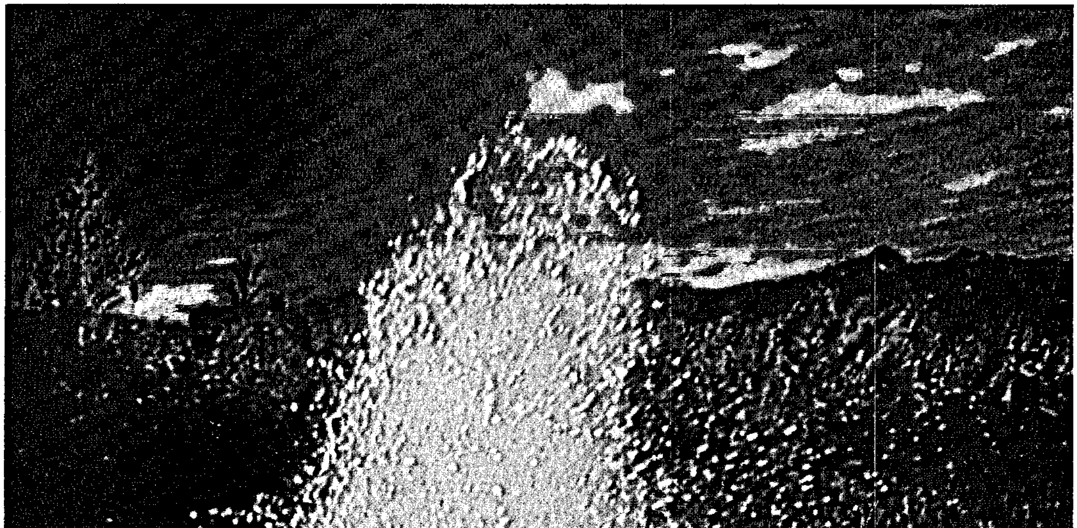
√

Geothermal Resources Council
Special Report No. 8

DIRECT UTILIZATION OF GEOTHERMAL ENERGY: A LAYMAN'S GUIDE

MASTER



GEYSER, CALISTOGA, CA

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Geothermal Resources Council Special Report No. 8

DIRECT UTILIZATION OF GEOTHERMAL ENERGY:
A LAYMAN'S GUIDE

Developed Under
A Joint Project of the
Geothermal Resources Council
and the
Geo-Heat Utilization Center
Oregon Institute of Technology
1979

9501507
9511423

✓

Edited by
David N. Anderson
Geothermal Resources Council
and
John W. Lund
Oregon Institute of Technology

Rewritten from the Technical Version by
Robert DeRosier

MASTER

NOTICE

The views and conclusions contained in this document are those of the participants and should not be interpreted as necessarily representing the official policies or recommendations of the Geothermal Resources Council, the Oregon Institute of Technology or the Department of Energy.

ISBN #0-934412-08-1

This project was developed under Department of Energy Contract ET-78-G-06-1108.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

PROJECT STAFF

Principal Investigators

David N. Anderson - Geothermal Resources Council
John W. Lund - Oregon Institute of Technology

Technical Committee

Patrick Muffler, Chapter 1
Jim Combs, Chapter 2
Jay F. Kunze, Chapter 3
Paul Lienau, Chapter 4
Charles Higbee, Chapter 5
Paul Rodzianko, Chapter 6
Syd Willard, Chapter 7
Robert C. DeRosier, Technical Writer

Support Staff

Beverly A. Hall, Project Coordinator
Katherine Elliott, Editorial Assistant
Lorraine Smith, Graphic Artist
Colleen J. Fry, Secretary
Alma Kesler, Secretary-Stenographer

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Man has utilized the natural heat of the earth for centuries. Historical records reveal its use as a direct source of heat for cooking, bathing, space heating and medicinal purposes in many areas throughout the world. Early in the 1900's in Italy, geothermal energy was used for the first time as a prime energy source for the generation of electricity. These two uses of the resource are commonly referred to as "direct use" (non-electric) and "electric." These terms usually appear in the literature as Megawatts thermal (MWt) and Megawatts electric (MWe).

Worldwide direct use of geothermal currently amounts to about 7000 MWt as compared to 1500 MWe now being used in electrical power generation. By the year 2000, the estimated worldwide utilization will be 190,000 MWt. The U.S. growth rate is estimated to be 10-15% per year or 32,000 MWt by the year 2000.

Since the early 1970's, dwindling domestic reserves of oil and gas, continued price escalation of oil on the world market and environmental concerns associated with coal and the development of nuclear energy have created a growing interest in the use of geothermal energy in the United States. This relatively clean and highly versatile resource is now being used on a limited basis in a multitude of diverse applications, e.g., space heating, vegetable dehydration, agriculture, aquaculture, light manufacturing and other applications requiring a reliable and economic source of heat.

Although used in direct applications for centuries, geothermal resources were not seriously considered a modern energy source in the U.S. until the late 1960's. Because of the relative youth of resource development, no single, comprehensive publication covering geothermal's numerous aspects was ever previously developed. This was not because the information did not exist, but because it occurred in a myriad of publications and papers not readily available to most libraries or to interested individuals. Furthermore, a large amount of information exists in unpublished reports, notes and in company files available only to those with the contacts to obtain it. Finally, much of the data needed for a comprehensive publication was developed only in the last few years.

It was to the development of both a comprehensive technical direct-use publication and a non-technical version that the project was directed. This non-technical version provides a background into the nature and occurrence of the resource, its development, utilization, economics, financing and regulation. In addition, it is documented with a bibliography of the major reference works.

The project was jointly developed and managed by the Geothermal Resources Council and the Oregon Institute of Technology and sponsored by the U.S. Department of Energy. It was directed by a steering committee made up of the chairpersons responsible for each of the seven chapters, the principal investigators and four other persons with varied responsibilities.

Most of the work was done during a workshop at Diamond Lake, Oregon, in February 1979. The chairperson of each chapter convened a group of experts in various fields to assist in the development of chapter outlines. The chapters were later more fully developed by the chairpersons and submitted to the principal investigators and the technical committee for review and editing.

For your convenience, the key reference documents for the discovery, development and utilization of geothermal energy and their publishers are listed below.

Armstead, Christopher H., 1978, Geothermal Energy: New York, NY, Halstead Press (Div. of John Wiley and Sons), 357 p.

Geo-Heat Utilization Center, Quarterly Bulletin, May 1975 to date: Klamath Falls, OR, Oregon Inst. of Technology.

Geothermal Resources Council, 1977, Transactions Vol. 1, Geothermal: State of the Art: Davis, CA, 310 p.

Geothermal Resources Council, 1978, Direct Utilization of Geothermal Energy: A Symposium (San Diego, California, Jan. 31-Feb. 2, 1978: Davis, CA, 145 p.

Geothermal Resources Council, 1978, Transactions Vol. 2, Geothermal Energy: A Novelty Becomes Resource: Davis, CA, 747 p.

Geothermal Resources Council, 1979, A Symposium on Geothermal Energy and Its Direct Uses in the Eastern United States (Roanoke, Virginia, April 1979), GRC Spec. Rept. No. 5: Davis, CA, 100 p.

Geothermal Resources Council, 1979, Transactions Vol. 3, Expanding the Geothermal Frontier: Davis, CA, 808 p.

Howard, J.H., ed., 1975, Present status and future prospects for non-electrical uses of geothermal resources, Reports UCRL-51926: Livermore, CA, Lawrence Livermore Laboratory, 162 p.

Kruger, Paul and Otte, Carel, eds., 1974, Geothermal Energy, Resource, Production, Stimulation: Stanford, CA, Stanford University Press, 360 p.

Lienau, Paul J. and Lund, John W., eds., 1974, Multipurpose Use of Geothermal Energy: Proceedings of the International Conference on Geothermal Energy for Industrial, Agricultural and Commercial-Residential Uses: Klamath Falls, OR, Oregon Inst. of Technology, 239 p.

Muffler, L.J.P., ed., 1979, Assessment of geothermal resources of the United States--1978: U.S. Geol. Survey Circ. 790, 163 p.

Petroleum Information Corporation, 1979, The geothermal resource: Denver, Colorado, 200 p.

Proceedings of the (First) United Nations Symposium on the Development and Utilization of Geothermal Resources (Pisa, Italy, 22 September to 1 October 1970), 1974: Geothermics, Special Issue 2, 2 volumes (the second in 2 parts), 1725 p.

Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources (San Francisco, California, 20-29 May, 1975), 1976: Washington, D.C., U.S. Govt. Printing Office, 3 volumes, 2466 p.

Wahl, Edward F., 1977, Geothermal Energy Utilization: New York, John Wiley and Sons, 302 p.

Wehlage, Edward F., 1976, The Basics of Applied Geothermal Engineering: West Covina, CA, Geothermal Information Services, 211 p.

OTHER SOURCES OF INFORMATION

Geothermal Resources Council
P.O. Box 98
Davis, CA 95616
(916) 758-2360

General information on electric and non-electric uses of geothermal energy.

Geo-Heat Utilization Center
Oregon Institute of Technology
Klamath Falls, OR 97601
(503) 882-6321

General and specific information on direct uses of geothermal energy.

National Water Well Association
500 W. Wilson Bridge Road
Worthington, OH 43085
(614) 846-9355

Information on water-well drilling and groundwater heat pumps.

The technical handbook and this non-technical version are available through the National Technical Information Center, U.S. Department of Commerce, Springfield, VA 22161, and for a limited time at the Oregon Institute of Technology, Geo-Heat Utilization Center, Klamath Falls, OR 97601 and the Geothermal Resources Council, P.O. Box 98, Davis, CA 95616.

Technical Handbook Reference

Anderson, David N. and Lund, John W., 1980, Direct Utilization of Geothermal Energy: A Technical Handbook, Geothermal Resources Council Special Report No. 7: Davis, California, the Geothermal Resources Council and Klamath Falls, Oregon, the Oregon Institute of Technology.

Blank

Chapter 1

NATURE AND DISTRIBUTION OF GEOTHERMAL ENERGY

The terms that are basic to a discussion of the nature and distribution of geothermal energy are geothermal gradient, heat flow and geothermal anomaly. Geothermal gradient refers to the increase of temperature as the depth increases: the deeper into the earth, the higher the temperature. Normally the temperature increases 5°F in 1000 feet. In many areas of the United States, however, the increase may exceed 25°F in 1000 feet because geologic setting and rock types differ. Thermal energy moves toward the earth's surface by conduction of heat through solid rock, by movement of molten rock (magma), or by movement of water. The vertical movement of thermal energy by conduction is called heat flow.

In some geothermal areas, temperatures at some depths are higher or lower than temperatures in nearby terrain. This temperature irregularity, called a geothermal anomaly, may be limited to a small area and only a single hot spring may indicate the anomaly. On the other hand, the area may be a region of thousands of square miles. Because drilling, developing and maintaining wells that will produce warm or hot water is expensive, geothermal exploration involves locating positive geothermal anomalies with relatively high temperatures close to the surface.

There are five major factors that cause geothermal anomalies in different geological settings. Understanding these factors aids the search for geothermal areas.

1. Heat travels at different rates in different regions. It is believed that fundamental differences in heat flow exist at depths of about 20 miles (the base of the continental crust). For example, beneath the Sierra Nevada, near the base of the crust, the heat flow toward the earth's surface is low; in the eastern United States, the flow is intermediate; and in the Basin and Range province, the rate is high.

2. Range in value of heat travel. At any depth in a sedimentary section, regardless of the type of rock, the heat is conducted at the same rate. Radioactive sources would, of course, change the rate. Normally the heat flows to the surface of the earth at a constant rate. However, if the heat conductivity of the medium is abnormally low, the temperature in the immediate area will be higher than that in nearby areas. Common rocks conduct heat at different rates; quartzite, for example, conducts six times as much heat as unconsolidated clay.

Thus, if the heat flow is constant, the geothermal gradient in one area can be as much as six times greater than the adjacent area, due to the differing rates of heat conduction. Lateral changes in rocks and their corresponding differences in heat conduction produce striking geothermal anomalies.

3. Differences in concentrations of radioactive elements. Other factors influence the extent of the geothermal gradient. Radioactive elements are concentrated in the upper crust but are more concentrated in granitic intrusive rocks. These concentrations increase the heat flow at shallow crustal levels. Up to two-thirds of the heat flow in some granitic rocks is the result of heat continually released by the decay of the radioactive elements uranium, thorium and potassium. Of these, uranium and thorium are about equal in importance and contribute approximately 80-90 percent of the heat associated with radioactive decay. It is worth noting that only modest amounts of uranium (5-10 parts per million) and thorium (20-80 ppm) in granite significantly raise the subsurface temperatures if the volume of granite is large enough. Thus, within a given heat-flow province, a lateral variation in the concentration of radioactive elements will cause differences in the geothermal gradient, even when the rocks are crystalline and of uniform thermal conductivity.

4. Young magmatic intrusions. The theory of plate tectonics (the movement of large flat sections of the earth's crust) has explained the occurrence of young centers of magma (molten rock) activity. Magma is generated along spreading ridges, along zones of plate convergence and at the intraplate melting anomalies such as occur in Hawaii and Yellowstone. The molten rock moving upward through the crust transfers heat to the earth's crust and can cause high geothermal gradients. The resulting intense geothermal anomalies may produce substantial geothermal resources.

5. Hydrothermal circulation. In many areas of the United States, fluid flowing along permeable sedimentary beds, faults, fissures or fracture zones transports heat faster than does rock. The hot water may be circulated by the heat from a young intrusive mass or the heat may be the result of water circulating to a depth in a region devoid of young igneous rocks. In either case, geothermal energy is transported to shallow depths in the crust and may cause major geothermal anomalies. Hot springs occur at places where the thermal waters rise to the land surface. At other places, shallow wells may reach the thermal waters.

Production of Geothermal Energy

Geothermal energy in the earth's crust is stored predominantly in rock and only subordinately in water, steam or other fluids that fill pores or fractures within the rock. This diffuse energy must be collected from large volumes of rock and transported to a discharge point to make the energy available for practical uses. The water contained in nearly all rocks within the upper few miles of the earth's crust provides the mechanism for collecting and discharging the energy.

To extract the water and its contained thermal energy economically, the rocks through which the water moves must store significant amounts of water and transmit it freely. The capacity of the rock to store water is termed the storage coefficient, and the ability of a rock to transmit water is termed the hydraulic conductivity or permeability. Rocks such as fractured quartzite and limestone, broken volcanic rocks or uncemented sand and gravel generally have moderately high storage coefficients and hydraulic conductivities and usually produce fairly large amounts of water.

Rocks with high hydraulic conductivity and large thickness are said to have high transmissivities. Rocks of high transmissivity form the principal aquifers (water-bearing strata of permeable rock, sand or gravel in groundwater systems) and constitute the most productive geothermal reservoirs. In order to produce energy over a long period, these aquifers must extend over a large area and be hydraulically connected to an adequate recharge area.

Various fracturing techniques (e.g., hydrofracturing, explosives or chemical treatment) can, theoretically, increase the productivity of low-permeability reservoirs, but such techniques have been used rarely in geothermal settings.

Energy from rock of low porosity and permeability can be extracted from a confined circulation loop, which is two wells connected by a network of fractures induced by hydraulic or other means. Cold water is pumped down one well, heated by conduction as it flows through the induced fractures and extracted as hot water from the second well. The rocks adjacent to the fractured volume must remain impermeable so that the fluid losses from the circulation loop are small. This procedure, commonly called "hot dry rock technology," is still experimental. Its widespread applicability and its economics have yet to be demonstrated. Hot dry rock is one end member of a series of hydrologic environments that extend, with increasing permeability, to conventional reservoirs or aquifers. Most rock in the earth's crust is likely to be too permeable to support a confined circulation loop but not permeable enough to produce the fluids it contains at economically acceptable rates.

Types of Geothermal Systems

1. Hydrothermal convection systems related to young igneous intrusions. The most spectacular evidence of the heat of the earth is a volcanic eruption. Although the lava extruded from such an eruption cools quickly on the earth's surface, the chamber in the earth's crust--the source of this lava --contains rock which will remain melted for many thousands of years. At present, it is not practical to tap these magma chambers directly by drilling. However, fractures and faults around the intrusion may allow the development of a hydrothermal circulation system: groundwater may circulate down to or near the cooling intrusion, absorb some of the heat and return to or near the earth's surface. The difference in density between hot and cold water causes the heated water to rise, just as it does in a tea kettle over a gas burner. Figure 1 illustrates this geothermal system.

2. Fault-controlled systems. Most hydrothermal convection systems are not located in areas where young igneous intrusions have been identified. Instead, these geothermal systems get their heat from the large volumes of rock by the water circulating deeply along permeable zones. These zones may be either stratigraphic beds or fault and fracture networks (Figure 2). The temperatures attained by the water depends primarily upon the amount of the regional heat flow and the depth to which the water circulates. Recharge to

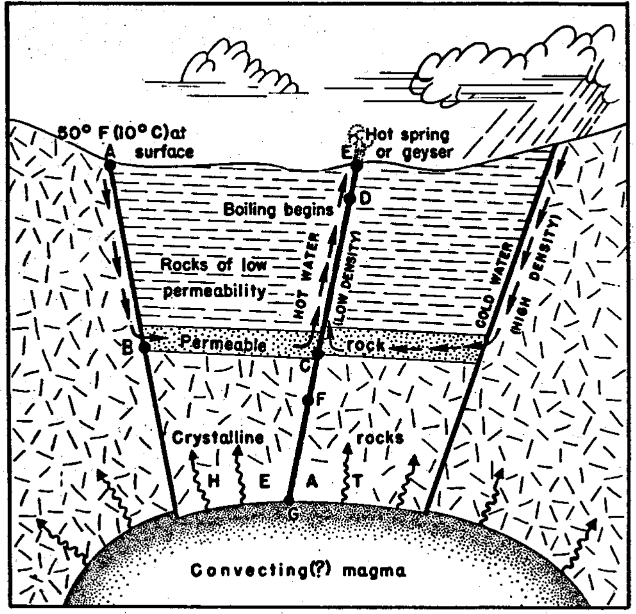


FIGURE 1. Schematic model of a hydrothermal convection system driven by an underlying young igneous intrusion (modified from White, 1968).

the downward-circulation limb of the hydrothermal convection system occurs over both mountain areas and adjacent valleys. The fractures and faults may differ from those shown in the generalized model in Figure 2; the only requirement is that the faults be permeable enough to transmit the rising hot water.

3. Radiogenic heat sources concealed beneath insulating sediments of low thermal conductivity. Granitic plutonic rocks are relatively rich in uranium and thorium. Radioactive disintegration of these elements gives off heat and thus heat flow in a radiogenic pluton is higher than that in the adjacent country rock into which it was intruded. If the granitic rocks are covered by sediments of low thermal conductivity, then relatively high temperatures can occur at the base of the sedimentary section which is over the radiogenic source. The areal extent of the geothermal anomaly depends on the shape and thickness of the radiogenic source, the concentration of uranium and thorium in the radiogenic source, and the thermal conductivity and thickness of the overlying sediments.

4. Geopressured-geothermal reservoirs. Geopressured-geothermal reservoirs are aquifers that are under pressure exceeding the pressure of a water column and approaching that caused by the weight of the overlying rocks. The less porous sediments that lie on top of the geopressured-geothermal zone prevent upward leakage of water that ordinarily would transport heat to the surface (Figure 3). Water in the geopressured sediments thus contains an anomalous amount of heat as well as substantial amounts of dissolved methane (the chief constituent of natural gas).

The technology for producing geothermal energy and the dissolved methane from geopressured-geothermal reservoirs is still being perfected, but basically it involves the use of the same tools and techniques required in deep oil drilling. This drilling is costly and usually limited to those organizations with substantial financial backing. At present, the hot water alone does not seem to justify the development economically, but if it can be combined with the associated methane, these geopressured-geothermal energy reservoirs may be profitable.

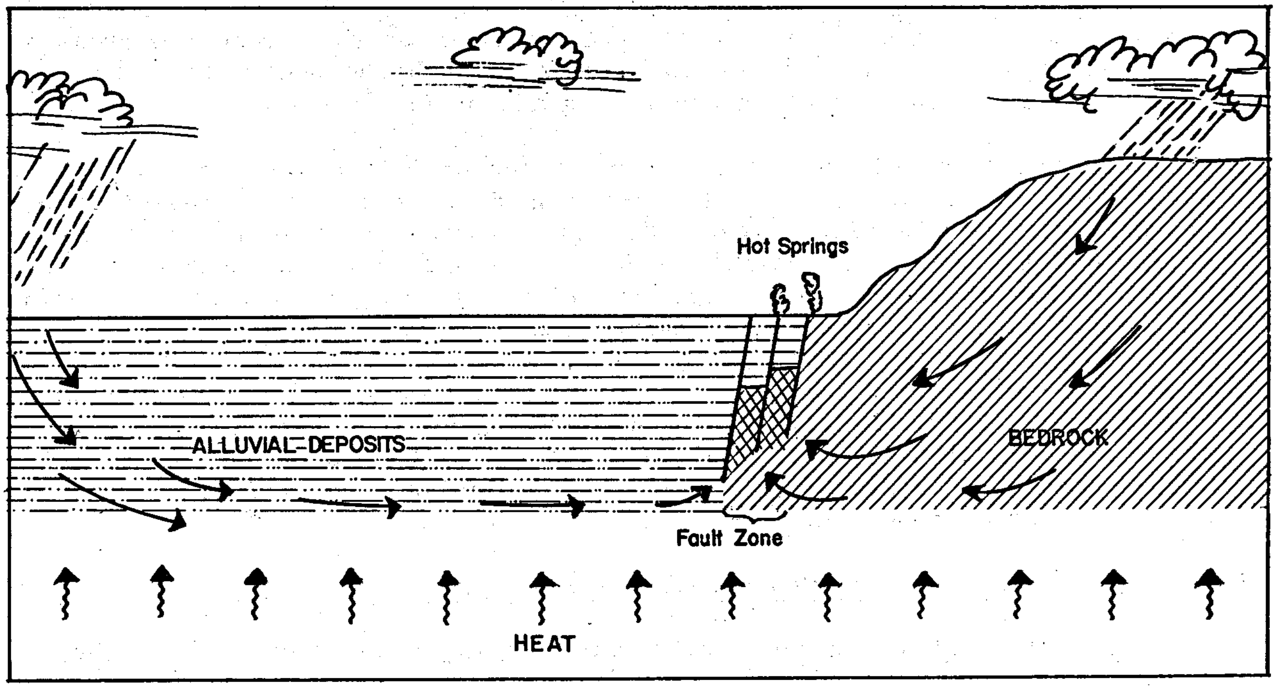


FIGURE 2. Schematic model of a hydrothermal convection system (fault-controlled) related to deep circulation of meteoric water without the influence of young igneous intrusions.

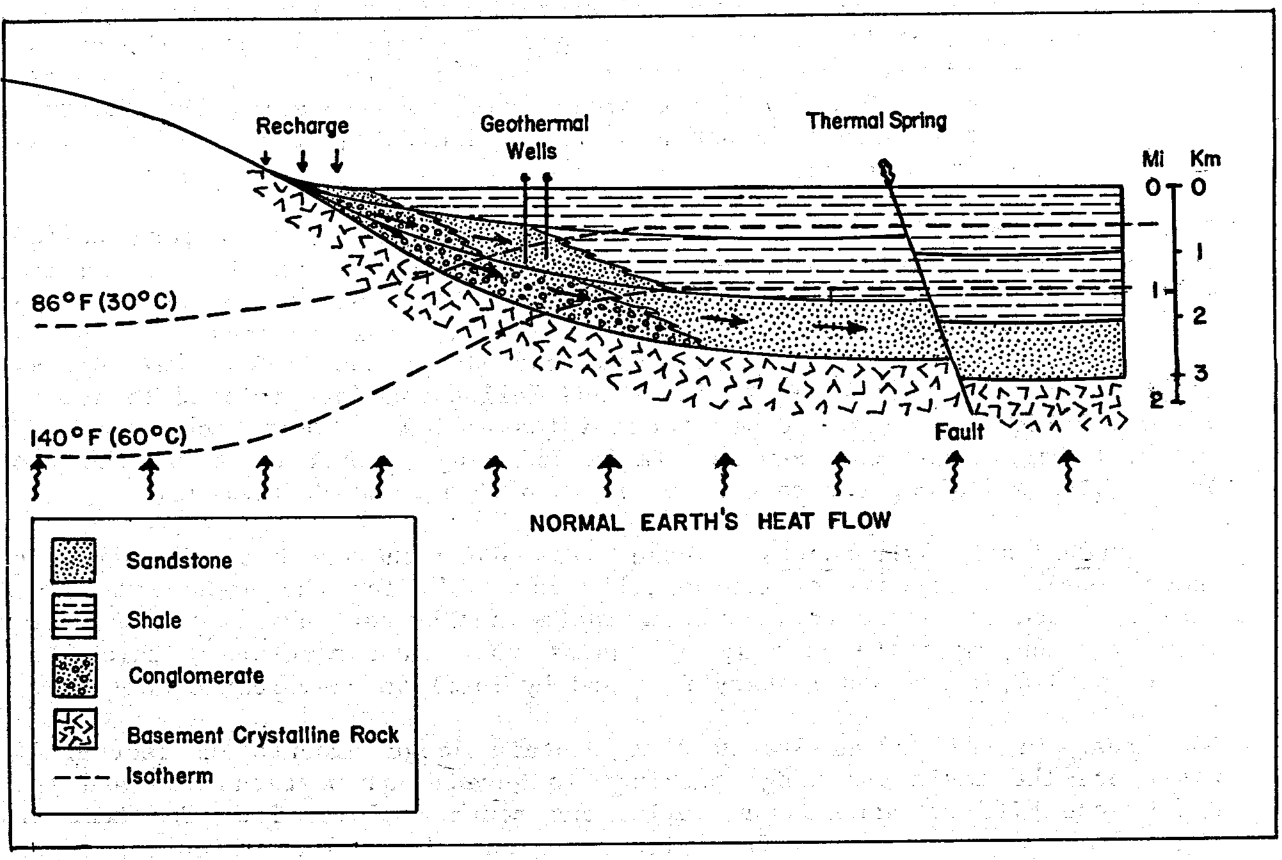


FIGURE 3. Schematic model of a geothermal reservoir in a deep regional aquifer.

5. Deep regional aquifers. Downwarped troughs in the crust form sedimentary basins that collect and transmit groundwater from recharge areas in adjacent highlands. This water moves down through the sedimentary deposits and is heated in the earth's geothermal gradient (Figure 3).

At places in these basins where hydraulic conductivities are unusually high or where fractures allow water to move upward under artesian pressure, geothermal water may be within reach of drill holes. Artesian pressure may be sufficient to force the thermal water to the surface. Isotherms in sediments of low thermal conductivity may curve toward the surface and bring geothermal water fairly close to the surface.

Deep regional aquifers with geothermal potential occur in the Williston Basin in the northern Great Plains and may occur in other large basins of the north-central and western United States. In the eastern and mid-western United States, such areas as the Allegheny, Michigan and Illinois Basins may offer geothermal opportunities.

Geologic Environments of Geothermal Systems

Volcanic belts. Volcanic belts are the major location of hydrothermal systems. Because most of the developments in the world are in these locations, it seems likely that many more developments will take place in these extensive volcanic mountain regions (Figure 4).

In the United States, major geothermal anomalies exist in volcanic belts and these anomalies contain substantial geothermal energy. In general, volcanoes less than one million years old are the best possibility for economic geothermal systems. Older volcanic areas are less favorable, but the volcanic rocks at the surface do not necessarily indicate the age of the rocks cooling beneath the surface.

There is a concentration of young volcanic belts in the western United States. Most volcanic rocks and associated intrusions are located in the Aleutian Volcanic Chain and the Cascade Range, both related to the converging margins of major plates. The Imperial Valley of southern California lies along the major spreading zone that extends up the Gulf of California. Hawaii, the eastern Snake River Plain and Yellowstone are related to intraplate melting anomalies. Other young volcanic belts occur along the east and west margins of the northern Basin and Range province, along the Rio Grande Rift and along the southwest margin of the Colorado Plateau.

Extensional environments. Those areas where the crust of the earth is under tensional stress are geologically favorable for the presence of hot water. These areas are frequently characterized by active faulting, by relatively young mountain ranges, by basins that have moderately thick but poorly packed, loose sedimentary fill and by local young volcanic activity.

Two areas in the United States that contain large amounts of geothermal water are the Basin and Range province in Nevada and western Utah and the Rio Grande Rift of central New Mexico and southern Colorado. The heat in these areas typically comes from either regional heat flow (which can be an important source of heat for a large region) or from young igneous intrusions (which can be locally important as sources of heat). Hot water in

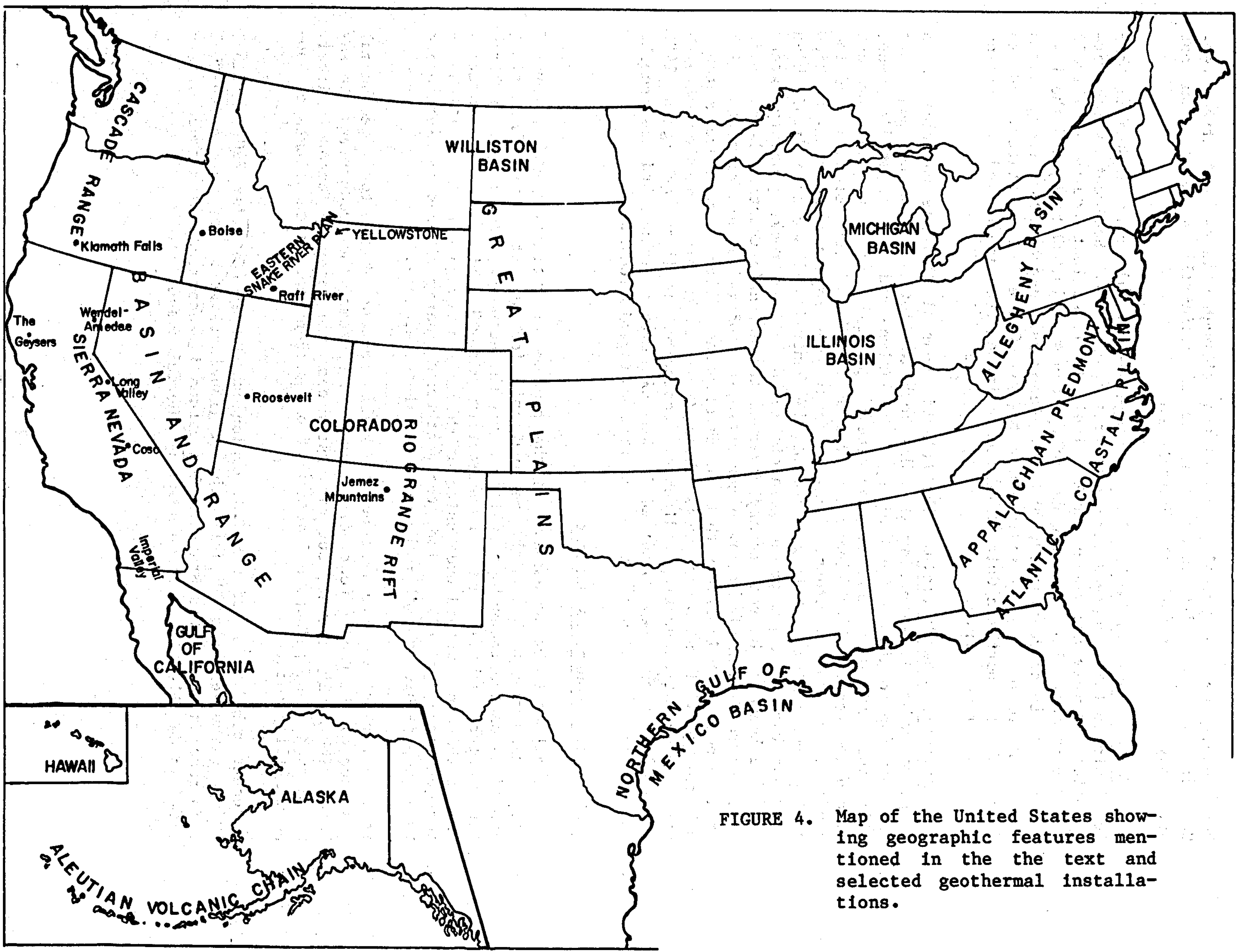


FIGURE 4. Map of the United States showing geographic features mentioned in the the text and selected geothermal installations.

both environments typically circulates through faults and fractures. However, in areas with thick sequences of basin-fill sediments, the hot water may be in the sediments themselves.

Northern Gulf of Mexico Basin. Large areas in the northen Gulf of Mexico Basin contain geopressured-geothermal reservoirs. Sediments which were deposited rapidly and conduct heat slowly trap the heat coming into their lower portions. This trapping generally occurs at 10,000 feet, and the reservoirs may be as deep as 50,000 feet. Geopressured-geothermal energy areas may exist in other deep sedimentary basins of the United States, but to date, only the northern Gulf of Mexico Basin has been identified as containing such a reservoir.

Atlantic Coastal Plain. The Atlantic Coastal Plain is underlain by a wedge of sediments extending from New York to Florida. The sediments are thickest (up to 10,000 feet) along the coastline and consist of limestone, siltstone, sandstone and conglomerate. Several major aquifers present within the Coastal Plain sediments include the Tuscaloosa Formation and the sands of the Potomac Group. Some wells in this region produce up to 3500 gallons per minute. A large area of the central and southern Appalachian Piedmont has outcroppings of granitic rocks. These rocks probably extend eastward beneath the sedimentary cover of the Atlantic Coastal Plain. Some of these rocks contain moderate concentrations of radiogenic elements which produce heat. It is likely that the development of low-temperature geothermal energy will occur in areas where these rocks are concealed beneath thick, non-heat-conducting sediments. Geothermal gradients as high as 24°F per 1000 feet have been observed in Coastal Plain sediments and are thought to be associated with concealed granitic radiogenic rocks.

Geothermal Resource Assessment

Geothermal resource assessment is the process of estimating the amount of geothermal energy that might be available for use at a specified time, depending on the technology available and the economy. The process is similar to the methods used for estimating mineral and petroleum resources except that this method uses units of thermal energy rather than millions of tons or barrels of oil. Also, the geothermal energy figures are referenced to a temperature, normally the mean annual temperature.

It is important to note that only a small fraction of the total geothermal resource can be used effectively. For some systems, the productive rate may be as high as 25 percent, but for most areas, the recovery factor is likely to be much less, perhaps a fraction of one percent for large volumes of low-permeability rock.

A recent publication of the U.S. Geological Survey (Circular 790, Muffler, 1979) discusses and depicts the regional distribution of geothermal resources in the United States. The volume is recommended for those interested in detailed information about geothermal resources.

Chapter 2

EXPLORATION, CONFIRMATION AND EVALUATION OF THE RESOURCE

A geothermal energy exploration project is quite involved and is composed of a number of phases, all of which are important. The three phases are: looking for a resource, confirming its existence and then estimating its value. They must all be conducted systematically. Three questions must be answered at the beginning of any drilling project for geothermal energy: (1) Where should the geothermal well be sited?, (2) How deep must the well be drilled to obtain the temperature required?, and, (3) How much heat (thermal energy) can be extracted in a given period of time after drilling a well to the required depth? (Note: the answer to the last question must be in the realm of economic feasibility or the project will not be undertaken.)

Essentially, thermal energy in the shallow crust of the earth is produced by bringing to the surface in a well the hot water and steam that occur naturally in the open spaces in rock. Where rock permeability is very low, the rate of thermal energy extraction (flow rate) is low. Therefore, in addition to adequate temperature, a minimum permeability is required if thermal energy is to be extracted economically. In order for the heat stored in solid rock to be extracted, there must also be a slow recharge, or replacement, of water into the produced geothermal system as the initial water is extracted.

In regions of normal geothermal gradient, it is necessary to drill deeper than 2-3 miles in order to obtain water above 212°F. At this depth, the geological environment is most likely to be a deep sedimentary basin, comparable to those in Hungary and France which provide hot water for direct geothermal use. Areas with highly faulted and folded rocks and a normal geothermal gradient may have natural channels (cracks in the rocks) for convective water to flow upwards or the area may have local shallow reservoirs of hot water suitable for direct use. It is possible also to find geothermal reservoirs that are economically useful at relatively shallow depths in those areas where the conductive geothermal gradients are very high.

Background

Applications of geothermal energy differ in use and, therefore, differ in temperature needs. The first step in exploring for geothermal resources is to define the physical requirements of the application in terms of temperature, flow rate and water quality. These, however, are not the only factors to be considered. There are others which involve the geography of the area. For example, a resource should be near the areas of probable use, but its development should not conflict with such present land uses as highways, metropolitan areas or industrial and agricultural centers.

Exploration can begin after temperature, quantity and location requirements have been determined. A literature search, the important first step, can determine land status and produce technical information. Local offices of the Bureau of Land Management (BLM) have detailed land status maps. These maps show the owners of the land (federal, state, Indian, military, recreational, and private). Procedures such as leasing, obtaining proper permits and environmental regulations are discussed in detail in Chapter 7. For the exploratory stage, it is sufficient to note that such documents or regulations can be found in the agency controlling the land or in the state land office.

The second part of any literature search involves locating the existing specific geothermal data and general geological information that may bear directly on the nature and location of geothermal resources. The U.S. Geological Survey has published two circulars (726, White and Williams, 1975; 790, Muffler, 1978) containing such specific geothermal information as the locations of high heat flow areas containing hot springs and hot wells and their estimated energy potential. These two circulars should be carefully studied as they contain a great deal of usable information. The American Association of Petroleum Geologists and the U.S. Geological Survey have published national heat flow maps (AAPG-USGS, 1976, a,b). The National Oceanographic and Atmospheric Administration (NOAA) has published a geothermal resource map of the western United States (see Muffler, et al., 1978). The U.S. Energy Research and Development Administration (now the U.S. Department of Energy) has issued an extensive bibliography of geothermal publications (ERDA, 1979) which is updated quarterly.

Geological literature has a wealth of information on specific sites. This information may take time to locate, but the results are well worth the effort. The most useful sources are the reports of the U.S. Geological Survey, state geological surveys and reports in the major geological publications.

In the early stages of exploration, the most useful information is that specifying the location and distribution of young volcanics and recent faults, chemical analyses of thermal and non-thermal waters, and the location of deep sedimentary basins. The literature will frequently supply the experienced explorer with this information. After searching the literature, evaluating the information and verifying the access to the land, the exploration team must decide if the potential for the area justifies further work on the site itself.

Geological Exploration

If the team decides an area has economic potential, their next major step is to collect geological data specific to that area. Geologic maps and aerial photography help the trained observer identify hot spring deposits and other hydrothermal features that suggest the presence of geothermal activity. The observer can trace such features as faults (cracks in the earth) or intersections of faults on the aerial photographs. With this information and the information gained from the literature search, it is possible to locate drill sites that will intersect the desired structures.

But not all decisions can be based on reports and maps. On-site investigation of the land is necessary in the search because hot thermal waters alter the minerals of the rocks they touch. Information may be obtained from the hot spring deposits of calcium carbonate (travertine) or opaline silica (sinter) commonly formed by these waters. Heavy travertine deposits indicate that the temperature of the aquifer feeding the spring is below 284°F. On the other hand, sinter deposits are solid evidence of temperatures exceeding 356°F. However, these higher temperatures tend to seal off the system and halt hot spring activity. The deposits will suggest that even though activity has ceased at the surface, the geothermal resource may exist deeper underground.

Another aid in site exploration is the type and age of rocks. The presence of rhyolites one million years old or less and other volcanic activity within the last two thousand years indicate anomalously high thermal gradients. Thus, radiometric dating of the rocks presents more data for final evaluations of the potential of an area.

Geochemical Exploration

Geochemical investigations also provide valuable information. They can reveal subsurface temperatures and locations of faults permitting upward movement of hot waters and gases. Chemical analysis can also reveal the presence of minerals which could cause scale or corrode the pipes which will be used later in the production phase. The investigations may also disclose possible waste-disposal problems and other items of technical and environmental concern.

A chemical analysis of the spring and well waters leads to estimates of the temperatures of the geothermal reservoir. The estimates are fairly reliable if three conditions are met: (1) a balance in the chemical reaction between the reservoir rock and the geothermal fluid; (2) little chemical action at lower temperature after the water leaves the reservoir; and (3) the geothermal fluid does not mix with any other water as it moves to the surface, or, if there is mixing, that the degree of mixing is known. Some forms of silica are commonly used as geothermometers, but each has its limitations and requires considerable interpretation. If chemical and isotopic geothermometers are to be used, samples must be collected, transported and stored properly and properly analyzed.

While geothermometers are most helpful, the results must be carefully interpreted by qualified people. For example, when using the silica geothermometer, several factors that may influence the readings should be considered. Most groundwaters with temperatures lower than 195°F will have silica concentrations greater than those predicted by the solubility of quartz; chemical reactions may also affect the concentrations. Another factor to consider is the pH (the degree of acidity or alkalinity) of the spring water; temperature affects pH. Experts can account for these changes and the factors causing them.

The sodium/potassium geothermometer, which has been used for several years, is unreliable at temperatures below 302°F; therefore, it should not be used for evaluating low-temperature resources. At these temperatures, the sodium/potassium/calcium method is reasonably reliable, but it, too, has its limitations.

Although the sulfate isotope geothermometer has been used recently, it cannot be used where some of the sulfate in the water is caused by low-temperature reactions, i.e., surface oxidation of H_2S, or by sulfide minerals, such as pyrite.

Mixing of hot and cold waters also causes inaccurate temperature estimates. When chemical geothermometers are used to estimate reservoir temperatures in geothermal systems, the estimate should also include an examination of hydrologic factors, that is the distribution and movement of water in the underlying rocks. Water that moves quickly and directly to the surface from a deep reservoir may retain most of its heat. But if it flows through a series of intermediate reservoirs, it may lose heat. Thus, the geothermometers applied to water at the surface will give information only about the temperature of the last reservoir. Temperatures also may be reduced by the water transmitting heat to surrounding rock, by boiling or by mixing with cooler shallow water. Other factors affecting temperature are the depth of the reservoir, the path the water follows, the rate of flow and the initial temperature of the water.

Geochemistry can help determine the extent and direction of the thermal and non-thermal groundwater in a given region. Information about heat distribution helps determine the point where recharge water enters the system and also helps determine the amount of reaction between rocks and water that occurred at high temperatures as that water moved through the system. The tritium content of water emerging at hot springs indicates the length of time the water has been underground. A lack of tritium indicates that the water has been underground for many years and it probably comes from a deep reservoir. Large amounts of tritium attest to the mixing with cold water near the surface.

Chemistry can also be used to analyze soil gases and groundwaters. Unnaturally high temperatures at shallow levels can cause gases to form. The presence of certain gases (helium, radon and mercury) in the soil can indicate the location of faults. Mercury, carbon dioxide and helium in the soil, and boron and ammonia in the groundwater are excellent indicators of shallow high temperatures. Such analyses are most useful when boiling water exists at depth. Unfortunately, the same results can be produced by fossil geothermal activity and gases escaping from deep in the earth's crust. Therefore, in fossil areas (cool geothermal sites), gas analysis may not be reliable.

Soil geochemistry is also useful in detecting anomalous trace elements which can outline geothermal resources. For example, arsenic and mercury anomalies reveal the upper levels of hydrothermal systems. Some explorers have been able to predict the proximity to hot water in their exploration holes after analyzing the drill cuttings for trace elements.

Obviously, no single method is successful by itself. Combining several methods enhances the accuracy of the predictions. Geophysical surveys can yield valuable information for the explorer in siting geothermal wells.

Geophysical Surveys

A geophysical survey consists of a set of measurements made over the surface of the earth, in the air above (and parallel to) the earth and in the boreholes within the earth. The survey measures variations in the physical properties of subsurface rocks. Geothermal systems commonly give distinct and measurable variations in physical properties such as high heat flow, low electrical resistivity and attenuation of high-frequency elastic waves. Therefore, the existence of geothermal resources can be inferred from the indirect measurements of these physical properties.

The most useful techniques for geothermal exploration are surveys of temperature and of electrical resistivity, determinations of heat flow and surveys of passive seismic conditions, such as microearthquake measurements. These geophysical methods can aid in estimating the boundaries of geothermal reservoirs and can furnish data on subsurface thermal processes. The accuracy of these methods depends on the degree of contrast between the physical properties of the rocks comprising the geothermal system and the rocks of the surrounding subsurface. Geothermal systems usually have irregular shapes and occur in rocks of complex structures and varying types. Exploration detects not only the existence of the system, but also the extent, length, width and depth of the system. Such data will aid in siting the geothermal drill holes.

Direct geothermal applications can make use of resources with temperatures lower than those needed for electrical application. But the lower temperatures of the resource make its detection more difficult because the irregularities are less distinct than they are in resources with higher temperatures. The risk will be greater under such circumstances. To reduce risks, several different surveys may be used.

Geophysical techniques or surveys can be placed in four categories: structural methods, electrical and electromagnetic methods, passive seismic methods and thermal methods.

Structural methods. Structural methods include active seismic methods, gravity surveys and magnetic surveys. These investigate the structure and nature of the host rocks, rather than the physical properties of the warm or hot geothermal fluids which are examined by thermal and electrical methods. Structural methods may be justified to improve a regional or local geological subsurface model, but they generally provide little useful information for defining geothermal reservoirs. They may be useful in defining fault zones in which geothermal resources occur.

Active seismic methods (both reflection and refraction) use man-made explosions or other sources of subsurface vibrations to generate elastic waves which travel through the earth. The reflection method measures the energy returned to the surface from the subsurface after being reflected by rocks of different physical properties. The refraction method uses seismic waves deflected horizontally along an interface and then back to the surface. Both methods determine the subsurface structures and the configuration and depth of the basement rocks.

Gravity surveys determine the density contrasts of subsurface rocks and can outline the major structural features and local positive and negative anomalies possibly related to geothermal systems. Local structural highs, buried volcanic rocks, intrusive rocks or hydrothermally altered rocks may cause local gravity anomalies. However, several factors can cause gross misinterpretations unless other exploration techniques are used in conjunction with this method.

The least useful method for defining geothermal drilling sites is the magnetic survey. Hydrothermal alteration may cause negative magnetic anomalies in some areas and very young intrusive and volcanic rocks may cause positive magnetic anomalies in other areas. However, in most other areas, so many factors influence the magnetic survey that the resulting magnetic map is difficult to interpret in terms of geothermal resources.

Electrical and electromagnetic methods. In geothermal exploration, electrical and electromagnetic methods measure the electrical resistivity (capacity for resistance--their ability to slow the movement of an electrical charge) of rocks at depth. Because the elements of the reservoir are different from the elements of surrounding subsurface, the resistivity of the reservoir is relatively lower than that of the host rocks. But the temperature in the geothermal reservoir is higher than that in the surrounding environment. Also, the porosity, salinity of fluids and the content of clays and zeolites are higher. These differences can be detected and measured by different electrical and electromagnetic methods. Two methods used are the telluric-audiofrequency magnetotelluric (AMT) and the magnetotelluric (T) techniques which measure variations in the natural electrical and magnetic fields of the earth.

Electrical techniques use man-made generators to put electrical current into the ground at two electrodes. A measurement of the current is made at two other electrodes. Because electromagnetic methods generate a magnetic field that varies with time, this method causes the electrical or magnetic field to arise from the currents induced in the earth. It is this field that is detected and measured.

It appears that the most useful electrical techniques are the profiling or sounding, which use DC resistivity, and the Wenner or Schlumberger linear arrays. With these arrays, the spacing of the electrodes is important in determining the depth to be probed. Thus, evaluating deeper prospects requires laying cables over a considerable distance. Obviously, laying cables in a rugged terrain would be difficult, so in such areas, the dipole-dipole array has been used. Although this array is fairly easy to use, effective investigations require careful analysis of the data because the data are subject to ambiguous interpretations.

Electromagnetic methods are fairly new, having been used in geothermal exploration only recently. The instrumentation and interpretation are more complex than in other methods, but electromagnetic methods have two advantages: measurements are easier to make and are quite accurate in geothermal areas, and high resistivity zones near the surface do not adversely affect the results.

It becomes obvious that the major problem with all electrical and electromagnetic methods is interpretation of the data gathered. Electrical resistivity of subsurface rocks is a complicated result of temperature, porosity, salinity and content of clays and zeolites. Thus, when a relatively low electrical resistivity anomaly occurs, it is necessary to determine the causal relationship by considering such other data as direct temperature or geothermal gradient measurements. Specifically, the magnitude of the measured electrical resistivity from low-temperature, highly saline, groundwater can be the same as those from a high-temperature, moderately saline geothermal system. Consequently, accurate analyses require people who are experienced in such interpretation.

Passive seismic methods. A characteristic of geothermal areas is that they have more microearthquake activity than do other areas. Passive seismic methods can detect such activity. Detecting these microearthquakes and their exact location helps locate the active fault zones in a geothermal area, a beneficial find, since the faults may be acting as conduits for geothermal fluids. In addition, results of the surveys can be used to estimate subsurface physical characteristics of the geothermal system. The data may indicate high-temperature zones of low rigidity, or they may indicate rock voids that are not filled with water and could be filled with steam.

Passive seismic methods are just beginning to be applied in geothermal exploration and are not completely understood. They do offer the potential of new and useful techniques for geothermal exploration.

Thermal methods. The most important physical characteristic of a geothermal system is the temperature within the reservoir. Thermal exploration methods measure the geothermal gradient (the temperature increase per unit of depth) in the boreholes and determine the heat flow. However, shallow techniques provide the most direct method for making a first estimate of the size and potential of a geothermal system. Such information is important because it is used to select the techniques to be used to extract the fluids. The method of extraction, in turn, depends on the physical and chemical processes in the reservoir.

An advantage of the thermal method is that measurements of temperature and gradient can be made at intervals rapidly and cheaply and can be used to detect anomalously hot areas. However, shallow temperature measurements are strongly influenced by near-surface effects: movement of groundwater, exposure to the sun, topography and precipitation. The movement of groundwater is important, for even a slow movement across a strong geothermal anomaly can carry away conductive heat flow and thus change surface temperature patterns. These factors will grossly distort gradient measurements.

Temperatures in boreholes 50-2000 ft deep have been used as the primary thermal method in geothermal exploration. These depths avoid most thermal disturbances near the surface and the gradient measurements obtained are both precise and reliable. Nevertheless, the effects of lateral and vertical movement of groundwater cannot be ignored. In most economically attractive geothermal areas, the gradients at shallow-to-intermediate depths are equal to or greater than 36°F per 1000 ft. A normal gradient is about 14°F per 1000 ft.

Gradient measurements will define the area of geothermal anomalies, but the magnitude of the anomalies must be used carefully. High temperatures at the surface do not necessarily guarantee higher temperatures at depth. The thermal conductivity of subsurface rock may vary from that of rock deeper in the ground. Also, thermal convection at depth will have an even greater effect in reducing gradients.

Temperatures taken during the drilling of the boreholes can indicate the magnitude gradient. If the rocks throughout the subsurface conduct heat at a constant rate, then the heat flow can be estimated because they are proportional to the geothermal gradients. Heat flow is the product of geothermal gradient and thermal conductivity. In areas having a variety of rock types, measurements of heat flow will provide the most accurate data on geothermal zones.

Drilling

The exploration methods that have been discussed are extremely important in selecting sites for drilling. However, drilling is the only way to confirm the presence of a geothermal resource. It can also be helpful in assessing the geological and hydrological controls of the geothermal system. Therefore, careful planning of the drilling program will insure obtaining all the information about the size and value of the resource. The drill plan should include basic well design, recovery of samples (including collection of cuttings and cores), geophysical logging and flow testing (which should include fluid sampling). These data will allow a proper reassessment of the geological, geophysical and geochemical data previously acquired. Such reassessment will provide a better understanding of the nature and extent of the geothermal resource.

Geophysical Logging

Geophysical logging applies to the borehole environment the same physical principles used for surface geophysics. In the borehole environment, these techniques provide more resolution than is normally obtained from surface geophysics. Geophysical logging has been the petroleum industry's primary tool for assessing the properties of rocks in petroleum reservoirs and much of this technology is directly transferable to the geothermal field because it is useful in evaluating the properties of rocks in geothermal reservoirs. Of course, most of the rocks encountered in geothermal exploration are significantly different from the rocks commonly found in petroleum explorations. Consequently, care must be taken to understand this difference and to interpret the data, not on the basis of a petroleum reservoir, but on the basis of a geothermal reservoir.

The potential of a geothermal reservoir can be estimated by assessing temperature, flow rate, porosity, elastic-wave velocity, electric resistivity, density and natural radioactivity. Many of these are useful in defining geological units and rock types for correlation with rock types in nearby boreholes. Such data help to define potentially productive zones, to specify the way to complete the well and to locate additional wells.

The nature and character of the logging will vary with the type of geothermal resource. The obvious parameters to be measured are temperature and flow rates, which can be obtained with temperature logs and flow meters; however, for most direct applications of geothermal resources, effective porosity is an important factor. It can be obtained by a gamma-gamma log, the neutron log or the sonic log. The fundamental tools are the SP (spontaneous potential) and the natural gamma.

A complete suite of geophysical logs from major petroleum logging firms is expensive. Some of these firms do have equipment capable of logging very hot holes. However, other firms can run logs less expensively in the relatively shallow and moderately hot holes drilled for direct applications. These firms may be geothermal and mineral exploration firms and some of their equipment is extremely portable.

Adequate logging services are available at a variety of costs. The acquisition of this data is, therefore, possible and essential to the orderly development of the resource.

Exploration Costs

The following table shows many of the exploration methods discussed in the previous sections. The costs are approximate and will be affected by many factors: survey detail, accessibility, terrain and weather. The borehole costs include the cost of drilling and completing the holes and of logging. The geochemical procedures include sample collections and analytical costs.

TABLE 1

Summary of costs, time frames and area covered with various geothermal exploration methods

Method		Time	Expense
Consulting geologist		< month	\$200-\$400/day
Airphoto interpretation		< month	\$5/mi^2
Water analyses		month	\$100-\$200/sample
Surface geochemistry		month	\$30/sample
Volatile geochemistry		month	\$20/sample
Temperature gradient/heat flow boreholes		> month	\$10-\$100/ft
Electromagnetic methods		month	\$200-\$1500/line mi
Resistivity		month	\$200-\$1500/line mi
Magnetics	- airborne	< month	\$25/line mi
	- ground	< month	\$200/line mi
Seismic	- refraction	< month	\$5000/line mi
	- reflection	< month	\$5000-\$10,000/line mi
	- microearthquakes	3-6 months	\$1200/day
Gravity		month	\$30-\$70 station
Magnetotellurics		month	\$1200-\$2000/line mi
Geophysical logging		< week	\$2000-\$20,000/hole

Blank

Chapter 3

RESERVOIR DEVELOPMENT AND MANAGEMENT

In the petroleum, natural gas and groundwater irrigation industries, the development and management of reservoirs have become well established sciences. In geothermal, however, this science is just developing. In the geothermal industry, the principal experience has been gained at several fields in four different countries. Electricity is being generated at these fields in minimum sized blocks of 75 MWe (megawatts electrical) or 350 MWt (megawatts thermal). Two of these fields are vapor dominated: Lardarello, Italy, and The Geysers, USA. The fields at Wairakei, New Zealand, and Cerro Prieto, Mexico, are liquid dominated, and steam is generated at the well heads by reduction of the pressure on produced fluids.

The techniques, considerations and plans for direct-heat applications discussed here will differ greatly from those mentioned above which produce electricity. Such use of geothermal energy is considered an "indirect use." Direct-use projects will range from 1 MWt to 50 MWt, obviously much smaller than the modules for electrical projects. Instead of the 10-100 wells in a field needed for electrical applications, direct application of geothermal energy may require only one or two wells. Electrical developers can call the first few production wells exploratory and hope to reduce their costs significantly on future wells. By contrast, the first direct-application wells may be the only ones needed, and perhaps the only ones drilled in the field.

Tests in the two applications also differ. In electric developments, interference measurements made between wells can help in the evaluation of the reservoirs. In direct-heat applications, having one well does not permit such tests. More wells could be drilled for this purpose, but the expense could be prohibitive. Thus, single well tests may be the only source of information for technically evaluating the long-term performance of the reservoir. The final difference lies in the relative costs of electric and direct-heat applications projects. A project costing one-tenth that of an electrical project cannot afford the same sophistication in a reservoir management program as one for a planned 200 MW electrical project. Such savings should be considered in the plans of the reservoir and development program.

Production Well Drilling

Drilling the well represents both the greatest expense and the greatest risk in the utilization of geothermal energy. Once the existence of a geothermal resource is fairly certain, the next steps are confirming its size, its usefulness, the cost of getting the energy out of the ground and determining the time needed to pay off the investment.

The previous chapter discussed locating well sites for drilling wells and estimating the size and temperatures of the resource. Once this information is available, it can be used to estimate the quantity of fluid from a single well. Most direct-heat applications will bring the fluid to the surface. For industrial use, large flow rates, 100 gallons per minute (gpm) are desired.

If a pump were used, shallow, low-temperature geothermal aquifers could produce 1000 to 2000 gpm. Free-flowing (artesian) geothermal wells that produce 500 gpm are rare. Geothermal wells deeper than 3200 ft that can be pumped to produce a sustained 1000 gpm do exist, but they are exceptional. A reasonable rate of flow would be 500 gpm from an average depth geothermal well.

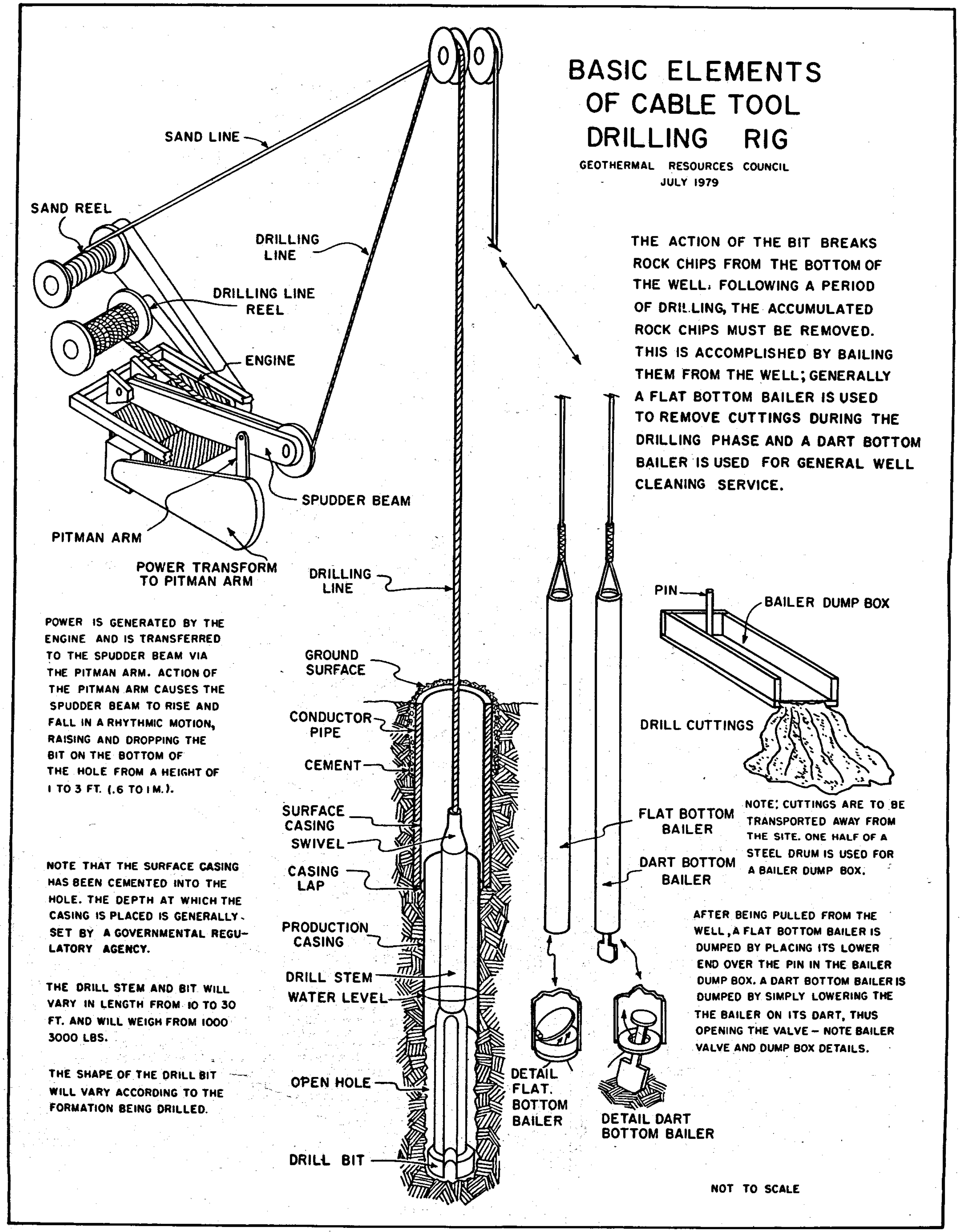
Although the equipment and techniques for drilling are similar to those used in oil fields, geothermal drilling practices resemble those used in water-well drilling. In both, drilling must be done as inexpensively as possible. One major difference is that the geothermal developer must have a user available at the location of the well. Transporting heat any great distance is difficult and expensive.

Another factor to consider is the type of drilling equipment to be used. The old-fashioned cable-tool drill (Figure 1) is the least common method for drilling geothermal wells. It is not a true drill since it does not rotate but uses a heavy hammer bit that pounds and crushes the rock. The rock then mixes with a water slurry and is bailed out of the hole. This method is frequently used in water-well drilling and does have advantages for drilling low- to moderate-temperature geothermal wells. The rig is inexpensive to buy or rent and can be operated by two men. Such a rig generally costs between $500 and $1000 for a 10-hour day. However, many operators will bid a footage rate, with higher prices for greater depths. Since the rig does not circulate water, it can be used in freezing weather and can be shut down at night with no danger. These are money-saving features. Also, the casing can be driven directly behind the drill, preventing the hole from caving in and losing circulation. A cable-tool rig will drill anywhere from 100-1000 ft per day.

Cable drilling does have disadvantages. Blowout preventers are not readily adaptable. For this reason, the rig should not be used on hot, free-flowing wells. The rate of drilling is slow and time consuming for depths below 1500-2000 ft. Interestingly, practically all the oil wells drilled in the first few decades of this century, some to depths of one mile, were drilled by cable-tool rigs.

The rotary drill (Figure 2), on the other hand, is more commonly used and is generally applicable for geothermal wells. The bit resembles a drill, even though its drilling action may chip and crush the rock. Fluid circulated down the drill pipe and back up the space between the drill pipe and the casing removes the "cuttings" from the hole. The fluid may be water, mud, air mixed with water and a foaming agent, or air alone. Mud is preferred where caving is a problem, but its use should be avoided in geothermal production zones because it could clog the reservoir passageways for water.

Rotary rigs vary in size from truck-mounted units that can be easily moved, to large rigs capable of reaching depths of 20,000 ft. The truck-mounted



BASIC ELEMENTS OF CABLE TOOL DRILLING RIG

GEOTHERMAL RESOURCES COUNCIL
JULY 1979

THE ACTION OF THE BIT BREAKS ROCK CHIPS FROM THE BOTTOM OF THE WELL. FOLLOWING A PERIOD OF DRILLING, THE ACCUMULATED ROCK CHIPS MUST BE REMOVED. THIS IS ACCOMPLISHED BY BAILING THEM FROM THE WELL; GENERALLY A FLAT BOTTOM BAILER IS USED TO REMOVE CUTTINGS DURING THE DRILLING PHASE AND A DART BOTTOM BAILER IS USED FOR GENERAL WELL CLEANING SERVICE.

POWER IS GENERATED BY THE ENGINE AND IS TRANSFERRED TO THE SPUDDER BEAM VIA THE PITMAN ARM. ACTION OF THE PITMAN ARM CAUSES THE SPUDDER BEAM TO RISE AND FALL IN A RHYTHMIC MOTION, RAISING AND DROPPING THE BIT ON THE BOTTOM OF THE HOLE FROM A HEIGHT OF 1 TO 3 FT. (.6 TO 1 M.).

NOTE THAT THE SURFACE CASING HAS BEEN CEMENTED INTO THE HOLE. THE DEPTH AT WHICH THE CASING IS PLACED IS GENERALLY SET BY A GOVERNMENTAL REGULATORY AGENCY.

THE DRILL STEM AND BIT WILL VARY IN LENGTH FROM 10 TO 30 FT. AND WILL WEIGH FROM 1000 3000 LBS.

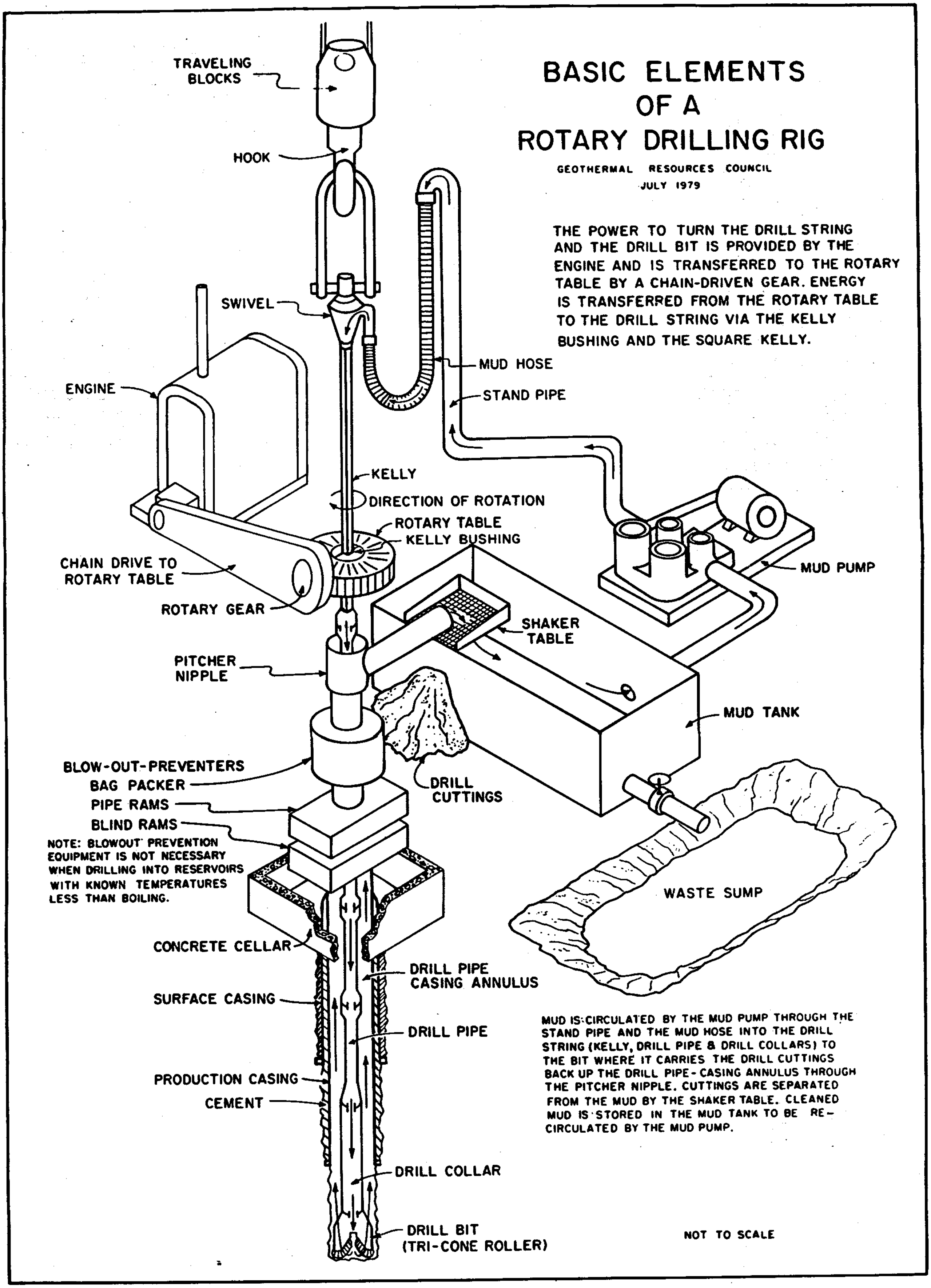
THE SHAPE OF THE DRILL BIT WILL VARY ACCORDING TO THE FORMATION BEING DRILLED.

NOTE: CUTTINGS ARE TO BE TRANSPORTED AWAY FROM THE SITE. ONE HALF OF A STEEL DRUM IS USED FOR A BAILER DUMP BOX.

AFTER BEING PULLED FROM THE WELL, A FLAT BOTTOM BAILER IS DUMPED BY PLACING ITS LOWER END OVER THE PIN IN THE BAILER DUMP BOX. A DART BOTTOM BAILER IS DUMPED BY SIMPLY LOWERING THE THE BAILER ON ITS DART, THUS OPENING THE VALVE – NOTE BAILER VALVE AND DUMP BOX DETAILS.

NOT TO SCALE

FIGURE 1



BASIC ELEMENTS OF A ROTARY DRILLING RIG

GEOTHERMAL RESOURCES COUNCIL
JULY 1979

THE POWER TO TURN THE DRILL STRING AND THE DRILL BIT IS PROVIDED BY THE ENGINE AND IS TRANSFERRED TO THE ROTARY TABLE BY A CHAIN-DRIVEN GEAR. ENERGY IS TRANSFERRED FROM THE ROTARY TABLE TO THE DRILL STRING VIA THE KELLY BUSHING AND THE SQUARE KELLY.

NOTE: BLOWOUT PREVENTION EQUIPMENT IS NOT NECESSARY WHEN DRILLING INTO RESERVOIRS WITH KNOWN TEMPERATURES LESS THAN BOILING.

MUD IS CIRCULATED BY THE MUD PUMP THROUGH THE STAND PIPE AND THE MUD HOSE INTO THE DRILL STRING (KELLY, DRILL PIPE & DRILL COLLARS) TO THE BIT WHERE IT CARRIES THE DRILL CUTTINGS BACK UP THE DRILL PIPE-CASING ANNULUS THROUGH THE PITCHER NIPPLE. CUTTINGS ARE SEPARATED FROM THE MUD BY THE SHAKER TABLE. CLEANED MUD IS STORED IN THE MUD TANK TO BE RE-CIRCULATED BY THE MUD PUMP.

NOT TO SCALE

FIGURE 2

units capable of drilling to 1500 ft cost between $500 and $1000 for 24 hours. Moving rigs of this size in and out can raise the cost up to $5000. Those rigs capable of drilling to 5000 ft cost up to $6000 for 24 hours with an additional transportation charge of approximately $35,000. Medium- sized rigs usually are sufficient for geothermal drilling requirements, having a range of 10,000 ft, using a 6-inch bit. Their costs range up to $8000 for 24 hours. Transporting a rig of this size, which may take 30 to 40 truck loads, costs approximately $100,000. Larger rigs are available, costing $15,000 for 24 hours and with a moving rate of $250,000. However, these larger rigs generally exceed geothermal requirements.

Air can be used to remove the cuttings where water or mud is being lost in the formation. But if adequate makeup water is available, continuing to drill with water is advisable because it is superior to air in its lubricating and cooling qualities. Air drilling requires huge compressors and high pressures, which create expensive and sometimes dangerous conditions.

Rotary drilling rigs are much larger and more expensive than cable rigs. They also require huge 200-400 horsepower engines--one engine for rotating the drill and two for lifting the drill out of the hole. Another engine to drive a mud pump or air compressor adds to the cost. Before recent cost increases, fuel for these engines could run from $500 to $1000 per day. In soft formations, the rig is expected to drill between 500 and 1000 ft in a day. In hard formations, the rate might be a slow 100 ft in 24 hours. Of course, as the hole goes deeper, more time is required to bring the worn bit out of the hole for replacement. A round-trip to 4000 ft can consume 3 to 7 hours. Such time is "lost" time, as the expense continues even though no drilling is done.

Other services may be needed during the drilling operation. Geologists and a mud-logging truck are needed to examine the drilling chips and record the types of rock found along with other pertinent information. If tools are lost in a hole, "fishing" services are also needed. For coring, costs include $7000-$10,000 for a diamond bit, plus fees for a technician and rental of a core barrel. In situations where sidetracking or whipstocking occur (directing a hole away from the vertical), turbine drilling services with an engineer on the site will start at $10,000/day.

Casing

Two of the items to be decided in the planning stage are the size of the casing and the diameter of the hole in the production zone. The size of the casing that is to be placed across the production zone must be established to allow the development of the total casing string and the specific size and type of casing at the surface. Generally, the production of the well will depend on two factors: the surface area of the well bore in the production zone and the difference in pressure from the bottom of the well to the surface. The pressure difference is of major concern for deep artesian wells. When well pressure exceeds production zone pressure, the well will cease to flow.

Well casing is available in two forms: pipe with threaded joints (necessary for deep wells) and unthreaded pipe, which has to be welded and can be used for shallow wells. The price for casing varies with type and size. The approximate price (FOB) for standard-size well casing ranges from $8 a foot for 6-7/8" threaded to $25 a foot for 20" threaded. The 8" regular casing costs $6 a foot, and the 20" regular costs $15 a foot. Casing shoes typically cost several hundred dollars. Threaded pipe, although more expensive, is needed because of the weight of the casing as it hangs in the well. Threaded pipe with couplings is stronger than welded pipe, and the casing can be dismantled if it becomes damaged. Most drillers prefer to assemble and install the casing on shallow wells; however, service companies are available to assist drillers in the installation of long casing strings.

Casing has its structural limitations. When demands on the casing approach the limits of the design, responsible drillers check the quality of the casings before placing them in the well. Many wells have been "destroyed" because the casing collapsed or the joints pulled apart. Consequently, reputable drillers will reject many pieces of casing if they are drilling deep wells. This rejected casing, which might serve adequately for the shallower, lower temperature geothermal wells, may then become available at a reduced price.

Some geothermal wells in France have used non-metallic casing. Plastic casing does not have the strength or the resistance to temperature of metal pipe. Not surprisingly, the French wells have temperatures around 130°F, a temperature not damaging to plastic pipe. Plastic casing costs about the same as steel casing, but the plastic is lighter and smaller rigs can handle it easily.

There are three types of casing used in geothermal wells: anchored casing, surface casing and production casing. Anchored casing (conductor pipe) may be 80 feet long and is cemented into the ground to anchor the well thoroughly against high pressure inside and the punishment of the drilling operation. For bigger and deeper wells, this casing is usually installed in a concrete-walled cellar, which also has room for equipment, the valves and other needed items.

The next string of casing, the surface casing, is cemented from its shoe (bottom) to the surface within the 2- to 4-inch space between it and the conductor pipe. This casing extends deeper than the casing of nearby domestic water wells and is generally required by law to prevent geothermal water from contaminating the shallow reservoirs that provide drinking water. If the regulatory body permits it, the surface casing may eventually house the pump turbine. The main valve and various safety valves are attached to its top.

Production casing, the third type, makes up the main casing string and has two functions: protecting the sidewalls of the well against collapse and conducting the fluid to the surface. If regulations do not allow the downhole pump to be placed in the surface casing, it must be placed in the production casing. In the latter case, a "hanger" is used to hang the production casing near the bottom of the surface casing.

If drillers have trouble with the sidewalls, they may use multiple layers of production casing, each set at a greater depth. Casing hangers are also used for this situation. Figure 3 shows the design of a typical well.

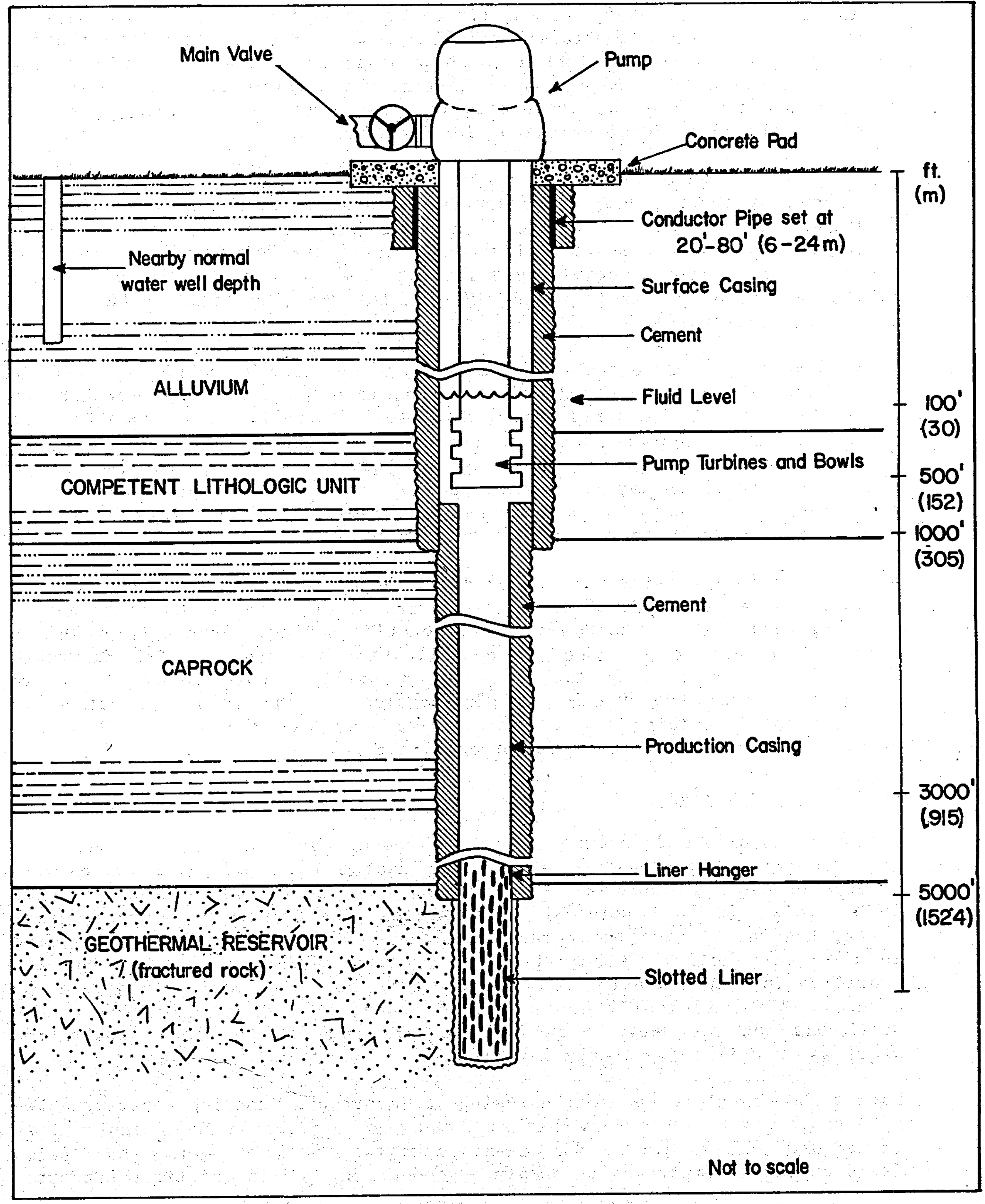


FIGURE 3. Typical design for a low- to moderate-temperature geothermal well.

It is important to determine the limits of the production area. Because geothermal liquids are generally indistinguishable from the drilling fluids, it is possible to drill right through a production zone and not know it. The well could quickly become free-flowing, which could cause difficulty in setting and cementing the production casing. Thus the drilling operation must be designed to identify the production zone.

High-resolution temperature sensors, preferably on logging cables that give a read-out at the surface, can identify the production zone. Examining the drilling chips returns also gives a clue to the production stratum. Furthermore, continual monitoring of the quality of the returning drilling fluids for electrical conductivity may indicate the point at which high-conductivity geothermal waters begin to mix with the drilling fluids (thus at the top of the reservoir).

It is possible to protect the production zone by using a technique common in oil wells. The zone is cased and cemented, then holes are shot through the casing to allow the desired fluids to enter the well. This technique is practical in geothermal wells producing from homogeneous formations of intergranular porosity. However, in formations which produce from fractures, the shots may not penetrate the fractures and there would be no production. Obviously, keeping cement and cement-like materials away from the production zones in fracture formations is essential.

Another completion method in the production zone is the use of a screen or a slotted liner (a piece of casing not cemented in place) which is hung from a casing hanger at the bottom of the production casing. Such a liner is not necessary in production zones in consolidated rock strata. One desirable technique for protecting the zone is to drill a hole below the known production zone; the deeper, unused portion of the hole can act as a "wastebasket," catching any material caving away from the walls. Thus, any debris will accumulate below the production zone.

Cementing and Casing

Casing is usually made secure by pumping cement down the inside of the casing and filling the space between the casing and well bore or between strings of casing. Methods for the cementing of casing are well established in the oil, gas and water-well industries. Temperatures in geothermal wells, however, harden the cement prematurely and cause problems not found in the other wells. Chemicals can slow the hardening process, but the reduction in time can allow convecting waters in the formation to dilute the cement. Also, if redrilling begins too soon, it can jar or break cement which has not yet set. Such failures are some of the more frustrating problems in drilling geothermal wells.

Having the cement bonded to the casing is important. Bonding can be checked by a sonic device, but such checking requires logging and is expensive. An inadequate bond or gap in the cement is difficult and expensive to repair. It is obviously important to obtain a good cement job in the first attempt.

Once the cement is set, it may provide an additional benefit--heat loss reduction. Heat loss can affect direct-heat application in low-temperature wells, since the temperature of heat traveling up the well can be reduced by as much as 15 degrees. In deep wells that go through cold-water aquifers, the temperature is greatly affected. So far, no one has attempted a significant reduction of heat loss, but two methods may be possible: (1) adding material to the cement that will improve its heat-loss resistance, and (2) anchoring the bottom of the surface casing with cement and then filling the rest of the space between the casing and the bore wall with a rigid, expanding foam. The latter technique has been much discussed but never tried. Both techniques are subject to approval by the regulatory agency with jurisdiction over the project.

Problems in Geothermal Drilling

In addition to the same problems that plague water- and oil-well drillers--broken bits, broken drill pipe, "lost" and stuck tools--the geothermal driller encounters two situations requiring solutions that contradict each other. The first is that drilling tools can get stuck in a hole when sidewall sloughs away and collects around the bit. A hole caving in is quite serious and usually occurs in the loosely consolidated formation in the first few thousand feet. To avoid this problem, drillers commonly use heavy drilling fluids, called mud. The mud, in addition to preventing caving, seals the walls to prevent losing expensive drilling fluid, floats cuttings to the surface and suspends them for a longer period of time when circulation is stopped and the bit is removed from the hole for replacement.

The second concern for the geothermal well driller (and just the opposite of the solution to the first) is to avoid using heavy or unnatural fluids in the suspected production zone. Such use in that region can cause serious problems: heat in the geothermal zone may solidify the drilling mud in the fractures; chemical reactions may help seal the pores; and the weight of the mud can prevent geothermal water from entering the hole.

When drilling approaches the expected production zone, it becomes risky. The driller may use ordinary water or water made lighter with the addition of air, hoping that the walls will not cave in and that the geothermal water will leak into the well bore. Keeping the fluid circulating and getting the drill string out of the hole as quickly as possible are extremely important.

Safety Considerations

The drilling process contains some dangers which call for certain safety procedures. For wells with temperatures above 140°F (which is hot enough to scald) safety requires having face shields, wet suits and insulated gloves available. Temperatures above boiling should be treated in the same way as steam system, with applicable codes, personnel protection and operating procedures to prevent accidents.

Free-flowing wells (artesian) generally are desirable, but they can create a difficult condition if they begin before cementing and casing is completed. The free flow can be "killed" by injecting cold water unless part of the reservoir is at a higher elevation than the well. Other methods to stop the flow are backfilling with sand (and later drilling the sand out) or using heavy mud. Obviously, it is desirable to complete the casing and cementing operations before drilling through any protective cap-rock that seals the production zone.

Artesian wells can be caused by a difference in the density of the hot water in the well and that of a cold-water hydrostatic head above the geothermal reservoir. The hotter the water, the greater will be the pressure. In comparison to cold water at 68°F, water 102°F will expand enough to rise in the well about 6.7 ft; water at 302°F, about 86 ft. This might be sufficient to make a well flow freely at the surface. Wells of this nature can be "killed" by pumping cold water into them. Air-lifting, or swabbing (rapidly pulling out a loosely fitting piston) can restart them.

Another feature of geothermal wells is that heat expands the casing. One hundred degrees of heat (F) can cause 1000 ft of steel casing to expand 8 inches. To cope with expansion, the common practice is to cement the entire casing in place with a tight bonding cement. Afterwards, casing expansion can be ignored unless the bond breaks. Keeping the well hot, even when it is not being used, reduces the possibility of the bond breaking.

As in most operations today, environmental regulations must be considered. Drilling fluids or the produced geothermal fluids may not be disposed of on the surface if their disposal will affect the environment. Consequently, all drilling operations must consider using hold-up ponds and the mechanisms for carrying the fluids to the ponds. Also, a reserve supply of cold water must be available for cooling the well if needed.

The final safety device is the blowout preventer. It is a valve at the well head which will shut off the flow, even with the drill pipe in the hole. Wells that are not free-flowing or have temperatures below 140°F need only a standard gate valve.

Drilling Regulations

State regulations of geothermal production often begin at given temperatures because it is an easy method of drawing the line for the more restrictive geothermal regulations. In the eastern states, any depth or temperature allowing heat to be extracted would probably be covered by a state commission on oil and gas or by any regulatory body that reviews oil and gas exploration and production. In most states in the more arid west, if the state limits for temperature and depth are exceeded, a geothermal-production or geothermal-injection permit may be required. Above the depth limit set by the state, a water right is required since western states have developed a comprehensive judicial and administrative system of water rights.

Water rights protect the user, but geothermal regulation protects the resource. Most western states have water rights based on the principle of "first-in-time, first-in-right." A geothermal permit covers such things as equipment for preventing blowout, casing requirements and logging as well as water withdrawal quantity. Both water rights and geothermal rights and permits should be obtained.

Leasing

Federal leased lands have many uses, such as recreation, wildlife preserves, livestock grazing, primitive areas, and mining and related claims. The Bureau of Land Management (BLM) of the Department of the Interior is the caretaker of federal lands. Congress sets the leasing requirements. However, the U.S. Geological Survey controls the geothermal rights and supervises drilling and production operations.

If leasing on government lands is being considered, the requirements of the regulations must also be considered. An environmental assessment is required, as are construction criteria and on-site inspections. The government also exacts a royalty, usually 10%, for the heat extracted. Bidding for the obvious geothermal lands (Known Geothermal Resource Areas) is competitive. The exact requirements and the implementing rules and regulations appear in the USGS Operating Regulations (30 C.F.R., parts 270 and 271) and in the BLM Leasing Regulations (43 C.F.R., part 3200). Appendix A of Chapter 5 discusses taxes and geothermal development; Chapter 7 presents the legal aspects of geothermal development in much greater detail.

Requirements for state-owned land are comparable to but less stringent than federal requirements. Generally, state land departments award the leases and apply modified gas and oil regulations to geothermal projects. These features are also discussed in Chapter 7.

Driller Licensing

The classification of well drillers depends on the type of well. The three classes are the (1) licensed water-well driller, (2) the mineral (slim-hole) test-well driller and (3) the oil- and gas-well driller. All three types have drilled geothermal wells.

Each state issues licenses to water-well drillers and the general public can review the driller files. State oil and gas regulatory agencies regulate oil- and gas-well drillers, review the drilling programs and inspect the operations on the sites. Mineral slim-hole drillers may not be required to have a license or to have their programs reviewed.

As in many businesses, the experience of the company, its resources and its equipment indicate its chances of success. While gas and oil drillers have knowledge, equipment and company resources, they are probably too expensive for drilling shallow geothermal wells. A licensed water-well driller can drill a shallow geothermal well if the rig is appropriate and the company has enough resources to complete the job in case it runs into difficulty. Wells below 2000 ft should be contracted to firms with larger rigs used by the gas and oil drillers because of their experience in handling the technical problems encountered at such depths. Such problems are high pressures and temperatures, blowouts and possible contamination of ground and surface waters. In comparison, the problems of drilling lower-temperature direct-application wells are negligible.

Disposal of Used Geothermal Fluids

Federal and state agencies will regulate the disposal of geothermal fluids during the drilling of production wells. The agencies generally require some guarantee that surface and groundwater will not be contaminated by a waste product. If there is a direct discharge to surface water sources or to containment ponds, the agency will monitor the water quality. However, water quality standards may be lowered because the geothermal disposal to take place is only temporary. But the lowering may be granted only if the proper agency is consulted first and then only if its requirements are met.

After the proper agency is consulted, the appropriate disposal method can be selected. Initial environmental safeguards such as lined ponds could be constructed before drilling begins with a net savings of rig time. During production testing, geothermal fluids may be disposed of by several methods: (1) the fluids may be directed to a known water course if their quality is acceptable; (2) they may be used for irrigation; (3) water may be allowed to seep into shallow stratum just below the surface by placing high quality water in an unlined pond; (4) the fluids may be stored in a lined evaporation pond, which requires a large size to be effective; (5) or the waste may be injected down a well into a stratum authorized by the regulatory agency.

Because of the complexity of geothermal drilling regulations, it is advisable to study them before drilling begins. Other documents to study are state codes that apply to geothermal and water laws, rules and regulations of state agencies, the Federal Geothermal Steam Act of 1970, USGS rules and regulations, and state leasing requirements. The Environmental Protection Agency is currently drafting geothermal exploration and development regulations which will affect drilling and disposal conditions and, therefore, merit study.

Injection of Used Geothermal Fluids

Of the methods for waste-fluid disposal, the injection method seems most efficient in the conservation of heat. This method has been successful in areas with high permeability near the surface. It has definite advantages: injecting waste fluid into the producing reservoir decreases or eliminates consumptive use, extends the life of the field and reduces the possibility of depleting the geothermal fluids in the well field. Another unusual concept of this process is that the heat of the region can actually be mined. Many installations use only 10-25% of the heat contained in the water because more heat is stored in the rocks than in the water. In passing through the rocks, the fluids absorb, or mine, heat from the rocks and thereby increase the amount of heat that can be removed. The benefit of this system is that the same water can be used many times to transfer heat to the surface. The temperature of the returned geothermal fluid is such that it will not significantly affect the reservoir. In most cases, a change of a few degrees does not greatly affect a space or process-heating use of geothermal fluids.

The cost for injection wells is probably similar to costs for production wells. Although the pipelines and monitoring equipment necessary for the injection well add to project cost, an injection well can accept more fluid than a production well can deliver, so fewer injection wells are needed. At present, actual operation of injection wells has been limited and chemical precipitation problems in the well bore are a concern. To minimize the problem, it is best to keep geothermal fluid under pressure all the way from the production well head to the injection well head.

The location of production and injection wells raises a number of issues. Injection wells should be placed some distance from the production wells to minimize mingling of waters and prevent rapid cooling. If two wells are the property of two different owners, then the question of royalties will arise. Do both share equally in the profits? Over the years, will the production and injection wells affect the thermal quality of the resource of adjacent property owners? These questions can be avoided by arranging to have the area established as a unit. The owners of the unit then can share proportionally in the royalties, regardless of which well is placed where and whether used for production or injection.

Other factors to consider are those regarding the environment. In natural areas, roads for transporting drilling equipment must be built. Existing roads may have to be changed to allow the huge rigs to navigate corners and cross streams. Such changes would involve state water resource agencies and require permits from private landowners or from state or federal agencies.

Preparing the drilling site also involves changing the land surface, as the site must be cleared and level. In addition, the site may require mud pits, holding ponds and parking and loading space for the trucks. All these affect the land. After drilling, when the well is producing, little space is needed, so the land site should be restored as near as possible to its original condition. Restoration projects cost additional dollars that must be included in cost estimates.

If drilling is in populated areas, environmental concerns such as noise, dust, trash and chemical pollutants must be considered. Wells can be drilled during high-noise periods in the neighborhood. Roads may have to be watered to control dust. All trash must be kept in containers; oil waste should be contained and disposed of in proper containers.

Even the pipelines to carry the heat will have to be designed to conform to the environment. Obviously, uses of the geothermal water should be close to the well site, keeping pipe length to a minimum. Burying the pipes not only eliminates an eyesore, it also uses the earth to insulate the pipes and retain much heat that would otherwise be lost. In addition, it permits the use of less expensive materials (asbestos or cement). A very real point: burying also hides the pipe from vandals and prevents it from being damaged by the reckless use of machinery.

Not all environmental considerations are so obvious. Removing geothermal water from the reservoir could have a variety of effects on conventional water supplies. The effects depend on the geological formation and the interrelationship of the groundwater system with the geothermal system. One effect could be subsidence, that is, the settling or sinking of land. Subsidence may be a problem, it could occur as the reservoir pressure is depleted. Where the reservoir is not consolidated (i.e., sand), the removal of fluid could cause a tighter packing of the sand grains with a net loss of elevation at the surface. In areas where the reservoir is made of competent rocks, the fluid does not provide support and its removal would not cause subsidence. In any case, injection of the used geothermal fluid back into the production reservoir usually minimizes the potential for subsidence, primarily through the maintenance of reservoir pressure.

If deep-seated subsidence did occur in an unconsolidated reservoir where the produced fluid was not injected, the movement could trigger seismic activity (earthquakes). However, injection into dry fractures or a faulted zone could lubricate faults and cause premature slippage, in effect, creating seismic activity.

Any major geothermal production scheme should protect itself against liability from supposed damage of surface structures or to shallower water wells. A periodic leveling and well-monitoring subsidence-detection program, preferably by an independent monitoring organization, could provide the protection needed. The organization may in part be tax supported.

Well Testing

Well testing is the general name for all techniques used to determine if a well is capable of producing usable fluids economically and over what period of time (usually in years). As mentioned previously, testing begins during drilling and, if done properly, continues as an ongoing program during the life of the well or reservoir. The tests measure temperature, pressure, flow rates of both heat and mass, and composition of the fluid. The production well or wells, other nearby wells, springs and injection wells are all tested.

Well testing is critical, for it provides information about the condition of the well. Thus it is essential that the proper instruments be used and that tests be made periodically. Table 1 indicates the equipment and instruments to be used for the various tests. Many of the tests have been adapted from those used in petroleum engineering and groundwater hydrology. The techniques generally can be used without modification, but some techniques have produced significant new methods (such as fracture-type curve analysis) to meet special conditions of geothermal reservoirs.

TABLE 1
Types and costs of measuring equipment

Increasing cost and complexity

Measured Quantity	Least Expensive				Most Expensive
Temperature	Maximum reading thermometer $20		Mercury in glass thermometer $50		Digital thermometer $300
Pressure	Simple mechanical gauges $20		Pressure recorders $900	Quartz gauges with recorders $3000	Downhole quartz detectors $15,000
Flow Rate	55 gal drum & stopwatch $25	Weir box $30	Free discharge manometer $50	Spinners $1000-$2000	Differential pressure across orifice plates $2000
Composition	pH paper $5	Ionization meters $300	Hach kits Draeger tubes $600	Other wet chemical $1000+	Gas chromatograph $6000
Water Level	Electric conduction probe				Pressure-tube water displacement device

Blank

Chapter 4

UTILIZATION

Introduction

Geothermal energy has been known and used in varying methods for centuries. Records show that the Chinese, Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori of New Zealand have used the resource for heating, bathing and cooking. These uses continue. Japan, for example, still has over 1500 hot-spring resorts.

Geothermal energy was used in the industrial sense by the ancient Etruscans of northern Italy, who made decorative enamels from the boric acid deposited by the steam and hot water at Lardarello. The acid was first extracted commercially in 1818. It quickly became quite useful, and by 1835, nine factories had been constructed in the region. The municipal heating district developed in Reykjavik, Iceland, in 1928 was another early industrial application. These uses of the resource were restricted to areas where the hot water or steam was easily accessible, so while it was marveled at, the concept did not become widespread. Its greatest deterrents were other forms of energy that were plentiful and inexpensive.

With modern technology, it is possible to use geothermal energy directly to heat our living space and to provide heat for industrial processes. Basically, hot water is hot water, whether it comes from a boiler or from the earth. The harnessing of this energy requires only straightforward engineering practices, rather than some revolutionary major scientific discoveries. The technology, reliability, economics and environmental acceptability have been demonstrated throughout the world. Table 1 below shows the direct use of geothermal energy in the world today.

TABLE 1

Worldwide direct use of geothermal energy

Country	Space Heating/ Cooling (MWt)	Agriculture/ Aquaculture (MWt)	Industrial Processes (MWt)
Iceland	680	40	50
New Zealand	50	10	150
Japan	10	30	5
USSR	120	5100	---
Hungary	300	370	---
Italy	50	5	20
France	10	---	---
Others	10	10	5
USA	75	5	5
TOTAL	1245	5570	235

Geothermal resources in the world currently supply 1245 megawatts thermal (MWt) for space heating and cooling, 5570 MWt for agriculture and aquaculture production and 235 MWt for industrial processes. Typically, agricultural applications use the lowest temperatures, ranging between 80-100°F. Almost all these agricultural uses are in the Soviet Union, which reports over 5000 MWt used in this field.

Space heating generally requires temperatures higher than those needed for agriculture (150-212°F). Iceland, where over half the country has geothermal heat, is the leading user of geothermal energy for space heating. At present, the only known cooling by means of geothermal energy is at the International Hotel in Rotorua, New Zealand.

Higher temperatures, up to 300°F, are needed for industrial processes. However, some applications such as the drying of various agricultural products may use lower temperatures. Although there are not many examples of industrial use of geothermal energy, they cover a wide variety of uses, from the drying of wool, fish, diatomaceous earth and timber to the processing of pulp and paper and the extraction of chemicals. The two largest industrial uses are the drying of diatomaceous earth at a plant in Iceland and paper and wood processing in New Zealand. Figure 1 on the following page shows the required temperatures for various direct uses of thermal energy.

From Figure 1, we can see that different uses require different temperatures. A process called "cascading" provides a way to get the most uses from available geothermal energy sources. The energy is first used for applications requiring high temperatures. Heat not used in these applications is passed on to other applications which need lower temperatures. The heat remaining after the second application is passed on to other applications which can use even lower temperatures, and so on. In this manner, the extracted heat is used efficiently. Figure 1 shows processes which could be involved in "cascading."

Traditionally, the direct use of geothermal energy by individuals has been on a small scale. At today's prices for labor and hardware, individual uses cannot save much. Large projects, however, can justify deeper wells, longer transmission distances, more sophisticated uses and lower temperatures. Thus, most modern developments are large-scale projects such as Iceland's heating district, greenhouses in Hungary and major industrial uses in New Zealand.

Heat exchangers necessary to these projects have been improved so that they are more efficient and better adapted to geothermal use. They will permit the use of lower-temperature waters and fluids high in saline. Another device useful in geothermal development is the heat pump, a mechanical system which absorbs heat and raises it to a higher temperature. The heat pump enables such traditional non-geothermal countries as France, Austria and Denmark, as well as the eastern United States, to take advantage of this natural resource.

Space Conditioning. Space conditioning is a term referring to the heating or cooling of air in the space where people live and work. The most famous space-heating project in the world is the Reykjavik municipal heating project, which serves almost all of the people in Iceland's capital city.

°F	°C		
392	200		
374	190		
356	180	Evaporation of highly conc. solutions Refrigeration by ammonia absorption digestion in paper pulp, Kraft	Temp. range of conventional power production
338	170	Heavy water via hydrog. sulphide proc. Drying of diatomaceous earth	
320	160	Drying of fish meal Drying of timber	
302	150	Alumina via Bayers proc.	
284	140	Drying farm products at high rates Canning of food	
266	130	Evaporation in sugar refining Extraction of salts by evaporation and crystalisation	
248	120	Fresh water by distillation Most multiple effect evaporations, concentr. of saline sol. Refrigeration by medium temperatures	
230	110	Drying and curing of light aggreg. cement slabs	
212	100	Drying of organic materials, seaweeds, grass, vegetables, etc. Washing and drying of wool	
194	90	Drying of stock fish Intense de-icing operations	
176	80	Space heating Greenhouses by space heating	
158	70	Refrigeration by low temperature	
140	60	Animal husbandry Greenhouses by combined space and hotbed heating	
122	50	Mushroom growing	
		Balneological baths	
104	40	Soil warming	
86	30	Swimming pools, biodegradation, fermentations Warm water for year-around mining in cold climates De-icing	
70	20	Hatching of fish; fish farming	

FIGURE 1. The approximate temperature required for various geothermal uses.

There, one geothermal field supplies the water which is delivered through pipelines over 12 miles in length. Insulated storage tanks maintain heat and volume to meet peak demands and provide an emergency supply in the event of a breakdown in the system. A back-up system, a fossil-fuel fired peaking station, boosts the 176°F water to 230°F during the 15 to 20 coldest days of the year. Nine pumping stations distribute the fluid through 200 miles of pipeline in the city.

In contrast to this centralized heating district are the heating systems for individual homes in Klamath Falls, Oregon. Over 400 wells heat the houses, using waters from 100-230°F. The system used most commonly to extract heat for these homes is the closed-loop downhole heat exchanger, which uses city domestic water in the loop.

An example of heating a larger space is the campus of the Oregon Institute of Technology in Klamath Falls. It uses 3 wells, the deepest 1800 ft, to heat approximately 500,000 square feet of floor space. Deep-well centrifugal pumps pump the 192°F water from the wells directly to the heating system in each building. The annual operating cost of the campus system is approximately $30,000, a savings of almost a quarter of a million dollars a year when compared to cost of heating with conventional fuels. Other notable uses in the community include the 311-bed Merle West Medical Center Hospital (Presbyterian Intercommunity Hospital) and nursing home and Maywood Industries, which uses 118°F water to heat a large manufacturing building.

Agriculture and Aquaculture. One notable use of geothermal energy is greenhousing. Hungary heats 13 million square feet of greenhouses geothermally and is second only to the USSR in this application. Many of its greenhouses are built on rollers so they can be pulled from their location by tractors, the ground cultivated, and the greenhouses returned to the locations. Much of the pipe supporting the greenhouse building structure acts as the supply and radiation system for the geothermal fluid. Sixty geothermal wells in Hungary are used for animal husbandry projects, mainly for heating and cleaning animal shelters, but agricultural projects are given priority for geothermal energy as they increase the volume and variety of production.

In Japan, a variety of vegetables and flowers are grown in geothermally heated greenhouses. Many large greenhouses are operated as tropical gardens for sightseers. Geothermally heated sheds in which 40,000 chickens are raised annually have under-the-floor heating systems. Another successful business is breeding and raising carp and eels. Eels, the most profitable, are raised in earthen pipes ten inches in diameter and twenty feet long filled with water held at 73°F by mixing hot-spring water with river water. Alligators and crocodiles being bred for sightseeing purposes are also raised in Japan's geothermal water.

Geothermal greenhouses also exist in the United States. The largest is the GeoProducts Corporation complex near Susanville, California, where a hydroponic system grows cucumbers and tomatoes, using geothermal fluid for heat. The corporation now has 30 greenhouses and plans to expand to over 200 units. A leader in U.S. aquaculture is Fish Breeders of Idaho whose farm near Buhl, Idaho, uses geothermal water to raise approximately 500,000 pounds of channel catfish annually.

Industrial Process. The range of industrial applications of geothermal energy can be illustrated by plants in New Zealand, Iceland and the United States. The Tasman Pulp and Paper Company in New Zealand uses geothermal steam for drying timber, pulp and paper, and evaporating black liquor (woodwaste residue). In Iceland, high-temperature geothermal steam is used to dry a diatomaceous slurry. The plant produces 27,000 tons annually of diatomite filteraids, which are used in beer processing in Germany.

In the western United States, two plants use geothermal energy in their operations. Medo-Bel Creamery in Klamath Falls, Oregon, uses a low-temperature fluid to pasteurize its milk. Geothermal Food Processors at Brady Hot Springs, Nevada, uses a high-temperature fluid to dehydrate onions and other vegetables. A third plant, Ore-Ida Foods, Inc., in Ontario, Oregon, has been investigating the possibility of converting its operation to geothermal.

Direct utilization of geothermal energy means that the heat is used in its original state to warm buildings and to provide heat for industrial processes. It is not converted to another form of energy such as electricity. Another use, not discussed to any degree in this chapter, is the generation of other forms of energy, such as electricity. There are advantages in using geothermal energy directly: it has a high energy conversion efficiency; it uses low-temperature resources which are numerous and readily available and can use many off-the-shelf items such as pumps, controls, pipes, etc.; the time needed to develop geothermal energy is much shorter than that for developing electrical energy; and, finally, the lower-temperature resources require less expensive well development.

All of these advantages add up to a favorable economic picture, especially when the rising costs of conventional fuels are considered.

Space Conditioning

General background. In areas of the United States requiring a significant amount of heat, three systems for heating residences are widely used: forced air, circulating water and radiant heat from electrical resistance. Forced air probably will remain popular for heating homes because the system can use a variety of fuels, the most common being natural gas, propane and fuel oils. The electric-resistance duct heater is also used. In large multi-dwelling and commercial systems, a steam coil or hot-water coil is often used to heat moving air. A boiler is the source of hot water or steam in a conventional system and the water in the system may be heated by a variety of energy sources. Figure 2 on the next page pictures the systems that can use geothermal heat.

In examining geothermal as an energy source, the houseowner has two possibilities: designing a system for a new house or converting the present system to use geothermal. The conversion, known as retrofitting, may present difficulties in that the specifications for the original system should match the specifications for the geothermal system. A match can be engineered between the two systems, but the conversion can be expensive. For example, a system designed for 50 gallons-per-minute flow at 180°F may require additional flow if the geothermal temperature available is below 180°F. The forced-air system is the most adaptable for retrofitting. Any of the

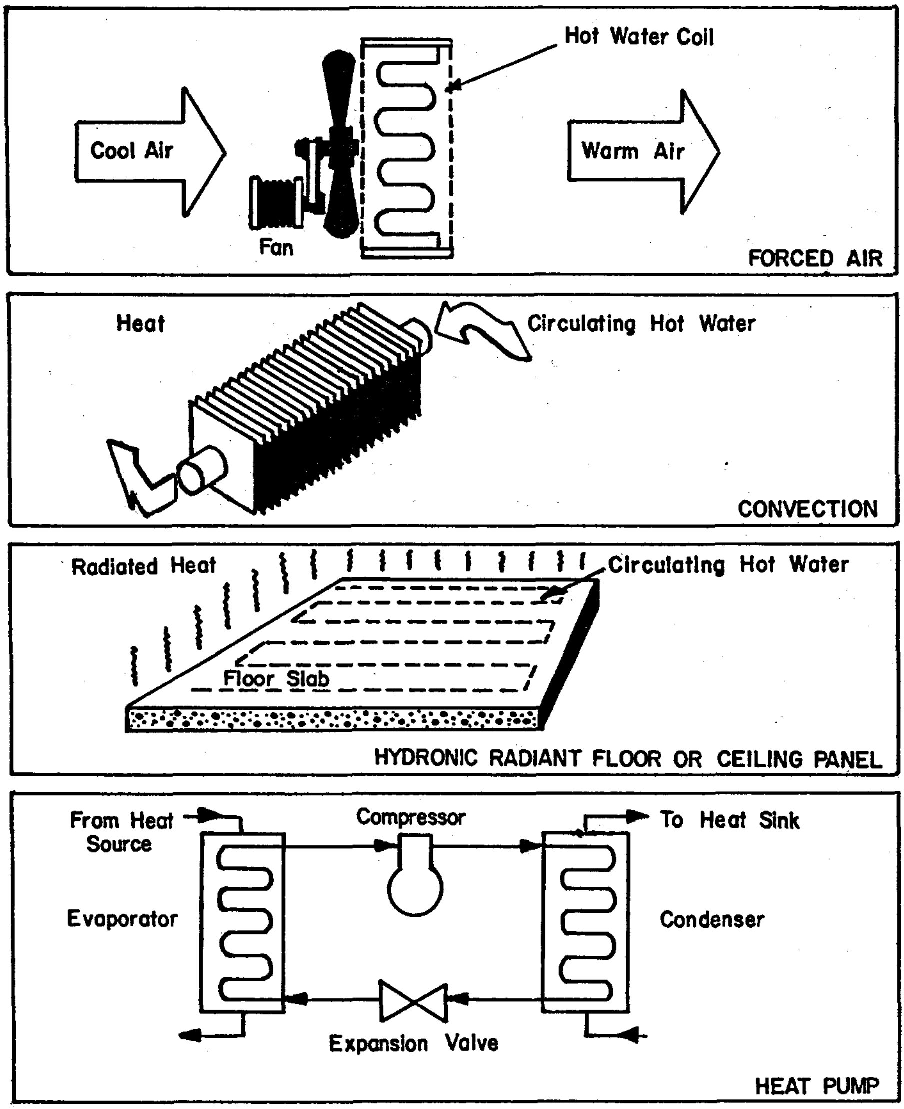


FIGURE 2. Space-heating systems suitable for geothermal applications (source: EG&G Idaho, Inc.).

hydronic systems (those using circulating hot water) that are properly designed and have automatic controls can usually provide a more even temperature than can a forced-air system.

In addition to the popular heating systems, the water-to-air heat pump has gained acceptance recently. This readily available device enables geothermal resources once considered marginal now to be used economically. An added benefit is that the heat pump can also be used for summer cooling. A standard heat pump at temperatures 60-90°F will have a coefficient of performance (COP) of about 3. In other words, its heat output will be about 3 times greater than the electricity needed to operate it.

Heat pumps are available in different sizes or can be custom-designed for special projects. However, when temperatures above 120°F are needed, the efficiency of standard units drops and the system may require special designs that use multi-stage compressors and special gases. Such units can produce 230°F temperatures, with COP's of 2. These units can be adapted to geothermal waters and to the waste hot waters from other processes. Figure 3 shows a typical two-stage unit.

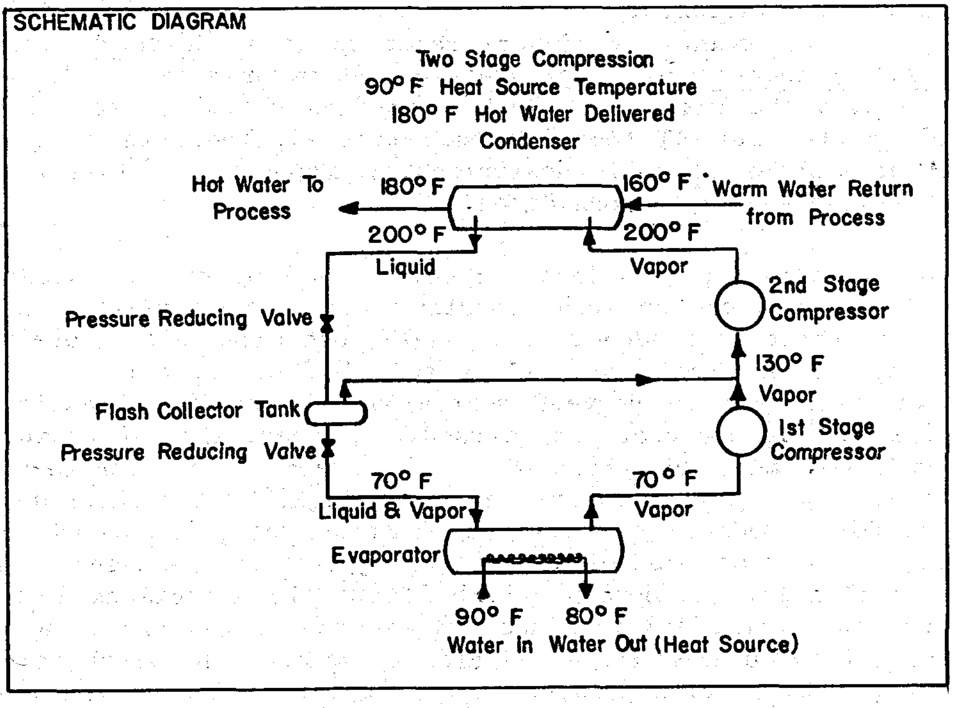


FIGURE 3. Two-stage heat pump (source: GRC Special Report No. 5, 1979).

When only one use of the water is possible, the economics of geothermal applications of heat pumps with COP of less than 3 should be studied carefully. The overall cost of that one use will include the cost of wells in addition to the pumps, an expensive investment. On the other hand, if geothermal waste water is available, heat pumps as an additional use become very economical.

Primarily as a result of emphasis on solar utilization, more people are becoming interested in the cooling applications of the absorption cycle of the heat pump. Lithium bromide units are available that will utilize water temperatures of 180°F and above. Above 270°F, custom-designed units using ammonia as the absorbing material are more appropriate. Both of these units are more practical in larger commercial installations than in single residences.

If a system is to be converted, the conversion must be carefully designed. The design of a new space-heating system using geothermal resembles the design of a conventional hot-water system. The difference is that the designer of the geothermal system has no control of the temperature of the water available; he must use what is there. Frequently, the water temperature of the resource is lower than that used in a conventional system. Economic factors to be considered are the costs of drilling the well and of the equipment necessary to bring water from the well to the residence. These factors can be economically feasible if the temperature that is available can be used effectively.

The primary goal is to remove as much temperature from the resource as possible. It is this factor, the amount of heat that can be extracted from a source, that is important. Engineers refer to it as delta T (ΔT) or as a change (loss) of temperature. For example, hot water enters a dishwasher at 150°F; it leaves the washer at 130°F. In this example, the ΔT would be 20°F. The greater the ΔT that can be extracted, the more economical and efficient the systems are. In designing new systems, the following points about each system should be considered.

A system using radiant panels in the floor or ceiling can use water at temperatures lower than can any other system except heat pumps. In order to achieve the required heat output, the panels must have coils closely spaced, a shallow pipe depth, small pipe sizes and high rates of flow. To reduce the cost of coils and to prevent corrosion and scaling, plastic pipe as small as 1/2 inch in diameter can be used. However, the temperature limits of various pipes must be observed: 125°F for acrylonitrile-butadiene-styrene (ABS), 150°F for polyvinyl chloride and 212°F for chloridepolyvinyl chloride (CPVC). Because of their low initial cost, baseboard convectors are generally the most economical heating system for residences and small commercial buildings. To obtain a high ΔT and the associated low rates of flow in the convectors, 3/4 inch and smaller tube sizes are required. The fins on the unit should be large and closely spaced, the width being longer than the height to provide greater heat transfer. Placing the units in a horizontal row, where space is available, provides nearly one and one-half times more heat output than does a vertical stacking.

In such units, heat output decreases rapidly as temperatures decrease. For this reason, it would be wise to use geothermal water directly and eliminate the temperature loss in a heat exchanger. But such use does entail certain precautions. In many low-temperature waters, iron pipe resists corrosion better than copper pipe. Before any method is selected, it is prudent to investigate the chemistry of the reservoir water and the subsequent cost and availability of special tube materials that can resist the corrosion of that reservoir.

Partly because of these conditions, forced-air systems are by far the most popular for residences and are used extensively for larger commercial buildings. Although large temperature drops are desired, the designer does not have to set a ΔT to be obtained by the system design. Rather he should attempt to obtain as low an exit temperature of the water as possible. For example, if 200°F water is available, then obtaining a 100°F drop is possible. But if the temperature is only 120°F, even a 40°F drop may be difficult to obtain. In many cases, a special fan-coil unit may have to be designed to obtain the high ΔT. Or the designer may use standard units in a series but have a special design for those units on the low-temperature end of the series.

Some examples of special considerations and their consequences are:

Desired parameter	Consequences
High ΔT extraction from water	1. Increased face area 2. Multi-pass coils with high ΔP water* 3. Serpentine coil paths with high ΔP water 4. Closer fin spacing with high ΔP air 5. "Stacked" coils with high ΔP air

*where ΔP = change or drop in pressure

Low Inlet-Temperature Water	1. Increased surface area 2. Closer approach temperatures (more efficient heat transfer) 3. Higher water-flow rates
Low Temperature Air Out	1. High air flow 2. Larger duct work 3. Higher ΔP air

If a hot-water system is to be converted (retrofitted) to a geothermal system, the conversion is not too difficult if geothermal water above 180°F is available. Most conventionally fueled systems operate at 180-210°F and many have the capacity to carry the heating load if water temperature is reduced 20-30°F. The older the system, the better are the chances of having a system designed for capacities greater than needed. Lacking the information now available, early designers apparently believed that it was safer to err on the side of over-designing. Frequently, systems over-designed by as much as 175% are found. A few simple observations and calculations, such as heat requirements versus capacity, will show if the capacity of the present system is sufficient.

A very simple way to test system capacity is to gradually reduce the conventional system-input temperature during the peak heating season until it reaches the temperature of the available geothermal fluid, or until the desired temperatures are not maintained. The usual result of this method is that the systems run longer in order to maintain the desired temperature. Since the operating costs of geothermal are usually low, conversion of such a system would prove economical.

Forced-air systems. Systems using hot water in fan-coil units are generally the easiest and least costly to convert. There are problems, however. Most geothermal systems require heat-exchanger devices which take the heat from one fluid and transfer it to another. This heat-transfer device is used to prevent geothermal fluid from entering and corroding the fan-coil tube. There is a 10°F temperature loss across the heat exchanger, but new coil units arranged in series with existing coils or new multipass coils will provide the required output with very little temperature loss from geothermal fluids that have surprisingly low temperatures.

When the available resource has temperatures that are considerably lower than the source in the original system, such adjustments as increasing the working time of the unit may not be sufficient. Other changes may be needed, such as increasing the coil-face area, reducing the spacing between fins and increasing the air volume. However, changing each or all of these will affect other parts of the system and require other changes. For example, an increase in fan speed or a larger fan motor increases the air volume, which affects the entire duct system because the velocity, pressure and noise have been increased. Consequently, additional duct work may be needed to handle the increase, and new outlets may be strategically located in areas requiring more heat. All these factors point to the need for carefully examining the entire system and its requirements before any decisions are made.

Electrical resistance systems using duct heating are similar to forced-air ducting systems, and the problems of converting them to geothermal are comparable.

The retrofit designer should remember that forced-air systems are the most complicated of the common systems and have the greatest number of variables. In most instances, these variables allow more manipulation to attain end results. Also, they require greater ingenuity and care in the design.

Hydronic systems. In contrast to forced-air systems, hydronic systems, whether baseboard or finned-tube units, have few variables to be considered to accommodate lower water temperatures. Therefore, calculations to determine heat load and heating-unit output must be carefully made to determine the minimum permissible average temperature from the existing system. One variable is flow rate. Increasing the flow rate can somewhat offset the lower inlet temperatures. But increased flows require an increase in pumping power and also an increase in the possibility of water hammer and other noises.

When a hydronic system is being retrofitted for lower temperatures, the best method is to install new or increased radiation surfaces. In these new radiation units, small tube sizes will allow reduced water flow for each radiation unit but produce nearly the same output. Thus, more radiation can be installed on existing piping systems. Hydronic systems having radiant panels in either the floor or ceiling are the most difficult to modify because they require expensive remodeling to install additional panels.

A hydronic system which uses steam in the convectors or radiators is probably the most difficult to retrofit. First, water temperatures must be high to use the existing radiation. Second, while steam lines are usually adequate to supply hot water, the condensate lines (with steam traps removed) often are not adequate in size. The inlet temperature for conversion must be at least 190°F. To aid conversion, more efficient radiation devices in convection units with fans could be added if the condensate lines are adequate for required flows. Also, the piping layout could be made more efficient.

In all of these systems, it may be possible to supplement the systems when the temperature of the available resource will not permit the existing system to meet demand. Often, supplemental units can be cascaded with the existing system. Such a combination can provide the needed heat with high temperature drops and an efficient use of the resource.

District Heating

A system that is much broader and more efficient than those previously discussed is one that heats an entire district. It is essentially a matter of transporting and distributing heat. The heat may be either low- (below 250°F) or high-temperature (above 300°F) water or steam. District heating conserves energy and reduces costs by using cheaper fuel and waste heat.

An individual heating system operates at 50-70% efficiency. District heating efficiency is 80%, obviously a more economical system. Another economic appeal of district heating is that the facility can be concentrated in one location, thus requiring fewer technical specialists and supervisors and fewer vehicles for transporting fuel. Obstacles to district heating are the cost of distributing the heat, the loss of heat in distribution, the high cost of heating one-family houses and the high initial capital investment.

In the United States, there are many different types of heating systems. At present, natural gas is a severe competitor to geothermal district heating systems, both economically and environmentally. Geothermal energy, however, has been very competitive when the resource is near the area to be heated.

Iceland has been highly successful in using geothermal energy for district heating, realizing a savings of approximately 30% over heating with oil. Approximately 65% of the buildings in the country and 97% of the buildings in Reykjavik are included in the district-heating system. Other European countries, notably Sweden and Denmark, are expanding their district-heating systems to conserve fuel.

An important economic factor for a heating district is the number of buildings in an area that can be supplied. An area that has a number of buildings concentrated in a small area can be served more efficiently by a heating district. The more consumers that can be served in a limited area reduces the cost because the distribution network to supply the heat is expensive. For example, a downtown area with many high rises or multistoried buildings could be served economically by a district-heating system. An area with many one-family homes may not.

Heat for the district may come from low- or high-temperature water or steam. Low-temperature (below 250°F) water in the main lines may permit direct connections at the consumers' buildings. The direct connection provides better efficiency and allows the use of smaller pipes (thus, less circulating hot water), which reduces heat loss. The design of the system is simplified because recirculation is eliminated. In turn, internal pumps in spaceheating installations are also eliminated, leading to lower installation and operating costs.

High-temperature (above 300°F) water systems usually require heat exchangers and recirculation pumps. These cause the distribution network to lose more heat than one using low-temperature water. Of the three systems (low-temperature water, high-temperature water and steam), steam is the least efficient as it cannot be transported as far as the other two.

In the future, low-temperature geothermal energy for space heating will be emphasized. Large-scale heating districts, such as those being developed in

Boise, Idaho and Klamath Falls, Oregon will become more common. With the rising prices of conventional fuels, district heating will be more economical. Also, the distance that heat can be transported will increase. At present, distances up to 60 miles are being discussed; theoretically, these distances are practical. Thirteen miles of transmission are now a reality in Reykjavik, Iceland. Modern technology is extending this figure with the introduction of insulated pipe in which fluids below 212°F lose only three-tenths of a degree F in one mile.

A geothermal district-heating system will generally have the same basic components as those in a conventional heating system. The geothermal production field (which includes the wells, pumps and collection mains) replaces the boiler. All other components (piping, valves, controls and metering) would be like those in a conventional system. The most desirable network for distribution from an economical standpoint would be the single pipe, or open-ended system with heat exchangers installed in each building. The geothermal fluid would be disposed of at the end of the consumer connection. This network would cost 30% less than a two-pipe network, which requires a central heat exchanger and pumping and control equipment. If it is necessary to inject the fluid into the reservoir, a two-pipe system might be the most desirable.

Financially, the geothermal application is becoming more attractive. At present prices, it will cost about one-third less than a corresponding fossil-fuel application. Because of the rising prices of fossil fuel, geothermal system costs will probably drop in 20 years to about 30-40% of conventional system costs. Most geothermal direct-use systems will pay for themselves in savings from conventional fuels in 5-10 years.

Agricultural Uses of Geothermal Energy

Geothermal uses in the growth cycle of agriculture are particularly attractive because the temperatures required are lower than for other applications. Geothermal resources with these lower temperatures are more common than are the higher, 300°F temperatures. Low-temperature heating can be used in greenhouses, animal husbandry, aquaculture, soil warming, mushroom raising and biogas generation.

Greenhousing.

Greenhouses are used to control the environment and increase the yield of plants. Essentially, the greenhouse traps solar radiation and heat by enclosing a growing area with glass, plastic film or Fiberglas. Of course, there are other elements beside temperature that must be present, such as plant nutrients in the growing media, carbon dioxide content in the air, humidity, plant spacing and so forth. But for our discussion temperature provided by geothermal fluids is the main concern.

Different crops require different temperatures, ranging from 65-80°F. Greenhouses can be heated by a variety of methods: air may be circulated over finned-coil heat exchangers carrying hot water; hot water may be circulated through pipes or ducts located in or on the floor; or finned units may be located on the walls or under benches. It is possible to combine two of these methods in the design of the heating plan. The water in these units can be as low as 90°F and still be sufficient to supply the needed heat. One advantage in greenhouse design is that most crops require lower temperatures at night when the outside temperature is coolest.

Animal husbandry. In animal husbandry (the raising of animals) there are significant advantages to controlling the environment of the animals rather than exposing them to outside temperatures. In the controlled environment, more newborns survive, grow faster and heavier, have fewer diseases and have lower fat levels in the final meat product. The heat for this environment may be floor heating (common in open, finish-feed lots for cattle) or both space heating and floor-slab heating in completely enclosed structures like those for raising pigs and chickens. Floor-heating temperatures are about 90°F to maintain 70°F in the building.

Aquaculture. Aquaculture is the cultivation of freshwater and/or marine organisms. One facet of aquaculture is the commercial raising and harvesting of fish. The species that can be farmed in this fashion are numerous and include buffalo fish, three types of carp, paddle fish, catfish, pike, eels, salmon, shrimp, lobster, oysters and scallops.

An aquaculture industry that is emerging but still needs improvement is the raising of vegetable species for human and animal foods. Such crops as water hyacinth, duckweed, algae and kelp can be raised in geothermally heated waters. However, the economics of harvesting and processing must be improved before these crops can be raised commercially.

Ponds for aquaculture can be heated to a desired temperature of 80°F by using pipes carrying hot water of 90-100°F or by adding hot water (70-90°F) directly to the pond. That water must not contain elements that would harm the fish or plants.

Soil warming. Another area showing promise in agriculture is the use of geothermal water to warm the soil, a technique used to increase production of certain crops. Experiments at sites throughout the world have shown that certain vegetables, previously considered "cool weather" crops and certain rapid-growth trees grow faster and larger if the soil temperature is maintained at 70°F.

One pleasing feature of this technique is that it can use geothermal fluids previously used in other processes. In other words, it can be the last step in cascading the energy. The geothermal water can travel through an underground network of inexpensive plastic pipe. Polyethylene tubing, available in lengths of 1000 feet and longer, is economical and will work in this application. If the pipes are spaced approximately three feet apart and installed two to three feet below the surface, crops can be planted, grown and harvested almost directly over the pipes without damaging the installation.

Mushroom raising. Mushrooms also flourish commercially in geothermally heated houses. From 1974-1976, the United States produced over 142 million pounds of the edible fungus, Agaricus bisporus, for the fresh-sales market and almost 168 million pounds for processing. Three stages in mushroom culture need to be heated: compost preparation (130-140°F), spawning (72-75°F) and the production stage (60°F). Exposed hot-water piping along the walls provides the heat. The cooling, which may be geothermally driven if the resource temperature is high enough, is usually provided by small, electrically powered units.

Biogas generation. Still another agricultural process requiring heat is the production of biogas. Essentially, it is the decomposition of organic matter in the absence of oxygen, a process called anerobic fermentation. This fermentation of organic products produces methane, carbon dioxide, hydrogen and traces of other gases. The residue is weed-free, rich in nutrients and high in nitrogen.

The most important piece of equipment is the enclosed tank for biomass digestion. The temperature is controlled by the addition of heat to maintain the desired 85-105°F range. Circulating hot water through metal coils, which may be either inside the tank or in the tank walls, produces the necessary heat. Insulation of the walls keeps the heat needed to a minimum.

The agriculture processes just discussed offer some significant economic advantages in the use of geothermal resources. If several of these processes were located near each other, one resource could be used for all processes in the cascading effect presented earlier. For example, a complex might use the highest-temperature water (200°F) for greenhouse space heating; pass the used water to a mushroom culture, which requires 110-140°F temperatures; send the water next to a biogas-generation process using 90-110°F; and finally use the water for aquaculture activities which thrive on temperatures below 90°F. In this manner, much more would be gained from the energy and the savings would be substantial.

Industrial and Agricultural Processing

In addition to uses in the agricultural field, geothermal is used extensively in the processing of agricultural products and in the industrial field. There is potential for increased geothermal use in a number of industries. In the industrial applications presented here, the temperatures needed range up to 300°F. These applications include preheating, washing, cooking, evaporating, sterilizing, distilling and separating, drying and refrigerating. Figure 4 graphically depicts the application temperature range of these processes.

Many manufacturing industries use boilers to distribute steam throughout the plants. Obviously, much of the steam is not returned, imposing a considerable load on the boiler heating the feed-water (water, often purified, heated to nearly boiler temperature and de-aerated before being pumped into a steam boiler by a feed pump) coming into the plant at 50-60°F. Geothermal heat can be used most effectively in this function, preheating the water and thus reducing the load on the boiler.

Several industries use large amounts of low-temperature energy (95-200°F) for washing and cleaning. The food-processing industry is a major consumer of hot water: meat packing uses hot water in scalding, cleaning and washing carcasses, and in clean-up; soft-drink bottlers use hot water for washing containers and returnable bottles; poultry dressing and canning also require water at scalding temperatures. Another large consumer is the textile industry, using wash waters at 200°F. The plastics and leather industries use smaller amounts of hot water but still need temperatures of 190-200°F and 120°F respectively. After being used, the water in these industries is pumped down drains and not used again. However, in another industry--the fabricating of metal products, machinery and transportation equipment--the

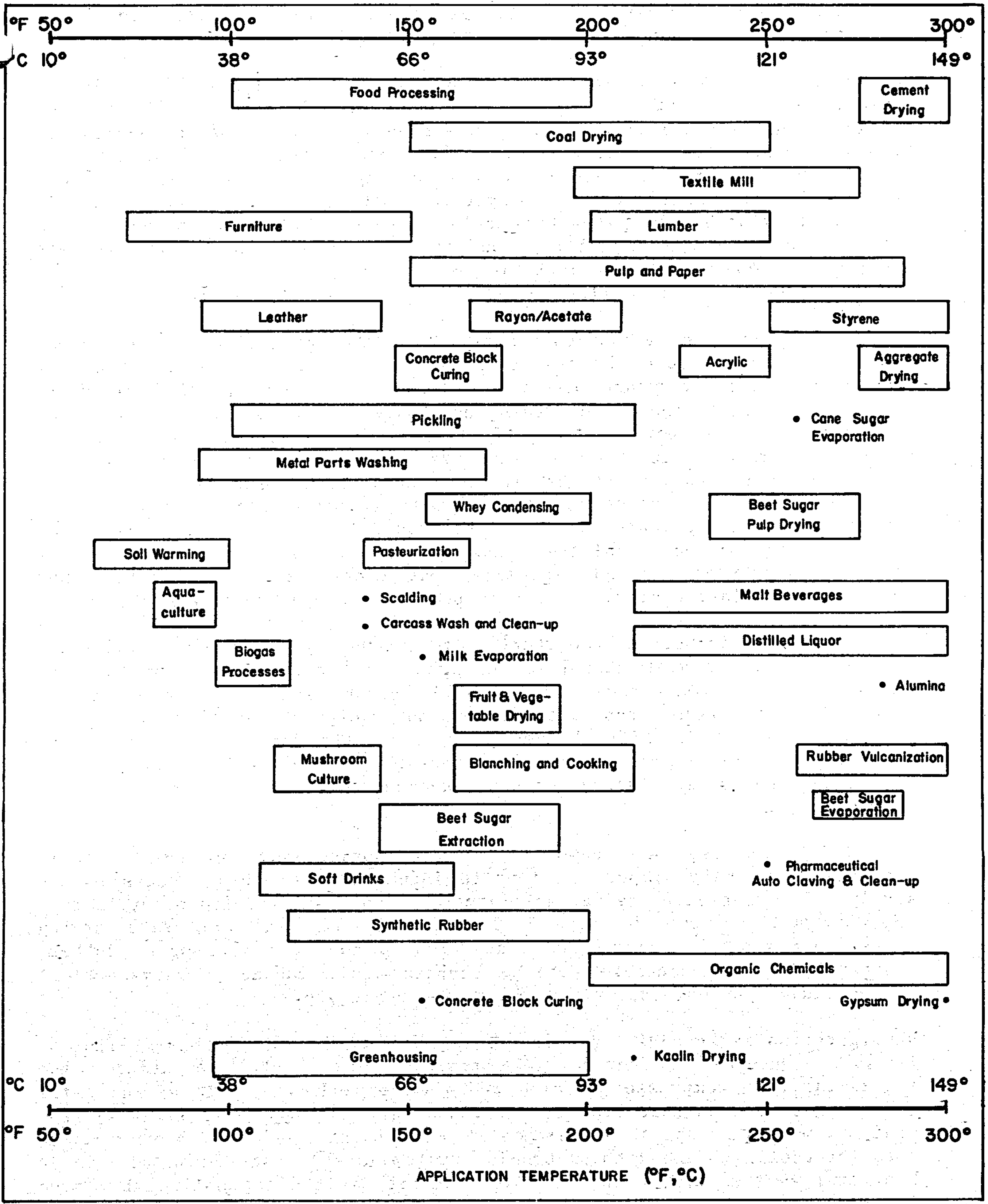


FIGURE 4. Application temperature range for some industrial processes and agricultural operations.

water loses about 10-20°F in the processing and is reheated and used again. Here, the water is used to degrease parts, bonderize and wash.

Hot water is also used in food processing for peeling and blanching. In the typical peeling operation, produce is placed in a hot bath. After being softened, the skin (or outer layer) is scrubbed or washed off mechanically. Blanching operations are similar to peeling operations. The blancher usually inhibits enzyme action, provides a coating for or cooks the produce. Typical blanching fluids require properties that are closely controlled. It is unlikely that geothermal water could be used directly in blanchers and peelers because of water quality, but it could provide heat for the heat exchangers. The temperature range for most peeling and blanching systems is 170-220°F, temperatures readily adaptable to geothermal resources.

Processing plants use evaporators and distillators to concentrate a product or to separate a product by distillation. Frequently, the evaporator will hold a product for a given time at a specific temperature, which naturally varies according to the product being evaporated. In the agricultural process, where water is being driven off, temperatures are typically 180-250°F. Evaporators running at reduced pressures can use lower temperatures and often improve the quality of the product. Sugar processing, mint distilling and organic-liquor processing are the most common users of evaporators. Depending upon temperature and flow-rate requirements, evaporators can readily be adapted to geothermal energy as the primary heat source. This energy can be transferred through secondary heat exchangers or, in some cases (depending on plant design), it can be used directly at the evaporator.

A wide range of industries use sterilizers extensively. The meat- and food-packing industries must sterilize equipment, and the canning and bottling industries their containers; but not all operate for the same length of time. Many sterilizers run continuously, but equipment washdown and sterilization may occur at shift changes or periodically during the shift. The operating temperatures for most sterilizers (220-250°F) could be provided by geothermal energy with the use of heat exchangers to heat the potable, sterilized water.

Many industries use heat under 300°F to evaporate water or to dry their products. The pulp, paper and textile industries use this process extensively. The beet-pulp drying, malt-beverage and distilled-liquor grain drying, hydraulic-cement drying and lumber industries also operate drying units. On a smaller scale are industries producing coal, sugar, rubber, leather, copper-concentrate potash, soybean meal, tobacco, pharmaceutical tablets and capsules, explosives and paving aggregate.

Refrigeration is an additional industrial application of geothermal fluids. It is a sequence of thermodynamic processes in which a substance, the refrigerant, is compressed, cooled and then expanded. As it expands, the refrigerant absorbs heat from its surroundings. Using either lithium- bromide or ammonia as the absorbing media, units using geothermal energy can be used for cooling. The lithium-bromide system is the most common because it has water as the refrigerant; it is, however, limited to cooling above the freezing point of water and is used primarily for chilling water to provide cool air for human comfort, for cooling in a process or for dehumidification. For refrigeration at temperatures below 32°F, geothermal-driven units, using the ammonia absorption system, can produce temperatures as low as -40°F. Such systems are usually applied only in situations requiring over 100 tons and have seen limited use. For lower- temperature refrigeration, the driving temperature must be at or above 250°F.

Potato processing. Food processing, crop drying and the forest-related industries have been extensively studied in regard to the use of geothermal energy. Potato processing provides a practical example of how geothermal energy could be used in a sophisticated industrial system where heat is required to perform different functions.

Many of the processing methods in the potato-processing system can use energy supplied by geothermal fluids with temperatures of 300°F or lower. However, a few of the operations, notably frying, will require temperatures higher than those provided by most geothermal resources. Usually in a potato-processing plant, there are potato-product lines and several by-product lines. Figure 5 illustrates a french-fried potato-processing line.

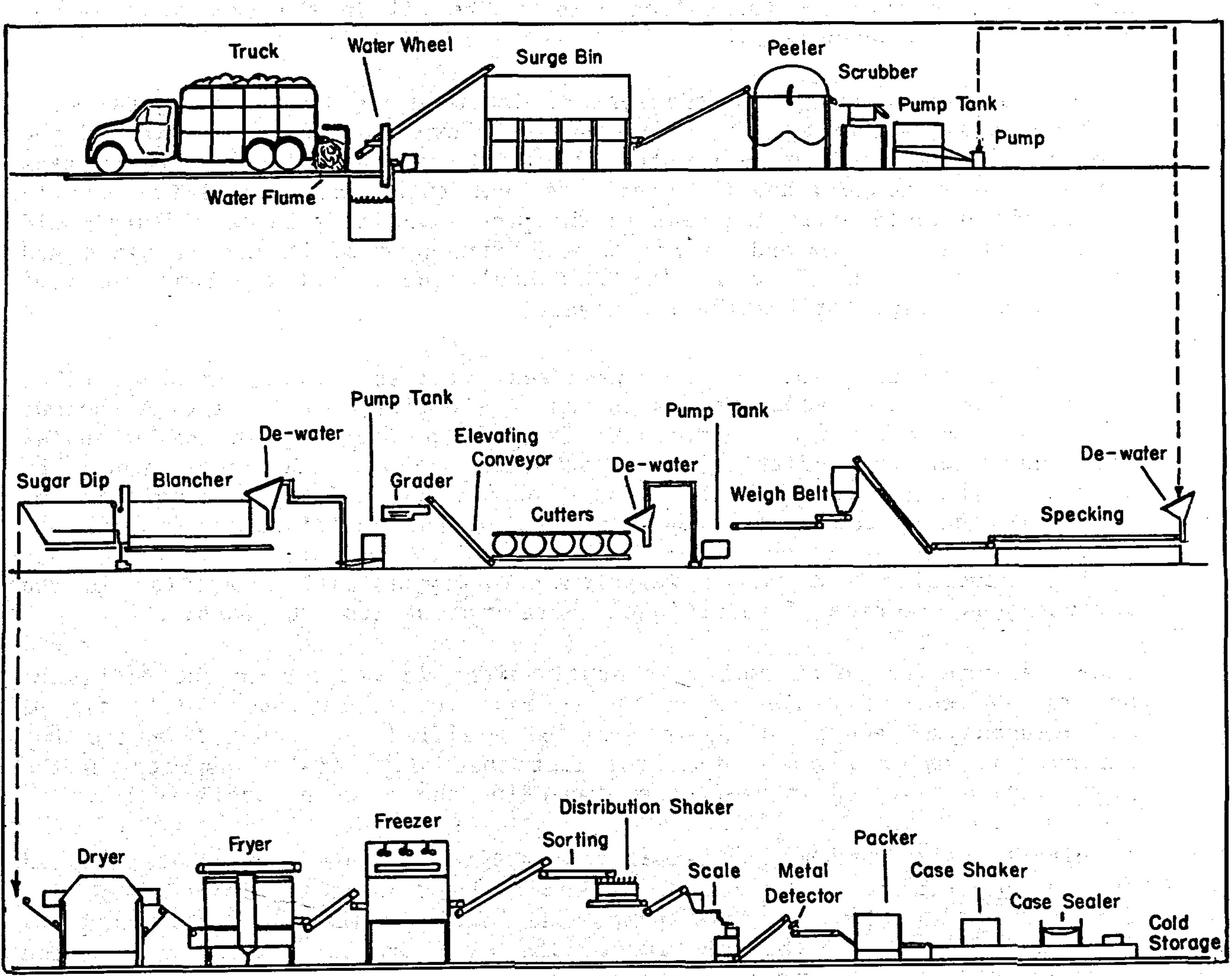


FIGURE 5. Potato-processing schematic.

The potatoes are conveyed first to a battery of scrubbers and then moved into a preheater, which warms the potatoes and softens the peel, making it easier to remove the skin. The potatoes are then chemically peeled by a 15 percent lye solution maintained at temperatures of 140-175°F. Upon leaving the chemical peeler, the potatoes travel to a battery of scrubbers which remove the peelings completely. Then they are scrubbed again and moved to the trim tables. The peels removed by the scrubbers are pumped to a holding tank and, following neutralization of the lye residue, are sold as cattle feed, a profitable by-product of the process.

After the potatoes are trimmed and defects removed, the product is conveyed to the cutter area. Shakers then sort the product before it is carried by gravity to the blanching system. From there, the potatoes are dewatered and fed through a sugar drag, which adds a slight amount of dextrose to the surface to impart a golden color when the potatoes are fried. The next stage, a dryer, removes surface moisture and prepares the potatoes for the two-stage frying process. The first stage cooks the product almost completely and the second provides the golden color. The oil in the fryers is heated to 375°F by heat exchangers.

To use geothermal energy in the system, intermediate heat exchangers would probably provide the heat to the process. To avoid any contamination of the product and the need to purify the fluid, the geothermal fluid would pass through the exchangers and transfers its heat to a secondary fluid, usually water, which would carry the heat to the process. The secondary fluid would be in a closed system and return to the exchanger to be heated again and again. A geothermal fluid of 250-300°F could supply all the heat needs of the process except for heating the fryers.

In addition to the aspects just presented, process heating involves other factors that could affect the design and feasibility of using the geothermal resource. Many large and complex industrial operations have the potential for conversion (retrofitting) to geothermal energy. But for these, the design of the geothermal system will probably be limited to supplying hot fluids to the system or to the boundaries of the buildings as it would be very expensive to modify internal equipment and to interrupt the process during conversion. A factor weighing strongly against conversion is the agribusiness practice of maintaining secrecy about its processes.

The potential for geothermal heat applications is greater in the design of new facilities. In this circumstance, base levels for heat loads can be established and equipment design can be modified to accommodate the hot fluids. Of major importance is the fact that all suitable aspects in the plant can be designed in view of an impending shortage in fossil fuels.

In situations where the geothermal temperature is lower than that required for the process or where the flow rate of the geothermal fluid is too low for the application, a heat pump will allow additional energy to be extracted from the geothermal fluid. The pump may be used in combination with a heat exchanger in these circumstances, but the decision will depend on the resource and the specific application. Also, an auxiliary energy, most likely electricity, will be needed. All these factors enter into the economic analysis and must be considered.

The design for geothermal applications must also take into account whether the fluid will be used directly or indirectly in the process. Direct use usually will eliminate additional heat exchangers, pumping and piping; however, the money saved here may be lost in the requirement for a peaking system, contamination of product and concerns for the environment. Present Environmental Protection Agency (EPA) guidelines will not permit injection disposal of geothermal fluids which have been chemically altered. But direct use may not be practical in many applications. For example, the process may need a standby or peaking capability provided by an auxiliary boiler, but the process may not permit the use of geothermal fluid in the boiler as feed water. Where the process has special water requirements, the use of geothermal water complicates the treatment and may prove uneconomical.

Certainly, the decision to use geothermal or to convert to geothermal is not a routine one. There are many factors affecting both the design of a system and the economics of such a design. Expert guidance is needed in both circumstances.

Production and Injection Equipment

As stated in Chapter 3, once the geothermal resource has been located and the drilling completed, the problem of production (that is, getting the fluid out of the reservoir) remains. There are a variety of methods for providing geothermal fluid to above-ground systems. Artesian wells provide surface water naturally, and some non-artesian wells can be induced to flow without pumping. However, wellhead pumps are necessary for non-flowing wells and may be desirable for wells that are self-flowing.

One method for creating flow in a non-flowing well is to reduce the density of the liquid column in the well. Mixing a gas with the liquid will reduce the density so that the pressure in the formation (reservoir) will force the liquid to the surface. This mixture may occur when the geothermal source is hot enough and the conditions sufficient to cause the liquid to "flash" into steam. This liquid-vapor mixture is low enough in density to produce a flow which will continue until the resource cools or the well is capped.

One drawback in this condition is that partial flashing will cool the fluid in the well and transmission lines, in turn causing the dissolved solids to solidify. When these solids form on casing walls (scaling), they reduce the flow of the liquid. Thus, the advantage of pumping a self-flowing well is that it maintains pressure on the liquid and minimizes downhole flashing and subsequent scaling. Also, if there is no flashing, the fluid discharged by the pump has a higher temperature than that which flows naturally. This temperature difference is important when the design of the system calls for high-temperature geothermal fluids.

Pumps play an important part in the geothermal system and fall into three types: vertical-turbine pumps, downhole pumps and systems circulation pumps. Each has its own function. Vertical-turbine pumps have been used for years to supply water for both domestic and irrigation uses and have been used successfully in geothermal wells. These pumps use centrifugal force, created by a shaft-driven impeller, to increase fluid pressure. To achieve the high pressure required in some geothermal applications, these pumps frequently have stages arranged in a series. The flow through each stage is the same, but each stage increases the pressure from the previous stage. A motor above the ground rotates a shaft the length of the pipe column to drive the impeller. The fluid flowing upward through each stage, and at the top of the well leaves the pipe column through the discharge head and enters the service piping. A sketch of a vertical-turbine pump appears in Figure 6 on the next page.

Vertical-turbine pumps may be either an "enclosed lineshaft pump" or an "open lineshaft pump." A point of consideration in choosing pumps is maintenance. The enclosed pump has tube bearings which support the shaft at 5- to 7-foot intervals and which must be lubricated. They can be lubricated by a fluid, either gravity-fed or pumped through the tubing. Oil, as a lubricant, has been used successfully in low-temperature geothermal applications. In high-temperature applications, water from the pump discharge or fresh water from a separate supply can be used as a lubricant. Softened water can avoid the problem of solids deposition on the bearings.

The open lineshaft system does not have bearings supported by the column pipe and can be lubricated by the fluid moving up the column. Because there is no lubrication oil to contaminate the water, these pumps are used commonly in domestic water systems. However, they have not been used successfully in geothermal applications.

Maintenance of open-lineshaft pumps is a factor to consider in the selection. Where the fluid is low in temperature and in solids, they can provide years of maintenance-free service. In other locations, where solids readily deposit on metal surfaces, pumps need to be cleaned and repaired within a year.

A problem associated with hot fluid is that metals in the pump expand. Since the metal of a lineshaft is frequently different from that of the pipe column and tube, the expansion rate will also differ. One common technique to solve this expansion difference is to make the shaft adjustable from the surface. Once the shaft is adjusted, after the entire pump, column and shaft have stabilized their temperatures, no adjustments are required.

The second pump type, downhole pump, is an electrical submergible pump used successfully by the oil industry for over 50 years. Its adaptation to geothermal use in the last decade is a natural extension of technical knowledge gained from 50 years of oil pumping.

A submergible pumping system has three major components: the drive motor, the protector section and the pump. Its surface components consist of an electrical junction box, switchbox and transformers. The motor is a 3-phase induction motor which is oil-filled for lubrication and cooling. Well fluid, moving past the motor section, carries away motor heat, allowing the unit to operate successfully in wells with temperatures over 300°F. These motors are available in a wide range of diameters, horsepower and voltages.

The second part of the pumping system, the protector section, is located between the pump and the motor and isolates the motor from the well fluid. Mechanical seals prevent the fluid from migrating along the pump shaft. A marine thrust bearing absorbs the axial forces caused by the pump.

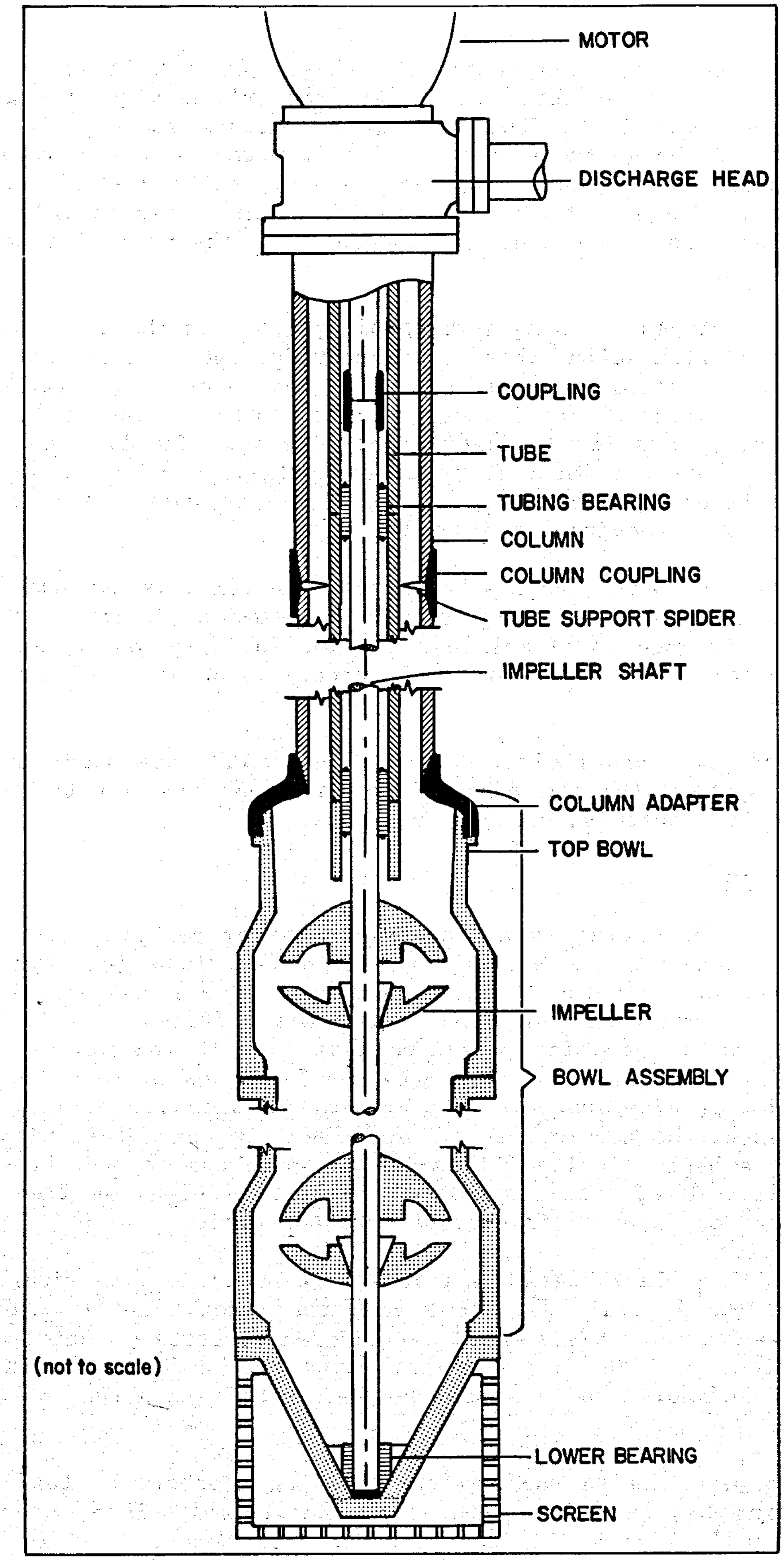


FIGURE 6. Vertical turbine pump.

The third stage, the pump section, consists of a multistage centrifugal arrangement similar to that in the surface-driven vertical-turbine pump. This unit can pump up to 2000 gallons per minute and can lift the fluid 15,000 feet. Although the amount of lift from each stage is relatively low, many stages (in some instances as many as 500) can be used to meet high head requirements. The use of corrosion-resistant materials minimizes pump wear and corrosion. In fluids normally encountered, the unit will work for long periods of time.

There are advantages to using submergible pumps. In the small diameter casing associated with wells, this system provides the largest amount of horsepower. Also, conventional designs can be used in crooked drill holes. This system has a minimum of requirments at the surface of the well, and it does not need costly pads for foundations or housing. Finally, the submergible pump confines pump and motor noise to the well bore--a point appreciated by environmentalists. A recent development permits easy and safe removal of the pump without removing the discharge pipe.

The third type of pump, the system circulation pump, is not used in the well but in a secondary closed-loop system to provide the pressure and flow. Pumps have been used to circulate hot water for many years, and the selection of one for a specific geothermal purpose is a matter of straightforward engineering.

The types of pumps and their uses have been well documented, so mating the geothermal system with the appropriate units becomes a matter of research and application, that is, good engineering.

Piping Systems

The standards for piping in a closed-loop system carrying city or drinking water have been set and appear in ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.) guidebooks. However, piping for transporting geothermal water has different requirements. The pipe most commonly used for pressures less than 125 pounds per square inch is black steel. Sections of this pipe may be joined by threading or welding or by gland-type couplers. It is necessary to know the chemical and temperature ranges of the couplers to be sure they are compatible with the water. Maintaining a high velocity will scour the pipe and reduce the accumulation of chemicals. Also, this system must be kept airtight as free oxygen produces an iron oxide which is corrosive to the pipes.

Pipes other than black steel are permissible under certain water conditions, but copper, brass, stainless steel and other exotic metals should be used only as a last resort because of their increased costs. Buried underground, metallic pipe will corrode; however, magnesium anodes can offset the galvanic action of soils and ground water, especially when the soil is moist or acid.

Nonmetallic pipe can be used in transporting geothermal fluids. Asbestos cement piping has carried discharges successfully. Some waters, however, will react with chemicals in the pipe and form solutions which cause it to deteriorate. Also, because of the porosity in these pipes, there is a possibility of oxygen entering the water. This condition is not insurmountable. A new type of pipe, cement aggregate mixed with various polymers, has been tested in various geothermal fluids and has shown resistance to etching, scaling and erosion. Even though tests are continuing, this pipe is available commercially. It is important to understand, however, that it has not been used enough in commercial application to provide sufficient data.

Plastic pipe is also applicable to geothermal uses. Any of the patented plastic pipes have excellent chemical resistance, sealing, higher flow rates and a wide range of thermal expansion and temperature limitations. However, a thorough study of their limitations is advised before using any of these pipes. A good idea is to provide the manufacturer with a chemical analysis of the geothermal water and request a written guarantee for the conditions and the use of the pipe. The reason for caution is that these have had only limited use in geothermal conditions and there is little experience on which to base design, operations and maintenance costs.

Some Fiberglas-reinforced plastic pipes meet rigid federal specifications and have been used for steam-condensate lines with good results. Over a 12-year period, maintenance costs have been nil and the pipes show no signs of deterioration. However, this pipe generally will not carry live steam because the steam breaks down the plastic, causing weeping and eventual failure.

Other factors to be considered in the selection of pipe for the system are: (1) sizing, (2) friction loss and (3) allowances for expansion. In any piping and utilization system, it is wise to prepare a preliminary layout and from this determine the preliminary pipe sizes, pressure drops, equipment sizing and pump selection. This preliminary design should then be examined and adjustments made in pipe size and pump size so a comparison may be made between the best first cost and the operating cost of the system. From these should come the best design. The pipe size is determined by the ΔT. As discussed previously, it is advantageous to use the largest temperature difference possible. The needed flow rates are determined by dividing the required heat output by the temperature differential.

The second consideration is the amount of friction in a system. When a pipe size is reduced, friction increases, calling for a bigger pump motor, which in turn calls for an increase in energy needed to operate the system. Using higher flow rates has two advantages. The higher rate provides a scouring action in the pipes and moves trapped air through the system. In addition to the friction in the pipes, friction in the heat exchangers or coil system will affect the flow rate of water passing through. The loss here is significant, but it can be easily calculated from information in the manufacturer's catalogs or from information requested from the manufacturer.

The third consideration is temperature, which is important in that it causes expansion which affects the construction of the piping. This phenomenon must be considered because the expansion must be taken up within the piping system. The method or devices used will depend on such factors as force limitations, cost, space available and serviceability. An interesting approach to the problem has been taken by several European countries. They preheat and direct-bury piping for their large central heating districts. In this method, insulated pipe is laid in trenches, preheated to a fixed temperature, which is between the middle of the normal operating range and the middle of the total temperature difference. The trench is then backfilled at that temperature. The "prestressing" eliminates the need for guides, anchors and expansion loops or compensators. Of course, the method requires a solid bond between pipe, insulation and the outer jacket, but it is said to reduce installation costs by up to 20% and also to reduce system failure. For systems where this technique is impossible, all expansion devices must be used in conjunction with anchors and guides to insure that expansion occurs as designed and alignment of the piping is maintained.

An economic consideration in the pipe design selection is the amount of heat loss that can be tolerated in a system. Geothermal water is a natural resource, and although it may appear to be unlimited, it should not be wasted. To fortify this conservation, recent legislation and energy codes dictate minimum insulation for piping, regardless of the heat source. These new codes mean that more factors are involved in the piping system. The thickness and type of insulation must be evaluated on cost, on location of the piping and on the temperatures involved. In an underground system, resistance to moisture absorptivity and to superimposed loads must be considered. In above-ground systems, insulation must be evaluated for its fire resistance. Most of the criteria for proper installation can be obtained from insulation manufacturers.

Heat Exchangers

The heat exchanger plays an important part within many heating systems. In geothermal systems, the heat exchanger confines the geothermal waters with their natural impurities to locations where corrosion and scaling can be controlled by material selection or where cleaning and replacement will be relatively easy. Thus, the heat exchanger protects the large and sometimes complicated piping and heat-emitter systems from geothermal fluids. Before making any decision about the use of heat exchangers, the designer should check the chemistry of the water and its effect on materials. Another point to remember is that any time a heat exchanger is used, there will be a temperature loss between the primary and secondary fluids (called the approach temperature).

As has been stated a number of times, the smaller the transfer temperature difference, the greater the expense. That holds true here also. An approach temperature of less than 10°F is often not economical. The decision will depend on the type of heat exchanger and its particular application. In some cases where well and piping costs are low, approach temperatures of 4-5°F have proven economical.

Six heat exchangers are available for use in geothermal systems. The first, the downhole heat exchanger (DHE), offers financial savings over surface heat exchangers in circumstances where a single-well system is adequate and may be economical under certain conditions at well depths up to 1500 feet. Figure 7 on the next page shows a typical hot-water system using a downhole heat exchanger.

The downhole heat exchanger avoids the problem of geothermal fluid disposal since only heat, not fluid, is taken from the well. The exchanger consists of a system of pipes or tubes suspended in the well through which "clean"

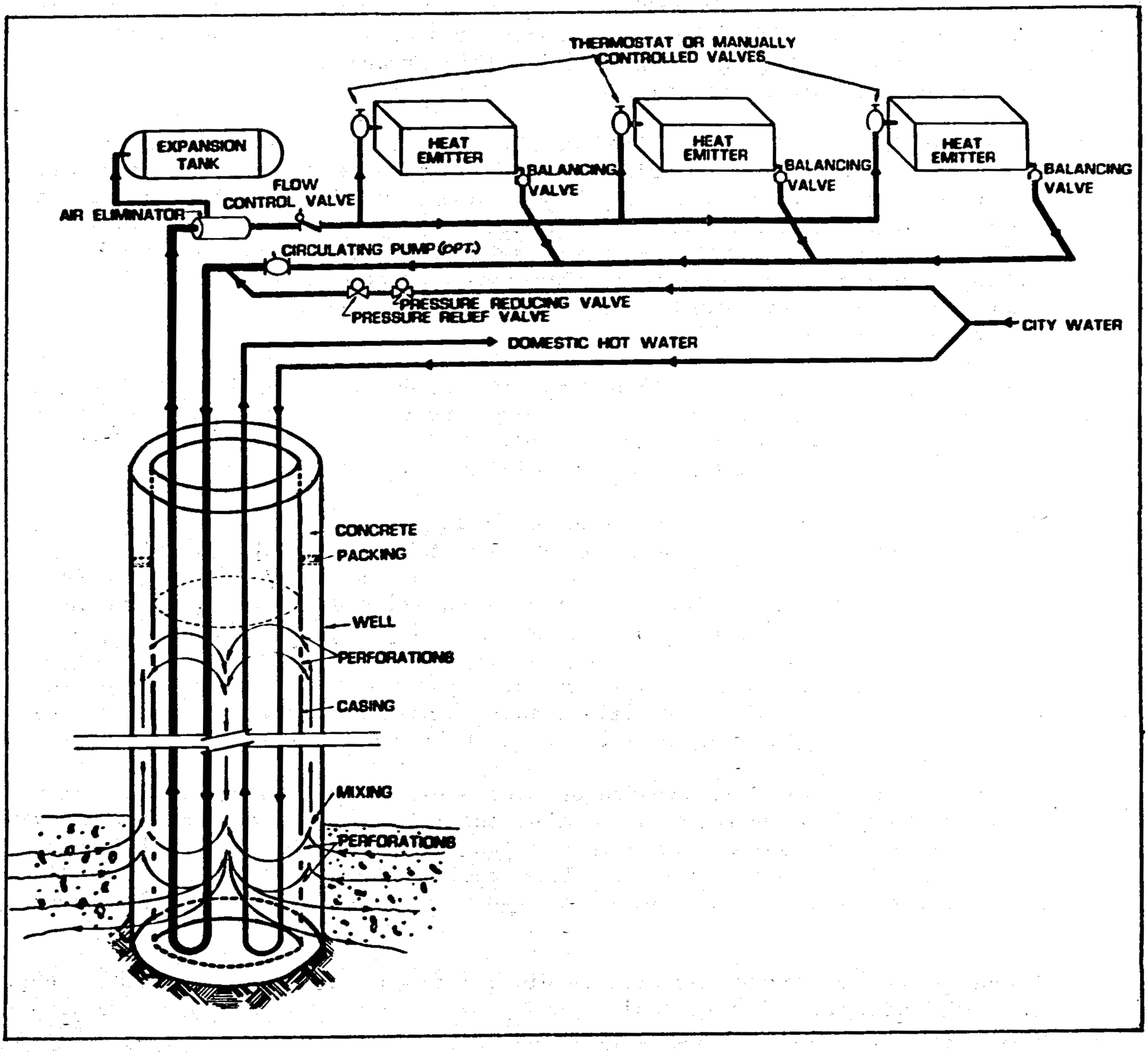


FIGURE 7. Typical hot-water distribution system using a downhole heat exchanger (Culver, 1978).

secondary water is pumped or allowed to circulate by natural convection. Circulated water absorbs heat from the well water. This heat is then used on the surface. Considering the life of the unit and replacement costs, the materials in the system should be selected to provide economical protection from corrosion. Because replacing the well casing is expensive, attention must be given to the electrical relationship between the exchanger and the casing. It seems that corrosion is most severe at the point where air and water meet. Stray electrical currents can increase this corrosion. Insulating unions should be used to isolate the exchanger from stray currents in building and city water lines.

The shell-and-tube heat exchanger is well known. It is placed above ground and can be adjacent to the well head or placed along the distribution system. The exchanger is a shell surrounding a series of tubes which normally carry the geothermal water. In a sense, this arrangement wraps the secondary system water around the tubes.

Impurities in the well water will determine the type of material to be used in the heat exchangers. Normally, the less expensive units use mild steel, but areas with corrosive waters will need stainless-steel shells and certain copper-bronze, silicon-bronze or stainless-steel tubes. When mild-steel shells and copper- or silicon-bronze tubes can be used, the shell-and-tube exchanger will be more economical than the next type, the plate exchanger. However, for the same demands, the shell-and-tube exchangers will generally require more space.

Although not too well known throughout the industry, plate heat exchangers have been used in the food-processing industry where cleanliness and resistance to corrosion are essential. They are also used in other applications where close approach temperatures are needed.

The plate heat exchanger consists of a series of plates held in a frame by clamping rods. The primary and secondary fluids are usually passed through alternating passages between the plates. The fluids flow in opposite directions, called a counter flow, and provide an efficient heat exchange in a small volume. The plates may be stamped out to provide different flow-path patterns and sizes. Plate exchangers can be constructed economically of corrosion-resistant materials because plate material is usually less expensive than tube material. Materials readily available for geothermal use are stainless steels, titanium, brasses and hastelloy (nickel alloy).

Plate units have specific advantages over shell-and-tube exchangers. They are more economical when materials other than mild steel are required. They require less floor space, are easy to disassemble for cleaning, and provide closer approach temperatures for less cost. Merely adding plates will increase heating loads, and series and parallel systems can be incorporated in one frame.

The plate heat exchanger has certain disadvantages. Low-density fluids such as vapors and gases are expensive to handle. Also, since gaskets between plates must be elastic (polyvinyl), temperatures must be limited to 500°F. Unless these disadvantages eliminate their use, they should be considered for all applications.

The direct-contact heat exchanger is one of the most efficient but simplest means of transferring heat from hot geothermal water to another working fluid. These exchangers have been used in petro-chemical applications for a number of years, usually in the exchange of heat between a fluid and a gas. The body of the exchanger consists primarily of a pressure vessel so piped that the hot fluid and the fluid to be heated are introduced countercurrent to each other. Each fluid is usually directed through a nozzle arrangement to provide the most efficient mixing and the maximum contact between the two. Once the mixing and heat exchange has taken place, the two fluids are separated as a result of change in their state or in density. The advantages for direct application include the simplicity of design and the small volume size required for rather large heat transfer rates. The direct contact heat exchanger has been used mainly in electric power generation, but it could be used with heat pumps.

The fluidized-bed heat exchanger is similar to a shell-and-tube in design and general appearance. It differs in that it uses a medium such as sand or ground walnut shells that will behave like a fluid if placed under pressure or with a fluid. This medium is maintained in the shell portion surrounding the tubes. It constantly scrubs the tubes and eliminates many fouling or scaling problems. Turbulent action around the individual tubes increases the contact time between hot and cold fluids. The unit is obviously an excellent choice for use with geothermal waters that have a potential for severe scaling.

Typical uses include many drying applications, especially those where the fluidized medium is actually the material being dried. This process can be a batch type or a continuous-flow process, with the medium constantly carried over and expelled when it reaches a certain moisture content. In this instance, geothermal water would be used in the tube side of the exchanger; the material to be dried, pushed by pressurized air, would move through the shell side.

Plastic-tube heat exchangers are available with an upper temperature limit of 122°F from a Swedish manufacturer. Higher-temperature units are reportedly being investigated. Completely corrosion-resistant to most geothermal waters, the unit should not be susceptible to scaling. It is versatile in that it has been used in heat-recovery systems where heat from corrosive water is transferred to air and where chemical-laden air is used to heat water. All components, bolts, manifolds, plates and spacers are plastic. With tubes made of highly cross-linked polyethylene, the units should withstand temperatures above 200°F and pressures of 150 pounds per square inch, although no such units have been tested to date.

There are no U.S. manufacturers producing either the highly cross-linked polyethylene or the plastic-tube exchangers. However, a unit using teflon tubes has been used for several years in the Blue Baths in Rotorua, New Zealand. The exchanger consists of a loose bundle of 640 small teflon tubes suspended in a circulating bath of 200°F geothermal water.

Corrosion, Scaling and Materials Selection

When properly managed, heating systems (whether they are boiler water, steam or hot-water) are free of the typical thermal fluid components. These fluids have little tendency to form scales by dissolved solids. On the other hand, the chemical species present in geothermal fluids are primary factors in corrosion and scaling when these fluids are used as heat sources. One of the unfortunate effects of having a high-temperature heat well is that these high temperatures increase the total of dissolved solids. The chemical content will vary with the location of the resource, but there are certain species found in varying degrees in all geothermal fluids. Table 2 on the next page lists these and the character of each.

Hydrogen concentration, shown as pH, appears as a result of other chemicals such as carbon dioxide. Oxygen is not present to a significant amount in

TABLE 2

Dissolved major corrosion and scaling species
in most geothermal fluids

Corrosion	Scaling	Character
Oxygen (in leakage)		Gas
Hydrogen Sulfide		Gas
Carbon Dioxide		Gas
Ammonia		Gas
Hydrogen		Ions
Sulphates		Solid
Chlorides		Solid
	Silicates	Solid
	Carbonates	Solid
	Sulfides	Solid
	Oxides	Solids

most geothermal fluids, since oxygen and hydrogen sulfide do not coexist in significant amounts at equilibrium. A significant amount of oxygen when hydrogen sulfide is present usually indicates that air is leaking into the piping system or that surface water is mixing with the geothermal fluids.

The effect chemicals have on various metals can influence design decisions. For instance, hydrogen sulfide attacks certain copper and nickel alloys, carbon dioxide accelerates the corrosion of carbon steels and ammonia can cause a cracking of copper alloys and speed up the overall corrosion of mild steels. Thus, detecting the chemicals in the individual resources and knowing their characteristics and subsequent effects can help design a sound system.

The volumes of fluid required for most geothermal applications are too great to allow corrosion inhibitors to be used economically. The EPA (Environmental Protection Agency) requires the removal of any chemical added to the fluid to control corrosion. Such requirements provide an incentive for other control methods. Scale, on the other hand, is not subjected to such rigid EPA requirements. However, both factors are points of concern for the system designer.

Table 3 on the following pages presents information about the performance of specific metals in liquid streams and offers data about limits and precautions. This information is helpful in situations where tests have not been done but materials must be specified.

Trying to prevent corrosion may produce some undesirable side effects: corrosion products could cause scale. The products may resist being dissolved in the fluid, causing a scale on the substrate metal. This scale transfers heat less efficiently than the metals which form them and is rougher than the substrate metal. Both conditions cause heat loss which, in turn, may call for larger heat exchangers and pumps. A small advantage is that the scales will cover cracks, pits and small holes that permit localized corrosion. But this action is not to be counted on to any great extent.

In summary, the control of corrosion and scale caused by corrosion inhibitors for conventional systems is best achieved by selecting proper materials for the geothermal system design. Economic and environmental factors limit the use of inhibitors. Obviously, great care must be exercised in the selection of materials because some metals depend on a stable corrosion product for general corrosion resistance. Subtle differences in the chemistry of the geothermal fluids frequently cause the designer to consider using heat exchangers and a "clean" secondary fluid for many heating applications.

TABLE 3

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
Mild & Low Alloy Steels	uniform	pH	Rapid rate increase below pH 6	Air in-leakage is a major hazard; local flashing in pipes can cause very high flowrates and erosion/corrosion
		chloride	Rapid rate increase above 2% Cl^-	
		flow velocity	Limit flow to 5-7 fps (1.5-2.1 m/s)	Avoid direct impingement on steel
	pitting, crevice	temperature chloride	Susceptibility increases with increasing temperature and chloride concentration	Avoid mechanical crevices
		scale	Remove mill scale; avoid deposits	
	sulfide stress cracking	H_2S	Can occur at very low H_2S levels	Complex interactions
		yield strength (hardness)	Use low strength material wherever possible (Rc < 22 g YS < 100,000 psi)	
		temperature	Hazard greater at lower temperatures	
	hydrogen blistering	H_2S	Use void-free materials	Possible at very low H_2S concentrations
	galvanic coupling	electrical contact with more noble metal	Avoid coupling close to large area of cathodic metal	More severe when material has porous coating or scale
Stainless Steels				
ferritic alloys	pitting, crevice	chloride	In general, susceptibility increases with increasing concentration and temperature	Lower alloys may also have high uniform rates in severe environments; O_2 is a hazard. Higher alloys are much more resistant; Cr and Mo most effective alloying agents
		scale	Avoid scale deposits	
		stagnant or low flow	Avoid stagnant or low flow conditions	
		oxygen	O_2 greatly increases susceptibility	

(continued)

TABLE 3 (continued)

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
	intergranular	chloride, temperature	Avoid by proper welding and heat treating procedures	
austenitic alloys	stress corrosion cracking	chloride oxygen temperature	Complex interaction; depending on other factors, cracking can occur for Cl^- > 5ppm; O_2 100 ppb; T > 140°F (60°C)	Hazard increases with increase in Cl^-, O_2, T; some alloys more resistant; protect exterior surfaces
	pitting, crevice	chloride temperature	See ferritics above	Resistance increases with Mo content; avoid mechanical crevices
		scale	Avoid scale deposits	
		stagnant or low flow	Avoid stagnation or low flow conditions	
		oxygen	O_2 greatly increases susceptibility	
	intergranular	chloride, temperature	Avoid by proper welding and heat treating procedures	
martensitic alloys	as above	as above	As above	
	sulfide stress cracking	H_2S, temperature, stress, hardness	More severe at lower temperatures; use low strength levels where possible	General corrosion resistance depends on composition
cast alloys	as above			See comments for equivalent wrought alloy; good crevice corrosion resistance needed for pumps and valves
Titanium Alloys	crevice, pitting	chloride temperature pH	Maximum temperature for resistance depends on chloride and pH	Several alloys have much better resistance than pure Ti. Precracked Ti may undergo stress corrosion cracking

(continued)

TABLE 3 (continued)

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
	galvanic coupling	electrical contact with more active metal	Coupling to large area of more active metal may cause hydrogen embrittlement of Ti	
Nickel Alloys	crevice, pitting	chloride, temperature	Similar to stainless steels except higher alloys more resistant to crevice corrosion; high flow rates	Resistance depends on alloy composition. May be susceptible to hydrogen embrittlement when coupled to steel
Copper Alloys	pitting, uniform, de-alloying	H_2S chloride, temperature, CO_2	H_2S as low as 0.1 ppm can cause attack	Usefulness limited in H_2S environment
	stress corrosion cracking	ammonia, pH		
Other Metals				
cobalt alloys			Avoid galvanic coupling to steel or other active metal	Several alloys have good sulfide stress cracking resistance at high strength
zirconium & tantulun				Resistant to low pH, not chloride solution
aluminum	pitting, crevice	Hg and Cu ions, pH, chloride, temperature, lack of oxygen	Poor results obtained in geothermal tests	May be useful as exterior siding and construction material

Chapter 5

ECONOMICS OF DIRECT-USE DEVELOPMENT

The economics of direct-use geothermal heat are as important as any other phase of geothermal development. Any project to develop geothermal energy should start with an examination of economic feasibility. Feasibility in this context means that the costs of using geothermal energy in the proposed system are less than those of using conventional energy sources to operate the same system.

A feasibility study of the total project must consider several elements of direct-use geothermal energy: (a) the geologic parameters of the resource; (b) the engineering criteria or the technical practicality of the project; and (c) the economics of the venture. The first two elements have been discussed in other chapters. Experienced entrepreneurs will usually examine the geologic and engineering detail carefully but fail to give the same attention to the economics of a project. But the question, "Will the annual savings provide sufficient return to the investor to justify the capital expenditure?", must be answered.

A primary consideration is the cost of finding, developing and utilizing the geothermal resource. Preliminary estimates are often unreliable due to a lack of accurate data. Nevertheless, this cost analysis must be made because the objective at this point is whether the project is practical. Even at its very worst, such a cost analysis is better than intuition or "gut feel."

Cost analysis has many variables, but these can be treated in a relatively simple manner. As in all phases of the project, the economic analysis should be carefully planned and include a dispassionate review of all available information to determine the probable value of the proposed project.

Although many approaches to economic evaluation exist, here is a rather simple procedure:

1. Collect data on the historical cost of conventional fuel used in the existing system. If no historical data are available, estimate the heat load and recent cost of conventional fuel.
2. Determine inflation rates for energy and also for operation and maintenance costs.
3. Estimate costs of geothermal equipment and its installation.
4. Estimate annual operation and maintenance costs of both the conventional and the geothermal operation.

5. Consider the effect of investment tax credit, depreciation and depletion allowance where applicable.

To illustrate the steps, this chapter briefly presents a hypothetical example of direct-use geothermal energy, modeled after an actual case. The cost estimates used here are for Klamath Falls, Oregon, in terms of 1979 dollars. For our hypothesis, we will assume that a city is located near a Known Geothermal Resource Area (KGRA) and wishes to develop a geothermal district-heating system for a ten-block business district.

Step One: Collection of Historical Fuel-Use Data

The first step is to examine the records of fuel consumption for the past three to five years and develop a history of the consumption and its costs. The search should examine monthly fuel bills to determine the type and amount of fuel used. The search should also state the type of heating system used in each building scheduled for geothermal heat.

Our case study assumes that the entire district slated for geothermal conversion now uses natural gas and $247,100 is now being paid each year to heat the district. The city plans to finance the geothermal project with an 8% municipal bond maturing in 20 years. Money lenders use the "capital recovery factor" to calculate the amount of yearly or monthly payments required to pay off a loan. Using this formula, we find that the city can invest $2,426,064 to avoid paying heating bills of $247,100 per year for the next 20 years. (This, of course, assumes the heating bill remains constant over the 20 years.)

The yearly costs for operation and maintenance of the geothermal system must be included in this calculation. If these costs were $10,000 a year and were subtracted from the present costs, the maximum amount that the city can invest becomes $2,327,883--less than originally planned.

This cursory examination could be taken to show that the project is not feasible economically. However, at this point we begin to see the value of a thorough analysis. Before a final decision is made, a more detailed study, using the rate of inflation for conventional energy, can markedly change the economic feasibility.

Step Two: Determination of Inflation Rates

To project inflation rates reasonably, we must review the historical data of the consumption and costs of conventional fuel. The rate paid by the city in 1976 has doubled in 1979. Therefore, we must consider this rapid escalation of the price of natural gas. By formula, we arrive at an annual inflation rate of 26% for these three years. It would be dangerous to assume that this rate of inflation, based on a three-year study, would continue for the next 20 years. An obvious danger is that exaggerated inflation rates would cause a project to appear feasible when, with lower rates of inflation, it is not feasible. Therefore, our example will use conservative inflation rates in determining the economic feasibility of the project. Based on conservative rates for conventional fuel furnished by the Oregon Department of Energy, and assuming an economic inflation rate of 7% per year, the inflation rate for natural gas would be 12.2% but would drop to 8.5% in 1987. With this rate, the 20-year costs of natural gas would be much higher. This change would increase the amount the city could afford to invest from $2,426,064 to $6,354,917, a dramatic increase. Such an increase could alter the decision about feasibility of the project. In the light of rapidly rising fuel costs, a project originally not considered economically feasible is now regarded as feasible.

Step Three: Estimate of Geothermal Costs

At this point, we must consider the costs of developing the geothermal resource and of the distribution system. A reputable consulting firm experienced in geothermal engineering should be asked to provide the design of the system and the cost estimates. Such a firm provided the data used here. The design included production wells, a primary pipeline to carry the main supply of geothermal energy, a centralized heat-exchanger system, another secondary pipeline to distribute the heat, an injection well, and a primary and secondary pumping system.

In the design, particular attention was paid to the coldest months of the year to determine the peak loads. A number of factors are used to verify the peak load. In heating systems using fossil fuel, an overdesign of 25% to handle the peak periods is quite common.

The peak load for the ten-block district is estimated to be 27.8×10^6 Btu's per hour. With an assumed well temperature of 200°F, the heating system will be designed to extract 40°F from the water pumped from the resource. This amount would require 1390 gallons per minute flow. To satisfy the peak load, three production wells would be required, each delivering up to 500 gallons per minute through an 8-inch primary transmission pipeline.

In many projects, it is not economical to design a system to satisfy the peak load if that load occurs infrequently. When adapting a geothermal system to an existing conventional system, the engineers often find it more economical to design the geothermal system to handle the major portion of the heat load and use a centralized, conventional fuel-fired boiler to make up the difference needed for the peak periods. Conventional fuels that can be stored, such as coal or heating oil, are desirable. These fuels could be stored and then used during the coldest period of the year. Such decisions are obvious when we realize that fuels such as natural gas or electricity cannot be stored and consequently would be in short supply when needed during the peak periods.

Our investigation shows that the heating district will require drilling three 1000-foot production wells drilled at a total cost of $116,694. The third well is needed because the peak period would require 80% production from the third well and because the city plans to expand the 10-block area to 54 blocks.

Wells drilled in the Klamath Basin call for either cable-tool or rotary rigs. Both types can drill through the "soft" and "hard" rock common to the area. Casing costs can be estimated at $1.05 per inch of diameter per foot of depth. Each well would be cased to the full depth. The cost for drilling and casing one 1000-foot well would be approximately $39,898. Any unusual circumstances could, of course, add to the cost.

Once the wells are drilled and cased, production well pumps are needed to supply fluid to the heat-exchanger building. This building will contain two plate-type heat exchangers, the control system and two circulation pumps. For the production well-head pumps, vertical turbine pumps with variable speed drive were selected because of their higher efficiency and lower maintenance costs. Each pump would cost $41,488. (In areas where the water in the resource is more corrosive, the costs of pumps and their maintenance will greatly exceed the costs cited here.) Vertical turbine pumps with variable-speed fluid drive have been used successfully at Oregon Institute of Technology and at the Merle West Medical Center in Klamath Falls. They are capable of maintaining a constant pressure in the supply lines under all conditions. Maintenance costs are minimal.

After investigating the types of circulating pumps, a vertical turbine pump was chosen again. Although more expensive, the pump's shaft packing life is much higher, and since the packing is constantly under positive internal pressure, it is nearly impossible for air to enter the closed-loop system. Air in the system increases the effects of corrosion. The system would need two such pumps.

Heat exchangers are also needed. The two plate-type heat exchangers were selected because of their high efficiency, small space requirements and ease of being cleaned. The exchangers can operate at the minimum flows required for domestic water heating during the summer months. As the district is expanded, they can also accept additional plates to handle increased loads while maintaining inlet and outlet temperature. Two are needed, at $14,000 each.

The primary pipeline for the system is to be 8-inch insulated steel, schedule 40, 4060 feet in length, placed in a 42-inch by 30-inch covered concrete tunnel. Estimated cost: $506,175. This figure includes cost of the pipe, expansion joints, fittings, pipe guides, excavation, bedding placement and backfill, a highway crossing, a railroad undercrossing and six precast expansion vaults.

Pipe made of Fiberglas, reinforced plastic, asbestos cement or steel is available. The pipe could be placed in concrete tunnels or buried directly. Although steel pipe in a concrete trough has the highest initial cost, it also has a life span nearly twice that of any other piping system. A major consideration in the selection of pipe for our model was the fact that both primary and secondary lines will be run in congested areas. Pipelines laid in tunnels beneath sidewalks will provide not only easy access, but as an added benefit, the heat will also melt snow.

The concrete tunnels for the primary line will be oversized to allow for planned expansion. Oversizing raises the initial cost, but it is much more economical than trenching, tunnel placement and backfill at a future date. An interesting note is that nearly all installed geothermal space-heating systems have provided for future expansion.

One other well will be drilled, an 800-foot injection well, at a cost of $30,000.

A summary of the total cost of the entire system appears below.

TABLE 1

Total cost summary

Item	Cost
A. Wells and Well Head Equipment:	
1. Production well (3) @ $38,898	$ 116,694
2. Production well pumps (3) @ $41,988	125,964
3. Well head buildings (3) @ $3,500	10,500
4. Power hook-up in buildings (3) @ $500	1,500
Subtotal	$ 254,658
B. Distribution Piping Network:	
5. Primary supply pipeline (8" steel in concrete tunnel)	506,175
6. Secondary supply pipeline (8" & 6" steel in concrete tunnel, 3" steel buried)	637,060
Subtotal	$1,143,235
C. Heat Exchanger Building:	
7. Plate heat exchangers (2) @ $14,000	$ 28,000
8. Control System, wiring, etc. (basic)	44,537
9. Circulation pump (2) @ $13,691	27,382
10. Expansion/surge tank	5,000
11. Building, including installation of equipment	90,000
12. Injection well (includes building)	33,500
13. Injection well pump	2,587
Subtotal	$231,006
Total Equipment and Installation Costs	$1,628,899
D. Overhead Costs:	
Engineering @ 10%	162,890
Contingency (inflation @ 5% for 6 mos)	81,445
Total Cost	$1,873,234

Step Four: Estimating Operating and Maintenance Costs

To complete the total cost for this project, we have one important step: project annual costs for the operation and maintenance of the geothermal system. Operating costs include the costs of electrical power to operate the pumps and wages for personnel operating and maintaining the system. However, for this model, we will omit labor costs because we can assume them to be the same as for maintaining the existing system. Electrical costs for operating the proposed system are estimated to be $11,044 annually. Projected over 20 years at electrical inflation rates, the cost is $60,781.74.

Maintenance must include a planned program of inspections, lubrications, periodic parts replacements and equipment overhaul. The annual cost of

$8,547 would be $33,074.19 in a 20-year period. The total over a period of 20 years would be $1,993,283.71 for both operating and maintaining the system.

A quick summary of these costs shows the value of converting the district to geothermal energy.

TABLE 2

20-year cash flow of the Klamath Falls Project

Year	Natural Gas Annual Cost 247,100	Geothermal Electrical Annual Cost 11,044	Geothermal Operation & Maintenance Annual Cost 8,547	Annual Savings	Present Worth 8%
1	277,246	12,093	9,145	256,008	237,044
2	311,070	13,242	9,785	288,043	246,950
3	349,021	14,500	10,470	324,050	257,242
4	391,601	15,878	11,203	364,520	267,933
5	439,377	17,386	11,988	410,003	279,041
6	492,981	19,038	12,827	461,116	290,582
7	553,124	20,846	13,725	518,554	302,571
8	600,140	22,635	14,685	562,820	304,074
9	651,152	24,577	15,713	610,862	305,583
10	706,500	26,685	16,813	663,001	307,098
11	766,552	28,975	17,990	719,587	308,618
12	831,709	31,461	19,249	780,998	310,145
13	902,404	34,161	20,597	847,647	311,678
14	979,109	37,091	22,039	919,978	313,217
15	1,062,333	40,274	23,581	998,478	314,762
16	1,152,631	43,729	25,232	1,083,670	316,313
17	1,250,605	47,481	26,998	1,176,125	317,870
18	1,356,906	51,555	28,888	1,276,463	319,434
19	1,472,243	55,979	30,910	1,385,354	321,003
20	1,597,384	60,782	33,074	1,503,528	322,579
			Total	15,150,805	5,953,737

The cost of the proposed geothermal system is $1,873,234. The conclusion is that the city could afford to spend $5,953,737 today to avoid the projected cost of natural gas for the next 20 years.

While essentially fictitious, this cost analysis is based on actual examples and is drawn from experience. It has been presented to illustrate the necessity of studying carefully all aspects of the cash flows in a proposed system and of comparing them to cash flows of an existing system. The decision to drill or not to drill must be based on all the available information. A precise cost analysis will provide information frequently overlooked. Time spent gathering and analyzing data can lead to solid, confident decisions.

So far, the discussion has been aimed at a nonprofit, nontaxable entity having to make decisions about geothermal energy. If a profit-making corporation were involved, other factors would apply. Obviously, there would have to be an economic incentive for a district to convert from natural gas to geothermal energy. It is doubtful that a corporation could charge the district the price of natural gas, allow this price to increase annually at the inflation rate of natural gas, and persuade users within the district to convert to geothermal energy. On the other hand, a corporation must charge a price that will cover its operating costs and provide an acceptable after-tax return on its investment. There are many methods of depreciation and treatments of intangible costs. However, there are limits placed on these various methods. The biggest factor is that the corporation must first make a profit and then owe taxes in order to reap the tax benefits.

By considering the options offered through tax credits, depletion allowance and depreciations, a corporation that requires an after-tax return of less than 15.5% on its investment could go ahead on a project of the dimensions of the hypothetical model.

This analysis indicates that a careful study of economics and tax laws is as vital in the preliminary planning for a geothermal project as a careful study of engineering and geology. A decision to use geothermal energy should be made only after all the factors have been examined.

Pricing Considerations

One point that may be emerging in this discussion is that while geothermal energy is available and is a natural resource, it is not free (unless one has a use located on top of a free-flowing supply) nor is it cheap. The price of geothermal energy is related to the cost of developing the resource and delivering the energy to the user.

Many direct-use geothermal systems supply energy at a fraction of the cost of conventional fuels. Experience shows, however, that other factors must be considered. The efficiency of the system, the daily hours of energy use, the distance the energy is to be transported, the drilling costs and costs of investment money significantly influence the cost of geothermal energy. Some other factors (water quality, site location and pumping depth) that influence cost have been discussed in other chapters. As technology improves, the effects of these factors will probably diminish.

There is no magic formula for pricing direct-use geothermal energy. Experience has shown that each application must be judged on its site-specific characteristics and evaluated accordingly. Some guidelines can be made to insure a positive benefit to the user of geothermal energy. First, resources at shallow depths that have flow rates and temperatures compatible to the needs of the user should be developed. Water that has few corrosive elements is desirable for keeping the costs down. Second, distances between the production well and the user should be kept to an absolute minimum; in short, short pipelines. Third, users must operate at least 25% of the time --50% is more desirable--if the cost is to be competitive with the cost of other forms of energy. Finally, the developer must obtain low-interest loans and be willing to reduce the short-run rate of return on the investment in order to reap the long-term benefits.

When the landowner and the developer are separate entities, the question of resource royalties (cost of the heat paid to the owner of the resource) arises. The amount of royalties charged should be determined for each site and application. The owner and the developer would do well to share the profits resulting from the use of geothermal energy. Because the return on investment capital is much lower for direct-use geothermal than for oil or gas, it would be inadvisable to determine royalties in the same manner as they are determined for fossil fuels. A royalty based on 10% of gross energy sales could easily be so costly as to make the geothermal project uneconomical. Production costs for direct-use geothermal energy vary greatly from site to site. The supply and demand for each application must be dedicated to each other. For these reasons, geothermal energy is unique and deserves unique consideration.

GEOTHERMAL AND TAXES

Taxes are likely to generate heated discussions in any context. However, to reduce the tendency to generalize, in this country we have 51 different tax systems: one federal and 50 state. State corporate and personal income-tax structures may or may not parallel the federal corporate and personal income-tax structure although generally the states have followed the federal government in constructing their tax systems.

Taxes for geothermal energy are relatively new. In the post-Proposition 13 mood of the electorate, it is not yet clear that the states will adopt tax incentives for geothermal resources. Moreover, the geothermal tax incentives adopted as part of the 1978 Energy Tax Act are new and there is uncertainty about their application, which will not be alleviated until the IRS issues its Treasury Regulations for these new Internal Revenue Code (IRC) sections. Until then, it is safe to assume that the IRS will follow the Treasury regulations and court cases that apply to the gas and oil industry.

The Federal Tax System

Before the Energy Tax Act of 1978 was passed, federal tax treatment of geothermal resources was based mainly on court decisions rather than on laws. One influential decision was made by the 9th Circuit Court of Appeals in 1969. It held that the intangible drilling deduction and percentage depletion allowance could be applied to geothermal drilling at The Geysers and defined geothermal steam as a "gas."

In 1975, the Code was revised to provide a 22% percentage depletion allowance for any geothermal deposit (in the U.S. or a U.S. possession) determined to be a gas. The IRS refused to accept either the court decisions or the new Code provision. It contested both the intangible drilling deduction and depletion allowance on activities and income from The Geysers.

The refusal of the IRS to compromise or change its position added to the murkiness of the distinction between hot water and steam. One was given certain tax benefits; the other was not. Not knowing exactly where the difference lies has caused a number of problems in the tax picture.

The Energy tax Act of 1978 eliminated most of the uncertainties of the tax treatment of geothermal exploration and development. The new provisions can be used to promote capital investment and to generate tax savings for the investor which reduce his risk of investment. Additionally, the act defines geothermal deposits to include all the various forms of geothermal energy, whether it be dry steam, hot water or dry hot rocks. For tax purposes, the Act covers three basic subjects: intangible drilling costs, depletion allowance and tax credits.

Deductible development costs. One provision of the Energy Tax Act gives a taxpayer the choice of deducting intangible drilling costs by calling them expenses. These costs include wages, fuel, repairs, hauling and supplies necessary for drilling the wells and preparing them for production. For tax purposes, the Act divides the costs into equipment costs and intangible drilling costs. Equipment costs must be capitalized and recovered through depletion or depreciation. On the other hand, intangible drilling costs may either be considered expenses or be capitalized. If considered expenses, the costs may be deducted in the year that they were spent. This choice provides an incentive in that the costs are depreciated rapidly. On the other side of the ledger, costs listed to be capitalized can be deducted over a period of time as depreciation or depletion.

The taxpayer must decide in the first taxable year which method to use. That choice then applies for all future years. However, if a well is dry or nonproductive, the taxpayer may reverse the original decision. The choice to deduct intangible costs immediately or deduct them over a period of time will depend on overall financial advantages.

Choosing rapid deduction does have its limitations. A noncorporate taxpayer, A Subchapter S corporation, or a personal holding company may be subject to a minimum tax, a limitation of the deduction or a recapturing of intangible deductions if the property is sold at a profit.

Percentage depletion. The second subject in the Energy Tax Act of interest to geothermal developers is percentage depletion. The code provides two methods for computing a depletion allowance: cost depletion and percentage depletion. Cost depletion allows a taxpayer to deduct the costs in the property in relation to the income gained from sale of minerals from the property. On the other hand, percentage depletion allows the taxpayer to deduct specified percentages of the gross income received from production. This deduction cannot exceed 50% of the net income from the property. A taxpayer must compute depletion by both methods and then claim the larger deduction.

The Act grants a percentage depletion for geothermal that is more favorable than that allowed for gas and oil. It is not limited to a specified amount of production, to 65% of taxable income or restricted to independent producers.

Tax Credits

The Energy Tax Act provides a nonrefundable residential tax credit for equipment which utilizes geothermal energy for heating, cooling or domestic hot water. The equipment must be installed in the taxpayer's principal residence in the United States, must be new, meet certain standards, and must be expected to remain in production for five years. The maximum credit is $1100. This credit may be carried over to future years for equipment purchased between April 21, 1977 and December 31, 1985.

A business investment tax credit of 10%, in addition to the normal 10% investment tax credit, is available for geothermal equipment which qualifies as either "alternative energy property" or "specially defined energy property." Public utilities can use the credit for "specially defined energy property."

The business energy credit is limited to 100% of tax liability except for solar- or wind-energy property on which the credit is refundable. Until the IRS issues its regulations on this new section, no one knows for sure which equipment qualifies.

State Tax Systems

Of the states having known geothermal resources, Nevada, Texas, Washington and Wyoming have no state personal or corporate income tax.

Alaska, Colorado, Hawaii, Idaho, Montana and New Mexico apply their income tax levies to adjusted gross income calculated for federal income tax. Five states have an independently determined income tax: Arizona, California, Louisiana, Oregon and Utah. These differences from the federal law are largely due to the state provisions concerning percentage depletion for industries which extract resources.

To illustrate the complexity of the state tax picture, we can consider some of the taxes in two states, California and Arizona. California has a franchise tax (a tax for the privilege of exercising a corporate franchise within the state); Arizona does not. California has a depletion allowance of 22% for gas and oil with limitations that apply only after the total accumulated depletion allowed exceeds the adjusted cost of the property. Arizona specifically provides a depletion allowance of 27-1/2% and depreciation in computing new income. For gas and oil, California provides for intangible drilling costs, but not for exploration. It does not specifically allow for geothermal exploration, development or depreciation. In practice it does allow the percentage depletion and deductions of intangible drilling costs for companies at The Geysers. Arizona allows up to $75,000 as a deduction for exploration.

When these taxes are considered in addition to those of the federal system, it is easy to conclude that a good person to have on the geothermal development team would be someone well versed in taxes.

Chapter 6

FINANCING DIRECT-USE PROJECTS

The successful completion of any direct-use geothermal project depends on arranging the financing. A major reason for the failure of new businesses is poor financial planning and inadequate capital. Therefore, the geothermal developer must evaluate his project from several points of view. He must identify the project risk factors because the financial characteristics and possibilities will be determined by them as well as by the intended utilization and the development program itself. Obviously, the project with a high risk will require a capital structure different from that of a low-risk project.

The developer must demonstrate to prospective lenders and investors that the project is well managed, technically sound and has economic potential. Financial sources will want to know whether the project will depend solely on the continued use of geothermal or whether retrofitting to conventional energy sources could be possible should the resource fail. Technical information they will want to know includes well-production rates, fluid quality, equipment life and marketability of the product.

The developer should consult experts in each area to obtain accurate and reliable information. To insure coordination of the financing aspects and the plan's overall development, the developers, financial personnel or consultants should be part of the earliest project planning and evaluation phases. Such integration will accelerate the financing of the project by providing the appropriate information necessary for the project's evaluation by investors and lenders. Also, tax and corporate attorneys are essential members for a project analysis and presentation team because of their expertise with respect to tax considerations and legal structuring. If outside experts are being considered, their credentials and capacity to perform should be evaluated before they are involved in the project. They should be paid only for services rendered.

Project Definition

In approaching the financing of a project, the developer must understand the business characteristics of the industry in question so he can avoid trying to finance one kind of business on the format of another.

The structure for capital varies with the type of business: industrial, agricultural or utility. Generally, agricultural businesses require the least capital, utilities the most; industrial projects fall somewhere in between. The direct use of geothermal resources represents an innovation in agribusiness projects because more capitalized equipment is generally necessary, but there is also an offsetting reduction in non-depreciable land investment. Because of these variations, it is important to know what institutions expect in financial structuring for different businesses.

Start-up businesses. These ventures represent the most difficult financing challenge, especially if the total investment of the project is such that outside investors have to be brought in. Basically, a new company faces many unknowns and variables. Investors will want to know if the industry will continue to grow and prosper for the time it takes them to earn a satisfactory return on their investment. Naturally, they will want an experienced management team and will expect the technological, resource, environmental and regulatory risks to be defined. As a result of the variables and unknowns, equity requirements and rate of return requirements may be significantly higher than for an ongoing business.

Ongoing businesses. Established businesses fall into two categories: new facilities and retrofits. Expansion of the existing business by means of a geothermally powered addition may be an attractive investment for a company dependent on high-priced energy alternatives. Financing such an addition may depend solely on the parent company's credit rating and past performance. If the existing facilities are competitive in the use of conventional fuels, they may be retrofitted if the geothermal resource fails. For both of these types of projects, financial participants will rely on the company's past performance and financial strength as well as the economic feasibility of the project.

Converting an entire facility to geothermal may be desirable because of cost-saving aspects or because an energy pinch could curtail conventional energy supplies. Voluntary retrofit would most likely be financed on a basis similar to the expansion described above. On the other hand, involuntary conversion may place disruptive financial pressures on the business. The need to convert may require a choice between discontinuing the operation at the site or writing off the existing facilities and installing geothermal ones. Additional factors in such evaluations are the company's ability to fund a significant part of the project internally, its present credit rating and its prospects for future growth.

Definition and Assessment of Financing Risks

Workable projects have been denied financing due to a lack of information or to a poor risk-management program. Therefore, the developer of any new project must educate prospective financial participants in every phase of the business, answering every question. A project based on a geothermal energy supply adds one more dimension to the risk of a project and therefore to the task of educating lenders. The financing participant will want to know about the geothermal resource, its availability, the feasibility of its use and its economic competitiveness with conventional fuels.

The geothermal developer must be familiar with the historical performance (flow and draw-down rates) and temperatures of the reservoir. He should also be familiar with pumping requirements and with such potential problems as scaling and corrosion and the methods to overcome them. If such an operating history is not available, he should present examples of other successfully developed resources having comparable temperature, pressure and salinity.

In addition, the developer should explain fully the proposed technology and specify if it has a long history of commercial use or is basically an unproven approach. The risks associated with the operation of the plant are as important as those associated with the performance of the resource.

Potential financial participants will also want to study the market potential for the output of the project, the operating costs and the cost benefits to be realized if a geothermal energy source is used. An evaluation of the back-up fuels available to the project helps the financiers assess the fuel supply risk.

Another area vital to the prospective investor is the track record of the project management. This aspect determines the success of any business endeavor. The points that should be presented are the background, qualifications and related business experience of the key principals. Their commitment to the project will be evident either by their own investment in the project, the employment contracts they may have, or their status as talented "free agents."

Finally, the structure of the business can also make a difference in appraising the various financial options. The choice of structure (partnership, limited partnership, corporation, etc.) will depend on the financial requirements of the major equity investors. Tax and legal experts can provide advice on whether the assets need the protection of a corporate structure, for example, or if the investors would prefer the greater flexibility of a partnership.

Sources of Financing

Because proposals to develop geothermal resources involve the use of an alternative energy source, financing is available not only from the private sector but also the public sector. In the private sector, financing can generally be obtained from various debt and equity sources. In the public sector, funds may come from debt, guarantees or outright grants.

The private sector has a variety of institutions whose financing capabilities include geothermal development. Banks are the most commonly known institutions. Commercial banks are generally the most conservative lending institutions because of certain constraints. A major constraint is that they cannot lend more than 10% of their total capital base to a single customer. This constraint could limit the size of a loan, but banks can participate in a project with other banks. This participation spreads the risks of the project. For any type of business transaction, a developer should approach a full-service bank in order to have a wider range of financing choices. The lending officer will explain any financial requirements. Start-up projects are extremely hard to finance from this source without adequate financial guarantees.

A second type of bank, the savings bank, invests primarily in modest-sized local residential mortgages. Savings banks are generally smaller in size and more local in nature than savings and loan associations.

Savings and loan associations (S&L) lend primarily on residential and commercial property in the form of real estate loans secured by land and buildings. A S&L might be approached for the mortgage financing of a proposed geothermal facility as well as for retrofit to geothermal space heating or air conditioning of existing structures. This type of project fits well in the S&L portfolio since they will lend for periods up to thirty years. Mortgage rates charged by S&L's are usually higher than those of other institutions, partly because they pay higher interest rates on savings accounts. If the loan is financed at a high rate of interest, it should be structured to allow paying it off and refinancing at a lower rate at a more favorable moment in the money market. The local S&L lending officer can answer inquiries about financing. The S&L will not likely be willing to take on any project risk, however.

Another institution that makes both mortgage and business loans is the insurance company. Its investments are long-term (ten to twenty-five years), but its fixed rates are higher than mortgage rates since the company accepts higher levels of risk. An insurance company can be approached by a commercial bank, a mortgage banker or an investment broker. Again, projects without a track record will be difficult to finance from this source.

Similar to the lending period (up to thirty years) of insurance companies are those offered by trust and pension funds. Such funds have been known to take greater risks than any of the lenders previously discussed. They lend at relatively high fixed rates of interest; however, recent rulings on the liability of fiduciaries have made all money managers more cautious. Usually, other financial institutions transmit or handle requests for these organizations.

Commercial finance companies specialize in lending to high-risk commercial customers through a wide range of short- and long-term debt arrangements. The interest rates charged by commercial finance companies are higher than those of most other lenders and are as varied as those of commercial banks, but their overall lending capacity is much smaller.

The most flexible of all lending institutions, the personal finance company, charges the highest rate of interest but usually limits the loans to $25,000. The loan is made personally to the developer for use in his business and depends on his credit rating. For a small business without an established credit rating, this institution may be the only means of obtaining a loan.

The mortgage banker usually acts as a broker, packaging a deal and selling it to a large investor for a fee; sometimes he makes the investment himself. Occasionally, he refinances first mortgages on projects with an existing equity investment and where the security is a subordinated interest in the asset. Refinancing the first mortgage may be a source of operating funds if it takes place when interest rates have decreased since the original loan was granted.

Investment banks, while not a source of funds, are a vehicle for obtaining funds. In general, investment bankers perform three basic functions: (1) financial counseling, (2) underwriting and (3) marketing and distributing corporate securities. The first and third functions are pertinent to the entrepreneur of geothermal business. Investment bankers come in contact daily with investors, and, for a fee, provide first-hand information on the availability of funds.

Another group of investors, equity investors, provide "at-risk" capital through purchasing common or preferred stock in the company or by lending money. Equity investors prefer to control the operation, at least in the initial phases, since they bear the greatest risk. Of course, they anticipate that the stock acquired will increase in value in addition to earning dividends. One of the requirements an equity investor may have in mind is to obtain the use of the tax benefits available to a start-up project. Depending on the structure of the investment, an investor could recover a significant portion of his investment through tax benefits alone. It is imperative that tax counsel advise on such matters. Investment banking houses can help identify equity investors; however, to date, only one investment banker specializes exclusively in geothermal activities.

Small business investment companies (SBIC) represent a special class of equity investors and lenders. SBIC's generally are privately owned investment companies which provide financing to small businesses that meet the special criteria of the government's Small Business Administration (SBA). The SBA licenses them and gives them incentives to specialize in investments such as low-cost loans to supplement their capitalization requirements. Most financing from an SBIC is supplied through the purchase of stock or "convertible debentures" (loans which can be converted to stock at a later date). The local office of the SBA can provide the needed information.

The final source for private-sector financing is the leasing company. In lease financing, another party owns, finances and leases the project's assets to the users. A financial lease is a non-cancellable contract committing the lessee to a series of payments to a lessor for the use of the asset. The lease period generally corresponds to 80% of the economic life of an asset, and the total payments the lessee agrees to will exceed the purchase price of the asset. This arrangement offers the advantages of flexibility, 100% financing of the assets and tax deductibility of the lease payment. One disadvantage is that the residual or terminal value goes to the lessor at the end of the lease period. Another disadvantage is that the interest cost is usually higher than the interest cost of debt when the amortization of the asset's cost and the tax benefits are taken into consideration. Many large financial institutions offer leasing services.

Public Sector Financing

Federal, state and local government agencies offer a variety of financing programs to private individuals and developers for energy projects. These agencies prefer projects which can visibly benefit society, such as projects which replace scarce fossil fuels or those which attract new business and jobs to an area. Such projects can help the agencies attain their chartered goals and can benefit society.

The U.S. Department of Energy (DOE) has two programs designed specifically for geothermal use: the Direct-Use Program and the Geothermal Loan Guaranty Program. Other agencies have aid programs that are tailored to conventional business and agricultural operations. Their considerations of geothermal projects will vary from case to case. Essentially, no geothermal-related precedents for financing have been established so that an approach to many of the agencies is likely to be one of the initial ones. The applicant will have to become aware of the proper presentation of the requirements and procedures.

It is possible to combine two or more public programs and finance different portions of a geothermal project. For example, the Geothermal Loan Guaranty Program (GLGP) could fund the resource portion and the Farmers Home Administration (FmHA) could fund the land and buildings. However, before such a step is taken, it is advisable to check first with the Department of Energy to determine the relationship between its financing programs and one's project needs. The next step is to ask the Department of Energy, the state or local Chamber of Commerce about complimentary agency programs that might be available. Local agencies will often provide funds for small projects, but they have neither the mandate nor the funds to assist in larger projects.

Before developers decide to apply to government agencies, they should be aware of several important characteristics of doing business in the public financing sector with government agencies. Knowing these characteristics may prevent some delays in securing funds for a project:

1. Some public agencies give assistance only after all private lending sources have been approached. Returning to private lenders again and again, as an agency dictates, consumes valuable time.

2. Public lending agencies may need six months to a year (or even longer) for their decision. If the paper work does not conform to agency requirements, more time will be required to develop the appropriate documentation.

3. More than one agency may review the project before it is approved. such agencies as environmental, local government planning agencies, county governments, etc. will need additional time to study the project in terms of their specific concerns.

4. Budgets to government lending agencies can be slashed without notice.

5. Public agencies generally require tight fiscal control and tight audit procedures. Because almost every management decision about expenditures can be questioned, such questioning can interrupt or delay project funding or even implementation.

6. Almost all agencies require that formal equal opportunity employment and other practices be followed.

7. The interpretation of loan criteria in one office may not be the same as that in the next office. People in the same agency have been known to disagree in their interpretations, thereby complicating the proposed transaction.

Although a number of government agencies have funds available for financing projects, the Department of Energy is the only one with programs designed especially for geothermal use. The first program, the Geothermal Loan Guaranty Program (GLGP), will guarantee up to 75% of total allowable project costs to the lender against loss of principal or interest in loans made to the borrower. The program will consider a variety of projects ranging from resource development to construction and operation of facilities. Depending on the project, processing takes between four months and one year. DOE specifies the terms and conditions for its loan guarantees. Projects below $500,000 in size may not receive encouragement.

The agency designed to assist small businesses with counseling, management and funding is the Small Business Administration (SBA) under the Department of Commerce. Its two programs are the Loan Guarantee Program and the Direct Loan Program. Under the Loan Guarantee Program, the SBA will guarantee up to 90% of a bank loan not exceeding $500,000. The participating bank will determine the rates on loans (which generally will be the prevailing rate for similar federal guarantees) and will require a service charge. The Direct Loan Program will lend up to $50,000 directly on low-risk projects. Interest rates are lower on these loans than on those secured from private sources. To qualify for one of these loans, a business must meet SBA requirements and show that funds were not available through normal channels.

Other possible sources for funds are the Farm Credit System (FCS), the Farmers Home Administration (FmHA) and the Economic Development Administration (EDA). Each has features which are distinct since each was designed to supply funds for different purposes.

There are numerous agencies--some smaller, some larger--and programs on all levels that can provide loans, grants and guarantees. The appropriate state Department of Commerce can supply a current list of these agencies. Initial contacts should begin with the local, municipal agencies as well as with Washington. Also one's financial advisor may be able to furnish advice on some of the lesser-known but applicable programs.

Types of Financing

Projects may be financed in a variety of ways, depending on the specific needs of the project. The private sector offers several methods with differing restrictions for financing projects:

1. Secured lending may be available to firms with little or no recorded business experience or whose ability to service debt is regarded as inadequate by bankers. The lender will require a security interest in the collateral of the borrower. Collateral which is sufficiently marketable may include certain buildings, accounts receivable, salable inventory, standard equipment or other assets of the borrower.

2. Project financing provides funds to a project which has a financially strong customer who will guarantee to purchase the output of the project. This plan transfers most of the credit risk to the established customer.

3. Lease financing is a contractural arrangement in which the lessee agrees to pay the owner of certain facilities and/or equipment a fixed fee for its use.

4. Mortgage lending resembles secured lending except that fixed assets, such as buildings and land, will usually secure the loan. The property securing the loan is described in the mortgage or first trust deed, giving the lender first claim to the property if the borrower defaults.

5. Term lending provides funds in return for an agreement obligating the borrower to repay the amount of the loan and the interest in a specified time. A long-term loan extends for more than seven years; an intermediate or medium-term loan is repaid in one to seven years; and a shortterm loan is repaid in less than a year.

6. Working capital lending provides cash for current operating needs and is usually both short-term and unsecured, provided the business has a demonstrated ability to repay. Such loans are considered "self liquidating" because the funds are utilized during periods when the company is "cash-short" and repaid when the company is "cash-rich." The cycle is generally less than a year.

Private Sector Equity Sources

In the private sector, all equity can be designated "risk capital" because it does not warrant a specific return but benefits from the earnings of the business. The private sector provides funds in several ways, each with certain expectations.

Venture capital is equity provided by investors, either singly or in groups, for direct private investment in small start-up companies or in development companies judged to have high potential for growth. In these instances, the risks are expected to be high, but the rewards (share of the profits) are also high. Because the risk is high, venture capitalists will focus on and perhaps participate in the management of the business. In spite of these conditions, the demand for venture capital far exceeds the supply, and venture capitalists have the option of selecting only the most promising projects.

Tax-shelter money, another source of funds, is capital from individuals in high income-tax brackets who are looking for investments to decrease their tax liability. Projects that offer tax benefits such as investment tax credits, depletion and depreciation, which are economically sound and which yield positive cash flow, are prime investment candidates for this group.

A business with a history of earnings may raise capital by selling a specified amount of its ownership, a technique referred to as stock placement. The stock may be sold privately to selected investors who buy substantial amounts, or it can be sold publicly to a number of smaller investors. The typical stockholder does not become as involved in the management as does the venture capitalist.

Finally, funds may be raised through the use of convertible securities, which are either bonds or preferred stock receiving specified return and which can be converted at the option of the holder into common stock. Convertibles carry a lower interest rate than stock without the convertible feature, but their advantage is that they pay interest to the holder immediately and also offer the opportunity to participate in the earnings if the company grows.

The financing of geothermal projects is relatively new; consequently, many sources of funds in the public sector have not created a policy to handle such investments. There are, however, three basic types of programs available. The first is the direct loan, which numerous government programs provide for the financing of agricultural, industrial or residential facilities. There is no provision for the use of these programs for geothermal projects. While each agency differs in its interest rate and conditions attached to its loans, direct loans from an agency may well have lower interest rates and longer terms than those from private sources.

In the second type, a loan guaranty, the government will guarantee up to 90% of a secured bank loan. The Geothermal Loan Guaranty Program guarantees up to 75% of total allowable costs of the project at no more than 1% per annum on the guaranteed loan balance outstanding. Other agency programs may also guarantee a loan up to thirty years in duration, will charge a guarantee fee and will require the bank loan to be secured by assets of the project.

Grants, the third form of financing, may be provided for studies as well as for demonstration projects. Generally, the agency requires the costs to be shared, but the funds, once advanced, need not be repaid.

Although many of the sources of money for geothermal projects will be adaptations of sources designed for other projects, the Intermediary Risk Assuming Company (IRAC) is the first financing vehicle designed specifically to provide capital for geothermal projects. These projects cover reservoir and utilization risks, including both electrical and non-electrical geothermal developments for industrial, space-heating and agribusiness purposes.

Developers can use the IRAC structure when they have identified a potential resource for utilization but cannot afford the financial risks involved in building a plant on a previously undeveloped reservoir. IRAC financing would supply the risk capital to develop required production levels from the reservoir and to finance utilization facilities and would maintain ownership of the development. The developers could agree to let the IRAC manage the operation or could contract to operate and manage the plant themselves. In any event, the developers would agree to purchase the product of the facility. Once the facility was operating and producing, the developers could exercise a pre-arranged option to buy the entire operation. A feature of this financing structure is that it can combine the flexibility of both public and private sector financing options.

These, then, are the sources for financing projects. However, it should be kept in mind that investors believe that the financial participant in a project should be adequately compensated for the risk taken. Persons seeking financing should be aware of all of the aspects involved in borrowing. To secure financing, they should gather all the data available, investigate both the engineering and economic possibilities and then prepare a proposal that will withstand the rigorous examination of prospective financiers. The package should develop the business objective of the project; the overall economic possibilities, including an analysis of the proposed market; the technological process and facilities; the business structure; the capabilities of the management; and all the perceived business risks and available countermeasures associated with the project.

Above all, investors and lenders must be convinced that the entrepreneurs have developed a plan thoughtfully and that the management is skilled and experienced enough in the chosen business to manage effectively, seize opportunities, solve problems and make profits.

Blank

Chapter 7

LEGAL, INSTITUTIONAL AND ENVIRONMENTAL ASPECTS OF DIRECT USES OF GEOTHERMAL ENERGY

By now, the reader realizes that upfront preparation for the development of geothermal energy for direct use is both indispensable and complex. Exploration to identify the resource, determination of the potential of the resource to supply energy, selecting the best use, financing of the project and the construction are vital preliminary steps. There is another area, however, which, if neglected, can cause delays and frustrations. The area of applicable federal, state and local environmental laws, regulations, ordinances and required permits is a critical part of the early planning.

If developers are aware at the very beginning of all the steps for obtaining the required regulatory approvals, they can schedule their project to include time for environmental investigations, personnel to do the work needed to obtain the permits, and the money to pay for this activity.

In general, geothermal projects for direct uses are smaller than those that produce electricity, have no extensive transmission lines, power-generation equipment or cooling facilities. Electrical applications require all of these. Direct use also requires fewer wells per development, shallower depths, lower temperatures and fewer surface-disturbing activities. Thus direct-use applications have less of an environmental impact than electrical applications.

But whatever the use, compliance with laws will be necessary. It is helpful to remember that regulations and laws are enacted to protect the general public as well as the environment. The key to operating successfully within the institutional, environmental and regulatory framework for a project is to identify early in the planning the required permits and potential environmental problems. Such information will allow sufficient time to obtain permits and to develop measures to cope with potential impacts.

In this process, certain steps must be followed. The first occurs after the specific geographic resource area has been identified. The developer must have access to the land and to the resource. At this point the developer may have to deal with two people: the owner of the land and the owner of the mineral rights. The person who owns the land may not own rights to the geothermal or mineral resources. The owner of the mineral estate frequently has the implied right to enter the land and use a part of the surface to develop the subsurface resource. The problems of ownership and access are aspects that must be checked by competent people in law and title practice. Frequently, access problems in geothermal are similar to those in the petroleum industry. Procedures used there can be helpful to the geothermal developer.

In addition to identifying the land and mineral owners, it is necessary to find owners of the water rights. Water rights for development may reside with the state or may be assigned to the surface owner, depending on the particular water laws of the individual state.

Obtaining the rights to the geothermal resource is more complicated than that of, say, coal. The geothermal resource has both water and mineral aspects. Trying to fit this resource into established definitions and categories poses a problem, as discussed in Chapter 5, and the solution is often uncertain. For example, Hawaii classifies the geothermal energy resource as mineral, but Wyoming considers it underground water. Obviously, it would be wise to examine the definitions of both federal and state statutes before starting a development. The wise developer may consider securing all resource rights that might affect the geothermal resources.

Once a resource is identified, the developer must be able to get to it. He may gain access by purchase; however, development rights are more often provided by geothermal lease. Sometimes an owner will permit entry to the land before leasing it so that a developer may conduct exploration activities such as geological mapping, drilling slim holes for obtaining temperature gradients, and heat-flow studies.

Obviously, access is important. Even more important is the need to have all parties involved in the use of the land agree to the lease conditions. Property may be under lease for agricultural or grazing purposes, for example. If so, the developer should obtain the consent of the lessee to avoid charges of trespass or other misunderstandings. A thorough investigation of the ownership and the rights involved becomes essential to a successful operation.

State-owned lands require different procedures. If the geothermal exploration does not disturb the surface, or disturbs the surface only slightly, the state might not require an exploration permit or lease. Some states allow developers to proceed after notifying the State Lands Officer. However, intensive exploration and development require permits and leases.

States differ in their requirements and the manner in which they issue permits and development leases. Some matters worthy of investigation are diligent work requirements, rentals, royalties, acreage limitations, lease terms and renegotiation provisions for leases.

Some states require a pre-lease evaluation of the environment. In this way the state can examine the potential effects of proposed exploration and development. Such an evaluation will delay the issuance of a lease. Furthermore, the state may require the developer to pay for the evaluation. These variations continue to point to the need for early planning.

The U.S. Bureau of Land Management (BLM) is the agency that has the authority to issue permits for access and the right to explore, develop and use geothermal resources on federal lands. The Geothermal Steam Act of 1970 gave this authority to the BLM, but it excluded Indian lands and Department of Defense lands. The BLM provides information about the procedures to follow in its phased operations. These procedures begin with activities that do not disturb the surface and end with full field development and utilization activities. Such procedures require time for study of the requirements and planning the subsequent steps.

Before a lease is issued, surface management agencies like the BLM and the U.S. Forest Service (USFS) will permit supervised, limited operations which are designed to provide a preliminary evaluation of the resource. These operations are allowed under the provisions of a Notice of Intent or another appropriate form. Generally, the environmental effects of such a preliminary evaluation are small and a negative declaration prepared by the issuing agency is usually sufficient. A negative declaration shows that the measures proposed by the developer will more than offset any damage to the environment.

Water Laws

Critical factors in geothermal development are state water-use regulations, existing uses of the water and characteristics of the groundwater. These factors determine the availability of groundwater for geothermal development and the reliability of groundwater geothermal supplies. The regulations also establish legal authority of the developer to transfer geothermal fluids from a well to a particular place of use. Thus, it is important to study state water laws, for they can relate to the production and use of geothermal fluids.

Water rights for development on state and private lands generally will be governed by one of two regulatory systems. Some states consider groundwater a part of the surface estate or land holdings. In such states, the developer will receive the right to produce water at the same time that he receives the rights to develop the surface.

Another concern is the appropriation (or assigning) of groundwater for a particular purpose. Under this system, the developer must determine if a water right of sufficient quantity is available for his project. If a groundwater basin has been set aside previously for other uses, the developer may not be able to produce the necessary geothermal fluids. Sometimes the developer may obtain water rights by buying them or by supplying present users with water from a different source. There are many aspects to water and its use. The complexities require competent people to handle them and advise the developers.

One problem to consider is a change in the existing water appropriation system. Diverting the water from a system to a place where it can be used may cause some problems. Generally, the appropriative rights system provides for diversion. However, in cases of "reasonable use" or riparian systems, the water right is attached to the surface. (The riparian system holds that the landowner has rights to water on or bordering his property, including the right to prevent diverting or misusing upstream water.) Such appropriative rights systems, however, may prevent transporting geothermal fluids away from the producing area.

Another possibility of conflict occurs when the resource is on federal or Indian lands. There, the development right includes fluid production. But the developer must be aware that the state may challenge this right and declare the water a public resource (under state jurisdiction). To avoid conflict and possible litigation, the developer should conform to state requirements, if possible. In addition, a federal geothermal lease permits the developer to produce geothermal fluids, but it does not guarantee a reliable supply. Under the rule of capture, it is possible for an adjacent producer to drain a federal lease, therein lessening the supply of water from the reservoir on federal land. In light of this, it is important that the reliability of the water rights be examined.

Development Regulations

After access to the land and geothermal development rights have been obtained, the developer can begin the next step: preparing for exploration and development. This phase involves getting permits from the agencies that have jurisdiction over the project. The regulatory bodies review the project before they issue the permits. A small project with one to three wells or one that does not require surface occupancy may be reviewed quickly (from ten days to three months). A more complex project may need up to a year for the review to be completed and the permits issued. The amount of time can depend on the elements involved in the procedures and the work load of the agency. In some instances, it is necessary to obtain permits in sequence, a situation demanding careful preparation and organization.

On private and state lands, permits are required to maintain and protect clean air and safe drinking water. They include conditional land-use permits to assure that the use complies with zoning guidelines; drilling permits; solid waste discharge permits; and permits which limit air emissions and water discharge.

Some states require an environmental analysis of the proposed project. Such a document should provide the regulatory body with a detailed description of the project, all the possible impacts and ways to handle them. This document takes time to prepare and more time to review. The preparation and review of an environmental impact document could take more than a year.

Federal Lands

The Geothermal Steam Act of 1970 laid out the provisions for exploring, developing and utilizing geothermal resources on most federal lands. The BLM issues leases and licenses power plants. The U.S. Geological Survey (USGS) supervises the subsurface operations. The USGS Conservation Division Area Geothermal Supervisor issues all necessary exploration and development permits. However, as mentioned earlier, some states may require additional permits which regulate such concerns as emissions to the atmosphere and disposal of liquids. The standards on federal lands are generally the same as those on state lands, but federal agencies enforce the standards on federal lands. In practice, the lessee may wish to comply with local or county regulations because the geothermal operation may affect lands other than the federal lands that he has under lease.

The Area Geothermal Supervisor requires a Plan of Operation for all activities on leased federal lands. The supervisor may require a separate plan for each phase. When we consider that these requirements mean a plan for exploration, one for development, one for plant or facility construction, one for production and injection, we can understand the time needed for their preparation. Sometimes these plans must be submitted in sequenc Other times, they can be submitted in combination. Either way, the tim needed to prepare and the time needed to review each plan can expand a schedule beyond the anticipated date.

Environmental Documents

The National Environmental Policy Act, requires filing of environmental documents for federal projects or projects on federal lands. Depending upon the level of anticipated impact, an environmental assessment (low impact) or an environmental impact statement (significant potential impact) must be prepared. To ease the preparation process, the federal government will prepare most of the documents to fulfill the requirements during the exploration and development phases. One exception may be the clearances from archaeologists for roads, drill sites and areas which will be disturbed. The developer generally employs a professional archaeologist for such an investigation and report. Such cooperation by the government does not release the developer completely. The USGS may ask the developer to provide other environmental data and to revise and add detail to the plans he prepares. Such details in the production of a resource include a description of the environment, covering such items as air, water and noise. The data must provide one year of environmental observations before the plan of production can be approved. For projects that affect the environment in only a small way, the Area Geothermal Supervisor has the authority to waive these requirements and can issue a negative declaration. Because of the complexity of collecting data for an entire year, the developer should consult with the Area Geothermal Supervisor as soon as possible to avoid delays and frustrations. Not surprisingly, the government requires that the applicant pay for the gathering of data.

Another permit is necessary for construction of facilities on federal lands. If the facility is small (one producing well and its attachments), the USGS Area Geothermal Supervisor can issue the permit. For larger project facilities, the USGS will offer technical advice to the BLM, which is the authority in this instance. Fortunately, the placing of facilities on federal lands requires only one basic permit.

Distribution and Use of the Resource

Once provisions have been made for the exploration and development of the resource, other provisions must be made to distribute the energy. Transportation of the geothermal fluid can raise some legal problems. In the private sector, the problems may occur in two situations: (1) If the use is limited to a private citizen who wishes to heat his house from a well on the same property, the only legal problems may be zoning compatible land use. These are fairly minor issues. (2) If the use is larger (for example, a city that wishes to use the resource to heat its public buildings and perhaps the homes of its citizens), the legal problems are more numerous. They may involve the right for the geothermal fluid pipeline to cross property not owned by the city and for access to the property to maintain the pipe. Buying the necessary strips of property outright might be costly. The city may have to use its legal power to acquire the property. Of course, the city must pay the market value of the property.

A more feasible alternative for public and private users is to obtain an easement in which the owner of the property allows the user the right to use that portion of the property. The agreement to use another owner's property becomes quite involved, requiring time and expertise to obtain.

Relationship with Existing Utility Systems

A surprising fact is that use of geothermal heat does not necessarily eliminate the need for gas or electrical service. Geothermal will reduce--sometimes dramatically--the need for these other services, but they are needed for a back-up or standby systems. Accordingly, the user of geothermal energy should know the legal obligations of the utilities. For instance, electrical utilities typically are required to provide service within their service area, but their prices and services may vary, depending upon the class of customers.

To cope with this situation, the user of geothermal energy should recognize that some standby service is necessary. In the early stages of planning the user should secure assurances from the supplier of new or continued standby service and check the costs for this service. The local gas or electrical company can provide answers to questions about the cost and service of supplemental energy.

Obtaining Institutional Information

It would appear that someone interested in developing a geothermal resource faces bureaucratic barriers that are insurmountable. There are, however, many agencies that can and will supply information about the technical and legal aspects of geothermal utilization. Their staffs are usually willing to share information and to recommend procedures for the development of geothermal projects.

Two good places to begin are the state Energy Office and the U.S. Department of Energy (DOE). The DOE has its headquarters in Washington, DC and field offices in Oakland, California; Las Vegas, Nevada; and Idaho Falls, Idaho. There are also regional representatives who can provide information.

For questions concerning the legal or environmental aspects of direct-heat use, federal laboratories (especially Lawrence Berkeley, Jet Propulsion, Battelle and the Idaho National Engineering Laboratories) can supply expert advice.

Two organizations that are easily accessible and that provide information are the Geo-Heat Utilization Center attached to the Oregon Institute of Technology in Klamath Falls, Oregon, and the Geothermal Resources Council in Davis, California. The Geo-Heat Center provides information on planning, obtaining permits, construction, economics and evaluation of resources. The information it provides is practical, derived mostly from hands-on experience.

The Geothermal Resources Council (GRC) is a nonprofit organization dedicated to providing geothermal information. It does this through educational seminars, short courses and special reports. The staff can direct telephone inquiries to the proper sources.

The National Conference of State Legislatures in Denver has published several informative documents which provide excellent summaries of issues and problems in the geothermal field. The documents are most helpful.

Finally, private consultants can provide valuable and expert assistance ranging from preparation of environmental impact reports to engineering and economic feasibility studies. The GRC Registry lists many consultants. Also, those who are already working in geothermal can provide names of consultants for particular purposes.

In summary, the legal, institutional and environmental aspects of geothermal development cannot be taken lightly. They require time, money and experts. Ignoring them in the planning stages can be expensive later, and the time needed to meet some of the obligations cannot be made up. If not included in the planning stage, the time for such studies for developing an environmental impact report can delay a project for a whole year or longer.

Perhaps one of the most valuable assets in a geothermal project is a carefully worked plan for attacking the project.