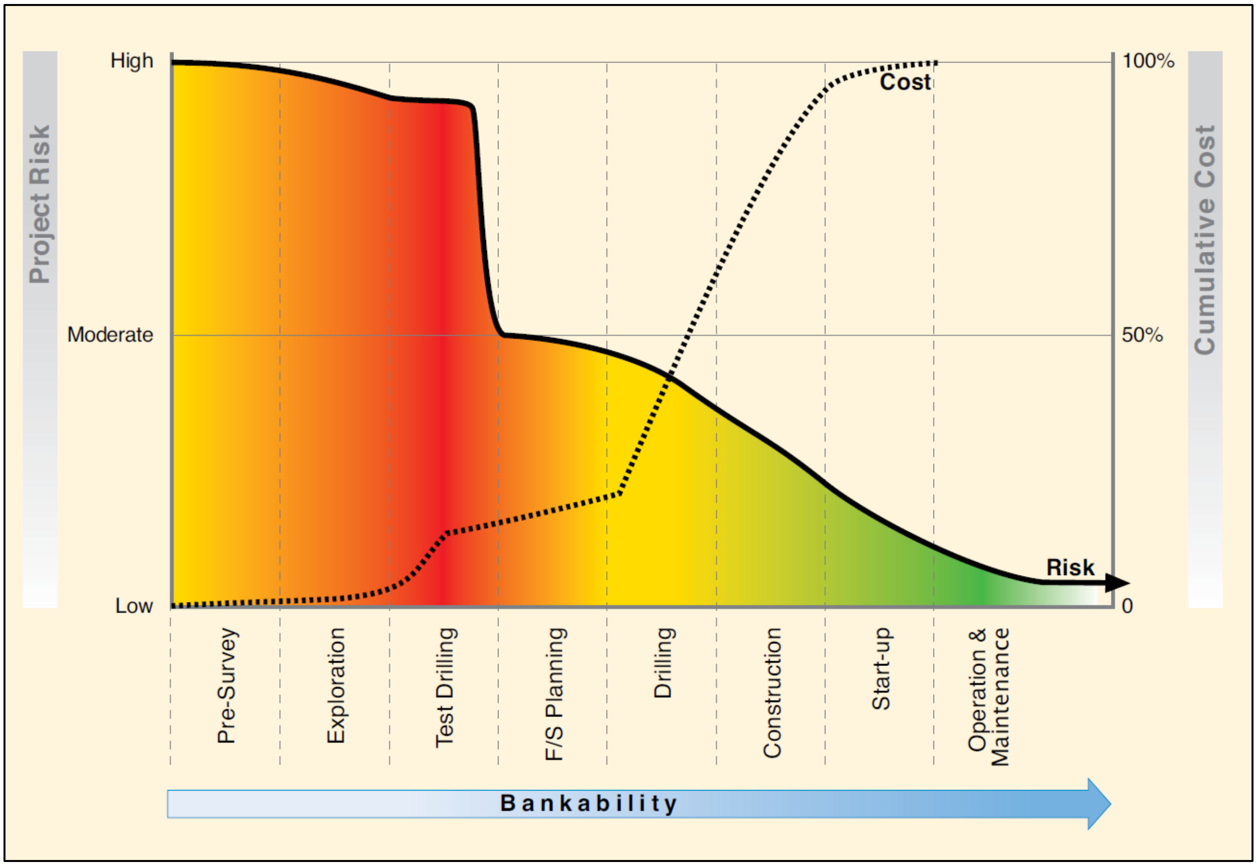
[13] Sanyal & Morrow 2010

The high up-front cost and the relatively long lead time to discover, confirm, and develop the geothermal resource can have an adverse impact on the financing of the project. Additionally, debt financing is typically unavailable during the early phases of the project, increasing the need to rely on more costly options such as equity capital. Even when both debt and equity are available, the high capital requirement and the long lead time drive up the initial project costs, even though the LCOE is reasonable.[14]

Figure 6: Project Cost and Risk Profile at Various Stages of Development



Source: Gehringer & Loksha 2012

The ability of a project to attract financing from commercial sources will gradually improve as each successive development phase brings more positive results and reduces uncertainty. However, resolving that uncertainty comes at a price. At the early stage of geothermal development, investors would require at least venture-level returns on their investment of risk capital that can reach up to 40%.[15] Even large-cap companies may struggle to internally justify projects with risks at this stage. As a result, two groups often conduct geothermal exploration at the earliest stages. The first group consists of well-capitalized, geothermal-focused developers capable of diversifying risk and absorbing the losses related to early drilling risk. The second group consists of equity partnerships or joint ventures in which early drilling risks are shared by multiple parties with a stake in the project.

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[14] Gehringer & Loksha 2012
[15] Taylor et al. 2013

Globally, financial risk is often seen as one of the most significant barriers to the development of new geothermal power projects. Worldwide, many governments, multilateral institutions, and quasi-government agencies have started programs to help lower costs and mitigate risks. The section titled "Past and Ongoing Successful Geothermal Programs to Reduce Risk" presents examples of programs that have reduced the financial risk related to geothermal power development (which is, essentially, the risk related to the geothermal resource itself) through outright funding, cost-sharing and insurance approaches.

1.3.4 Operational & Maintenance Risks

Sustaining Reservoirs

Sustainably managed geothermal reservoirs can maintain energy production for decades and even longer. For example, the Wairakei geothermal power project in New Zealand has generated power since the late 1950s, and The Geysers geothermal field in California has generated geothermal power since 1960. Still, over-exploitation may occur, for reasons commonly related to:

- Insufficient knowledge about the geothermal resource;
- A lack of communication and operational integration of a resource developed by multiple operators;
- The improved cost-effectiveness of larger projects vs. smaller projects (leading to the development of a larger project than can be sustained by the resource); or
- A poor injection strategy.

Any of these factors can lead to greater-than-anticipated pressure or temperature declines, which have the potential to reduce performance and sustainability. Careful monitoring, data collection, data analysis, and reservoir modeling are essential for sustainably managing a geothermal power project.

Changing resource conditions can have an impact on the plant operation and efficiency and may sometimes necessitate a modification to the power system to match the new resource conditions. For example, when The Geysers geothermal field experienced significant pressure decline, many of its power plants were retrofitted to operate at a lower turbine inlet pressure. While they increase the capital and/or operating costs, such modifications facilitate the long-term use of geothermal resources. Another example was the de-rating of the high-pressure steam turbines at the Wairakei project. This occurred a few years after start-up, and steam was re-routed to intermediate-pressure turbines without a substantial loss in generation. The operators of both of these fields responded to changing resource conditions in a way that significantly extended the operating lives and enhanced the sustainability of geothermal power production.

Wellfield Maintenance via "Make-Up Wells"

Geothermal power plants have typical lifespans of 30 years or more, and in many cases, the resource may outlive the power plant. For example, the average geothermal plant in California has already generated electricity for at least 24 years, and most of those plants are still operating today.[16] The geothermal resource must provide geothermal fluid consistently and reliably to the plant during this timeframe. There is a natural rate of resource degradation that occurs during routine operation, leading to the need for additional production and injection wells during the life of the project to maintain generation rates at or near the initial production level.[17] The rate of resource degradation is typically highest during the first few years of production and gradually tapers off thereafter. Implementation of a suitable reservoir monitoring program and the development of a well-calibrated numerical reservoir model are essential for understanding and effectively remedying resource degradation, thus optimizing the use of the resource.

There is a long history of effective geothermal field management. Examples can be found in many fields, including Wairakei and The Geysers, the two longest-running major geothermal power developments in the world. At Wairakei, the initially exploited Eastern Borefield declined significantly, requiring additional drilling of new wells further to the west, first in the Western Borefield and later even further west in the highly productive Te Mihi area, which now provides most of the produced geothermal fluids. At The Geysers, field operators initially responded to pressure and productivity declines by drilling make-up wells. However, this practice eventually stopped due to diminishing returns, and the operators then investigated and implemented major augmented injection programs to successfully replace the produced steam. Other projects have successfully modified their injection strategies (sometimes requiring the drilling of new injection wells) to improve pressure support to the production areas, thus helping to sustain production.

The risks associated with resource degradation, including the proper placement and operation of make-up production wells and replacement injection wells, are best understood and mitigated through the implementation of a robust monitoring program. There is nearly always a program of make-up well drilling anticipated at the start of the project and included in the project’s economic model.

Seismicity

Low levels of induced seismicity can occur in and around operating geothermal fields. This seismic activity has never caused any damage nor impeded any geothermal power project in the U.S. The National Research Council (NRC)[18] found that the seismic events induced by geothermal operations are in most cases is too weak to be detected without a seismometer.

“Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems” notes that the impact of an induced seismic event in a geothermal project is significantly different from those associated with a natural earthquake: in geothermal power projects, seismic activity has been categorized as an annoyance, as with the passing of a rail transit

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[16] Author
[17] Finger & Blankenship 2010
[18] USGS 2012

vehicle or large truck, whereas natural earthquakes have been known to cause damage in moderate to large events. [19]

The moment magnitude (**M**) scale is a logarithmic scale used to quantify the amount of energy released during seismic events. Nearly all seismic events related to production and injection in geothermal fields can only be detected by seismometers and are not generally felt by people because their magnitudes are low (<**M** 2). Occasionally an event with **M** 3 or **M** 4 occurs; these are felt, but are rarely strong enough to cause damage. Damaging natural earthquakes that make major headlines are traditionally **M** 5 or higher. In comparison, induced seismic events that may result from the operation of a geothermal project are 1,000 to 10,000 times weaker than natural earthquakes that make news headlines.

As discussed above, an effective resource management program maintains the balance between production and injection, helping to minimize reservoir pressure and temperature decline. This practice minimizes seismicity,[20] providing another demonstration of the importance of resource monitoring to mitigate geothermal risks.

Geothermal Fluid Chemistry

Although some geothermal fluids may contain potentially damaging chemicals to the turbines, equipment, and surrounding environment geothermal resources have been effectively and safely used for decades, owing to a wealth of information and techniques for mitigating operational issues caused by fluid chemistry. For example in Kenya, some of the geothermal power plants are located inside national parks and safely coexist with the natural fauna and wildlife. Some typical examples of chemical issues are summarized below.

- If Chloride (Cl) in the steam enters the steam turbine, there is a potential for corrosion damage to internal turbine components. This risk can be easily mitigated by the appropriate separator station and steam scrubber design coupled with an effective steam wash program. However, this is not applicable to binary power plants.
- Steam contaminants such as Cl or Hydrogen Sulfide (H_2S) require that portions of the power plant are built with specialized materials to prevent corrosion problems. Sensitive electronics or other copper-containing materials can degrade the presence of H_2S emissions and may require segregation into climate-controlled areas.
- In particular, H_2S discharge from well testing or plant operations also have the potential to create a health risk to the local population and operating personnel; however, existing technology - including the use of well-established systems for H_2S abatement - is available and can readily mitigate this risk.
- The presence of H_2S, NH_4, or N_2 in condensed steam can lead to bio-fouling in condensers and cooling towers, but this risk can be readily mitigated through the appropriate design of cooling and chemical treatment systems.
- Hyper-saline brines (such as those produced in the Salton Sea geothermal field) require robust fluid monitoring and management systems that either keep dissolved solids in

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[19] Majer et al. 2012
[20] NRC 2012

solution or promote and control mineral precipitation. The recovery of valuable metals and elements from geothermal brine is an area of active research and has the potential to add another income stream to a project. The waste product from systems that promote precipitation of solids is tested and disposed of into the appropriate class of landfill.

- The presence of Silica (Si), Calcium Carbonate ($CaCO_3$), or Iron (Fe) in geothermal brines creates a potential for both scaling and erosion of injection system, injection wells, and heat exchangers. Appropriate geochemical assessment and an injectate treatment program can mitigate the risk of damage to the geothermal power plant.
- If a hydrocarbon-based working fluid is used in a binary geothermal plant, there is a risk of air pollution and even fire if there is a leak in the working fluid system. This risk is commonly addressed by routine monitoring using a "sniffer" to detect leaks and by having an adequate fire protection system and operation program. If the working fluid is a refrigerant, geothermal plant operators monitor the system carefully to detect and repair any leaks, thus reducing the high cost associated with replacing these fluids. Experienced designers and engineers can easily engineer a plant and operational practices that minimize volume of fluid used and mitigate potential leakage points.

The long history of geothermal power production and the use of industry-standard monitoring, analysis and abatement techniques have enabled geothermal operators to effectively mitigate the risks associated with fluid chemistry.

Section 2: Past and Ongoing Successful Geothermal Programs to Reduce Risk

Many of the programs summarized briefly in the following section are dedicated to reducing one or two major areas of risk associated with geothermal projects, including exploration, drilling success, and/or the ability to obtain project financing. In many countries, government or quasi-government organizations take on the responsibility of exploration and early drilling, in some cases with grants or loans from multilateral or international institutions, thus reducing the level of risk. For example, the Kenyan government has lead geothermal development, through a government owned company, because the private sector was unwilling to accept the risks of geothermal development.

More favorable economic and political climates in other countries enable private entities to accept and manage the risks associated with geothermal projects. In many cases, these private entities received support from government-sponsored research to address a particular risk prior to development. For example, the U.S. Department of Energy invested heavily in research that enabled the hyper-salinated brine of the Salton Sea to be effectively used for geothermal power production.

Figure 1 at the beginning of this document illustrates the most common geothermal project development and risk-sharing models used around the world.

2.1 A Selection of Government or Quasi-Government Exploration and Drilling Programs

2.1.1 Overview

In some countries, a state-owned agency explores for geothermal resources, then leases the discovered resources to developers to build power plants or sells steam to an Independent Power Producer (IPP) that produces the power, leaving the state entity to supply the geothermal fluid and manage the resource.

For example, the Geothermal Development Company (GDC) is a 100% state-owned company that was formed by the Government of Kenya as a Special Purpose Vehicle to fast-track the development of geothermal resources in the country. This approach has moved the risk of developing geothermal resources away from the private sector and toward the government, which takes on the riskiest part of a geothermal power project to promote the development of an indigenous resource.

In the early stages of its geothermal development, The Philippines adopted a similar risk mitigation strategy. The Energy Development Corporation (EDC), a subsidiary of the Philippine National Oil Company, was set up to explore, drill and develop geothermal projects, later selling steam to IPPs who would generate power. A few geothermal fields in The Philippines were licensed to the U.S. company Unocal Geothermal for all exploration and development.

In Mexico and Costa Rica, the state-owned electricity companies in both countries (Comisión Federal de Electricidad or CFE and Instituto Costarricense de Electricidad or ICE, respectively) took on the development of the resource and the power plant for several geothermal projects. In Costa Rica, the first geothermal power plants were owned and operated by ICE, but additional geothermal power plants are owned and operated by private IPPs. In Mexico, CFE has historically controlled both the resource and the power plant in all geothermal power projects developed to date, but there is a gradual shift to enable more participation by the private sector, and the results of exploration and drilling by CFE are being leveraged to this end.

In other scenarios, governments have mitigated geothermal risks by:

- Providing extensive research data on geology and geothermal resources to developers at no cost (as the U.S. Geological Survey did in its seminal analysis of the geothermal potential of the United States in 1978 [Circular 790]);
- Cost-sharing exploration and early drilling in geothermal fields (as has been done in Japan and the U.S.);
- Mandating attractive feed-in tariffs for geothermal power; and
- Providing loans, loan guarantees, or grants to ease the ability to raise capital for geothermal projects.

Additional details of various geothermal risk mitigation programs are presented in the following sections.

2.1.2 Selected Historic U.S. Exploration & Drilling Programs

United States Geological Survey's Geothermal Resources Studies

In response to the oil crisis of the early 1970s, the U. S. Geological Survey (USGS) conducted research and performed government-funded exploration as part of a program to characterize the nation's geothermal potential. Although The Geysers geothermal field had already begun to produce power in 1960, it and every other known geothermal resource or hot spring area was investigated, characterized and quantified to demonstrate the significant additional geothermal potential in the U.S. The now-famous USGS Circular 790 presented the results. Classification standards for geothermal resources on public lands had already been established by the Geothermal Steam Act of 1970 (Public Law 91-581). The combined impact of the USGS nationwide geothermal assessment and the Public Utilities Regulatory Power Act of 1978,[21] led to a large-scale expansion of geothermal capacity in the U.S. Thus, a combination of policy, legislation and government-funded research reduced risk (or provided a reason to take risk) and catalyzed geothermal development.

The USGS effort was complemented by an interagency effort to support exploration and development of the U.S. geothermal resource base initiated under the Geothermal Research, Development and Demonstration Act of 1974. This included the establishment of an Interagency Geothermal Coordinating Council, which was coordinated by U.S. DOE after it was established in 1977.[22]

U.S. Department of Energy (U.S. DOE) Geothermal Drilling Research Program

Historically, U.S. DOE's research into geothermal drilling technology was conducted mainly through Sandia National Laboratories and has resulted in expertise and technological advancements in the following technology areas:

- Improved drill bits for faster penetration and longer life.
- High temperature downhole instrumentation to monitor the drilling process and evaluate reservoir.
- Rig instrumentation to monitor operating conditions, optimize drilling performance, and identify problems.
- Lost circulation analysis and treatment to mitigate lost circulation through early detection and develop new technology for plugging loss zones.
- Slimhole drilling to enable cheaper exploration with smaller diameter wells.
- Systems analysis to ensure that the right problems are being solved.
- Field operations to demonstrate new technology in real drilling situations.
- Program management to integrate a multi-disciplinary research program.
- Work with industry to develop partnerships, contracts, and cooperative agreements with over 50 companies.[23]

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[21] PURPA required investor-owned utilities to purchase power from IPPs at the average cost of generation in their own systems, with a bonus for renewable power.

[22] Ball et al. 1979

[23] U.S. DOE 2010

U.S. Department of Energy Resource Exploration and Definition Phases I, II, III

In this past program, The U.S. DOE's Geothermal Resource Exploration and Definition (GRED) was a cooperative project between government and industry stakeholders to find, evaluate, and define additional geothermal resources throughout the western United States. The GRED program was unique for its focus on small grants for early exploration. For example, in 2008 the U.S. DOE supported GRED grants to 11 projects within a total budget of $2 million. [24]

The ultimate goal of the program was to increase electrical power generation from geothermal resources by aiding in exploration and development. Funds granted to industry stakeholders reduced the financial risk associated with their project. So far, GRED had three phases (GRED I, II and III) which were effective in establishing new geothermal targets (Figure 8). This program laid the groundwork for many high-priority geothermal targets in the U.S., and some of these are now producing power. The knowledge and information resulting from this program was useful in aiding both DOE and industry parties to reduce many forms of geothermal risk. The small grants from this program reduced the financial risk associated with the necessary research into geothermal resources and technologies to reduce drilling, resource, and O&M risk of geothermal power projects.

Table 2: Geothermal Resource Exploration and Definition Program (GRED) I, II, & III Awardees and Locations

GRED I	Location	State
Presco Energy, LLC	Rye Patch	Nevada
Noramex Corp.	Blue Mountain	Nevada
Utah Municipal Power Agency	Cove Fort/Sulphurdale	Utah
Calpine Siskiyou Geothermal Partners LP	Fourmile Hill	California
SB Geo, Inc.	Steamboat Springs	Nevada
Coso Operating Company, LLC	U-Boat	Nevada
Lightning Dock Geothermal, Inc.	Lightning Dock	New Mexico
GRED II	**Location**	**State**
U.S. Geothermal	Raft River	Idaho
Noramex Corp.	Blue Mountain	Nevada
Calpine Corporation	Glass Mountain	California
Lake City Geothermal, LLC	Lake City	California
AmeirCulture	Animas Valley	New Mexico
Advanced Thermal Systems	Fly Ranch	Nevada
Layman Energy Associates	Truckhaven	California
Northern Arizona University	San Francisco Mountain	Arizona
GRED III	**Location**	**State**
Ormat Nevada	Grass Valley	Nevada
Earth Power Resources	Hot Sulfur Springs	Nevada
Esmeralda Energy Co	Emigrant	Nevada
Noramex Corp.	Pumpernickel Valley	Nevada

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[24] U.S. DOE 2013c

AMP Resources	Cove Fort/Sulphurdale	Utah
New Mexico Tech	Socorro Mountain	New Mexico
Fort Bidwell Indian Community	Fort Bidwell	California
Western Geothermal Partners	Reese River	Nevada
NGP Power Corp.	Upper Hot Creek Ranch	Nevada
Arizona Public Utility Service	Clifton	Arizona
Chena Hot Springs Resort, LLC	Chena Hot Springs	Alaska

Source: U.S. DOE 2010

More information can be found on the Web site of the U.S. Department of Energy Geothermal Technologies Office and in the DOE publication entitled "A History of Geothermal Energy Research and Development in the United States."

2.1.3 Select Current U.S. and International Exploration & Drilling Programs and Initiatives

The National Geothermal Data System (NGDS)

The NGDS is a distributed, interoperable network of data repositories and state geological surveys from across all fifty states and the nation's leading academic geothermal centers. This program reduces both drilling of resource risk by building a large, free, and publically available database of past geothermal information and research. This gives plant developers the ability to acquire previous research easily and accurately determine the optimal location for geothermal power plants.

The system serves as a sharing platform for consistent, reliable geothermal data. The hope is that this aggregated data will support new scientific findings and ultimately broaden the development of commercial-scale geothermal energy production by reducing the up-front risks associated with characterization of subsurface resources. Wider access to distributed data should, therefore, result in lower costs for geothermal development.

The DOE's Geothermal Technologies Office (GTO) funded NGDS to be a free and accessible system to deliver geothermal data for a variety of applications. In the finished system critical geothermal attributes such as temperature at depths, flow rates, and resource characterization will be available to the public.

For more information please visit the National Geothermal Data System Web site.

California's Geothermal Grant and Loan Program

The California Legislature established the Energy Commission's Geothermal Grant and Loan Program in 1980. This program (also known as the Geothermal Resources Development Account, or GRDA), distributes funds to promote the new geothermal technologies and projects. GRDA funds are derived from royalty and lease payments made to the U.S. government by geothermal developers operating on federal land in California. Financial assistance is provided to private and public entities for geothermal research, development and commercialization projects. Since 1980, the Geothermal Program provided funding for over 174 geothermal research, development, and demonstration projects. Additional geothermal program support comes from the California Energy Commission itself, which is funded via a levy on the electricity bills of all Californians.[25]

For more information, please visit the California Energy Commission's Web site.

East Africa Risk Mitigation Facility

Three organizations, the African Union Commission (AUC), the German Federal Ministry for Economic Cooperation and Development, and the EU-Africa Infrastructure Trust Fund via KfW Entwicklungsbank (KfW) have established the Geothermal Risk Mitigation Facility (GRMF) to fund geothermal development in East Africa. The GRMF, launched in April 2012, is providing cost-shared funding for exploration and drilling projects in East Africa, using a current fund of €50 million available to finance exploration. A first round of cost-share grants and loans has been awarded, and a second round is underway.

For more information, please visit the GMRF Web site.

Geothermal Risk Insurance

Geothermal risk insurance insures the productivity of a well or group of wells, providing geothermal developers with a level of financial security for the risk capital needed for resource development, thus facilitating the raising of equity and debt capital. This method is a relatively recent geothermal risk mitigation instrument, and to date, its implementation has been limited by (1) the relatively small size of the geothermal sector and (2) the lack of actuarial data, and the high premiums, which are related to the high level of uncertainty related to exploratory drilling in previously undeveloped fields. As noted earlier in this report, drilling risk insurance is likely to be more appropriate for development drilling, after at least two successfully drilled wells.

World Bank's Global Geothermal Development Plan (GGDP)

Development banks such as the World Bank offer risk mitigation funds to help with development of geothermal resources. In 2013, the World Bank announced a $500 million Global Geothermal Development Plan (GGDP) to better manage and reduce risks of exploratory drilling and help expand geothermal power generation in developing countries. GGDP's initial target is to mobilize $500 million dollars for geothermal projects. The GGDP is to be managed by the World Bank's longstanding Energy Sector Management Assistance Program (ESMAP). The Bank Group's financing for geothermal development has increased from $73 million in 2007 to $336 million in 2012, and now represents almost 10% of the Bank's total renewable energy lending.[26]

The GGDP allows risk to be shared across a wide range of projects while at same time partners are able to fund projects through the modality of their choice, including through contributions to existing international climate finance instruments, additional financing of existing projects, or co-financing of new projects. This method has already begun with the allocation of ESMAP

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[25] Gutierrez 2011
[26] The World Bank 2013

co-funding for the Djibouti Geothermal Power project. Other investment-ready opportunities of the GGDP are in countries which have benefitted from support from the Climate Investment Funds such as Mexico, Turkey, Indonesia, and Kenya.

For more information, please visit the GGDP Web site.

2.2 Standardized Geothermal Reporting Codes and Exploration Practices

National Renewable Energy Laboratory & GTO's Geothermal Regulatory Roadmap

In the past, uncertainty regarding the duration and outcome of the permitting process deterred investment in renewable energy projects, especially geothermal. Reducing the permitting time, or reducing the number of required permits, can significantly lessen total project costs and investor risk, encouraging geothermal developments. NREL & GTO's regulatory roadmap is an ongoing project designed to develop a working guide for agency, industry and policymaker use in an effort to understand regulatory processes and timelines and identify potential areas of concern.

The roadmap, still under development and partially completed for certain states, is divided into three parts. Part one of the Regulatory Roadmap will develop an online set of documents (flowcharts, narratives, and links to supporting documents, Web sites and regulations) that outline the geothermal regulatory process at the state and federal levels. Some states are completed and others are still under development.

Part two will identify regulatory concerns with the permitting and regulatory processes with the end goal of decreasing project risk by reducing delays and costs and eliminating uncertainties and providing greater assurance to stakeholders that the project are conducted in a technically, environmentally, and socially responsible fashion.

The third part will be analyses of best management practices and success stories for the concerns identified. Information and examples will be collected both within the geothermal industry, as well as those in other industries such as mining, oil and gas, and other renewable technologies. These analyses will serve as models for implementation of these practices throughout the geothermal permitting process.

For more information, please visit the Geothermal Regulatory Roadmap Web site.

Reporting Codes

Geothermal reporting codes can help investors understand project risk by establishing standard practices and common reporting procedures for geothermal projects. Adapted from similar codes that regulate the reporting on mineral exploration and development projects, geothermal reporting codes have been developed in Australia (which has <2 MW of geothermal power on line at present) and Canada (which has none). Nevertheless, resource reports prepared according to these codes helps financiers and the interested public to understand the resource potential, viability, and risk of a given project using standard resource quantification methodologies.

No international geothermal protocol has been established because of geothermal resources are unique depending on location. Industry experts believe that each geothermal resource should be evaluated on its own merits and risks and that a standardized reporting code limits the ability to properly present those merits and risks. Nevertheless, a few geothermal resource reporting codes have been produced and presumably have been used as a risk assessment tool by potential investors.

For more information on geothermal reporting codes, please see:

- The U.S. Geothermal Energy Association's "New Geothermal Terms and Definitions"
- The Australian Geothermal Energy Association & Australian Geothermal Energy Group's "Code for Reporting Geothermal Resources and Reserves"
- The Canadian Geothermal Energy Association's "The Canadian Geothermal Code for Public Reporting"

Geothermal Exploration and Drilling Best Practices

In geothermal resource exploration, the high risks necessary for resource determination is one of the key barriers facing the industry. Several published guides describe best practices for geothermal exploration to help geothermal developers understand the most respected and most recognized methods for geothermal exploration. Companies that can demonstrate that their project has followed standardized and accepted exploration practices may find it easier to find project financing.

However, setting up a standard protocol for geothermal exploration is considered by some industry experts to be both too limiting and overly complicated (*i.e.*, it is difficult for the authors of such a protocol to consider every possible case). For example, a developer who seeks to produce geothermal fluids from deep sedimentary basins would use significantly different exploration methodology than would be appropriate in the more "traditional" volcanic terrain.

For more information and examples of standardized exploration guides please see:

- International Finance Corporation's Geothermal Exploration Best Practices: A Guide to Resource Data Collection, Analysis, and Presentation for Geothermal Projects
- U.S. DOE Sandia National Laboratories' Handbook of Best Practices for Geothermal Drilling

2.3 Technological Advancement

Enhanced Geothermal Systems

Enhanced Geothermal System (EGS) projects are those in which the subsurface resource is hot but has low permeability that must be enhanced to yield commercially productive wells. Three EGS categories can be defined: in-field, near-field, and green-field. In-field projects are typified by low-permeability zones within an otherwise productive hydrothermal field. Near-field projects are located on the margins of existing hydrothermal fields, and green-field projects are those with hot rocks at depth but no previous geothermal development.

The goal of these projects is to enhance the permeability of tight rock in the subsurface, thus expanding the portfolio of sites that could be developed for geothermal power. EGS projects are being supported by government R&D organizations in several countries to determine how and where they may be implemented. The hope in the longer term is that new techniques and technologies discovered through these projects could help mitigate risk, reduces costs, and give rise to new untapped geothermal resources. At the moment, many of these techniques and technologies are still demonstration projects.

Past examples of successful demonstrations funded by U.S. DOE using EGS technology to improve existing hydrothermal systems include but are not limited to:[27]

- Ormat Technologies leveraged $5.4 million in U.S. DOE funding matched by $2.6 million in industry investment to increase power output by 38% for an operating geothermal field at Desert Peak, Nevada, generating an additional 1.7 MW of power.
- Calpine Corporation's EGS demonstration in Middletown, California at The Geysers, completed stimulation at an abandoned well in the largest geothermal complex in the world. The new and distinct reservoir that was created has successfully yielded enough steam to produce 5 MW of electricity.
- At the Raft River geothermal field in Idaho, the University of Utah is developing and demonstrating the techniques required to create and sustain EGS reservoirs, including thermal and hydraulic stimulation, with the ultimate goal of improving the overall performance and output of the field.

For more information, please visit the U.S. Department of Energy Geothermal Technologies Office's Web page on Enhanced Geothermal System or DOE's publication titled "A History of Geothermal Energy Research and Development in the United States."

Geothermal Coproduction

According to U.S. DOE estimates, 823,000 existing wells in the U.S. produce hot water concurrent with oil and gas production. The water produced annually by oil and gas fields could generate up to 3000 MW of base-load power using binary geothermal units.[28] In 2012 and 2013, several projects successfully generated emission-free, distributed generation, or co-production projects with low-temperature geothermal resources around the world. The integration of coproduced geothermal power into the power grids provides ample opportunity for new sources of electricity by shifting the supply curve to more geographic locations and scenarios where geothermal power is a viable option for electricity generation.

2.4 Notable Recent U.S. Reports

UNR-DOE-GEA Workshop Report

In September 2010, The Great Basin Center for Geothermal Energy (GBCGE), in collaboration with the U.S. DOE Geothermal Technology Office and the Geothermal Energy Association (GEA),

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[27] U.S. DOE 2013b

[28] U.S. DOE 2013a

convened a 1.5-day workshop of invited geothermal professionals to discuss the state of knowledge of exploration for geothermal resources. Thirty-eight people participated with broad representation by the industry, government agencies, and academic communities. Many of the attendees have a long history and knowledge base in geothermal exploration.

The workshop report reviews the discussion of historical efforts, state of current exploration technologies, and recommendations made by those participating. Notably, first among the recommendations made was:

> "The Department of Energy (DOE) should set a goal of identifying within the next ten years sites capable of producing 50,000 - 100,000 MW of geothermal power (5-10% of total US power generation), utilizing the full range of technologies, through a sustained national exploration effort, significantly supported by long-term federally funded programs."[29]

U.S. DOE Blue Ribbon Panel

In 2011, the U.S. DOE convened a panel of industry and technical experts to make recommendations for its priorities. The "Blue Ribbon Panel" recommended:

> "…that DOE efforts be focused on identifying hidden resources that can increase current geothermal capacity while developing the technology to optimize these resources, and accelerating the development of enhanced geothermal systems (EGS).
>
> Panel members suggested that the Program focus its R&D resources in two major areas:
> 1. Exploration - Reduce the cost of confirming known hydrothermal resources and identifying undiscovered hydrothermal resources to accelerate the growth of the industry in the near term.
> 2. Enhanced Geothermal Systems (EGS) - Prove the technical and economic feasibility of EGS to enable geothermal resources to be a significant contributor to the U.S. energy supply in the long term.
>
> They also recommended that the Program allocate some R&D resources to reducing operations and maintenance (O&M) costs of hydrothermal systems, e.g. more efficient dry or hybrid cooling technologies, and consider creating a dedicated field laboratory to test new technologies, validate reservoir engineering techniques, and gather empirical data on EGS and other geothermal systems."[30]

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[29] Calvin 2010

[30] U.S. DOE 2011

Given the small size of the geothermal industry, it relies more heavily than the oil and gas industry on DOE's research program. The key elements of that program as related to resource risk are characterized above.

For more information, please visit the U.S. DOE Geothermal Technologies Office's Web site.

Section 3: Conclusion

The processes and timelines for geothermal power development are notably different from most if not all other energy technologies. As a result, in the public forum, geothermal power is often grouped in with the other major types of renewable energy and then frequently misconstrued as having similar risks and economics. In reality, the risks and economics of geothermal are unique.

There is a spectrum of development strategies used to lessen the risks associated with initial exploration and drilling caused by geothermal power development. In some countries, the government serves as the resource and power plant developer, essentially taking the risk. Elsewhere, governments fund the initial geothermal exploration and leases already discovered resources to private developers or government entities to build the plants. Then in some countries a private developer takes on a significant portion of the risk and exploration from early exploration to plant operation.

Although an integral part of geothermal power plant is choosing the most economically viable resource from which to extract geothermal fluids and generate power, the biggest uncertainty in geothermal power projects are the size and quality of the geothermal fluids that can be extracted from the underground resource. These resource characteristics affect the design parameters downstream in a plant's development.

While there are higher upfront capital costs with geothermal power, sustainably managed reservoirs can maintain energy production for decades. Careful monitoring, data collection, data analysis, and reservoir modeling are essential for sustainably managing a geothermal power project. Changing resource conditions can have an impact on the plant operation and efficiency and may sometimes necessitate a modification to the power system to match the new resource conditions. However, the lack of fuel and other variable costs give geothermal power an extremely low levelized cost when compared to other technologies.

Many of the programs summarized in this report dedicated to reducing risk focus on one or two major areas of risk associated with geothermal projects including: exploration, technological barriers, drilling success and/or the ability to obtain project financing.

Drilling and exploration risks are two of the largest barriers to the development of conventional hydrothermal systems. Historically, a range of efforts have been initiated to help overcome the hurdles created by these risks. The U.S. provided significant exploration assistance in the 1970s and 1980s, but has focused most of its efforts to data support and EGS in recent years. Internationally, the World Bank, and other international lenders have launched major new initiatives to incentivize new and developing countries to develop their geothermal resources.

In total, about 500 MW of new geothermal power came on line across the globe in 2013, and the geo power industry is poised to place at least 500 MW on line per year in the subsequent years. Recent announcements in the U.S., Ethiopia, Kenya, the Caribbean, and others have increased the developing projects of geothermal power to about 13,000 MW of identifiable projects in some phase of development, on 30,000 MW of geothermal resource in some phase of development globally at the end of 2013.[31] Investment in many of these projects would not be possible without government efforts to mitigate the high risks associated with geothermal power exploration, drilling, and financing.

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