

**“The international geothermal power market is growing at a sustained rate of 4% to 5% per year”**



Geothermal energy is one of the environmentally friendly resources and is suitable for various uses. These resources can be classified according to the type of rock formation and/or form of its liquid and temperature, ranging from 20°C to above 300°C. Hitherto, there has not been a general consensus on ways of classifying geothermal resources and production. However, we understand geothermal resources as being divided into two categories, namely high enthalpy and low enthalpy (based on their energy content). High enthalpy resources above 150°C are usually used to generate electricity with a conventional cycle, while the low enthalpy resources below 150°C are typically used in direct-heat for heating as well as to generate electricity using a binary fluids cycle.

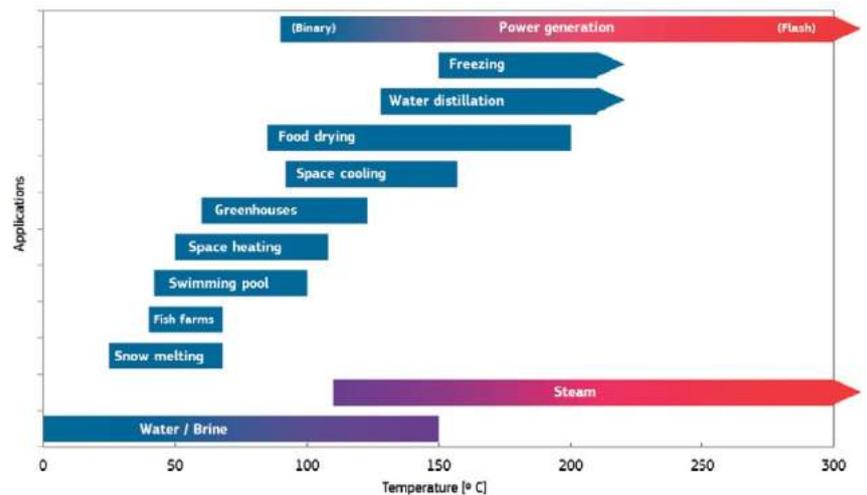
Geothermal heat and power sources vary according to the depths and temperatures. The use of geothermal heat is classified into:

- Power generation
- Direct use
- Ground source heat pumps

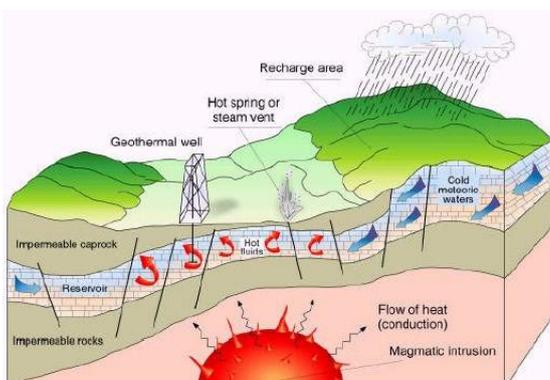
Some important usage of geothermal heat currently present in the market are for power generation, district heating and cooling, industrial processing, greenhouses, de-icing, and spa bathes.

Economically, geothermal power business resembles closer to oil and gas industry rather than to other renewable energy business because the geothermal resources need to be discovered, drilled, and extracted.

**Figure 1.** Temperature of geothermal water and steam suitable for various application (Lindal, 1973)



Source: Joint Research Centre (European Commission)



Source: Geodynamics

Similar to oil and gas resources, geothermal energy is a resource that requires exploration. The difference, however, is that once the oil and gas materials are found, they can be immediately exploited before being sold. Meanwhile for geothermal resources, even after the discovery and drilling processes, they cannot immediately generate return on investment until construction is completed and connected to the power grid. Thus, there would be a significant delay before revenues can be realized.

The cost of geothermal development can hardly be predicted due to the uncertainty in geothermal drilling. In general, the cost of geothermal drilling is the main obstacle in the development of geothermal energy. The drilling cost of a low-temperature geothermal project is typically of around 10% - 20% of the total cost of development, while for high-temperature geothermal field is usually in the range of 20% to 50% of the total costs.



## Competitiveness of Geothermal Energy

For more than four decades, geothermal industry has expanded rapidly and has commercially produced on a scale of hundreds of MW around the world, both for power generation and for direct use. Compared to conventional energy sources and other renewable energy sources, geothermal energy is more competitive because of several features:



- ◆ Can be operated continuously, without constraints such as weather conditions;
- ◆ An energy source that is reliable, safe, and does not require fuel storage or transportation;
- ◆ Efficient and competitive;
- ◆ An indigenous sources of energy that reduced the demand for imports of fossil fuel;
- ◆ Has an inherent storage capability and is suitable for base-load demand;
- ◆ Has a high positive impact on the environment by eliminating the combustion of fossil fuels;

Several studies have shown the economic and industrial potential of geothermal energy as well as its environmental risks (e.g., CO<sub>2</sub> and SO<sub>2</sub> emissions, thermal pollution of seawater). Some indicates that geothermal water used for bathing, cooking, and space heating by the Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori of New Zealand.

The environmental impact such as emission of harmful gases, noise pollution, water use and quality, land use, and impact on natural phenomena, including wildlife and vegetation, must be considered in utilizing geothermal resources. The environmental advantages of renewable energy can be determined by comparing it with the non-renewable energy, for instance, a coal-fired power plant. The latter can produce about 25 times more of carbon dioxide (CO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>) emissions per MWh.

Nevertheless, the content of hydrogen sulphide (H<sub>2</sub>S) from geothermal power plants should also regularly be treated and converted to elemental sulfur since about 0.08 kg of H<sub>2</sub>S may be generated from each MWh of electricity generated. Nonetheless, this figure is significantly lower than oil-fired power plant and natural gas-fired plant, where each generates 814 kg and 550 kg of H<sub>2</sub>S per MWh, respectively. The environmental benefits and sustainability of geothermal energy for electricity production clearly showed a significant reduction in emissions of CO<sub>2</sub>, SO<sub>2</sub>, and H<sub>2</sub>S as well as the very low usage of fresh water compared to oil- and coal- fired power plants.

The first commercially generated electricity using geothermal energy developed in Italy a century ago with a capacity of 250 kWe. Then it followed by: a similar plant at Wairakei (New Zealand) in 1958; an experimental plant at Pathe (Mexico) in 1959; the first commercial plant at The Geysers (United States) in 1960, and at Matsukawa (Japan) in 1966. All of these early plants used the steam obtained directly from the earth (i.e. dry steam fields), except for New Zealand, whom was the first one to used flashed or separated steam to run turbines.

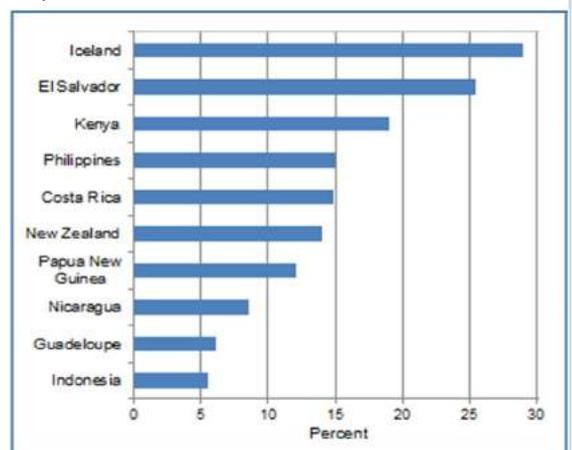
Using a 3 MWe non-condensing turbine, Iceland produced the first power in Namafjall (Northern Iceland). These were followed by plants in El Salvador, China, Indonesia, Kenya, Turkey, Philippines, Portugal (Azores), Greece and Nicaragua in the 1970s and 1980s. Iceland is widely known as the most successful country in the world for geothermal energy development. With just over 300,000 residents, the country is fully powered by various forms of renewable energy, and is the highest ranked country in terms of electricity generation using geothermal resources.

**Table 1.** Comparison of harmful emissions and fresh water usage from different energy sources

Energy Source	in Kg/MWh			in L/MWh
	CO <sub>2</sub>	SO <sub>2</sub>	H <sub>2</sub> S	Fresh Water Used
Coal	994	4,71	-	1370
Oil (& Gas)	893 (599)	-	814 (550)	1170
Geothermal	40 - 120	0,16	0,08	20

Source: *Energies Review*

**Figure 2.** Geothermal Share of Electricity Generation in Top 10 Countries



Source : *Earth Policy Institute*



“ Iceland with about 300k people generates about 600MW of geothermal; about 50% of the generation of Indonesia with 240m people



Typically, we would avoid the need for heat storage in the utilization of geothermal energy such as desalination power generator. Fortunately, the output of geothermal energy sources are generally stable compared to other renewable energy sources such as solar and wind. Geothermal power plant is not affected by climate and season, thus it can be operated at a constant load at day and night throughout the year. Several studies have proven that the soil temperature at a certain depth is relatively constant throughout the year. Ground zones can be grouped into three; surface, shallow, and deep, with geothermal energy sources that are classified according to temperature measured as; low (<100°C), medium (100-150°C) and high (> 150°C).

Meanwhile, the technology of geothermal exploration has been developing rapidly and has a great potential to extract thermal energy at the core of the earth. The direct use of geothermal energy for heating is also commercially competitive compared to conventional energy sources. The use of geothermal heat pumps has an environmental advantage by significantly reduced CO2 emission compared to fossil-fueled boilers by at least 50%. Having said that, renewable energy sources can make a significant contribution to mitigate climate change by reducing fossil fuel usage.

### Geothermal Heat Processing and Technology

Majority of geothermal projects used a mixture of steam and hot water that required a single or double separator system to separate the hot water. In general, high enthalpy geothermal field is only exist in the areas with volcanic activity (the other fields contain a low or medium enthalpy resources). The geothermal power plants currently available are based on the four technology options (Long et al, 2003).

#### ✓ Dry steam plants

Dry steam generators typically use condensing turbines. The condensate is being re-injected back (close cycle) or evaporated in a wet cooling towers. Usually, these plants have a capacity of around 50 to 60 MWe, although currently 110 MWe plants are already exist and operating (EGEC, 2009).

#### ✓ Flash plants

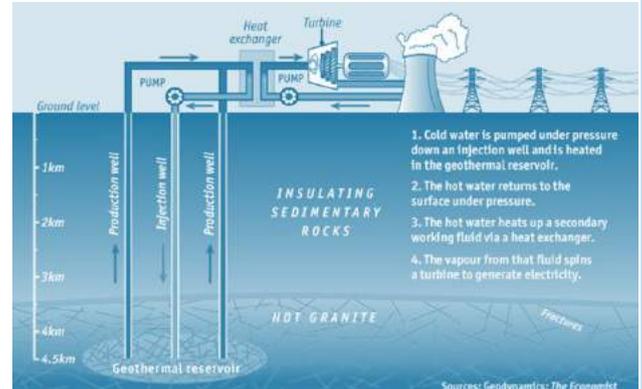
Similar with dry steam plants, geothermal flash plants are used to extract energy from the high enthalpy resources. However, the steam is obtained from a separation process (flashing). The steam is then directed to the turbines and the resulting condensate are then re-injected (further flashing) at a lower pressure. The fluid fraction from the separators and the steam condensate (except for the condensate evaporated in the wet cooling system) is usually re-injected back into reservoir (Fig. 5). The typical size of flash plants are between 2 to 45 MWe.

#### ✓ Binary plants

The binary plants are usually applied to low or medium enthalpy geothermal fields where the resource fluid is used to heat the process fluid by using heat exchangers in a close cycle. The process fluid such as ammonia/water mixtures used in kalina cycles or hydrocarbons used in organic Rankine cycles (ORC) has physical properties (i.e. boiling and condensation points) that match to the geothermal resource temperature.

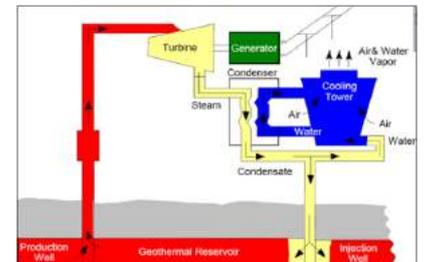
For binary plants, the exhaust resource fluids are often re-injected into the ground with the entire original constituents. Therefore, these plants exclude discharge technologies (Fig. 6). The typical size of binary plants is below 5 MWe.

Figure 3. How engineered geothermal systems work



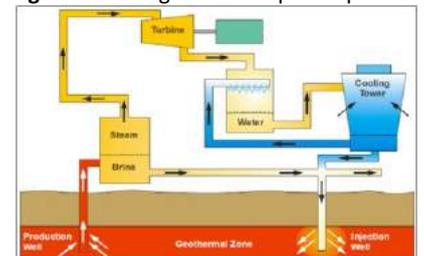
Source: Geodynamics

Figure 4. Direct steam geothermal power generation



Source: ETSAP

Figure 5. Flash geothermal power plant



Source: ETSAP

Figure 6. Binary cycle geothermal power plant

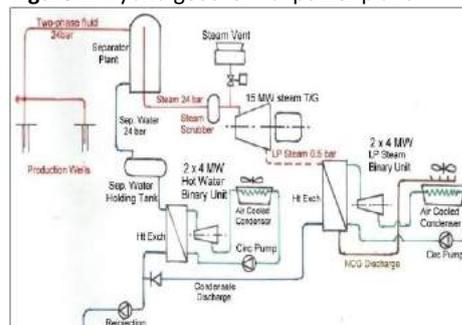


Source: ETSAP

✓ **Combined-cycle or hybrid plants**

The geothermal power plants in New Zealand and Hawaii used traditional rankine cycles at the top end and binary cycles at the bottom end (Fig. 7). The two consecutive cycles provide relatively high electrical efficiency. The typical size of combined-cycle plants ranging from just a few up to 10 MWe.

Figure 7. Hybrid geothermal power plant



Source: ETSAP



“ Governments can either control development & own 100% of resource and power plants or they have to rely solely on the private sector to develop geothermal potential

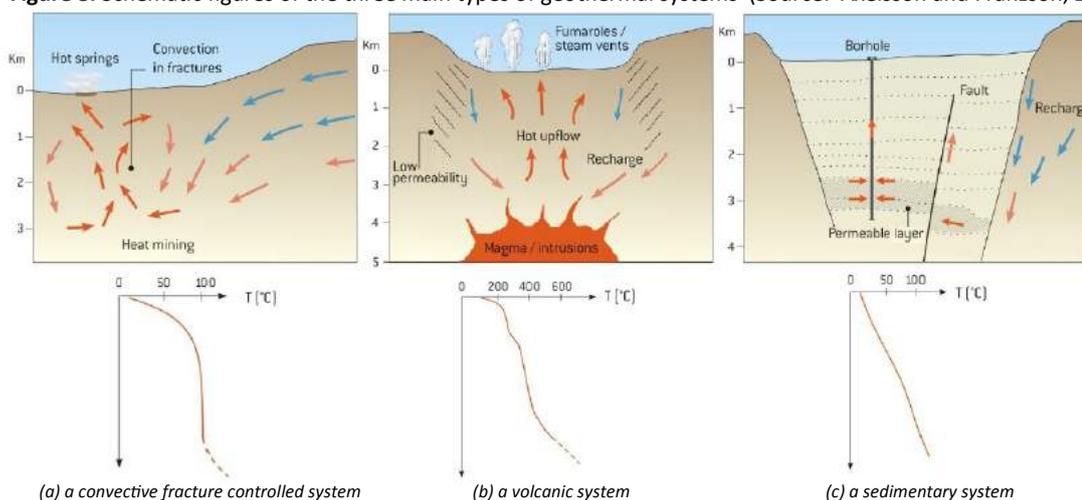
**Geothermal Systems**

The classification of the geothermal systems and reservoirs can be based on several aspects such as reservoir temperature or enthalpy, nature and geological setting, as well as the physical state of the fields. Axelsson (2008) and Saemundsson et al. (2009) have summarized the grouping based on those three aspects, namely the high temperature (>200°C) or low temperature (<150°C) system, liquid-dominated system or vapor-dominated system (or two phases system), and high enthalpy (>800 kJ/kg) or low enthalpy (<800 kJ/kg) system.

Geothermal systems can also be classified according to the nature and geological setting of the fields:

- a. **Volcanic systems** are related to a volcanic activity. The heat sources of the systems are magma or hot intrusions. They are most often located inside, or closed to, volcanic complexes such as calderas and/or heat spreading centers. Fault zones and permeable fractures primarily controlling the flow of water in the volcanic systems.
- b. The heat source of a **convective fracture controlled systems** is the heat crust at the depth that is tectonically active regions with the heat flow above average. To extract heat from rocks, the geothermal water is circulated into a considerable depth (> 1 km), mostly through a vertical fracture.
- c. **Sedimentary systems** found in many major sedimentary basins in the world. These systems exist because of the presence of permeable sedimentary layers at the very deep (> 1 km) depths and above-average geothermal gradients (> 30°C/km). Naturally, this system is conductive instead of convective, though the faults and fractures play some role in cases. Some convective systems can even be embedded in sedimentary rocks.
- d. **Geo-pressured systems** are analogous sedimentary system to geo-pressured oil and gas reservoir where the fluid trapped in stratigraphic traps may have pressure that is close to the lithostatic values. This kind of system is generally deep enough to be categorized as geothermal.
- e. **Hot dry rock (HDR) or enhanced (engineered) geothermal systems (EGS)** is composed of many rocks that have been heated to a sufficient temperature by volcanism or a high heat flow but has a very low permeability or almost water proof. In that sense, they cannot be exploited conventionally. However, a number of experiments have been conducted in some locations using hydro-fracturing to create artificial reservoir in the system, or to enrich existing fracture network. These systems will be mainly used through a combination of production and reinjection wells.
- f. **Shallow resources** refer to the thermal energy stored near the surface of the earth’s crust. Recent developments in the application of ground source heat pumps created a new dimension in utilizing these resources.

Figure 8. Schematic figures of the three main types of geothermal systems (Source: Axelsson and Franzson, 2012)



Source: ETSAP



The development of geothermal power generation has an objective to reduce CO<sub>2</sub> emission from the power system by promoting its benefit including economically and environmentally friendly. Geothermal power plants are designed and built to minimize potential impacts on environment such as wildlife and vegetation. A thorough environmental review is fully required before starting the construction of generators. Subsequent monitoring and mitigation of environmental impact continues throughout the life of the plant.

The development of a large-scale geothermal power generator is generally limited to a tectonically active areas such as regions near plate boundaries, mantle plumes or hot spots, and rift zones. These active and high heat-flow regions includes countries around the 'Ring of Fire', such as Japan, Indonesia, Philippines, Central America, New Zealand, and the US West Coast, while the rift zones including Iceland and East Africa. For the next few decades, these regions are the most promising areas for the development of geothermal energy.

**Table 2.** Summary of Geothermal's Resources and Reserves

	Geothermal Resource			Geothermal Reserve	
	Inferred	Indicated	Measured	Probable	Proven
<b>Commerciality</b>	Commerciality not yet established. Probably feasible with current or future technology, prevailing and/or more favourable market conditions			Commercial. Feasible with existing technology and prevailing market conditions	
<b>Defenition</b>	The Recoverable Thermal Energy with area/volume that has enough direct indicators of Geothermal Resource character or dimensions to provide a sound basis for assuming that a body of thermal energy exists, estimating temperature and having some indication of extent.	The Recoverable Thermal Energy with a more reliability characterised volume of rock than the inferred Geothermal Resource. Sufficient indicators to characterise temperature and chemistry, although with few direct measures indicating extent.	The Recoverable Thermal Energy with a drilled and tested volume of rock within which well deliverability has been demonstrated, with sufficient indicators to characterise temperature and chemistry and with sufficient direct measurements to confirm the continuity of the reservoir.	The part of and Indicated Geothermal Resource for which commercial production for the assumed lifetime of the project can be forecast, or : That part of a measured Geothermal Resource for which commercial production for the assumed lifetime of the project cannot be forecast with sufficient confidence to be considered a Proven Geothermal Reserve. The chance of occurrence is 'more likely than not'	Applies directly to production satisfying all Modifying Factors. Directly related to that part of a Measures Geothermal Resource for which commercial production for the stated lifetime of the project can be forecast with a high degree of confidence.

Source: Australian Reporting Code

### Types of Geothermal Wells

The different types of geothermal wells are as follow:

- Temperature gradient wells** are generally both slim and quite shallow. Usually it is only about 50 meters depths although in some cases it can reach up to several hundred meters. The main objective of this well is to study the shallow temperature conditions (temperature gradient) and estimates the heat flow. In contrast to other geothermal wells, this well can be classified as an exploration tool at surface. Its use has been very effective for the exploration of fracture controlled low-temperature geothermal resources in Iceland, particularly for its hidden geothermal systems.
- Exploration wells** are deeper wells which are intended to achieve a specific target by extending the depth of geothermal systems being explored. Its main objective is to study the conditions of temperature, permeability, and the chemical of the target. There are two forms of exploration wells: (1) slim wells with a diameter of less than 15 cm which are drilled only to determine the depth of the target; (2) full diameter wells which are designed to be production wells. The first can be used to estimate the capacity of production wells while the later drilled to reach the target. The second can be converted into a production wells, but only if the exploration is successful. Slim wells are of course considerably less expensive than full diameter wells and can be considered to be more appropriate when the risk involved is relatively high.
- Production wells** are wells drilled with the sole purpose of enabling the production of geothermal energy from a specific target or a geothermal reservoir (in the form of hot liquid, two-phase mixture, or steam). The design of the well is very important, both to ensure the spontaneous discharge through the boiling reservoir (high temperature reservoir) and for the application of down-hole pump (lower temperature reservoir).
- Step-out wells** can be either exploration or production wells. They were drilled to investigate the extent of geothermal reservoirs which already been confirmed. Step-out wells can be drilled either around/close to the edge/at the boundary of a reservoir or drilled beyond the edge. Numerous step-out wells in different directions may be necessary if the reservoir is in an extensive field.

The design of geothermal power plant gives a minimum visible impact by adjusting the usage of land with the available field. These plants usually consist of small modular plants below 100 MWe, which is much smaller when compared to coal or nuclear power plants of around 1,000 MWe. The geothermal facilities typically used 400 square meters of land per GWh, which is also much smaller when compared to coal facilities that used a larger area nearly ten times per GWh or a wind farm that used three times larger area to generate the same power. The downside is that the subsidence and induced seismicity (i.e. earthquakes) are the two issues of land that must be properly addressed for withdrawals of liquid from the ground. Nevertheless, this can usually be overcome by injecting fluid back into to the same reservoir.

- e. **Make-up wells** are production wells drilled inside an already confirmed reservoir being utilized for energy production, to make up for production loss caused by damages (collapse, scaling, etc.) or declining capacity.
- f. **Reinjection wells** are used to return energy-depleted fluid back into the geothermal system or even inject water from a different origin as supplemental recharge. The location of reinjection wells is variable as reinjection can either be applied inside a production reservoir, on its periphery, above/below/outside the main production field depending on conditions and the purpose of the reinjection.
- g. **Monitoring wells** are used to monitor changes in geothermal systems (mainly after utilization starts) and mostly pressure/temperature changes. In most cases, this is an existing wells such as exploration wells or abandoned production wells. Active production wells sometimes used for monitoring purposes (chemical content, temperature, and pressure). Carefully designed and comprehensive monitoring is the key to management success of geothermal resources during utilization. Monitoring wells are also used to monitor transport of chemicals, such as during tracer tests.
- h. **Unconventional wells** are either wells of unconventional design or wells drilled into parts of geothermal systems generally not used for energy production. A good example is the well of the Iceland, in the deep drilling program (IDDP, 2010). The aim of the program is to drill down to 4–5 km depth at high-temperature volcanic systems, where supercritical fluid conditions were expected. The first IDDP well was, furthermore, drilled into magma at around 2 km depth, i.e. conditions which surely are unconventional.

Each type of wells play a role during different stages of geothermal development as can be seen in Table 3 (example of a geothermal development project plan in Iceland). The plan includes a subdivision of well categories. The success of geothermal development depends on a great extent of drilling success.

### Phases of Geothermal Power Development

Generally, there are five phases in the development of geothermal energy:

- ◆ Exploration and reconnaissance
- ◆ Pre-feasibility
- ◆ Feasibility
- ◆ Detailed design and construction
- ◆ Operations and maintenance

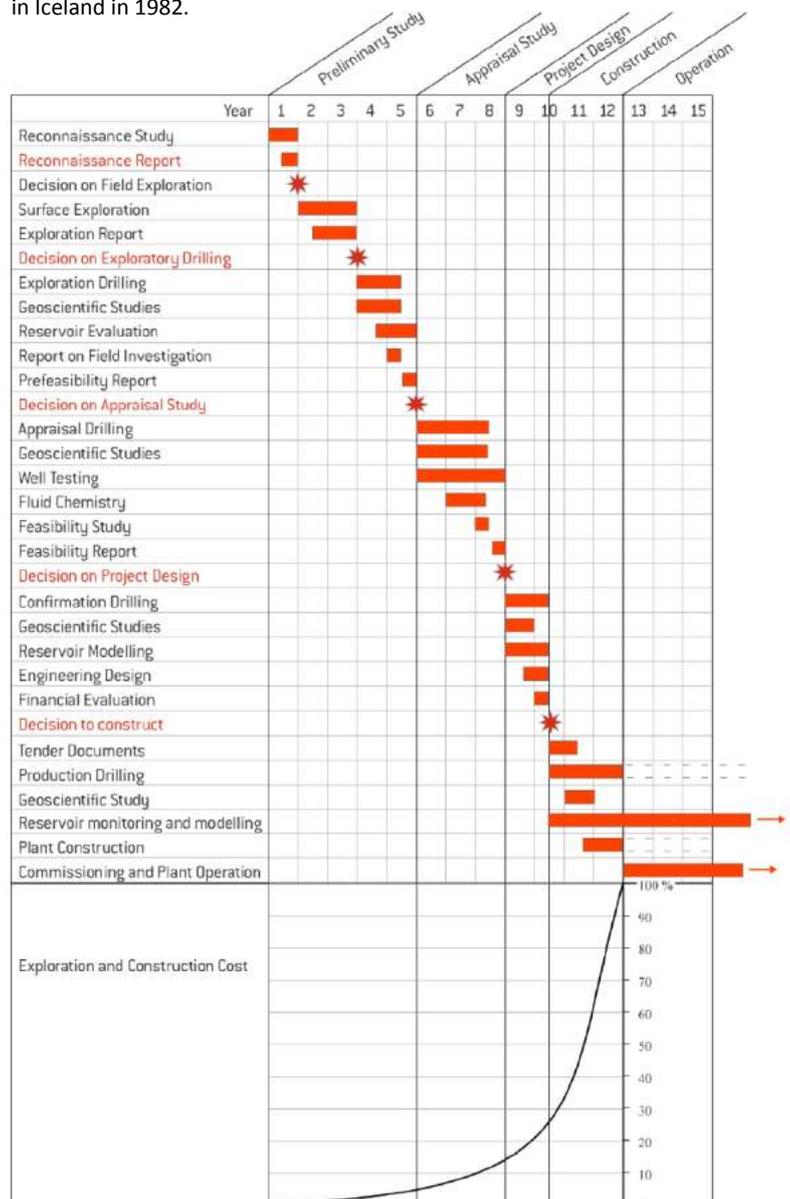
#### Exploration and Reconnaissance Phase

This phase is intended to determine the existence of geothermal resources and whether it can be exploited commercially. The activities include the collection and analysis of all available data about the geothermal field and the surrounding environment in order to determine the resources and the scope of subsequent exploration activities.

The field works required are including:

- ◆ Geological mapping → to recognize the geological structure of the geothermal system;
- ◆ Geochemical analysis of fluids from the surface manifestations or shallow wells → to get an indication of the reservoir's temperature;
- ◆ Geophysical explorations, i.e. resistivity measurements, gravity and seismic profiling → to get better understanding of the subsurface features of the geothermal resource;
- ◆ Shallow drilling of exploration wells (typically 50-300 m) → to measure temperature gradients in order to locate the up-flow zone of hot fluids in the geothermal reservoir.

**Table 3.** Generic project plan for phases of geothermal development proposed in Iceland in 1982.



Source: Steingrímsson et al., 2005

This phase is very important because it can confirm the existence, exact location, and the potential of geothermal reservoirs, as well as the estimated costs. This phase is also expensive, reaching up to USD 15 to 25 million per field, or approximately 10 percent of the total capital expenditure on a new geothermal projects.

### Pre - Feasibility Phase

This phase is carried out after the exploration phase produced a positive result. It focus on the exploration of some favorable location. The typical activities include:

- ♦ More focused geophysical exploration
- ♦ Drilling of slim wells (+300 m)
- ♦ Environmental impacts assessment
- ♦ Drilling of deep exploration well
- ♦ Fluid chemical analysis
- ♦ Production potential assessment
- ♦ Analysis and reporting of pre-feasibility data

### Feasibility Phase

In this phase, the commercial value of geothermal resources will be obtained by the following activities:

- ♦ Environmental impact assessment
- ♦ Drilling of production/injection wells
- ♦ Fluid sampling and chemical analysis
- ♦ Feasibility data analysis and reporting
- ♦ Well testing and well logging
- ♦ Conceptual modeling
- ♦ Production potential assessment (reservoir modeling)
- ♦ Preliminary design of power plant and surface equipment

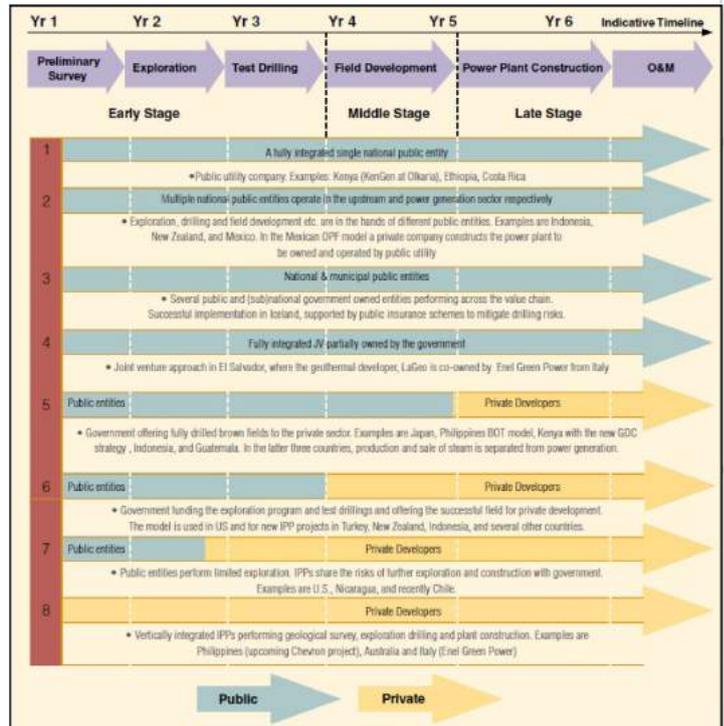
**Table 4.** Typical disturbances by phase of geothermal resource development

Development Phase	Disturbance Estimate per Plant
<b>Exploration</b>	<b>2 – 7 acres</b>
Geologic mapping	negligible
Geophysical surveys	30 square feet <sup>1</sup>
Gravity and magnetic surveys	negligible
Seismic surveys	negligible
Resistivity surveys	negligible
Shallow temperature measurements	negligible
Road/access construction	1- 6 acres
Temperature gradient wells	1 acre <sup>2</sup>
<b>Drilling Operations and Utilization</b>	<b>51 – 350 acres</b>
Drilling and well field development	5 – 50 acres <sup>3</sup>
Road improvement/construction	4 – 32 acres <sup>4</sup>
Powerplant construction	15 – 25 acres <sup>5</sup>
Installing wellfield equipment including pipelines	5 – 20 <sup>6</sup>
Installing transmission lines	24 – 240 <sup>7</sup>
Well workovers, repairs and maintenance	Negligible <sup>8</sup>
<b>TOTAL</b>	<b>53 – 367 acres</b>

<sup>1</sup> Calculated assuming 10 soil gas samples, at a disturbance of less than three square feet each.  
<sup>2</sup> Calculated assuming area of disturbance of 0.05 to 0.25 acre per well and six wells. Estimate is a representative average disturbance of all well sites. Some wells may require a small footprint (e.g., 30x30 feet), while others may require larger rigs and pads (e.g., 150x150 feet).  
<sup>3</sup> Size of the well pad varies greatly based on the site-specific conditions. Based on a literature review, well pads range from 0.7 acres up to 5 acres (GeothermEx 2007; FS 2005). Generally a 30MW to 50 MW power plant requires about five to 10 well pads to support 10 to 25 production wells and five to 10 injection wells. Multiple wells may be located on a single well pad.  
<sup>4</sup> One-half mile to nine miles; assumes about ¼ mile of road per well. Estimates 30-foot wide surface disturbance for a 18-20 foot road surface, including cut and fill slopes and ditches.  
<sup>5</sup> 30 MW plant disturbs approximately 15 acres; 50 MW plant disturbs approximately 25 acres.  
<sup>6</sup> Pipelines between well pad to plant assumed to be ¼ or less; for a total of 1½ to seven miles of pipeline in length, with a 25-foot-wide corridor.  
<sup>7</sup> Five to 50 miles long, 40-foot-wide corridor.  
<sup>8</sup> Disturbance would be limited to previously disturbed areas around the well(s).

Source: Bureau of Land Management

**Figure 9.** Model of Geothermal Power Development in International Practice



Source: Gehring et al 2012

### Design and Construction

This phase will be conducted after the geothermal project has been declared feasible both technically and financially. The power purchase agreement has also been agreed and financing has been secured. The project then progressed to a more detailed design and construction phase through the following activities:

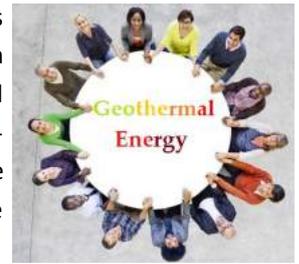
- ♦ Production/injection wells and drilling platform design
- ♦ Drilling of production/injection wells
- ♦ Infrastructure facilities design and civil works
- ♦ Detailed design of power plant and steam gathering system
- ♦ Detailed design of power transmission lines and point of access determined
- ♦ Service providers contracted for detailed design, engineering, procurement, construction and project management
- ♦ Construction of the power plant and facilities
- ♦ Training of operators and commissioning

### Operations and Maintenance

After operational, geothermal power plants will begin to provide a sustainable energy to the clients. If the plant is regularly maintained and accompanied with a responsible reservoir management and utilization, the plants will be able to provide renewable energy in a very long-term of future.

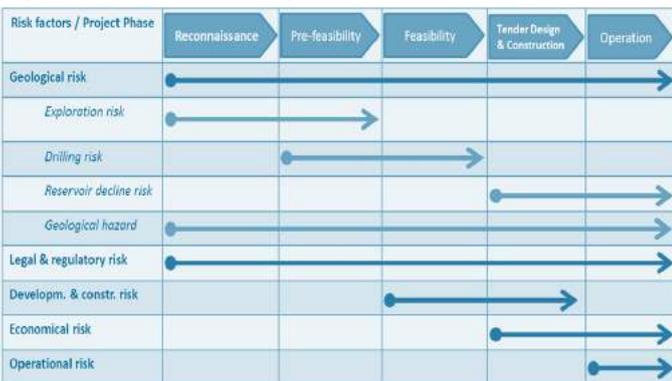


All geothermal projects bear various risks until its resources have been completely proven. The risks referred are covering: natural hazards, reservoir-related, production, technical, financial, and legal in which each of them has different probabilities of occurrence and impacts. Because exploration and drilling has the largest component of upfront investment, the risk of reservoir is significant for geothermal projects investors. This is especially true for low-temperature projects in terms of the unachievable required flow rate that resulting high economic risks, or in this case a total failure of the project.



For an investor or developer, geothermal projects have significant benefits with unique risks. The positive values of geothermal energy include creating employment opportunities, limited land use, and producing a near-zero emission. Many of the unique risks are related to finding, developing, and producing the geothermal resources. Therefore, the policy aimed at incentivizing renewable power for taking a “one size fits all” approach is unsuitable for geothermal investments due to their risk profile.

Figure 10. Characteristics of geothermal risks



Source: Geo-Elec

design parameters of the power plant. Unlike fossil fuels plant where the amount of energy produced from coal combustion can be predicted more accurately, in the geothermal plant, the quality and quantity of resources determines the size of the power plant, the technology to be used, and other technical aspects. Therefore, the quantity and accuracy of information at the early stage of the project will lead to a more accurate reservoir models, thus lowering the risks and uncertainties associated with geothermal power project.

There are six characteristics of geothermal resources which will significantly affect the selection of appropriate type of power plant to be built in a particular field.

### 1. Reservoir Temperature

Generally, the liquid to be extracted from the reservoir must have a minimum temperature of 120°C (preferably around 150°C) to be able to produce electricity efficiently at an economical cost. However, there has been some experimentation of new technologies using geothermal water with temperatures as low as about 90°C to produce power.

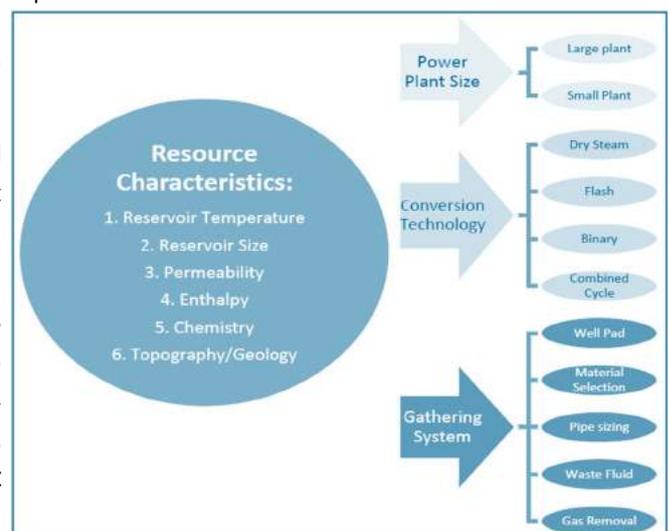
### 2. Reservoir Size

The size or volume of reservoir is one of the most sensitive parameter of geothermal resources and usually estimated based on the availability of the ‘container’ (i.e. the wide and thickness of the reservoir) and ‘filler’ (i.e. reservoir’s porosity). These characteristics were estimated prior to the drilling by combining the results from various types of geophysical survey data, especially shallow heat flow, and various surveys of the potential field. The first several drilling of wells in the project is to test the theory of geometry and characteristics of the resource and provide evidence of existence of commercially exploitable geothermal systems.

The economics of geothermal power is to choose the most economical resource to extract geothermal fluids to be converted into power. Some studies show the cost of drilling will increase exponentially with depth. These days, most of geothermal projects in the world is rarely do drilling with depths deeper than 4 km. Therefore, the project will seek an optimal combination of temperature and permeability sought within this depth range. Figure 11 illustrates the relationship between geothermal power technologies, depth, temperature, and economic feasibility.

The major uncertainty in geothermal development project is the size and quality of the geothermal fluids that can be extracted from geothermal sources. This uncertainty will then affect the

Figure 11. Resource characteristics and project development aspects



Source: Hadi et al. 2010

### 3. Permeability

Reservoir permeability is a measure of how easy geothermal fluids can move through the system. Permeability can be found in rock unit that can maintain fragility of fractures, particularly around the fault zone. Before the drilling is undertaken, exploration data was evaluated and integrated by experts to identify the permeable formations or a structure that makes it possible to have a good resource. Drilling is the only means available to measure permeability. Inadequate permeability is a significant barrier in many projects of geothermal power plants and is one of the biggest risks in determining the size and operating characteristics of the geothermal power plant.

### 4. Enthalpy

Enthalpy of liquid describes the amount of heat energy per unit mass contained in the fluid of geothermal reservoir and is determined by its temperature, pressure, and chemical composition. Enthalpy has a major impact on the choice of power generation technology, engineering design costs, and the number of wells. Although, enthalpy can be estimated using chemicals geothermometry, direct measurements of fluid in the reservoir site is truly recommended to accurately measure this valuable parameter.

### 5. Geochemistry

Geochemical data is used to understand the size and temperature of the geothermal reservoir as well as determine its suitability to generate electricity. Geochemical studies is intended to understand the source of the geothermal fluid and the paths of flow and assess the potential operating issues in the next stage of development or even in the optimum conditions (i.e. when the power plant is fully operated). Factors taken into account in the measurement of geochemical aspects include wellbore scaling, corrosion, and non-condensable gas concentration.

### 6. Topography and Geology

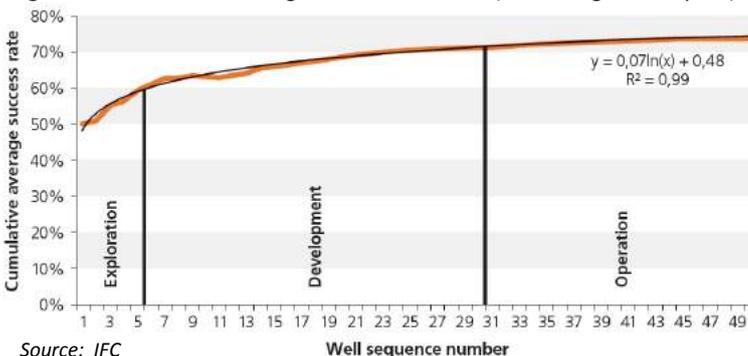
The location where hot springs firstly developed is mainly determined by the topography. Thus, the topography affects how and where the geothermal power plant will be excavated, constructed, and how the arrangement or layout of production and injection wells will be.

## Geothermal drilling risks

On average, drilling costs is estimated to be around 35% to 40% of the total capital cost of a geothermal power project – majority of which will be incurred in the determination of size, location, and power capacity of the geothermal resource. A single project may have cost of between USD 1 to USD 7 million, depending on the geographical location of the resources, geological conditions of surrounding, and the depth and diameter of reservoir. Most of the proposed geothermal projects in Australia require extensive drilling with depths of 3,000 to 5,000m depending on the project geology. This investment will be a loss if later on, no resource is found. For that reason, it is crucial that project developers and financiers have a clear understanding of the level of risk inherent in any specific project in order to assess the value of such project against its cost of capital. Accordingly, it takes a substantial financial commitment before the characteristics of geothermal resources are entirely known.

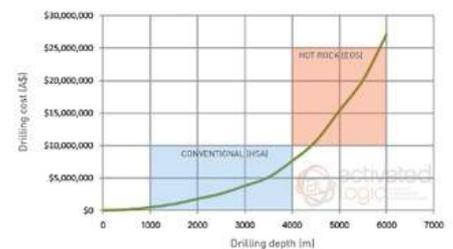
One option to reduce drilling risk is by drilling cost sharing method which is very popular in Japan and the United States as a catalyst for the development of geothermal energy. In this case, the government agencies and developers sharing the costs and risks of the drilling. Without this program, private developers should self-finance the project or enter into equity partnerships in order to share the risks.

**Figure 13.** Cumulative average well success rates (a Learning Curve by IFC)



Source: IFC

**Figure 12.** Estimated drilling cost vs depth



Source: Activated Logic, 2009

Other risk mitigating option is risk insurance of resources for geothermal wells, which are sufficiently developed in a few countries. However, because of the information required for actuarial calculations is limited in the early stage of exploration, insurance approach is considered more suitable for advanced drilling stage, after the resources have been discovered and confirmed. Insurance is only applicable to some risks, not all, and is not available in all countries.

The characteristics of the geothermal reservoir formations are very different from one field to another field even within same field. To have a better understanding about the

formation characteristics, the developer usually spent millions of dollars for pre-drilling activities to increase the chances of success during the initial exploration. A detailed analysis may significantly affect the success rate for drilling plan. Even if the first well is unsuccessful, conceptual modeling process will provide a basis of understanding the reasons for the failure, which can increase the chances of success in the second well and so on. It is assumed that the first well drilled in the field tend to be less successful than the second and the next wells, because the developers will be benefited from a better understanding on the size, location, and the dynamics of the target reservoir obtained from previous drilling.

To assess the success rate of geothermal wells drilling, the International Finance Corporation (IFC) funded a study to analyze the risks associated with geothermal drilling. They developed a global database of wells in geothermal fields which gathered from approximately 71% of the installed capacity of geothermal power plants around the world. This database has been compiled for more than four decades, covering a total of 2,613 wells worldwide.

The key finding of the study is that overall, 78% of wells drilled whose status could be verified, were successful. IFC noted that “out of 52 fields analyzed, the poorest-performing field achieved a success rate of 35 percent only. However, two thirds of all fields surveyed recorded a success rate of above 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.”

There is a strong effect of the learning curve in geothermal drilling. The success rate of well drilled for the first time on average is 50 percent, while the average success rate for the first five wells drilled is 59 percent. This figure increased to 74 percent during the development phase, and further increased to 83 percent for wells drilled during the operation phase. Figure 13 shows the increase in the cumulative average success rate of geothermal wells after the field is developed.

## Geothermal Financing Risks

Although it has a high upfront capital costs, geothermal energy remains cheaper than the competing renewable energy technologies for each MWh of electricity produced. Although it requires high up-front capital costs for well drilling, the absence of fuel costs and other variable costs over a period of more than 50 years over the life of the project, geothermal levelized cost is remained the lowest (USD 89.6/MWh) compared to any other renewable energy technologies with the exception of wind power (3% lower with USD 86.6 / MWh).

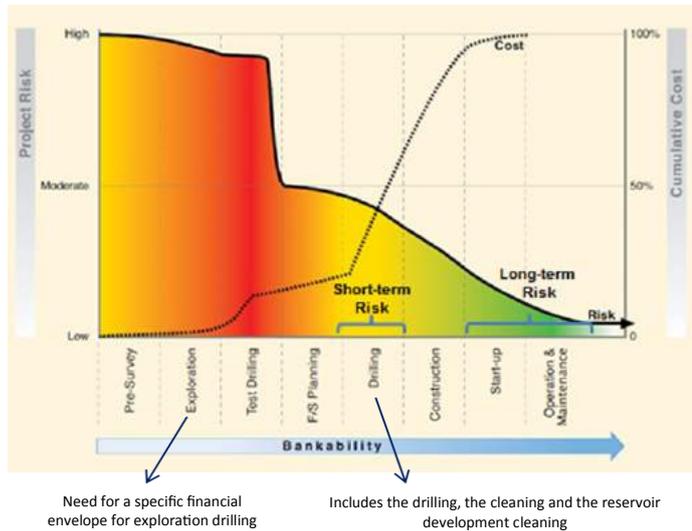
**Table 5.** US Estimated Average Levelized Cost (LCOE) for Plants Entering Service in 2018 [ in USD/MWh]

Plant type	Capacity Factor	Levelized capital cost	Fixed O&M	Variable O&M (incl. fuel)	Transmission investment	Total system levelized cost
<b>Coal</b>						
Conventional coal	85	65.7	4.1	29.2	1.2	100.1
Advanced Coal	85	84.4	6.8	30.7	1.2	123.0
Advanced Coal with CGS	85	88.4	8.8	37.2	1.2	135.5
<b>Natural Gas</b>						
Conventional Combined Cycle	87	15.8	1.7	48.8	1.2	67.1
Advanced Combined Cycle	87	17.4	2.0	45.0	1.2	65.6
Advanced CC with CGS	87	34.0	4.1	54.1	1.2	93.4
Conventional Combustion Turbine	30	44.2	2.7	80.0	3.4	130.3
Advanced Combustion Turbine	30	30.4	2.6	68.2	3.4	104.6
<b>Other Technologies</b>						
Advanced Nuclear	90	83.4	11.6	12.3	1.1	108.4
Geothermal	92	76.2	12.0	0.0	1.4	89.6
Biomass	83	53.2	14.3	42.3	1.2	111.0
<b>Non-Dispatchable Technologies</b>						
Wind	34	70.3	13.1	0.0	3.2	86.6
Wind-Offshore	37	193.4	22.4	0.0	5.7	221.5
Solar PV	25	130.4	9.9	0.0	4.0	144.3
Solar Thermal	20	214.2	41.4	0.0	5.9	261.5
Hydro	52	78.1	4.1	6.1	2.0	90.3

Source: EIA's Annual Energy Outlook 2013

The “extra” up-front capital costs is frequently regarded as a lifetime advance purchase of “fuel” for producing electricity. The high upfront costs and relatively long lead time of projects can have a negative impact on the financing of geothermal projects. Additionally, debt financing is typically unavailable during the early phases of the project, increasing the need to rely more on costly options such as equity capital. Even when both debt and equity are available, the high capital requirement and the long lead time driven up the initial project costs, even though the LCOE is reasonable. Over the time, the project will gradually be able to attract funding from commercial sources because each stage of project development will successively have more positive results and simultaneously reduces the uncertainty of the project.

**Figure 14.** Geothermal’s Unique Risk Profile



Source: Gehringer & Loksha 2012

A price should be paid to overcome the uncertainty. In the earliest stage of geothermal development, the required return on investment of investors can reach up to 40%. Companies with a large capital may struggle to internally justify the project with high risk at this earliest stage. The type of investors that frequently took early stage geothermal exploration are those well-capitalized and geothermal-focused developers that are capable of diversifying risk and absorbing the early losses. The other type consists of equity partnerships or joint ventures where early drilling risks are shared by multiple parties with a stake in the project.

Generally, the financial risk is often regarded as one of the most significant obstacles in the development of new geothermal power projects. Many governments, multilateral institutions, and quasi-governmental agencies have begun to initiate programs in order to reduce the costs and lower the risks through outright funding, cost-sharing, and insurance approaches.

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Any complaint in the process of financing irregularities can be submitted to:

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