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HIGH TEMPERATURE GEOTHERMAL POWER PLANTS AND OVERVIEW OF WELLHEAD GENERATORS

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ABSTRACT

Utilization of geothermal resources is largely dependent on the resource temperatures. High temperature geothermal resources are commonly used for power generation by conventional geothermal power plants. Medium temperature geothermal resources are also used for power generation through binary power plants. Low temperature geothermal resources are commonly used for direct applications such as heating and recreation.

1. INTRODUCTION

Geothermal energy refers to the heat energy that emanates from beneath the earth's crust. The molten interior of the earth contain infinite amount of heat that occasionally find its way to the surface in the form of volcanic eruptions. During volcanic activities, some of the molten rocks remain within the earth's crust and because the crust is a poor conductor of heat, the molten rocks cool slowly thus providing accessible heat that constitute geothermal energy (Dickson and Fanelli, 2004).

After drilling of geothermal wells, they have to be subjected to a series of tests to determine their potential outputs and the nature of the reservoir that the well has intercepted. By testing the potential outputs of the well, the kind of utilization suitable for the well can be determined. High temperature resources ($> 200^{\circ}\text{C}$) are suitable for high temperature geothermal power plants and high temperature industrial uses. Low temperature geothermal resources ($< 100^{\circ}\text{C}$) are suitable for direct uses (recreation, heating and drying).

High temperature geothermal power plants are energy converters that convert high temperature geothermal energy to electricity. The plants use steam turbines to convert the heat and pressure energies in the steam to mechanical energy. The generators then convert the mechanical energy to electrical energy.

This paper discusses the types and processes of high temperature geothermal power plants. The paper also presents wellhead generation concept as a type of high temperature geothermal power plant. In the paper, chapter 1 discusses the post drilling well tests, the method and objectives of the tests. Chapter 2 discusses

the decision processes for the utilization of the geothermal resources acquired. Chapter 3 discusses the principles of steam turbines used in high temperature geothermal plants. Chapter 4 discusses the high temperature geothermal power plant processes. Chapter 6 presents a case for the wellhead generation technology. The last part of the paper takes a look at the future of geothermal power generation and gives conclusions.

2. POST DRILLING WELL TESTS

Upon completion of drilling of a geothermal well, several tests must be conducted to determine the reservoir characteristics intercepted by the well and the production potential of the geothermal well (Geothermal Resource Group, 2012). The following post drilling well tests are normally conducted:

1. Completion tests;
2. Heat up tests;
3. Discharge tests;
4. Shut in tests;
5. Post discharge tests – profiles;
6. Interference tests; and
7. Tracer tests.

2.1 Completion tests

These tests are conducted immediately after drilling before the well is capped (master valve installed). The tests include conducting pre-injection temperature and pressure profile to establish the feed zones, heat up temperature and pressure profiles to confirm the feed zones and determine rate of recovery and maximum temperatures as baseline, Injection capacity tests to estimate permeability and storage capacity of the reservoir (size of reservoir)

2.2 Heat up tests

Heat up tests involves conducting down hole pressure and temperature profiles over the period the well is heating up after drilling. The heat up tests are conducted at intervals normally takes a minimum of 28 days but could take longer depending on the rate of heating up of the well. It is normally conducted until the well is fully heated up with no more changes in the down hole pressure and temperature profiles. The heat up tests is conducted to monitor the rate of recovery of the well which gives an indication of the potential of the reservoir. The heat up down hole pressure and temperature profiles also help to establish the static formation temperature of the reservoir.

2.3 Discharge tests

Discharge tests are conducted once the well has fully heated up. The objective of discharge tests is to measure the discharge characteristics of the well under different discharge pressures. During discharge testing, the well is normally discharged through portable silencers. The common method of measuring the well discharge is the Russel James lip pressure method in which different sizes of discharge pipes are used to vary the discharge pressures of the well. Other measurement methods include use of different sizes of orifice plates or tracer flow method.

Where the well has low pressure and cannot self discharge, it is stimulated to discharge by compressing the well in order to air lift the well fluids or pouring detergents to lower the density of the well fluids. Sometimes the well fails to discharge and can be used for re-injection.

2.4 Shut in tests

After the well has been discharge tested and its output potential determined, the well is shut in (master valve closed) to await decision on its utilization. Immediately the well is shut in, the down-hole pressure and temperature profiles are taken to establish a baseline to be used for monitoring of future changes before and after commercial production.

2.5 Other tests

Besides the tests above, additional tests can be carried where there are more than one well drilled. They include interference tests to determine shared reservoirs where neighboring wells are monitored while one well is discharging. Tracer tests where a tracer chemical is injected in one well and samples taken from neighboring wells and analyzed for returns of the tracer chemical. Tracer tests are commonly used to select injection wells.

3. DEVELOPMENT PLANNING AND DECISION MAKING

After confirmation of the potential of the well or group of wells through discharge tests, the field developer will have to decide and plan for its utilization. In doing this, the developer will have to take into account:

- ✓ Resource constraints
- ✓ Financial constraints
- ✓ Logistical constraints
- ✓ Time constraints

Utilization of a geothermal resource is mainly dependent on the temperature of the resource. High temperature resources ($> 200^{\circ}\text{C}$) are commonly used for high temperature geothermal power plants and high temperature industrial applications. Medium temperature resources ($< 100^{\circ}\text{C} > 200^{\circ}\text{C}$) are commonly used for Binary power production and industrial uses. Lower temperature resources are commonly used for direct uses (Geothermal Education Office, 2011).

The Lindal diagram shown in Figure 1 provides a guideline to potential uses of geothermal resources based on resource temperatures.

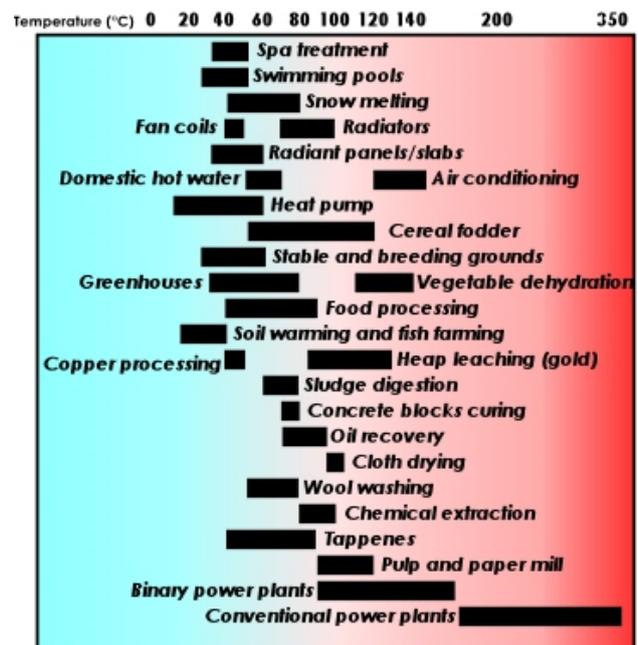


FIGURE 1: Lindal Diagram showing different applications of geothermal resources based on temperature

4. PRINCIPLES OF OPERATION OF STEAM TURBINE

High temperature geothermal power plants use steam turbines as the prime mover. Steam turbines operate on the principle of the Rankine Cycle. Steam expands through a series of rotating and stationary rows of blades and in the process part of the energy in the steam is converted into mechanical energy. Not all heat energy received by these plants can be transformed into mechanical power, according to the laws of thermodynamics. There is always heat rejected to the environment as illustrated by the thermal cycle Figure 2. The amount of steam energy that can be converted depends on the isentropic efficiency of the steam turbine. This efficiency is governed by the minimum possible exhaust conditions of the steam (exhaust steam quality).

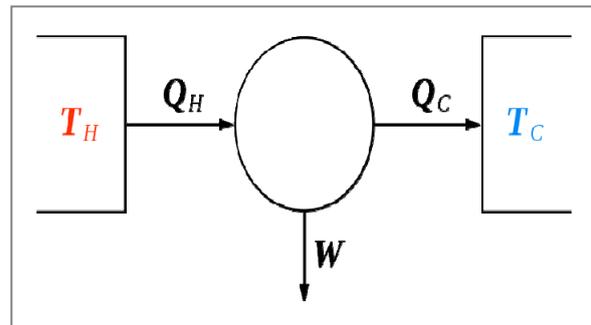


Figure 2: Thermal Cycle showing heat flow through an energy conversion system

Steam turbines operate with dry steam because wet steam is detrimental to its blades which are expensive to replace. Blades of modern steam turbines are normally lined with expensive material that is more resistant to corrosion and erosion and this allows the steam flowing through the turbines to be expanded to a much lower exhaust pressures (wet regime) (Kapooona et al., 2008).

The mechanical energy is converted into electrical energy via a dynamo (generator) that is driven by the turbine. The process is illustrated by Figure 3 below.

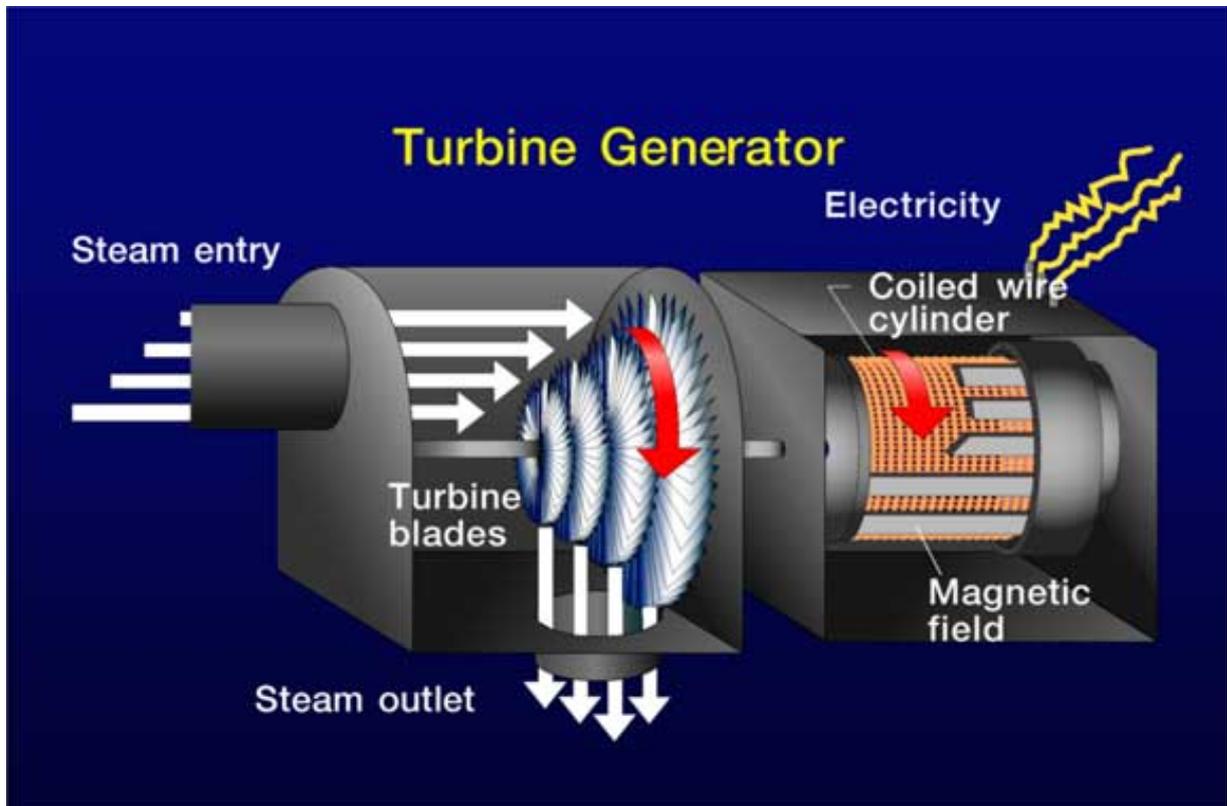


Figure 3: Illustration of the energy conversion process through a Turbine-Generator

5. TYPES OF HIGH TEMPERATURE GEOTHERMAL POWER PLANTS

High temperature geothermal power plants are classified according to the type of geothermal fluid produced by the well(s). Where the well(s) produce dry steam only, the power plant is referred to as dry steam power plant. There are very few geothermal fields that produce dry steam geothermal fluids. Where the well(s) produce a mixture of steam and brine (water), the power plant is referred to as flashed steam power plant. In flashed steam power plants, the mixture of steam and brine is separated using suitable separators and the steam transported to the power plant for energy conversion (Geo-Heat Center, 2013). Most geothermal fields worldwide produce mixture of steam and brine. The two types of power plants are illustrated by Figure 4.

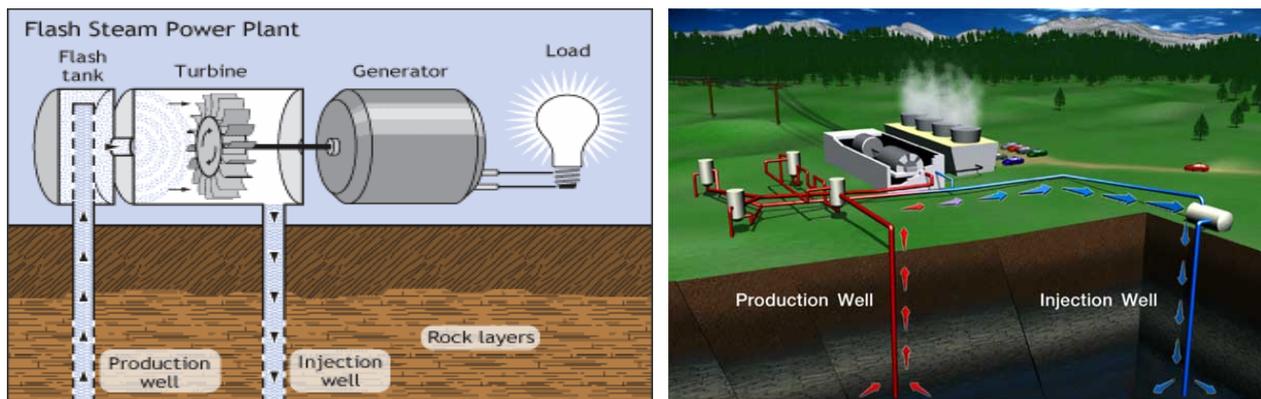


FIGURE 4: Dry Steam power Plant and Flashed Steam Geothermal Power Plants

6. DESCRIPTION OF HIGH TEMPERATURE GEOTHERMAL POWER PLANTS

6.1 The Process

The fluid from the well(s) is received at the surface into surface equipment. Where the fluid consists of dry steam only, the steam is transmitted through insulated steam pipes to the turbine. Where the fluid is a mixture of steam and water (brine), the two fluids are separated and the steam transmitted to the turbine. Where the fluid consists of high temperature, high pressure water, part of the water is flashed into steam by reduction of pressure and the steam separated from the remaining water and the steam transmitted to the turbine for energy conversion.

Steam is normally transmitted using insulated steam pipelines that are designed to minimize pressure and heat losses. Drain pots and steam traps are normally installed along the steam pipelines to collect and remove any condensate that forms on the steam pipeline. Interline pressure controllers are installed at the power plant interface to maintain desired steam pressure and protect the system against unexpected steam pressure surges. The desired steam pressure is set by desired design turbine inlet pressure.

The steam enters the turbine through governing valves and enters the turbine nozzles that direct the steam into the first row of rotating blades. The first rows of rotating blades are impulse type followed by impulse-reaction types of blades. The steam then expands through the series of alternating rotating and stationary blades through which part of the energy in the steam is transformed into mechanical energy by rotating the turbine rotor. The turbine rotor in turn rotates the generator which transforms the mechanical energy into electrical energy. The steam exits the turbine with reduced energy and is exhausted into a condenser where it is condensed into liquid. The condensers can be direct contact (mixing of steam and cooling water) or indirect contact (no mixing). For back pressure turbines, the exhaust steam is rejected

into the atmosphere. Back pressure turbines are less efficient and are not commonly used (Kapoor et al., 2008).

The condensate formed in the condenser is pumped to a cooling tower where it is cooled down and circulated back into the condenser to provide continuous flow of cold water for condensing the exhaust steam. Cooling towers can be wet type, air type (dry) or hybrid. The choice depends on the need to conserve water and the ambient conditions of the location of the power plant. Excess condensate can be pumped for disposal (injection) or for other water uses.

Geothermal steam consists of varying quantities of non condensable gases. For condensing turbines, these gases must be removed from the condenser in order to sustain the performance of the condenser. Gas extraction systems are installed to remove these gases from the condenser.

All the processes above work in tandem and are normally monitored and controlled via a centralized control system. Figure 5 illustrates the processes of a high temperature geothermal power plant.

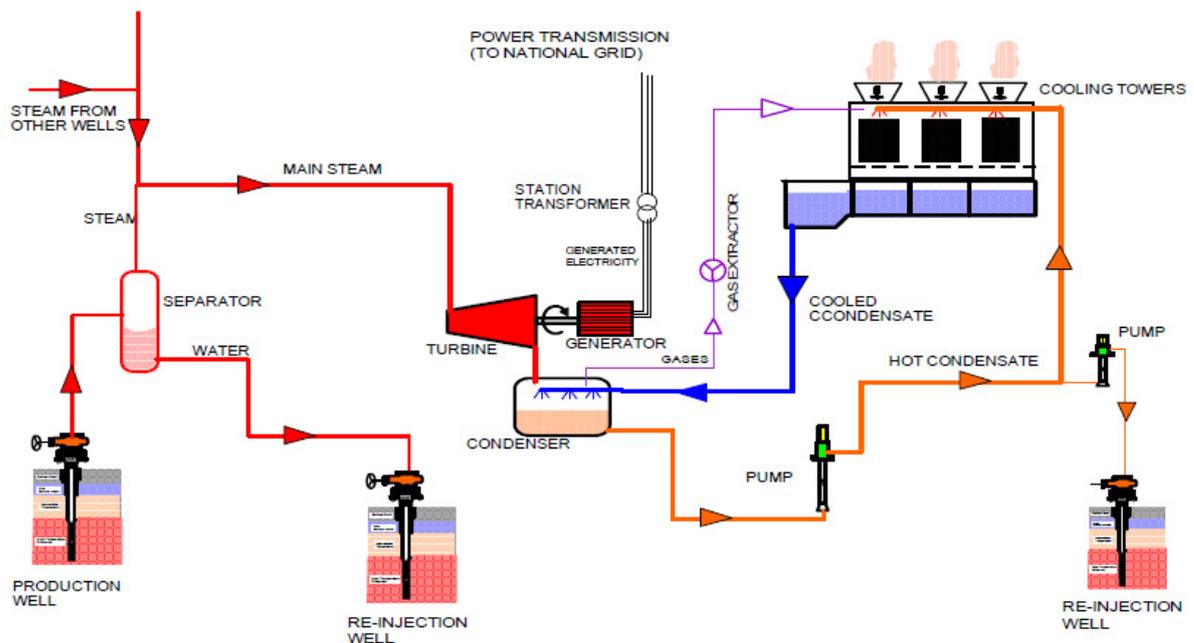


FIGURE 5: Processes of high temperature geothermal power plants

6.2 Main systems of a high temperature geothermal power plant

High temperature geothermal power plants consists of a number of interconnected systems that work in tandem to convert the heat energy of the geothermal fluids into electrical energy. The main systems are described below:

6.2.1 Steam Supply System

The steam supply system starts from the well to the turbine inlet. The system receives the fluids from the well, processes the fluid to provide steam and disposes the brine and condensate. The function of the

steam supply system is to collect the fluids from the wells, separate the steam from the brine and efficiently transport the steam to the power plant for energy conversion to electricity. The main components in the steam supply system include the following:

1. The well(s) – the wells are the source of fuel for the power plants;
2. Separators – a type of pressure vessels installed at the well pad or at a central point in the steamfield to separate steam from brine. The most common type of separators are the cyclone type;
3. Steam transmission – network of insulated carbon steel pipes that transport the steam from the separator to the power plant; and
4. Pressure controllers – these are installed on the steam pipeline to control the steam pressure and maintain desired pressures in the steam supply system.

6.3 The energy conversion system

The energy conversion system converts some of the energy in the steam into electrical energy. The main components of the energy conversion system include:

1. Turbine – this is the prime mover for the power plant. The turbine converts the heat energy in the steam into mechanical. The turbine in turn drives the generator electrical energy;
2. Generator – converts the mechanical energy generated by the turbine into electrical energy; and
3. Exciter – provide excitation power to the generator.

6.4 The cooling system

The cooling system is used to cool down the condensate from the turbine to provide continuous flow of cold water for condensing the steam. The cooling system consists of the following main components:

- a) Condenser – cools the steam exiting the turbine;
- b) Cooling Towers – cooling the condensate from condense; and
- c) Circulation Pump – circulate the condensate to the cooling towers.

6.5 Gas extraction system

Geothermal fluids contain non condensable gases. The gases flow with the geothermal steam. When the steam is condensed in a condenser, the non condensable gases remain and can build back pressure in the condenser. These gases are removed using gas extractors. The extractors can be steam jet ejectors, vacuum pumps or hybrid of steam jet ejectors and vacuum pumps.

6.6 Control System

To ensure safe operation of the power plant, governors are used to regulate rotational speed for the turbine so that the frequency of the electric power generated by the generator is kept within the design limit. Logic control units are used to control the power plants. Plant Interlock ensure safety measures to ensure safe operation of the power plant.

7. WELLHEAD GENERATION CONCEPT

Wellheads are small geothermal power plants (1 – 10 MW) that are installed at the well pad of a geothermal well. The wellhead power plants are designed to best optimize production characteristics of an individual well or group of wells on a given well pad. Wellhead generators can be made modular to allow for easy relocation to another well when needed. The following are some of the advantages of wellhead generation.

1. They can be delivered in a shorter time – the larger geothermal power plants take long to plan, design and install. Wellhead generators can be installed in as short as six months to commissioning;
2. Can be installed during well discharge testing – during well discharge tests, the geothermal fluids are discharged into the atmosphere. The wasted steam can be put to use using wellhead generators;
3. Reduce the time between first drilling and power generation and revenue earnings. Wellhead generators can be installed while the field is being developed;
4. Low capital investment – The capital cost of the wellhead generators is low and therefore attractive to investors; and
5. Wellhead generators are designed to match individual characteristics of a well. This ensure that full potential of the wells are utilized.

Although wellhead generators have some advantages over conventional power plants, they also have some disadvantages. Below are some of the disadvantages of wellhead generators:

1. Small Capacities – several wellhead generators required to match the centralized power plants. This translates to increased land requirement and logistical challenges in evacuation of power from the many units;
2. New technology – the concept is still new and therefore still has some technological challenges;
3. Higher steam consumption – the steam consumption per MW is higher than conventional larger power plants;
4. Potential high O&M costs – High operating speeds (7500 rpm) required to enhance efficiency hence high wear and tear. Many units compared to a centralized system hence higher O&M inputs to manage the plants; and
5. Dependency on an individual well or group of wells on a well pad. When the wells are exhausted, unit need to be moved, new wells need to be drilled.

Figure 6 below shows a typical layout of a wellhead generator.

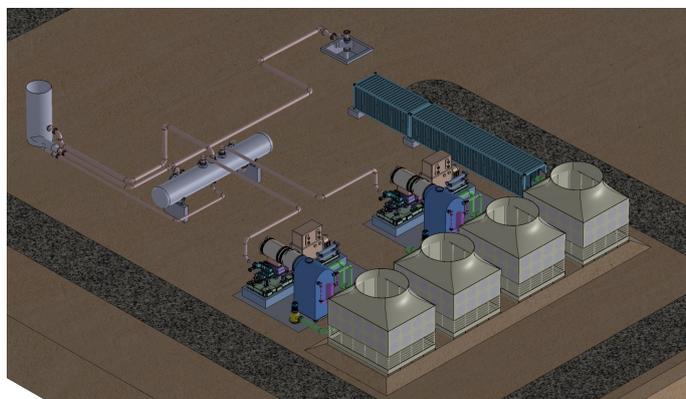


FIGURE 6: Typical layout of a wellhead generator installed by Green Energy Group in Olkaria, Kenya (Green Energy Group, 2011)

8. FUTURE OF GEOTHERMAL POWER PLANTS

Geothermal energy is a natural energy resource that is environmentally friendly. Worldwide, there is abundance of this geothermal resource, only a fraction having been exploited (Fukuda et al., 2008). The following factors are expected to further support growth in geothermal energy utilization:

1. Improved technologies for geo-scientific exploration will help locate hidden geothermal systems and target better production wells;
2. Improved drilling technologies will help lower drilling costs and hence reduce the costs of geothermal energy; and
3. Improved energy conversion technologies will help improve efficiencies and generate from previously ignored resources - Wellheads, 2phase turbines, screw.

9. CONCLUSIONS

1. There is increased drive for green energy and this will help focus world resources to expansion of geothermal energy;
2. There are many financiers willing and ready to finance geothermal projects. Developers need to take advantage of this opportunity;
3. Improved technologies in resource exploration, drilling and energy conversion will help spur geothermal energy; and
4. World energy resources are dwindling fast, but geothermal energy remains abundant.

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