SMALL GEOTHERMAL POWER PLANTS: DESIGN, PERFORMANCE AND ECONOMICS

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A BRIEF HISTORY OF GEOTHERMAL POWER GENERATION

Ninety-five years ago, in the Tuscany village of Larderello, electricity first flowed from geothermal energy when Prince Piero Ginori Conti powered a 3/4-horsepower reciprocating engine to drive a small generator. The Prince was thereby able to light a few bulbs in his boric acid factory situated amid the boron-rich geothermal steam field. He upgraded the power system to 20 kW in 1905 [1].

Commercial delivery of geothermally-generated electric power occurred in 1914 when a 250 kW unit at Larderello provided electricity to the nearby cities of Volterra and Pomarance. Prior to being destroyed in 1944 during World War II, Larderello had a total power capacity of 136,800 kW, an annual generation greater than 900 GWh, and an average annual capacity factor of more than 75 percent. The plants were rebuilt after the war and extensive development of the steam field began. Today, there are over 740 MW installed at Larderello and the other nearby geothermal fields in the Tuscany region of Italy. Many of the power plants are in the 15-25 MW range, qualifying them as small power plants.

New Zealand was the first country to operate a commercial geothermal power plant using a liquid-dominated, hot-water type reservoir (as contrasted with the steam-type at Larderello). This took place at Wairakei in 1958. The United States became the third country to use geothermal energy to generate electricity in 1960 when the Pacific Gas & Electric Company (PG&E) inaugurated an 11 MW Geysers Unit 1. This small plant later earned the designation as a Mechanical Engineering Historical Landmark. The U.S. has become the largest generator of geothermal electricity with an installed capacity of 2850 MW [2,3]. A summary of the state of worldwide installed geothermal electric generating capacity is given in ***Table 1*** [4].

INTRODUCTORY REMARKS

The rest of this article will cover the basic geothermal energy conversion systems with regard to their design, thermodynamic performance, and economics. It draws heavily on a recent encyclopedic contribution by the author to the Second Edition of the McGraw-Hill *Standard Handbook of Powerplant Engineering* [5]; the interested reader is referred to this source for more details than can fit in this introductory article. Although much of the contents of this article are generally applicable to geothermal powerplants of any size, the specific characteristics of small plants will be of particular interest.

Small power plants have played an important role in the development of geothermal energy. Since it is not practical to transmit high-temperature steam over long distances by pipeline owing to heat losses, most geothermal plants are built close to the resource. Given the required minimum spacing of wells to avoid interference (typically 200-300 m) and the usual capacity of a single geothermal well of 4-10 MW (with some rare, spectacular exceptions), geothermal powerplants tend to be in the 20-60 MW range, even those associated with large reservoirs. Much smaller plants, in the range of 500-3000 kW, are common with binary-type plants.

Table 1
Summary of Worldwide Installed Geothermal Power Capacity (as of 1998)

Country	MW	No. Units	MW/Unit	Plant Types[1]
United States	2850	203	14.0	DS,1F,2F,B,H
Philippines	1848	64	28.9	1F,2F,H
Mexico	743	26	28.6	1F,2F,H
Italy	742	na	—	DS,2F,H
Indonesia	589.5	15	39.3	DS,1F
Japan	530	18	29.4	DS,1F,2F
New Zealand	364	na	—	1F,2F,H
Costa Rica	120	4	30	1F
El Salvador	105	5	21	1F,2F
Nicaragua	70	2	35	1F
Iceland	50.6	13	3.9	1F,2F,H
Kenya	45	3	15	1F
China	28.78	13	2.2	1F,2F,B
Turkey	21	1	21	1F
Portugal (Azores)	16	5	3.2	1F,H
Russia	11	1	11	1F
Ethiopia	8.5	2	4.2	H
France (Guadeloupe)	4	1	4	2F
Argentina	0.7	1	0.7	B
Australia	0.4	1	0.4	B
Thailand	0.3	1	0.3	B
Total	**8147.78**			

[1] DS=Dry Steam, 1F=Single Flash, 2F=Double Flash, B=Binary, H=Hybrid
Note: A unit is defined as a turbine-driven generator. Data from Ref. [4] and various other sources.

DIRECT-STEAM PLANTS

Direct-Steam plants are used at vapor-dominated (or dry steam) reservoirs. Dry, saturated or slightly superheated steam is produced from wells. The steam carries noncondensable gases of variable concentration and composition. Steam from several wells is transmitted by pipeline to the powerhouse where it is used directly in turbines of the impulse/reaction type. Between each wellhead and the plant one finds in-line centrifugal cyclone separators situated near the wellhead to remove particulates such as dust and rock bits, drain pots (traps) along the pipelines to remove condensation which forms during transmission, and a final moisture remover at the entrance to the powerhouse.

Figure 1 is a simplified flow diagram for a Direct-Steam plant. A Nomenclature List at the end of the article identifies the items in this and the ensuing flow diagrams [5]. A condensing plant is shown as typical of an installation in the United States. In some countries, back-pressure, exhausting-to-atmosphere operation is possible in accordance with local environmental standards. Because of noncondensable gases (NCG) found in geothermal steam (typically 2-10% by wt. of steam, but sometimes higher), the gas extraction system is a critical plant component. Usually, 2-stage steam ejectors with inter- and after-condensers are used, but in some cases vacuum pumps or turbocompressors are required.

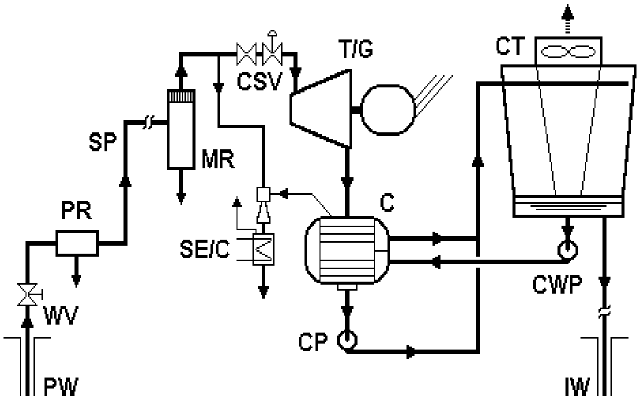

Figure 1. Simplified flow diagram for a direct-steam geothermal power plant (5).

A surface-type condenser is shown but direct-contact condensers are often used. The former is preferred whenever the NCG stream must be treated or processed before release to the atmosphere, e.g., whenever emissions limits for hydrogen sulfide would be exceeded. In such cases, an elaborate chemical plant must be installed to remove the hydrogen sulfide. Most units at The Geysers in northern California use Stretford (or similar) systems for this purpose, yielding elemental sulfur as a by-product. Such an elaborate system would not be economically justified at a very small plant.

A water-cooled condenser is shown. Since the steam condensate is not recirculated to a boiler as in a conventional powerplant, it is available for cooling tower makeup. In fact, an excess of condensate (typically, 10-20% by wt. of the steam) is available and is usually injected back into the reservoir. Long-term production can deplete the reservoir and novel ways are being developed to increase the amount of fluid being returned to the reservoir [6,7]. The use of air-cooled condensers would allow for 100% return but so far have been uneconomic. Mechanical induced-draft cooling towers, either counterflow or crossflow, are mostly used for wet cooling systems, but natural-draft towers are used at some plants.

Recent practice, particularly in Italy, has seen nominal powerplant ratings of 20 or 60 MW per unit, the smaller units being of modular design for rapid installation. Flexible design allows the basic unit to be adapted to a fairly wide range of actual steam conditions.

Table 2 lists major the equipment typically used in the four basic types of geothermal powerplants [5,8].

Table 2
Major Equipment Items for Geothermal Powre Plants

	Type of Energy Conversion System			
Equipment	**Dry Steam**	**Single Flash**	**Double Flash**	**Basic Binary**
Steam and/or Brine Supply:				
Downhole pumps	No	No (Poss.)	No (Poss.)	Yes
Wellhead valves & controls	Yes	Yes	Yes	Yes
Silencers	Yes	Yes	Yes	No
Sand/particulate remover	Yes	No	No	Yes
Steam piping	Yes	Yes	Yes	No
Steam cyclone separators	No	Yes	Yes	No
Flash vessels	No	No	Yes	No
Brine piping	No	Yes	Yes	Yes
Brine booster pumps	No	Poss.	Poss.	Poss.
Final moisture separator	Yes	Yes	Yes	No
Heat Exchangers:				
Evaporators	No	No	No	Yes
Condensers	Yes (No)	Yes (No)	Yes	Yes
Turbine-Generator & Controls:				
Steam turbine	Yes	Yes	Yes	No
Organic vaopr turbine	No	No	No	Yes
Dual-admission turbine	No	No	Yes	No
Control system	Yes	Yes	Yes	Yes
Plant Pumps:				
Condensate	Yes (No)	Yes (No)	Yes	Yes
Cooling water circulation	Yes (No)	Yes (No)	Yes	Yes
Brine injection	No	No (Poss)	Yes (No)	Yes
Noncondensable Gas Removal System:				
Steam-jet ejectors	Yes	Yes	Yes	No
Compressors	Poss.	Poss.	Poss.	No
Vacuum pumps	Poss.	Poss.	Poss.	No
Cooling Towers:				
Wet type	Yes (No)	Yes (No)	Yes	Poss.
Dry type	No	No	No	Poss.

Notes: Yes=generally used, No=generally not used, Poss.=possibly used under certain circumstances.

FLASH-STEAM PLANTS

Dry steam reservoirs are rare, the only known major fields being Larderello and The Geysers. The most common type of geothermal reservoir is liquid-dominated. For artesian-flowing wells, the produced fluid is a two-phase mixture of liquid and vapor [9]. The quality of the mixture (i.e., the weight percentage of steam) is a function of the reservoir fluid conditions, the well dimensions, and the wellhead pressure which is controlled by a wellhead valve or orifice plate. Typical wellhead qualities may range from 10 to over 50 %.

Although some experimental machines have been tested which can receive the total two-phase flow and generate power [10-12], the conventional approach is to separate the phases and use only the vapor to drive a steam turbine. Since the wellhead pressure is fairly low, typically 0.5-1.0 MPa (75-150 lbf/in^2, abs), the liquid and vapor phases differ significantly in density ($r_f / r_g = 175\text{-}350$), allowing effective separation by centrifugal action. Highly efficient cyclone separators yield steam qualities ranging as high as 99.99 % [13].

The liquid from the separator may be injected, used for its thermal energy via heat exchangers for a variety of direct-heat applications, or flashed to a lower pressure by means of control valve or orifice plate, thereby generating additional steam for use in a low-pressure turbine. Plants in which only primary high-pressure steam is used are called Single-Flash plants; plants using both high- and low-pressure flash steam are called Double-Flash plants.

SINGLE-FLASH PLANTS

A simplified flow diagram of a Single-Flash plant is shown in ***Figure 2*** [5].

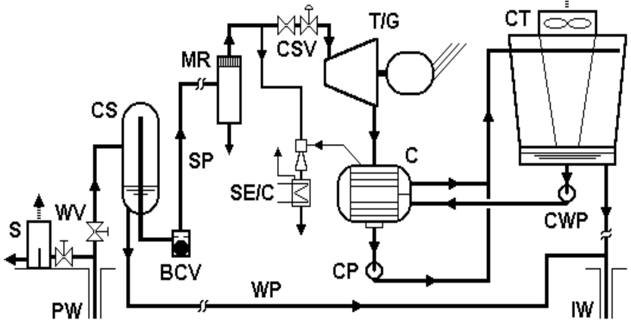

Figure 2. Simplified flow diagram for a single-flash geothermal power plant (5).

The two-phase flow from the well(s) is directed horizontally and tangentially into a vertical cylindrical pressure vessel, the cyclone separator. The liquid tends to flow circumferentially along the inner wall surface while the vapor moves to the top where it is removed by means of a vertical standpipe. The design shown is called a bottom-outlet separator and is extremely simple, having no moving parts. Baffles and guide vanes are sometimes used to improve the segregation of the two phases. A ball check valve provides insurance against a slug of liquid entering the steam line during an upset. The steam transmission lines are essentially the same as in the case of dry steam plants and are usually fitted with traps.

The balance of the plant is also nearly identical to the dry steam plant, the main difference being the much greater amount of liquid that must be handled. Comparing 55 MW plants, a typical Single-Flash plant produces about 630 kg/s (5x10^6 lbm/h) of waste liquid, whereas a Direct-Steam plant produces only 20 kg/s (0.16x10^6 lbm/h), a ratio of over 30 to 1. If all of the waste liquid is injected, a Single-Flash plant would return to the reservoir about 85 % of the produced mass; this should be compared with only 15% for a Direct-Steam plant. The major equipment items for a typical Single-Flash plant are given in ***Table 2***.

DOUBLE-FLASH PLANTS

About 20-25% more power can be generated from the same geofluid mass flow rate by using Double-Flash technology. The secondary, low-pressure steam produced by throttling the separated liquid to a lower pressure is sent either to a separate low-pressure turbine or to an appropriate stage of the main turbine (i.e., a dual-pressure, dual-admission turbine). The principles of operation of the Double-Flash plant are similar to those for the Single-Flash plant. The Double-Flash plant is, however, more expensive owing to the extra equipment associated with the flash vessel(s), the piping system for the low-pressure steam, additional control valves, and the more elaborate or extra turbine. ***Figure 3*** is a simplified flow diagram for a Double-Flash plant [5]. An equipment list is given in ***Table 2***

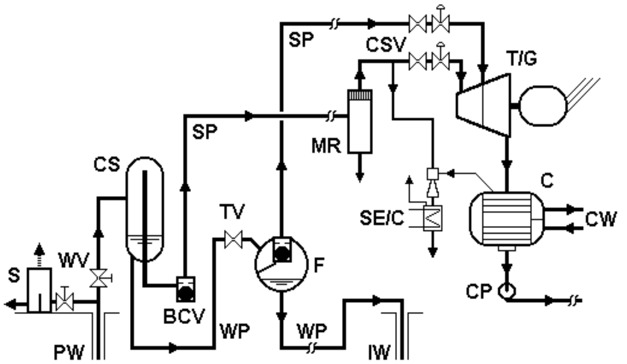

Figure 3. Simplified flow diagram for a double-flash geothermal powerplant [5].

BINARY PLANTS

In a Binary plant, the thermal energy of the geofluid is transferred via a heat exchanger to a secondary working fluid for use in a fairly conventional Rankine cycle. The geofluid itself does not contact the moving parts of the power plant, thus minimizing, if not eliminating, the adverse effects of erosion. Binary plants may be advantageous under certain conditions such as low geofluid temperatures, say, less than about 150 C (300 F), or geofluids with high dissolved gases or high corrosion or scaling potential. The latter problems are usually exacerbated when the geothermal liquid flashes to vapor as typically occurs in a self-flowing production well. Downwell pumps located below the flash level can prevent flashing by raising the pressure above the saturation pressure for the fluid temperature [14]. Most binary plants operate on pumped wells and the geofluid remains in the liquid phase throughout the plant, from production wells through the heat exchangers to the injection wells.

It is an interesting historical note that the first commercial geothermal powerplants at Larderello were, in fact, binary-type plants [15]. The geothermal steam was used to evaporate clean water to run steam turbines because the materials available at that time did not allow the corrosive steam to be used directly in the turbines.

A flow diagram for a typical Basic Binary plant is given in ***Figure 4*** [5]. The power cycle consists of a preheater, an evaporator, a set of control valves, a turbine-generator set, a condenser and a feedpump. Either water or air may be used for cooling depending on site conditions. If wet cooling is used, an independent source of make-up water must be found since geosteam condensate is not available as it was in the case of Direct- or Flash-Steam plants. Owing to chemical impurities the waste brine is not generally suitable for cooling tower make-up. There is a wide range of candidate working fluids for the closed power cycle. In making the selection, the designer tries to achieve a good thermodynamic match to the particular characteristics of the geofluid, especially the geofluid temperature. Hydrocarbons such as isobutane, isopentane and propane are good candidate working fluids as are certain refrigerants. The optimal fluid will give a high utilization efficiency together with safe and economical operation.

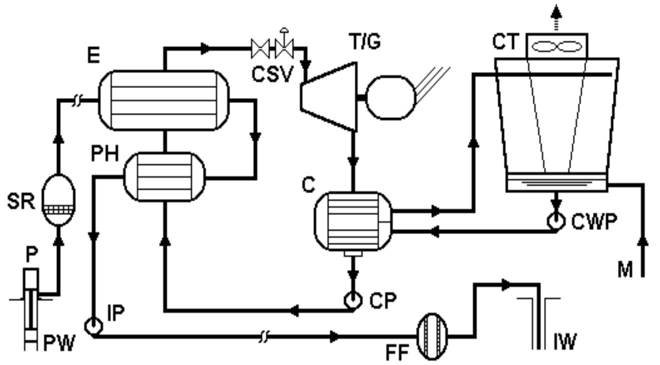

Figure 4. Simplified flow diagram for a basic binary geothermal powerplant [5].

Binary plants are particularly well suited to modular power packages in the range 1-3 MW per unit. Standardized, skid-mounted units can be factory-built, tested, assembled and shipped to a site for rapid field installation. A number of units can then be connected at the site to match the power potential of the resource. ***Table 2*** contains the major equipment items for a Basic Binary plant.

If a mixture is selected as the working fluid, (e.g., isobutane and isopentane, or water and ammonia), then the evaporation and condensation processes will occur at variable temperature. This characteristic allows a closer match between the brine and the working fluid (evaporation), and the cooling water and the working fluid (condensation), giving higher heat exchanger efficiencies and better overall system efficiencies [16,17]. Furthermore, if the turbine exhaust carries significant superheat, a heat recuperator may be utilized to preheat the working fluid [18]. Both of these features are the basis for the Kalina version of the geothermal binary plant [19], shown schematically in ***Figure 5*** [5]. A 12 MW pilot plant of this type has been designed and is planned for installation at Steamboat Springs in Nevada.

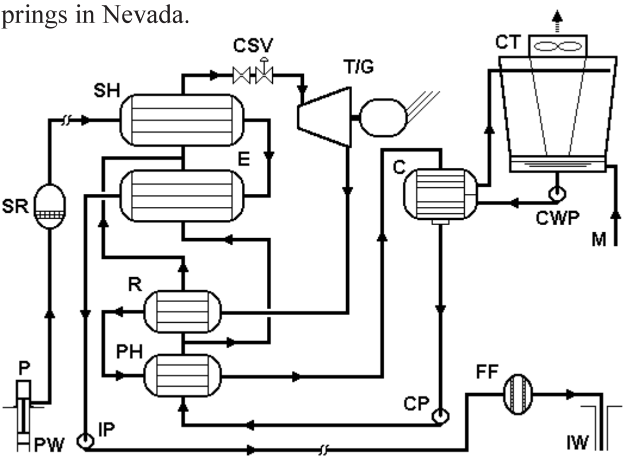

Figure 5. Simplified flow diagram for a Kalina binary geothermal powerplant [5].

COMBINED OR HYBRID PLANTS

Since geothermal fluids are found with a wide range of physical and chemical properties (e.g., temperature, pressure, noncondensable gases, dissolved solids, pH, scaling and corrosion potential), a variety of energy conversion systems have been developed to suit any particular set of conditions. The basic systems described in the earlier sections can be combined to achieve more effective systems for particular applications. Thus, the following hybrid or combined plants can be designed:

Direct-Steam/Binary Plants [5]
Single-Flash/Binary Plants [5]
Integrated Single- and Double-Flash Plants [20,21]
Hybrid Fossil-Geothermal Systems [22-24].

Properly designed combined or hybrid systems achieve a synergistic advantage by having a higher overall efficiency compared with using the two systems or "fuels" (in the case of the fossil-geothermal plants) in separate state-of-the-art plants. The intricacies of the design of these systems are beyond the scope of this introductory paper and the reader is referred to the references cited above.

POWERPLANT PERFORMANCE

The modern approach to measuring the performance of energy systems is to use the Second Law of thermodynamics as the basis for assessment. The concept of available work or energy has been widely used for this purpose [25]. Geothermal powerplants are an excellent illustration of the application of the Second Law (or utilization) efficiency, h_u. Since geothermal plants do not operate on a cycle but instead as a series of processes, the cycle thermal efficiency, h_{th}, for conventional plants does not apply [9, 26].

The one instance where the cycle thermal efficiency, h_{th}, can be meaningfully applied to geothermal powerplants is the case of Binary plants. Even in this case, however, the thermal efficiency must be used solely to assess the closed cycle involving the secondary working fluid and not the overall operation involving the flow of the geofluid from the production wells, through the plant, and ultimately to the fluid disposal system.

The utilization efficiency, h_u, measures how well a plant converts the exergy (or available work) of the resource into useful output. For a geothermal plant, it is a found as follows:

$$\eta_u = \dot{W} / \dot{m} e$$

where $\dot{W}$ is the net electric power delivered to the grid, is the required total geofluid mass flow rate, and e is the specific energy of the geofluid under reservoir conditions. The latter is given by:

$$e = h(P_1 - T_1) - h(P_0 - T_0) - T_0[s(P_1 - T_1) - s(P_0 - T_0)].$$

The specific enthalpy, h, and entropy, s, are evaluated at reservoir conditions, P_1 and T_1, and at the so-called "dead state," P_0 and T_0. The latter correspond to the local ambient conditions at the plant site. In practice, the design wet-bulb temperature may be used for T_0 (in absolute degrees) when a wet cooling system is used; the design dry-bulb temperature may be used when an air-cooled condenser is used.

The major design specifications and actual performance values for selected powerplants of the Direct-Steam, Single- and Double-Flash types are given in ***Table 3***; similar data are given in ***Table 4*** for selected small Binary powerplants. The specific geofluid consumption, SGC, is given as one measure of performance. One will observe a dramatic increase in this parameter (i.e., a decrease in performance) when comparing Binary plants with geothermal steam plants, particularly Direct-Steam plants. It can be seen that Direct-Steam plants operate at quite impressive efficiencies based on exergy, typically between 50-70 %. Each utilization efficiency given in ***Tables 3*** and ***4*** was computed using the appropriate site-specific dead-state temperature.

The contemporary use of small modular binary units is exemplified by the SIGC plant [27,28]. Several small units, 2.7 MW_n, are clustered together receiving geofluid from several wells through a manifold and generate a total of 33 MW_n. The small sacrifice in efficiency of the modular-sized units, istics of the wells are known.

The influence of resource temperature and power rating on plant costs for small-size Binary units are summarized in ***Table 6*** [30]. Capital costs (per kW) vary inversely with temperature and rating; annual O&M costs increase with rating but are independent of fluid temperature (over the range studied). These costs are favorable when compared to other renewable energy sources, and are absolutely favorable for remote locations where electricity is usually generated by diesel engines.

Table 3
Design Conditions for Selected Geothermal Steam Plants (after [5])

Plant	Valle Secolo, Unit 2	Miravalles, Unit I	Beowawe
Location	Larderello, Italy	Guanacaste, Costa Rica	Beowawe, Nevada
Start-up year	1992	1994	1985
Type	Direct steam	Single flash	Double flash
Rating, MW	57	55	16.7
Output power, MW-net	52.2	52	16.0
Geofluid flow rate, kg/s	111.1	759.5	157.5
Resource temperature, C	204	230	215
Turbine:			
inlet pressure, kPa: primary	550.3	600.0	421.4
secondary	—	—	93.1
inlet temperature, C: primary	200-210	159	146
secondary	—	—	99
mass flow/turbine, kg/s: primary	111.1	114.0	22.3
secondary	—	—	12.2
exhaust pressure, mm Hg	59.94	93.73	33.02
last stage blade height, mm	na	584	635
speed, rpm	3,000	3,600	3,600
Condenser:			
type	DC	DC	DC
heat duty, MWt	245	243	71.8
CW flow, kg/s	2,785	4,234	1,474
NCG system:			
steam-jet ejector	no	yes	yes
stages	—	2	1
steam flow, kg/s	—	4.06	na
compressor	yes	yes	no
stages	2	4	—
power, MW	1.4	0.4	—
vacuum pump	no	no	yes
Plant performance:			
SGC-net, kg/MWh	7,666	52,572	35,437
η_u, %: gross	62.9	31.2	48.7
Net	57.6	29.5	46.7

Table 4
Design Conditions for Selected Geothermal Binary Plants (after [5])

Plant	Second Imperial Geothermal Co.	Mammoth-Pacific, Unit I	Amedee
Location	Heber, CA	Mammoth, CA	Wendel, CA
Start-up year	1993	1985	1988
Type	dual-pressure	basic	basic
No. of units	12	2	2
Rating, MW	40	10	2
Output power, MW-net	32	7	1.6
Net power/unit, MW	2.7	3.5	0.8
Geofluid flow rate, kg/s	999.0	220.5	205.1
Resource temperature, C	168	169	103
Downwell pumps	yes	yes	yes
Working fluid	isopentane, C_5H_{12}	isobutane, C_4H_{10}	R-114, $C_2Cl_2F_4$
Evaporator(s):			
No. per unit	2	6	1
type	shell & tube	shell & tube	shell & tube
heat duty,MWt	413.2 (e)	86.75	28.72
geofluid temperature, C:			
inlet	168	169	104
outlet	71 (e)	66-88	71
Turbine:			
type	axial flow	radial inflow	axial flow
inlet temperature, C	na	138	83
pressure, kPa: inlet	na	3,379	993
outlet	na	variable	276
mass flow/turbine, kg/s	na	92.0	100.8
speed, rpm	1,800	11,050	3,600
Condenser(s):			
No. per unit	2	11	1
type	shell & tube	finned tube	evaporative
heat duty, MWt	269.2	79.72	na
coolant	water	air	water
coolant temperature, C: inlet	20.0	variable	21.1
outlet	28.1	variable	na
Plant performance:			
SGC-net, kg/MWh	85,049	113,399	462,669
η_u, %: gross	44.5	32.4	17.4
net	35.6	22.7	13.9
η_{th}, %: gross	14.0	11.5	7.0
net	13.2	8.1	5.6

ECONOMICS OF GEOTHERMAL POWER

The costs associated with building and operating a geothermal powerplant vary widely and depend on such factors

- Resource type (steam or hot water)
- Resource temperature
- Reservoir productivity
- Powerplant size (rating)
- Powerplant type (single-flash, binary, etc.)
- Environmental regulations
- Cost of capital
- Cost of labor.

The first three factors influence the number of wells that must be drilled for a given plant capacity. Using typical costs and power potential for production wells, a single well can cost $100-400/kW. The next three items determine the capital cost of the energy conversion system; whereas, the last two affect the cost of running the plant (i.e., debt service, and operations and maintenance [O & M]).

Table 5 gives capital costs for a variety of plants in the United States (29). Note that all values are in "as spent dollars" for the year quoted. Furthermore, the figures for the Direct Steam plants (all at The Geyers) do not include field development costs but cover only the powerplant. The other figures (all estimated) include both field and plant costs.

Table 5
Capital Cost for U.S. Geothermal Plants (after [5])

Type/Plant Name	Year	Power, MW_n	Cost, $/kW
Direct Steam			
PG&E Geysers:			
Unit 1	1960	11	174
Unit 8	1972	53	109
Unit 13	1980	133	414
NCPA-1	1983	110	780
Single Flash			
Blundell	1984	20	3000 (e)
Steamboat Hills	1988	12	2500 (e)
Double Flash			
Desert Peak	1985	9	2000 (e)
Beowawe	1985	16	1900 (e)
Heber	1985	47	2340 (e)
Dixie Valley	1988	66	2100 (e)
Brady Hot Springs	1992	24	2700 (e)
Binary			
Empire	1987	3	4000 (e)
Stillwater	1989	12	3085 (e)
SIGC	1993	33	3030 (e)

Table 6
Capital and O&M Costs for Small Binary Geothermal Plants (1993 $) [5]

Net Power, kW	Resource Temperature, C			Total O&M Cost
	100	120	140	$/year
	Capital Cost, $/kW			
100	2,535	2,210	2,015	19,100
200	2,340	2,040	1,860	24,650
500	2,145	1,870	1,705	30,405
1,000	1,950	1,700	1,550	44,000

SUMMARY AND OUTLOOK

Extensive research and development over the last two decades has resulted in an impressive array of commercially available technologies to harness a wide range of geothermal resources. "Off-the-shelf" power systems of the Direct-Steam, Flash-Steam or Binary types can be ordered for use with low-to-high temperature resources of the vapor- or liquid-dominated variety, with any level of noncondensable gas or dissolved solids. If new plants are to be built, however, they must demonstrate an economic advantage over alternative systems. The economics are governed by site-specific and time-specific factors. For example, in the United States in the late 1990's, it has been difficult for any energy source to compete with natural-gas-fired plants, particularly combined steam-and-gas-turbine cycles.

The effects of deregulation on the electric industry have also had a negative impact on geothermal plants. No longer endowed with favorable power purchase agreements, geothermal plant must now compete openly with other energy systems. Interestingly, privatization in many other countries, particularly those lacking in indigenous fossil fuels, has actually enhanced the attractiveness of geothermal plants which often turn out to be the lowest cost option among new electric power plants.

Since geothermal projects are heavily loaded with up-front costs for exploration, reservoir characterization, and drilling, all of which carry a measure of risk for investors, research directed at improving the technology in these areas is appropriate. Also, better methods of monitoring and predicting reservoir behavior, both prior to and during exploitation would allow more systematic and reliable development strategies to maximize energy extraction over the long term.

In countries with long histories of operating geothermal plants (such as Italy, the U. S. and New Zealand), geothermal re-powering projects are replacing older, less efficient units or units that no longer match the resources (due to long-term reservoir changes) with modern, high-efficiency, flexible systems. In many countries, both large and small, which are endowed with abundant geothermal resources, there is good potential for strong growth in geothermal power capacity. Of particular interest are Indonesia, the Philippines, Mexico, Japan, Italy, Kenya, and countries in Central America including Costa Rica, El Salvador, Guatemala and Nicaragua. In the United States, further development of its abundant geothermal resources will depend strongly on the prices of competing conventional fuels.

Geothermal is now a proven alternative energy source for electric power generation. Because of its economic competitiveness in many situations, the operational reliability of the plants, and its environmentally friendly nature, geothermal energy will continue to serve those countries endowed with this natural energy resource.

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NOMENCLATURE FOR PLANT FLOW DIAGRAMS (Figs. 1, 2, 3, 4, 5)

BCV - ball check valve
CP - condensate pump
CSV - control and stop valves
CW - cooling water
E - evaporator
FF - final filter
IW - injection wells
MR - mositure remover
PH - preheater
R - recuperator
SE/C - steam ejector/condenser
SP - steam piping
T/G - turbine/generator
WP - water piping
C - condenser
CS - cyclone separator
CT - cooling tower
CWP - cooling water pump
F - flasher
IP - injection pump
M - make-up water
P - well pump
PW - production wells
S - silencer
SH - superheater
SR - sand remover
TV - throttle valve
WV - wellhead valves