Geothermal Technology Brief

Creating Value for Early Stage, High-risk Financing, RET Projects

MAJOR FEATURES AND BENEFITS

- O&M costs are low compared to fossil fuel plants
- With emission control systems, geothermal energy provides an environmentally attractive alternative to base-load gas, oil, coal and nuclear-fueled electricity.
- Commercial geothermal power generation is a mature and established industry around the world, with total plant capacity in excess of 7,000 MW
- In geothermal power plants, the resource determines the maximum temperature at which the cycle can operate and thus to a large extent, the cycle efficiency. Geothermal resources, even the highest temperature ones, produce temperatures far less than those at which conventional power plant cycles operate at.

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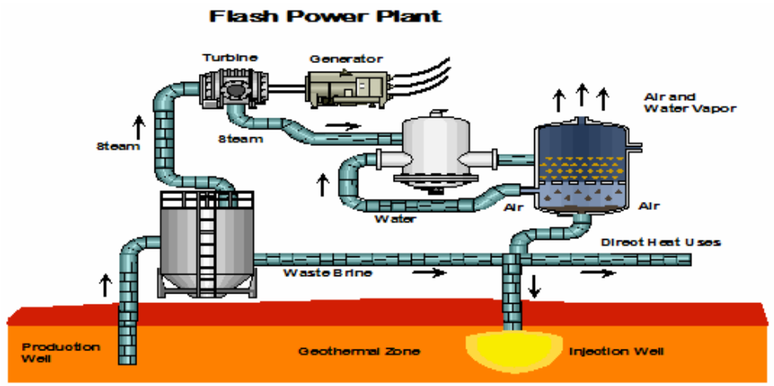

Figure 1: Geothermal Flash Power Plant

Geothermal Resources:

Geothermal resources may be categorized as:

- **Hydrothermal Resources**: *In hydrothermal reservoirs, water becomes heated and then rises until it is either trapped beneath impermeable strata, forming a bounded reservoir, or reaches the surface as hot springs or steam vents.*
- **Hot Dry Rock (HDR) Resources**: *HDR resources are relatively deep masses of rock that contain little or no steam or water, and are not permeable. They exist where geothermal gradients are well above average (>50°C/km).*

Strong Similarities and Differences are:

- Mostly, power plants are similar for both systems
- Well drilling methods a very similar for both systems
- A very important difference is that Hydrothermal systems are commercial today, while HDR systems are not
- Typically and where these have been assessed (such as the US), HDR systems are enormously larger (~3,000 times) than Hydrothermal resources

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Environmental Impact:

- The geothermal fluid may contain substantial amounts of dissolved solids and non condensible gases (particularly carbon dioxide and hydrogen sulfide).
- When the hydrogen sulfide in the gases requires abatement, the geothermal plant must include H_2S control equipment.
- Emissions for binary plants are essentially nil because the fluid is never exposed to the atmosphere.
- By comparison, sludge may be as high as 6 kg/MWh for crystallizer/clarifier technology.
- Geothermal power provides significant environmental advantage over fossil fuel power sources in terms of air emissions because geothermal energy production releases no nitrogen oxides (NO_x), no sulfur dioxide (SO_2), and much less carbon CO_2 than fossil- fueled power.

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Hydrothermal Resource Characteristics:

A geothermal hydrothermal reservoir consists of hot rock with substantial permeability, and aqueous fluid in situ. The temperature of the fluid ranges from 100 ºC to 400 ºC (212 ºF to 752 ºF). The fluid may contain substantial amounts of dissolved solids and non-condensible gases (particularly carbon dioxide and hydrogen sulfide).

Hydrothermal Resource Categories:

Hydrothermal resources are categorized as dry steam (vapor dominated) or hot water resources, depending on the predominant phase of the fluid in the reservoir.

- Dry Steam (vapor dominated) geothermal resources are relatively rare
- Hot Water geothermal resources may further be categorized as:
  - ◊ Low Temperature: <100 ºC (212 ºF)
  - ◊ Moderate Temperature: between 100 ºC (212 ºF) and 200 ºC (392 ºF)
  - ◊ High Temperature: >200 ºC (392 ºF)

Wells for production and injection of geothermal fluids range in depth from 200 to 3,500 meters. The wells are drilled and completed using technology for deep wells that has been incrementally adapted from oil and gas well technology since the 1960's. The produced fluids range from totally liquid to liquid-vapor mixtures (with two-phase flow at the wellhead).

Indicator Name	Units	Generation Plant Technology	
		Flash Plant	Binary Plant
Gaseous			
• Carbon Dioxide	kg/MWh	45	0.0
• Hydrogen Sulfide	kg/MWh	0.015	0.0
Solid			
• Sludge	Kg/ MWh	6.0	0.0

Table 1: Environmental Impacts of Geothermal Plants

Note 1: The zero value for sludge in Table 1 assumes use of "pH modification" technology at locations where silica scaling would otherwise be high.

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TECHNOLOGY OPTIONS:

- ***Direct Steam:*** the geothermal steam, after passing through separators (which remove small sand and rock particles) is fed directly to the steam turbine.
- ***Flash Power Plant:*** The fluid from the well is delivered to a flash tank where a portion of the water flashes to steam and is directed to the turbine.
- ***Binary Power Plants:*** heat is transferred from the geothermal fluid to a secondary working fluid in a closed cycle and with a lower boiling temperature than water. The secondary fluid vaporizes and is used to drive a turbine
- **Advantages of Binary cycle systems:** Electricity can be generated from reservoirs with lower temperature, and the binary cycle system is self-contained and therefore, produces virtually no emissions.

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Performance and Cost Indicators :

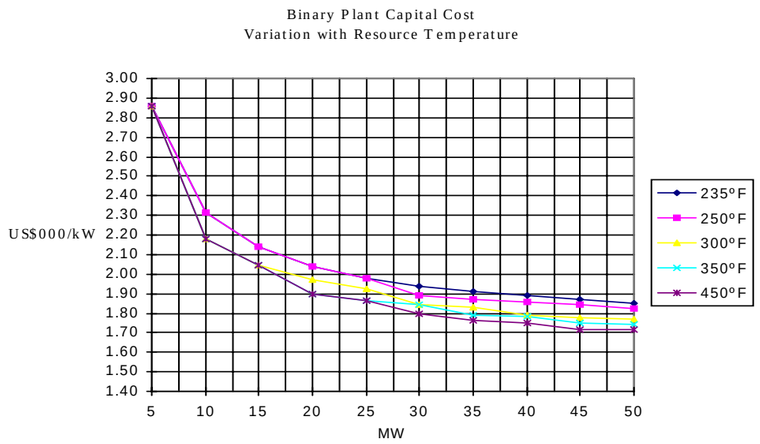

Figure 2: Binary Plant Capital Cost

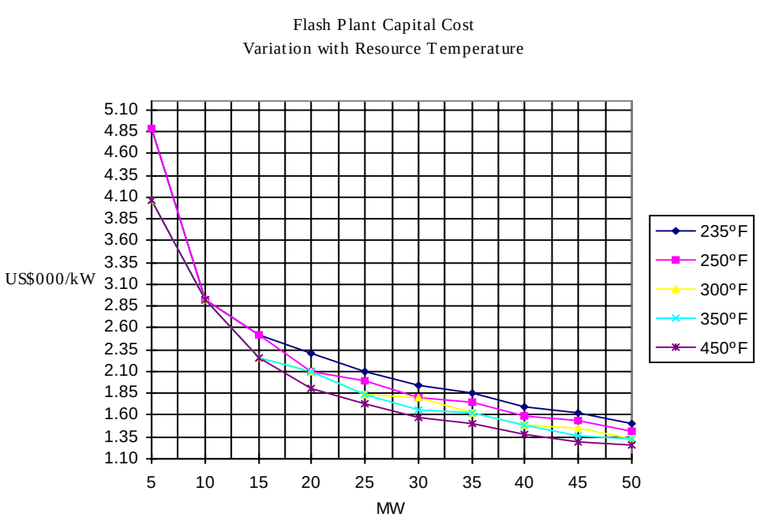

Figure 3: Flash Plant Capital Cost

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TECHNOLOGY ISSUES:

- For moderate temperature resources, Binary Technology is more efficient
- Flash power plants use high-temperature hot water and/or steam
- Current secondary fluids for binary plants are hydrocarbons (isobutane, pentane, etc) of HFC type refrigerants with the specific fluid chosen to match the geothermal resource temperature.

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O&M COSTS:

Geothermal O&M Costs by Plant Size			
Cost Component	**Small Plants (<5MW)**	**Medium Plants (5-30MW)**	**Large Plants (>30MW)**
	(US cents/kWh)		
Steam Field Field O&M and Rework Makeup Wells Relocate Injection Wells	0.35-0.70	0.25-0.35	0.15-0.25
Power Plants	0.45-0.70	0.35-0.45	0.25-0.45
Total	0.80-0.14	0.60-0.80	0.40-0.70

Table 2: Typical O&M Costs by Plant Size

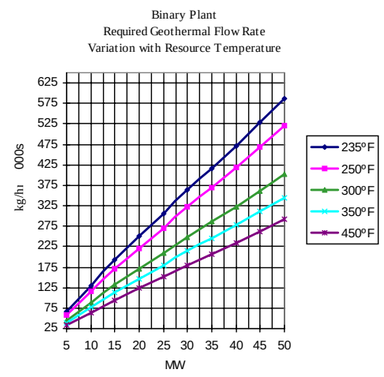

Figure 4: Binary Plant: Typical Geothermal Flow by Plant Size

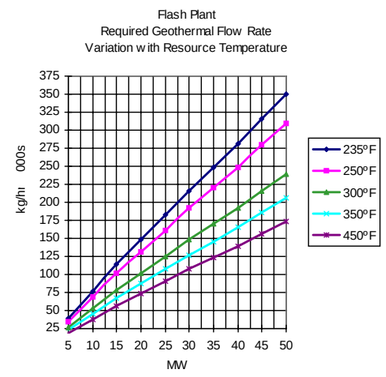

Figure 5: Flash Plant: Typical Geothermal Flow by Plant Size

Notes on Performance & Cost Indicators:

- Plant construction period is assumed to require 10-18 months
- Values depend highly on reservoir temperature, geology and hydrology
- Uncertainty in cost per unit well may be in the range of ±15%
- Plant net effectiveness continue s to improve due to better matching to reservoir conditions
- Plant O&M cost is expected to continue declining with increasingly higher degrees of automation