AN OVERVIEW OF GEOTHERMAL ENERGY IN THE UNITED STATES

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Robert J. Schultz

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Edward G. DiBello

EG&G Idaho, Inc.

Idaho National Engineering Laboratory

Idaho Falls, Idaho

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An abundant source of energy lies right under our feet - the earth's interior heat. In some areas, this heat appears dramatically at the earth's surface in the form of hot springs, fumaroles, and geysers. At present, in the United States, geothermal energy is primarily used for electrical power production. However, other applications, such as space conditioning and industrial processing, will greatly benefit the economy of many regions of the country as we seek alternatives to fossil and nuclear fuels.

Geothermal energy has been used for centuries. Early use included balneology (therapeutic baths) and religious ceremonies, while the Romans used geothermal water for heating buildings 2000 years ago. The first geothermal field to be developed commercially was a dry steam field at Larderello, Italy. An experimental generator was set up and operated in 1904, and a 250 kW atmospheric exhaust turbine driven alternator was installed in 1913.

In the United States, geothermal power production began in 1920 at the Geysers with the operation of a small captive use unit. Large scale commercial development of the Geysers by Magma and Thermal Power, Union Oil, and Pacific Gas and Electric started in 1960. Currently, 520 megawatts are on-line and another 135 megawatts will come on-line within the next few months. The major non-electric developments in the United States are space heating projects. It is startling to realize that the commercial use of geothermal energy predates the commercial use of natural gas. District space heating by the Artesian Hot and Cold Water Company was initiated in 1893 in Boise, Idaho. This distribution system for the homes bordering Warm Springs Ave. at one time serviced a peak load of 400 customers. Currently, the space heating requirements of approximately 200 homes are met by the system.

The residents of Klamath Falls, Oregon, have been using their geothermal resource on a localized basis since the turn of the century. It is estimated that Klamath Falls has approximately 400 hot wells for the space heating of 600 structures. Single family residences, apartment houses, hospitals, commercial facilities, and swimming pools utilize downhole heat exchangers to tap this valuable energy supply.

Now that we have reviewed the history of geothermal development, let's take a brief look at the resource. The resource can be divided into three major categories as shown in Table I.

The hydrothermal convective resource exhibits a broad range of potential temperatures at reasonably shallow depths. There are two types of hydrothermal systems. The vapor dominated, or dry steam, resource generally has a temperature greater than 200°C and produces superheated steam. It is the easiest to use for electrical production, but is the rarest form of geothermal resource. It is estimated to constitute less than 0.5% of the resource base. The liquid dominated hydrothermal resource is estimated to contain 10% of the geothermal energy base. It is a very attractive energy source from the utilization aspect. Temperatures range from normal groundwater temperature to in excess of 350°C. It is not known whether steam and liquid dominated resources are renewable, because fluid extraction on a time scale of years inevitably upsets the natural cycle of heat supply and dissipation, which is on a geologic time scale.

TABLE I

GEOTHERMAL RESOURCE CLASSIFICATION[1]

Resource Type	Temperature Characteristics
1. Hydrothermal Resources (natural water or steam carries heat upward from depth by convection)	
a. Vapor dominated	about 240°C (464°F)
b. Hot water dominated	
1) high temperature	150°C to 300°C or higher
2) moderate temperature	90°C to 150°C
3) low temperature	less than 90°C
2. Hot Igneous Rock Resources (rock intended in molten form from depth)	
a. Part still molten	higher than 650°C
b. Not molten (hot dry rock)	90°C to 650°C
3. Conduction - Dominated Resources (heat carried upward by conduction through rock)	
a. Radiogenic (heat generated by radioactive decay)	30°C to about 150°C
b. Geopressured (hot fluid under high pressure)	150°C to about 200°C

The largest geothermal prospect, some 70%, is classified as hot igneous rock or hot dry rock. Hot dry rocks are non-molten rock structures which do not possess sufficient water to be considered hydrothermal convection systems. Rock temperatures can reach 650°C. In excess of 650°C, rock becomes molten and thus the magma resource is formed. Since temperatures increase with depth, independent of hydrothermal convection, it is reasonable to assume that much more heat is stored in the rock matrix than in circulating water. Since porosity generally decreases with depth, it can be assumed that vast volumes of hot dry rock exist at greater depths within the earth's crust.

The conduction-dominated resources are subdivided into radiogenic and geopressured categories. The radiogenic resources are located in the eastern states coastal plains. These plains are blanketed by a layer of thermally insulating sediments. In certain areas, beneath this thermal blanket, rocks having enhanced heat production due to a higher radioactive element content are believed to occur. Geopressured systems consist of water from 300°C to 400°C containing dissolved methane under pressurized conditions. The fluid is trapped under impermeable shelf caps in sediments where compaction has taken place over geologic periods. These resources are capable of providing heat, mechanical energy and methane. Conduction-dominated resources are estimated to contain 20% of the U.S. geothermal resource potential.

Geothermal energy resources are concentrated to a large extent along belts of higher earthquake activity and recent volcanism. These belts of high volcanic activity, seismicity and hot spring activity are associated with geologic plate boundaries and cover approximately 10% of the earth's surface. The belts are shown in Figure 1. It has been estimated that the upper 10 kilometers of the earth's crust may contain more than 8×10^{24} calories of heat; however, the majority of this heat is too diffuse to be economically exploitable as an energy source. Thirty-seven states in the United States have indications of geothermal energy that may be presently economically exploitable. The most current USGS estimate for the usable resource above 90°C in the U.S. is 4×10^{20} calories.

GEOTHERMAL REGIONS OF THE WORLD

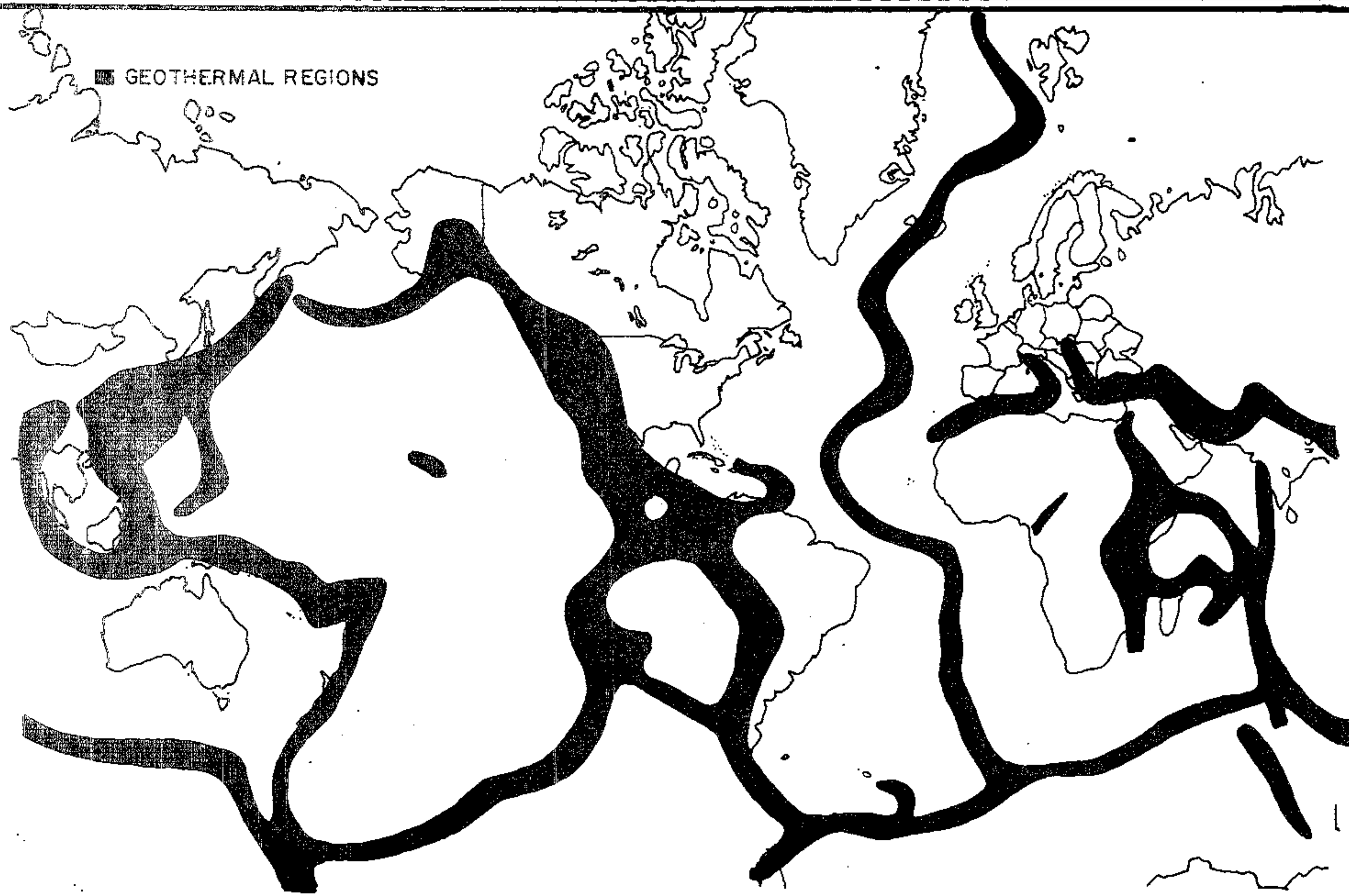

Figure 1

Interest in the production of electric power from geothermal resources has increased significantly in the last several years. Most of the interest, both public and private, is focused on the exploitation of liquid dominated reservoirs for the simple reason that there are only two vapor dominated reservoirs in the U.S., the Geysers and Yellowstone Park. The USGS, in Circular 790, estimates there are fifty-one systems with resource temperatures greater than 150°C. All major geothermal electric plants operating today use condensing steam turbines for generation. At the Geysers, the steam is obtained from a vapor dominated system. At Cerro Prieto, Mexico, and in the future at the Valles Caldera, New Mexico, the steam is obtained from liquid-dominated reservoirs by flashing the hot geothermal fluid. Using this technology, the nominal economic electric power generation temperature approaches 190-205°C.

Figure 2 is a schematic of a dry steam power plant typical of those used at the Geysers. Steam flows from the well and is routed directly through the turbine. As the steam moves through the turbine, it expands and imparts rotational motion, which in turn is transmitted to the generator. The steam, at a lower temperature, and pressure exits the turbine and is condensed and reinjected. Waste heat is removed from the condenser and is vented to the atmosphere through a cooling tower.

Figure 3 is a schematic of a flash steam power plant typical of the Cerro Prieto, Mexico project, and the 50 MW plant at Valles Caldera, New Mexico. The fluid produced from the well is hot geothermal water. The fluid is kept under pressure as it flows from the well bore to prevent it from flashing to steam. Flashing in the well bore can cause well bore deposit buildup and subsequent flow reduction or blockage. The hot fluid is routed to a flash tank where pressure is reduced and the fluid flashes to steam. Typically, 12-15% of the fluid changes state. The hot residual liquid in the flash tank may be used for direct applications prior to reinjection. The remainder of the process is similar to the dry steam system.

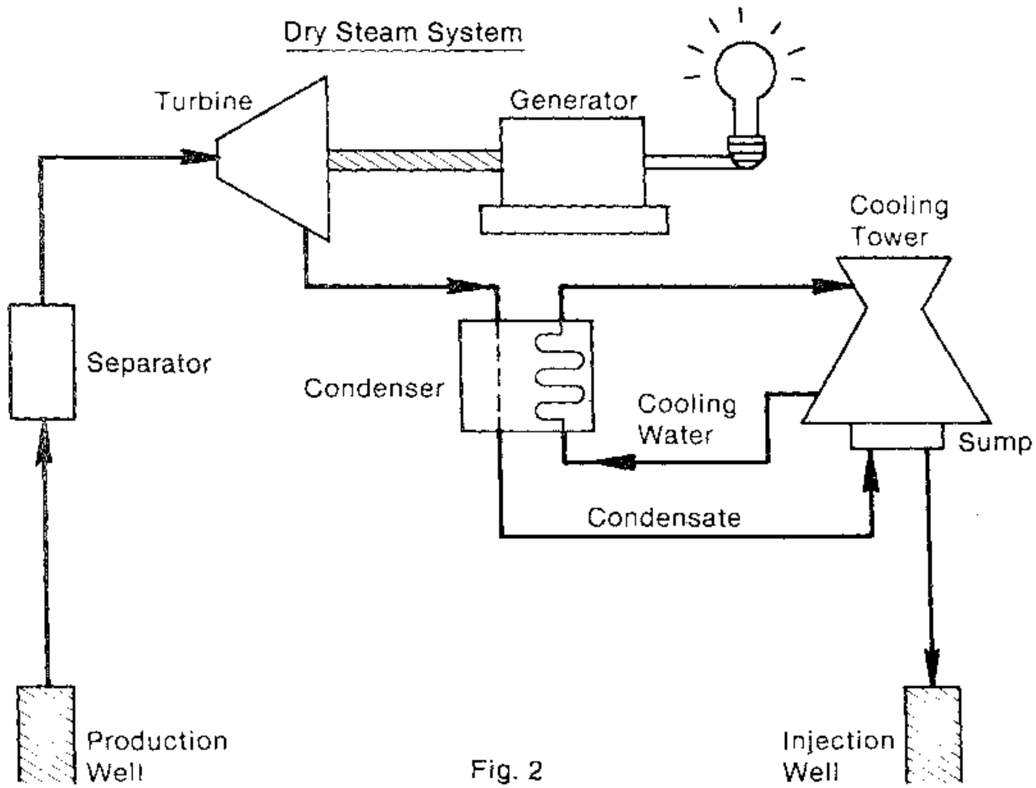

Fig. 2

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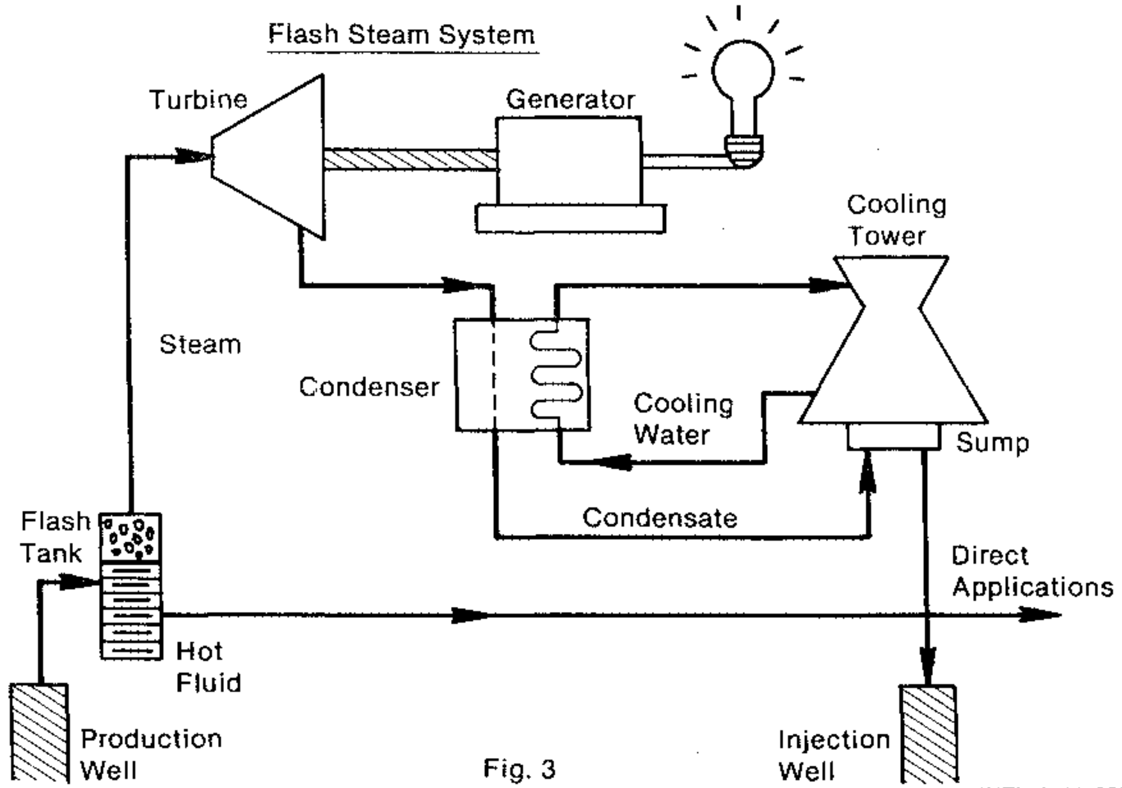
Flash Steam System
Turbine
Generator
Cooling
Tower
Steam
Condenser
Cooling
Water
Sump
Condensate
Flash
Tank
Direct
Applications
Hot
Fluid
Production
Well
Injection
Well
INEL-A-11 935

Fig. 3

Lower temperature resources can be economically utilized using a binary cycle power plant. Figure 4 is a schematic of a typical binary system. In this cycle, the heat from the geothermal fluid is transferred to a lower boiling point working fluid, which vaporizes and is used to drive the turbine. The working fluid is usually an organic fluid such as isobutane.

The Geysers in California continues to be the only major U.S. site where geothermal energy is used for electrical power production. As mentioned previously, 520 MWe are currently on-line and generating capacity will be increased to 655 MWe within the next few months. By 1985, 1500 MWe are planned to be on-line and by the year 2000, the Geysers - Clear Lake area could contribute up to 3000 MWe. Electrical development activities are underway at four other areas. They are:

a) Imperial Valley, California: Five fields are under investigation or development. Magma Power is nearing completion of a 10 MWe binary plant at East Mesa, Chevron has entered into a contract with Southern Cal Edison for a 50 MWe dual flash steam plant at Heber, Republic Geothermal has obtained a geothermal loan guaranty for final development at East Mesa, and Union Oil Company and Southern California Edison have recently procurred a 10 MWe condensing steam turbine for installation at the Brawley field. This turbine is expected to go on-line in mid-1980.[3]

b) Valles Caldera, New Mexico: The DOE demonstration geothermal plant at Valles Caldera is the first large (50 MWe) flash steam plant under construction in the U.S. This program is being conducted in cooperation with Public Service of New Mexico and Union of California.

c) Roosevelt-Cove Fort-Sulphurdale, Utah: This region of Utah is one of the more active development areas. Phillips Petroleum Co., and Rogers Engineering are designing a 50 MWe flash steam plant for Roosevelt. O'Brien and VTN are also planning a 50 MWe unit for the Roosevelt field.

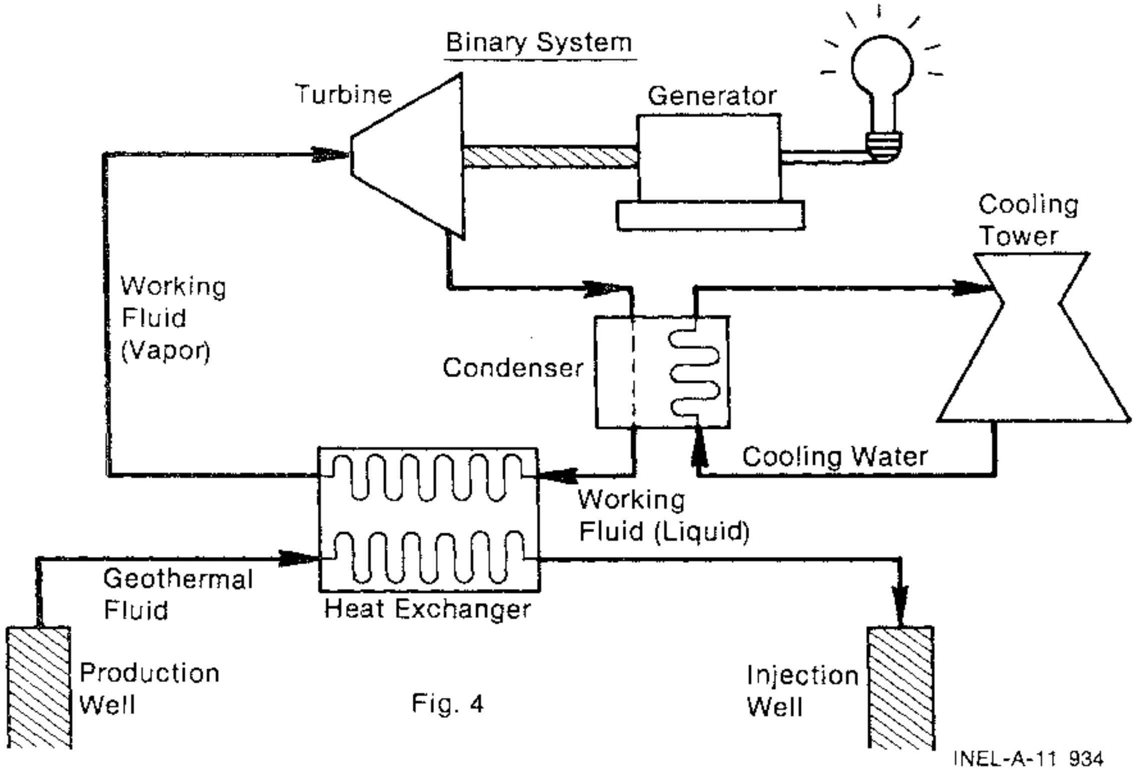
Binary System
Turbine
Generator
Cooling
Tower
Working
Fluid
(Vapor)
Condenser
Cooling Water
Working
Fluid (Liquid)
Geothermal
Fluid
Heat Exchanger
Production
Well
Injection
Well
INEL-A-11 934

Fig. 4

d) Nevada: Recent discoveries in Nevada have increased the development interest in this area. The Desert Peak resource discovered by Phillips Petroleum looks extremely exciting. Other areas that exhibit promising potential are Dixie Valle, Stillwater, Soda Lake, Rye Patels, and Beowawe. Sierra Pacific Power is planning a 50 MWe unit for this last area.

As an outgrowth of the research and development work on moderate-temperature hydrothermal resources, a 5 MWe binary cycle plant is being built at Raft River, Idaho. This plant will use state-of-the-art components, but will employ a dual boiling power cycle using isobutane as a working fluid. It is designed to operate at a nominal geothermal fluid temperature of 150°C. The facility should begin operation by mid-1980.

In the U.S., direct applications of hydrothermal energy are minimal, a result of our former abundant, inexpensive fossil fuel supply. However, with reduced fossil fuel supplies and increasing energy requirements, the nation can no longer delay implementing the significant contributions that direct applications can make to meeting energy demands. Reducing uncertainties, assisting industry in developing confidence in the applications of hydrothermal fluid, removing unnecessary barriers, solving environmental issues, demonstrating uses and providing incentives are necessary activities if the objective of widespread utilization of geothermal resources is to be attained.

Although hydrothermal resources have been utilized for limited amounts of space heating for many years, they have only recently been employed for industrial processing in the United States. The first of these operations was the Medo-Bel Creamery in Klamath Falls, Oregon. Medo-Bel has been using this energy source since 1973 for milk pasteurization. Recently, Geothermal Food Processors have initiated onion and celery drying operations at Brady Hot Springs, Nevada.

Since industrial use represents 40% of our national energy consumption, the single largest share, these energy consumers must be addressed from the geothermal utilization standpoint.

The energy used by industry can be broken into the following categories:

Process Steam	40.6%
Electric Drive	19.2%
Electrolitic Process	2.8%
Direct Process Heat	27.8%
Feedstocks & Chemicals	8.8%
Other	0.8%

Process steam and direct process heat account for 68.4% of the total industrial use of energy, much of which can potentially be supplied by hydrothermal energy. Today, high-temperature processing is being practiced in many cases only because those are the temperatures naturally achieved when fossil fuel is consumed. In many processes, time and temperature can be traded-off to permit the use of lower-temperature energy sources. Thus, there are potentially many additional processes which can be adapted to low-temperature energy sources.

Many applications of geothermal heat are straightforward applications of existing technology, but there are also applications, such as industrial drying with low- to medium-temperature geothermal fluids, where technical issues remain to be resolved by experiment, demonstration, or analysis. Small scale and pilot testing is an important incentive to demonstration and full-scale applications of industrial processes. At the Raft River Geothermal Test Site in southcentral Idaho, a highly successful aquaculture experiment has demonstrated the desirability of raising aquatic species directly in geothermal fluids, a fluidized-bed geothermal dryer has converted potato wastes into high protein fish food, and an agriculture/irrigation experiment has explored the benefits and detriments of raising field crops with spent geothermal fluids. In addition, the first U.S. geothermal-powered air conditioner cools a Raft River office building, on-line building space heating is being examined, and new heat exchanger designs are being evaluated for highly corrosive and scaling water applications.

To further promote the development and early commercialization of direct applications, the U.S. Department of Energy has issued two Program Opportunity Notices for field experiments. Currently, twenty-two projects have been selected as joint private sector/government cooperative ventures. This program has stimulated industrial developments in food processing, aquaculture, and agribusiness.

Each project, with minor variations, is organized to include the following major phases:

a) Environmental Report Preparation
b) Resource Assessment
c) Well Drilling
d) Well Evaluation
e) Corrosion Evaluation
f) Water Disposal Method Decision
g) System Design
h) System Construction
i) System Monitoring

The type and complexity of the current projects vary from space heating and grain drying to food processing. While only existing technology is being employed to carry out the projects, they will provide an excellent baseline for future commercial development. Valuable environmental, technical, operational, and economic information will be generated as a result of these projects. In addition, institutional barriers will be tested, private firms and organizations will gain experience, and public awareness of hydrothermal energy will be increased.

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