GEOTHERMAL POWER

The pressure on energy resources has generated new interest in the earth's heat. The emphasis is on exploring for new geothermal areas and developing new ways to extract work from steam and hot water

by Joseph Barnea

An old source of power for man's work has begun to attract new interest. Natural underground reservoirs of steam and hot water are now being tapped on a significant scale, and it will come as a surprise to many people to learn that the harnessing of this geothermal energy has already reached an aggregate capacity of a million kilowatts in plants around the world. At the present rate of development it is likely that by the end of this decade the production of electric power from steam fields will be quadrupled.

The heat of many geothermal reservoirs comes from a large body of molten rock that has been pushed up into the earth's crust from great depths by geologic forces. This dome of magma heats the rocks in the crust near the surface, which in turn heats the water in fissured or porous rocks to a temperature of perhaps 500 degrees Fahrenheit. Being at depths of as much as six miles, the water is under high pressure and is therefore liquid. Where the hot water can escape through a fissure it begins to boil, and part of it flashes off as steam. The geothermal energy can be tapped by a well driven into the fissure or down to the porous layer.

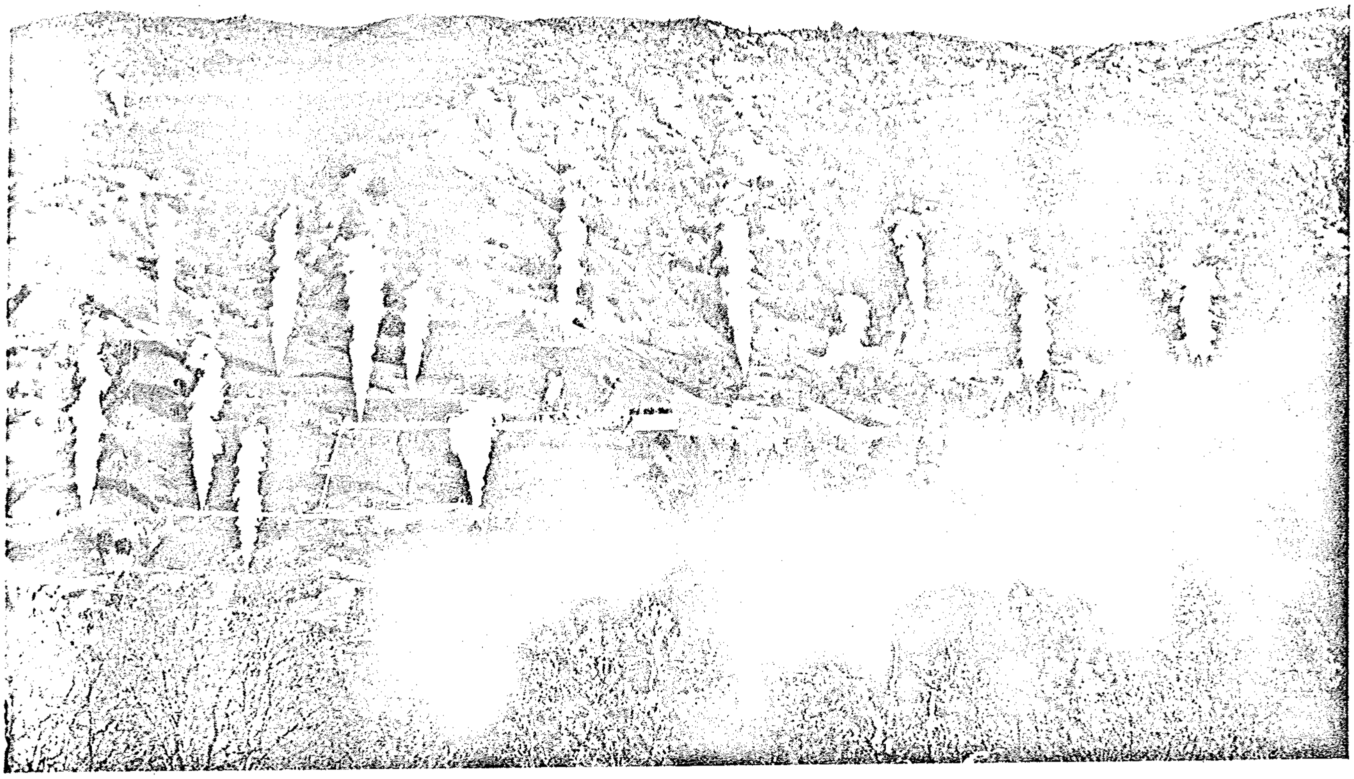
Interest in this source of energy has quickened in the past few years. Recent explorations have revealed that the resource is larger and more extensive than had been supposed. A generation ago the hot springs and steam fields that had long been known in a few localities around the world were believed to be merely local freaks of nature. There is evidence now that reservoirs of steam and hot water are actually widespread in the earth's crust. Signs of their presence have been detected on most of the continents and on a number of islands. It seems possible that such fields will also be found under the seas. Some of the explored fields are known to hold large quantities of energy. A single steam field in northern California, the Geysers field, is estimated to have a potential capacity of three million kilowatts, and surveys that have been made in the Imperial Valley of southern California have indicated a potential of 20 million kilowatts in that area.

The incentive for undertaking a major effort to tap geothermal fields has been heightened by projects showing that in addition to electric power they can yield other useful products. The geothermal steam or hot water can be applied to desalting seawater, to heating houses, greenhouses and swimming pools and to providing nonelectrical energy for refrigeration and air conditioning. Moreover, the hot water itself is a source of extractable minerals and can serve to provide potable water. These additional dividends increase the economic attractiveness of investment for the exploitation of this great earth resource, which up to now has served man mainly as a resort attraction (in the form of health spas) and as a somewhat esoteric and certainly minor source of power supporting small generating plants at a few sites around the globe.

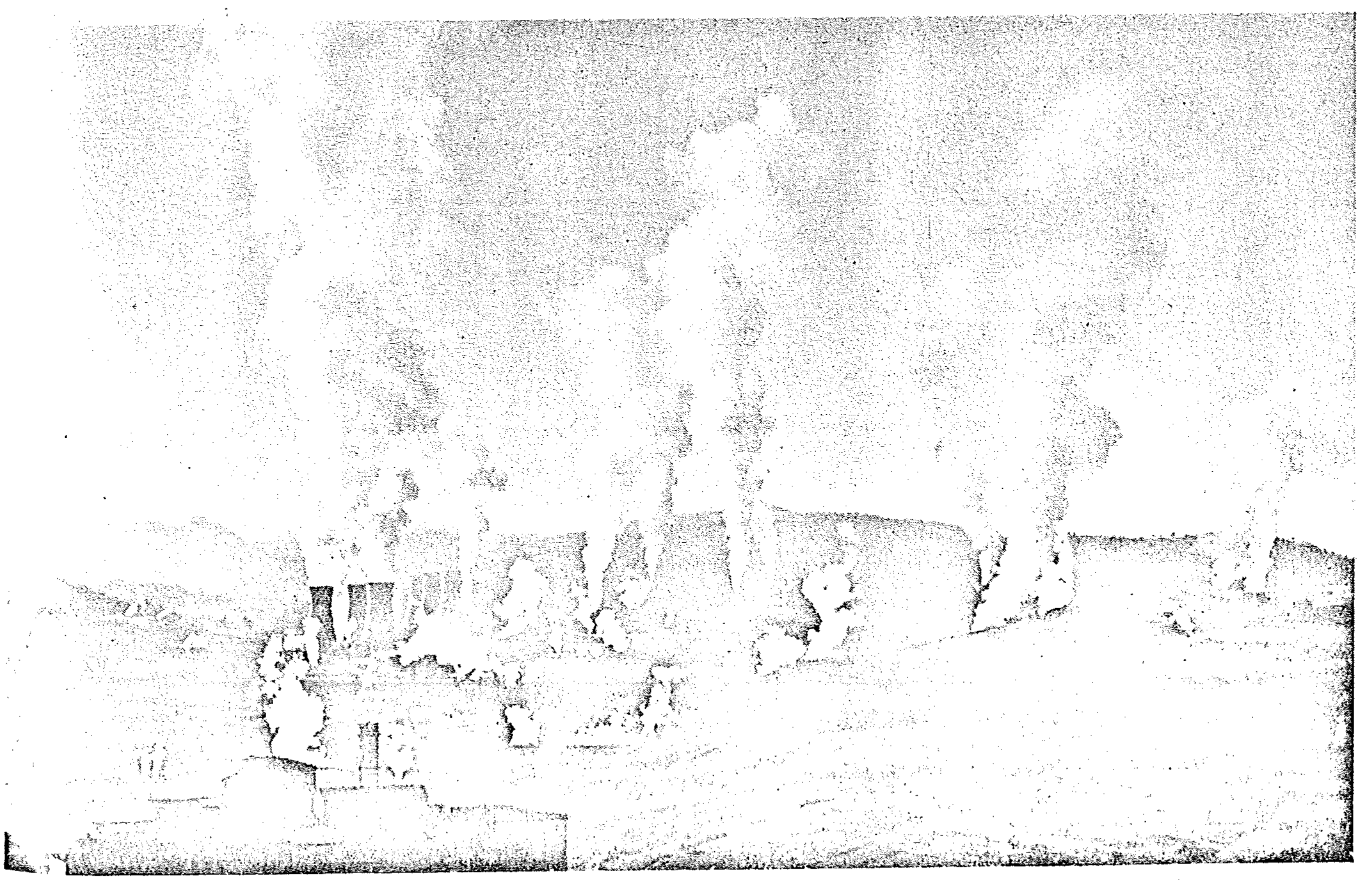
Hot springs, where water from heated strata flows naturally to the surface, have of course been known and used since ancient times. The Romans developed these watering places for medical and recreational purposes all around the Mediterranean and to the outskirts of their empire as far as Bath in the British Isles; there were also medical spas in ancient Japan and elsewhere in the Far East. Hot springs still flourish as health resorts today in Japan, in France and other centers in continental Europe, in Africa and in many other places outside the Anglo-Saxon world.

The realization that the steam in the crust might be tapped for power came at the beginning of this century. In 1904 the first electricity plant so powered was built and plugged into a steam field in northern Italy now known as the Larderello field. Over the following decades there was a slow and tentative growth of interest in geothermal energy. More plants were built on the Larderello field, and other small-scale projects for the use of natural steam or hot water for power, industrial purposes and heating were developed in Japan, Hungary, the U.S.S.R., Iceland, New Zealand and elsewhere. In the U.S. the first geothermal power plant, of 12,500-kilowatt capacity, was commissioned in 1960 on the Geysers field, which is by far the largest field yet discovered in the world.

To those investigators who early recognized the potentialities of geothermal energy the development of this resource has seemed agonizingly slow. There are several reasons why things have not gone more rapidly. Judging from the surface indications (the comparative rarity of hot springs or steam holes) the geothermal energy that might be available appeared to be highly localized and minor in amount. The explorations and the discovery of fields have been limited to those that show surface signs, because little information has been available on geological indications that might signal the presence of hidden fields. In the past such fields could be found only by speculative drilling, and it seemed that the expense of drilling would be justified only for fields located at a shallow depth. The paucity of research and information on the geothermal resources in the crust, the lack of guides for exploration and the shortage of trained specialists and



STEAM WELLS tap geothermal energy for the production of power at a plant operated by the Pacific Gas and Electric Company at The Geysers, about 90 miles north of San Francisco. Since 1960 the company has brought plant capacity at the site to 192,000 kilowatts.



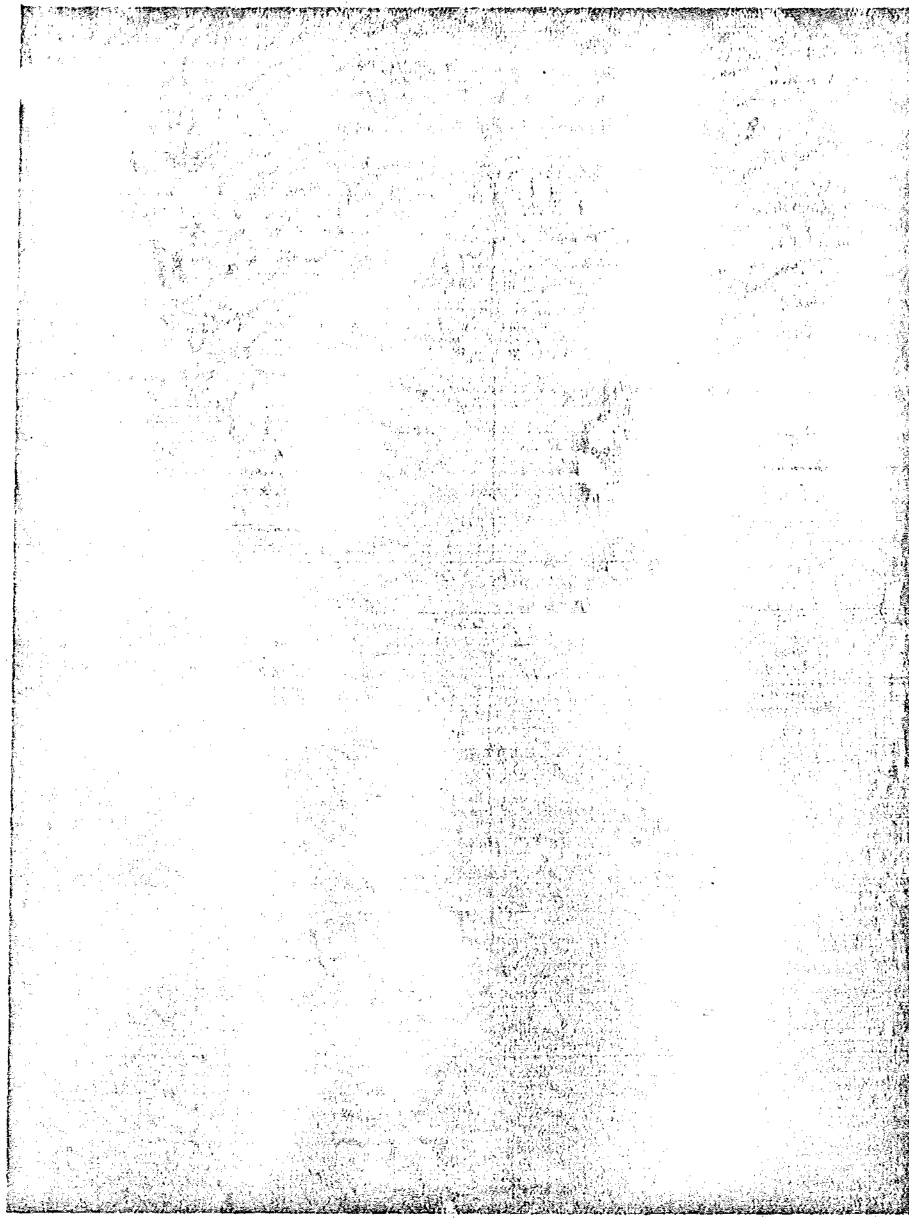
LARDERELLO GEOTHERMAL FIELD in Italy has been used for generating electric power since 1904. It now has a capacity of 380,000 kilowatts. The chimney-like structures at left are hyperbolic cooling towers that are associated with the power plant at the site.

GEOTHERMAL SOURCE associated with a volcanic crater in the Rift Valley in Ethiopia was explored by means of infrared photography in a project carried out by the United Nations. The explorations were made by airplane using black-and-white infrared film, which shows hotter areas as white and cooler areas as progressively darker shades of gray. Promising photographs, such as the one shown here, were processed through a densitometer, which converts the density of the photograph in terms of ground temperature and applies a predetermined color scheme to indicate the differences. In this photograph the hottest areas are orange and the coolest ones are blue. The technique provided the first measurement of the extent of this geothermal source and range of temperatures in area.

technicians in this field have in the past combined to retard progress.

Nevertheless, the enterprise is now moving forward at an accelerating pace. It has been given impetus in the U.S. by the Geothermal Steam Act, adopted by Congress in December, 1970, which establishes the development of U.S. geothermal resources as a national goal. What is now needed is a worldwide expansion of efforts in research, exploration and the training of experts for this work.

The sources of usable geothermal energy in the earth fall into three classes: dry steam fields, wet steam fields and fields of lesser heat content consisting of water at temperatures below the boiling point (at atmospheric pressure). Each type of geothermal energy has its special uses and also capabilities for a variety of applications.



INFRARED VIEW of the steam field at The Geysers was obtained by the U.S. Geological Survey. The aerial photograph was made before dawn in order to minimize the effect of the sun on the temperature of the ground. Light areas at right center are geothermal areas.

The dry steam fields are filled mainly with steam itself, under pressure and at relatively high temperatures. This steam is usable directly for the production of electric power. It can be piped right to the turbine and therefore simplifies the requirements for plant equipment; the investment in plant may be as low as $100 per kilowatt. In order to minimize piping costs the plant must be located close to the steam wells; moreover, since the steam emerges from the field at low pressure and large amounts of steam must be handled, the effective size of the turbines is limited. This means that the plant cannot be very large. The upper limit at present is about 55 megawatts. Power generators of this magnitude, each fed by 10 to 15 steam wells, are now being installed at the Geysers field in California.

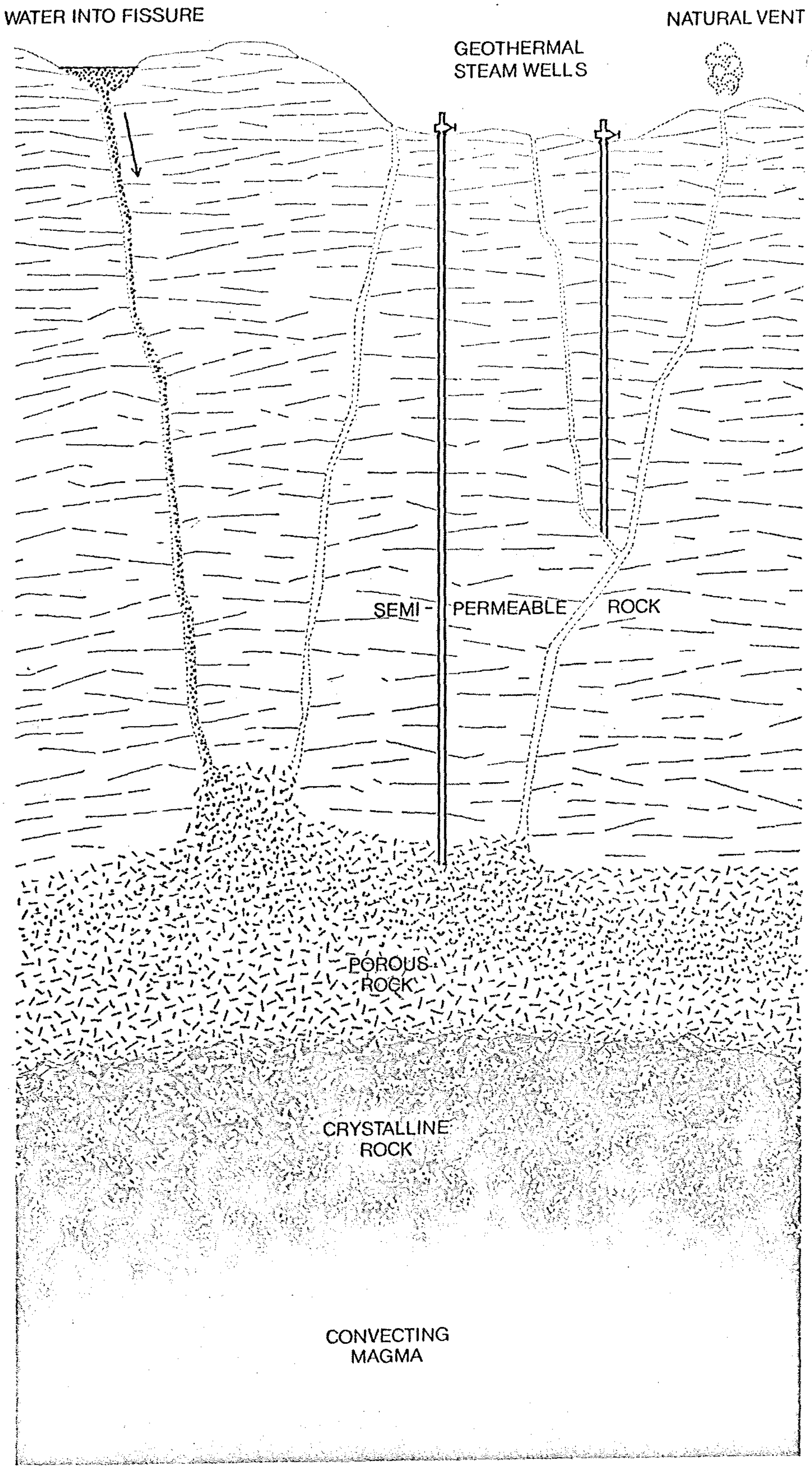
The steam from a dry field can be put to uses other than power production. The water condensed from the steam after it has given up its energy can provide a supply of fresh water. In locations near the ocean or a saltwater lake the steam could be employed as a heating medium in distillation plants for producing potable water by subatmospheric boiling, the steam in this case being provided without any cost for fuel.

So far the existence of five important dry steam fields has been established: the Larderello field in Italy, the Geysers field in California, the Valle Caldera field in New Mexico and two fields in Japan. In the absence of systematic exploration it is not yet possible to estimate how many other such fields may lie hidden in the earth's crust.

On the basis of discoveries made to date, it seems that wet steam fields may be 20 times more abundant than dry steam fields. The wet field is filled with hot water (above its boiling point at atmospheric pressure) that does not become steam until the pressure is released by drilling into the field. The superheated water in the wet field, typically at temperatures ranging from 180 to 370 degrees Celsius (about 350 to 700 degrees Fahrenheit), flashes into a mixture of steam and water as it comes to the surface. About 10 to 20 percent of the discharge, by weight, is steam; the rest is hot water. The steam can be used for power production; the hot water has a multitude of potential uses.

The pioneering stages of the harnessing of geothermal energy have been marked by concentration on a single application of the yield from the wells. At the Wairakei wet steam field in New Zealand, for example, the steam fraction is fed to a power-generating plant and the hot water is discarded into a river. In this respect geothermal energy has paralleled the history of the discovery of petroleum, which at first was used only for kerosene lamps. Now geothermal development is entering a more sophisticated stage through the analysis of its components and their combination into multipurpose projects.

There are already installations in which the steam of a wet steam field is devoted to the production of power and some of the hot geothermal water is distilled, without the addition of any more heat, to make fresh water. (Distillation is possible because the pressure in the flash-distillation plant is kept below at-



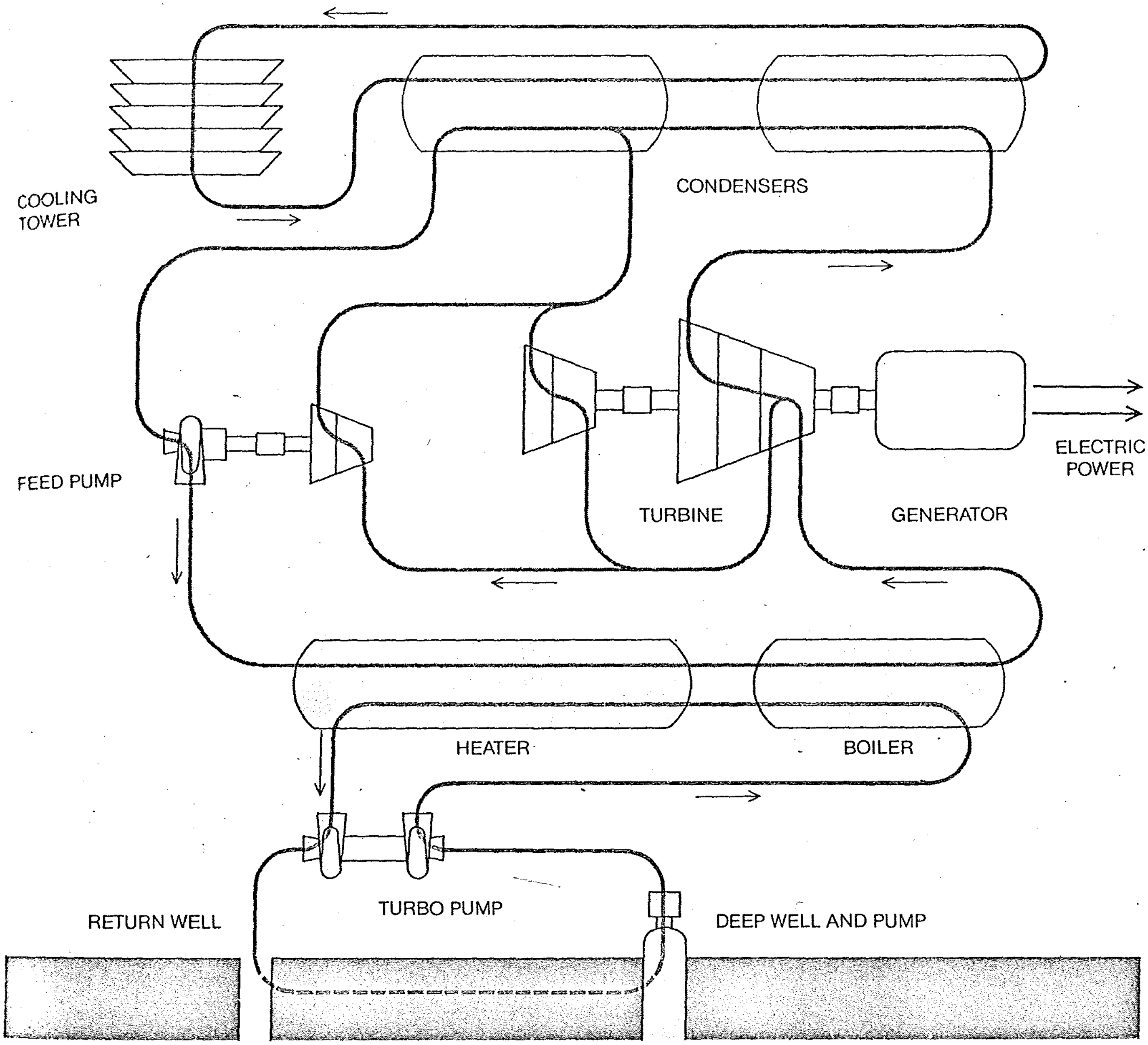
GEOLOGICAL SETTING of a geothermal energy source is portrayed. The heat comes from magma, or molten rock, that has been pushed up into the earth's crust. By convection of the magma the heat moves through crystalline rock to a layer of porous rock containing water that has percolated down from the ground, sometimes to great depths. Over the porous rock is relatively impermeable rock that serves as a cap to contain the heat. Being deep in the ground, the water is under high pressure and is therefore liquid, although its temperature may be some 500 degrees Fahrenheit. It expands and rises in a natural vent; as the pressure drops, water begins to boil and produce steam. A well can tap the vent or the porous layer.

mospheric pressure by exhaust pumps. A further step is planned at a wet steam field recently discovered at El Tatio in Chile. There the Chilean government in cooperation with the United Nations is investigating the development of a facility that will generate three products [*see illustration on page 77*]. The steam will first be used to produce electricity. Hot water produced from the steam will go through a desalination plant, producing fresh water, and the effluent from the hot-water feed will be concentrated in a mineral-rich brine from which valuable minerals will be extracted in evaporation ponds.

Following the accidental discovery of mineral-rich geothermal brines in southern California and in the Red Sea the UN began a systematic search for mineral brines as part of its program of geothermal investigations. Two discoveries of potential economic importance have been made so far, one in Ethiopia and one in Chile.

At Kawerau in New Zealand a paper and pulp company is using the hot water from a wet steam field for heating in industrial processes. In Iceland the hot water from such fields has long been applied to industrial uses and household and district heating. In Japan the applications include uses in experimental fish-farming projects, cleaning, cooking, soil-heating and bathing. Househeating with hot-well water is being developed on a large scale in several countries, notably Japan, the U.S.S.R. and Hungary (where the cost of such heating is reported to be only a fourth of that with fuel-burning systems). In the U.S. househeating from hot wells is being applied on a small scale in Boise, Idaho, and Klamath Falls, Ore.

The use of geothermal water in air conditioning is based on a process that employs water as the refrigerant and a solution of lithium bromide as a low-temperature absorbent fluid. As in other refrigerating systems the refrigerant is vaporized, thereby extracting heat from the surroundings. Then, however, the refrigerant is taken up by the absorbent. External heat (in this case supplied by geothermal water) drives the refrigerant off the absorbent as a gas; the gas is condensed to liquid, which returns to the evaporator to begin the cycle again. Two Russian investigators of applications of geothermal energy, A. N. Tikhonov and I. M. Dvorov, recently reported that a machine of this kind, used in a system providing refrigeration in summer and heat in winter, is being mass-produced



POWER PLANT using geothermal hot water instead of steam has been designed with a low-boiling-point heat absorbent such as Freon or isobutane as the driving fluid. Geothermal water is pumped through a heat-exchange system (*bottom*), where the absorbent takes up the heat. The absorbent evaporates and drives the system of turbines connected to the generator. Absorbent next goes to the condensers, where it is condensed into liquid again by water from the cooling tower and returned to heat exchanger for a new cycle.

in the U.S.S.R. Such a system has also been installed in a hotel in New Zealand, which reports that the energy cost, using geothermal water, is only a tenth of that for a system using electrically operated compressors.

The third type of geothermal field, called a low-temperature field, has only recently begun to receive attention. Fields in this class generally consist of large bodies of water in the range of 50 to 82 degrees C. (about 120 to 180 degrees F.). They are found in sedimentary deposits, notably in Hungary, where the field was discovered accidentally while drilling for petroleum was in progress. The hot water from this type of field is most efficiently used for heating: in houses, greenhouses, mines in cold climates and industrial plants. The use of such water from low-temperature fields in the U.S.S.R. is reported to have represented a saving of about 15 million tons of fuel in 1970.

The new Geothermal Steam Act of the U.S. stresses the multipurpose approach in the development of geothermal energy resources. To this end it will be necessary to plan on a comprehensive scale, treating the problem with an approach like that for the development of an entire river basin. This means that we shall need planners who are acquainted with all the technologies and economic considerations involved, from exploration to the numerous possible applications.

Much study has already been given to the costs of exploitation of geothermal energy for various purposes. Since a number of special factors are involved in this new technology, standards for estimating costs have not yet been developed; however, the UN, in response to a proposal made at the Symposium on the Development and Utilization of Geothermal Resources, which was held in Pisa in 1970, is expected to appoint a committee of experts to formulate uniform costing procedures, so that costs in various situations and various countries can be compared.

Some of the costs are already well known from experience. Drilling a steam well costs from $50 to $150 per meter, depending on conditions, so that the drilling cost of a field 1,000 meters deep will be between $50,000 and $150,000 for one well. There are also ready answers on the costs of piping, valves and the various items of equipment for a power plant. The cost of operation for delivery of the heat from a steam field to the plant is likewise well established; with proper management this cost is only about one to three cents per million British thermal units.

What, then, are the special costs? The most important ones are related to the question of the life expectancy of the available heat supply in a field or a given well. This obviously is difficult to estimate. There are reasons to believe, however, that with proper management a geothermal field will last for many years, particularly if it is recharged by ground water or by artificial injection of gas or geothermal effluent water. At the present stage of development I believe the lifetime of a typical field can prudently be assumed to be about 30 years for purposes of estimating the amortization of the investment used in developing it. To the initial investment we must add a special cost having to do with maintenance: the wells have to be cleaned regularly and sometimes even redrilled because of the precipitation of chemicals from the steam or hot water.

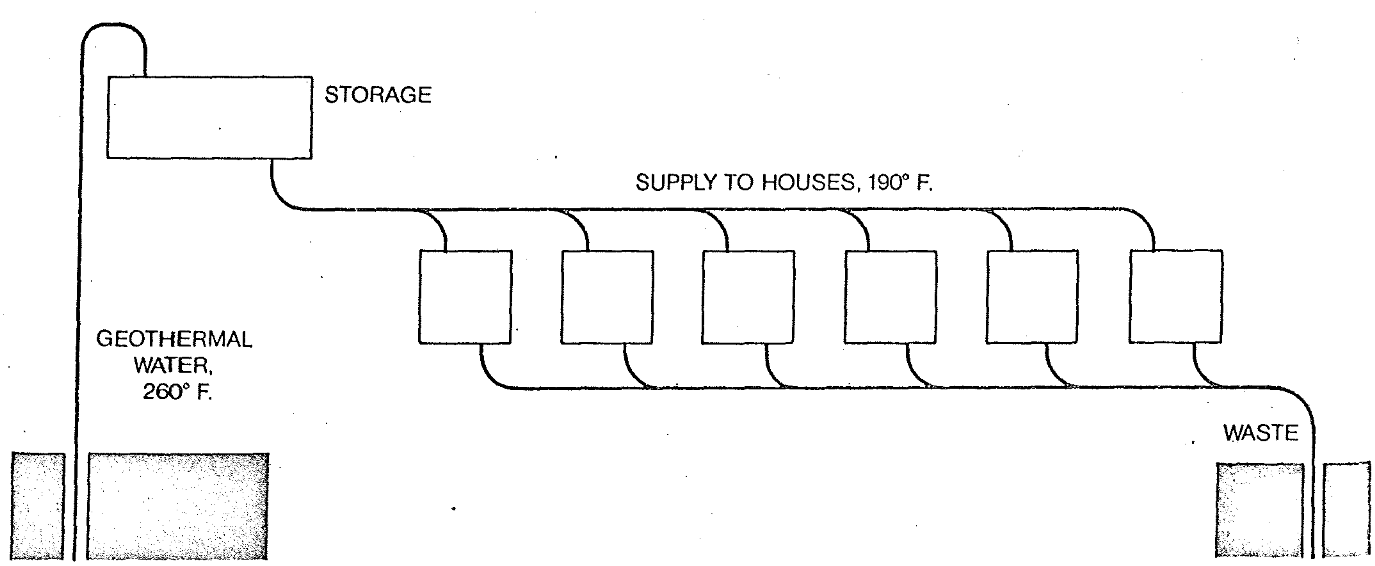
The experience thus far gained furnishes us with approximate cost figures for the various applications of geothermal energy. In a single-purpose installation producing only electric power at base load the cost of the power produced is between three and six mills per kilowatt-hour, including full amortization of all the investments over a reasonable period. In desalination plants the cost would probably be in the range of 20 to 50 cents per 1,000 gallons of freshwater yield—far below the costs of other desalination systems. For househeating, air conditioning and similar purposes the use of geothermal energy makes possible savings of up to 90 percent or more, as we have already noted. A hotel in the city of Rotorua in New Zealand reports that the operating cost of a heating and air-conditioning system based on the use of geothermal energy in a lithium bromide absorption installation is only 12 cents per million kilocalories, as against $2.40 per million kilocalories for an oil-burning system involving approximately the same investment in equipment.

These estimates are calculated from the experience of single-purpose facilities. With the development of multipurpose plants the dividends made possible by extraction of all the benefits in the crude outflow from the geothermal field (like the extraction of the various products from crude petroleum) should reduce the cost of the individual applications.

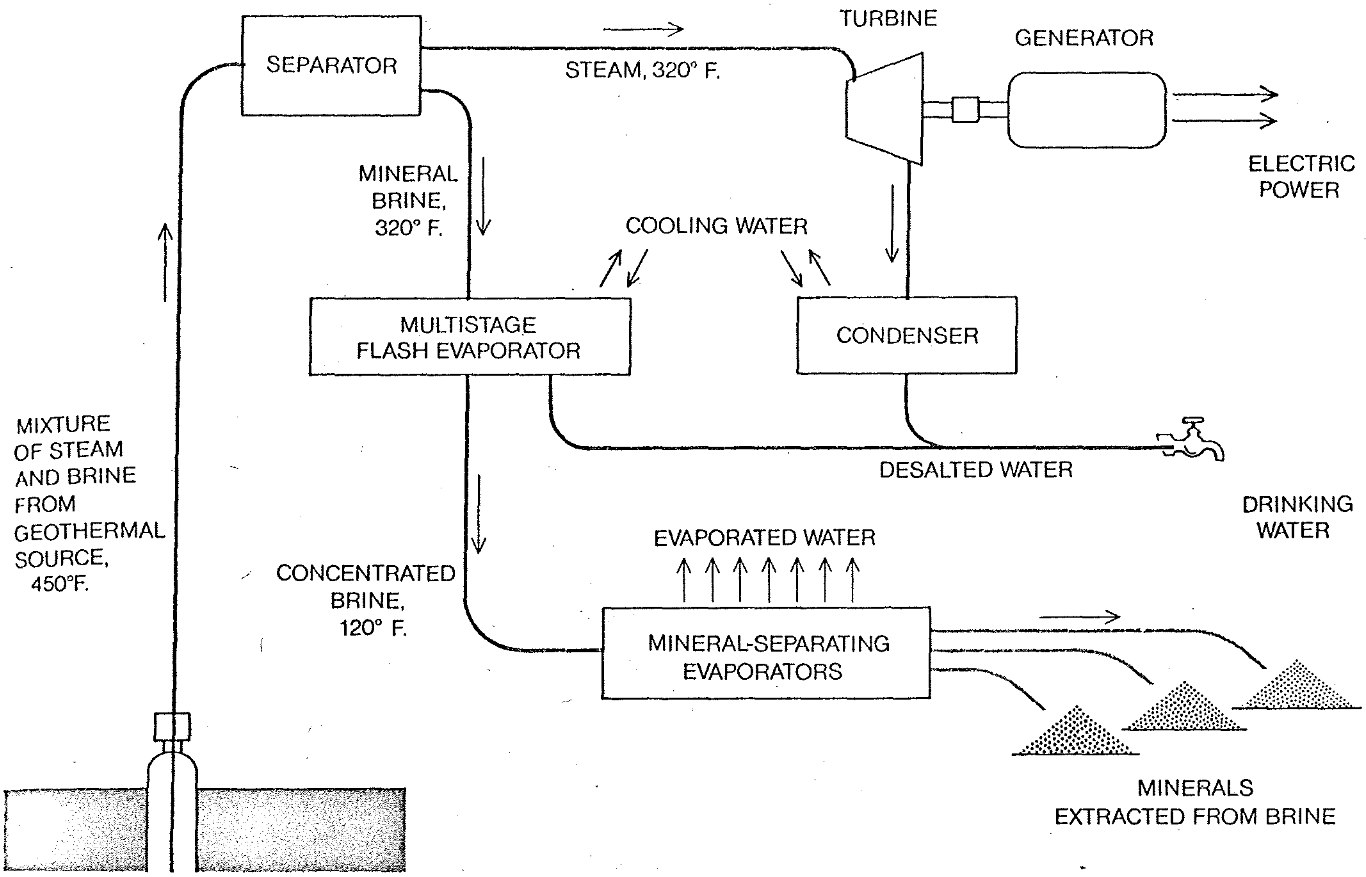
Not the least of the attractions of geothermal energy is that it can be used at little or no cost to the environment. Unlike fossil or fissionable fuels, it does not pollute the biosphere with combustion products or radiation; unlike hydropower systems, it does not flood fertile lands or generate stresses that may lead to earthquakes. It does present two hazards. The steam and hot water from many fields contain small amounts of boron and other chemicals, which can be harmful when discharged into streams. Trials at the Geysers field and at a geothermal field in El Salvador have shown, however, that the contaminated effluent can be injected back into the field without reducing production from the wells. There is reason to believe this problem will not be difficult to control. The other hazard is that the land may subside where large amounts of water are withdrawn from geothermal reservoirs. Some subsidence has occurred at the Wairakei field, which has been depleted of 70 million tons of water per year and as a result has changed in part from a wet to a dry steam field. This problem too can be controlled, by limiting withdrawals from the field to a safe rate and by recharging it with water, as is now done to prevent subsidence in petroleum fields.

The UN is taking an active interest in geothermal energy. In cooperation with the government of Italy it conducted the symposium on geothermal energy in Pisa, where it was demonstrated that geothermal applications are marked by considerable international interest and collaboration. Although the scale of this research is severely limited in funding, a variety of imaginative ideas are being explored.

One project is concerned with the possibility of producing electricity in low-temperature fields. The heat from the geothermal water is used in a heat exchanger to boil a secondary fluid with a



HEATING OF HOUSES and other buildings is done in a few places by a scheme such as the one shown here. Geothermal water is pumped to a storage tank, from which it flows to the buildings. Such systems are in use or being developed in several countries.



MULTIPURPOSE DEVELOPMENT based on geothermal energy is being designed by the UN and the government of Chile for a geothermal field recently discovered in Chile. In this case the geothermal source produces a mixture of steam and mineral-rich brine. The steam and brine are separated, and the steam drives a turbine to produce electric power while the brine is put through an evaporator that concentrates it, thereby producing desalted water. The concentrated brine goes to a separator that extracts the minerals.

low boiling point, which then drives the power turbine. Such a plant, installed on a field providing water at 81 degrees C., is in operation at Kamchatka in the U.S.S.R.; it uses Freon as the secondary fluid. Similar small plants have recently been built in Japan.

Among all the research needs the paramount one is the development of techniques of exploration to search the earth for geothermal reservoirs, hidden as well as visible. This will call for extensive geological, geochemical and geophysical studies and testing. (The UN recently resorted to infrared surveying in a large-scale search from the air for possible geothermal sites in Ethiopia and Kenya.) From the standpoint of geology, interest naturally focuses on areas underlain by rocks of high porosity, since these are likely to hold large quantities of water. From the standpoint of utility and benefit, one hopes to find geothermal reservoirs in arid areas where underground water itself, as well as energy and minerals, would be a boon to the region.

From surface indications alone it appears there are belts of geothermal reservoirs along the western side of the Americas from Alaska all the way down to Chile, in the Middle East (Turkey) and East Africa throughout the African Rift Valley and in the Far East along the "Circle of Fire" of volcanic activity that surrounds the Pacific Ocean. In Turkey two-thirds of the country is believed to have geothermal potential, and there are good prospects for this resource in almost all the countries around the Mediterranean. The many spas of hot waters throughout Europe suggest that geothermal reservoirs should be widespread on that continent. Recent discoveries by drilling in Europe and elsewhere also indicate that a potential exists in many regions that had not previously been considered for exploration. The U.S. may have similar possibilities: drillers came on geothermal reservoirs in Louisiana and Texas recently during deep drilling for petroleum.

Inexpensive power and heating would be very helpful to many developing countries. Some of them, notably in Central America, are rich in geothermal resources—indeed, Central America has much more of this potential energy than it could use itself. Large-scale exploration and development of its abundant geothermal fields would be very worthwhile, however, particularly for the region's economy, if the power potential were fully developed and marketed in the U.S. by way of long-distance transmission lines.

As new information becomes available the magnitude of geothermal energy resources is beginning to be appreciated. On the basis of a reconnaissance, which included airborne infrared scanning over a large area, carried out by the government of Ethiopia and the UN it has been estimated that a part of the Afar region in Ethiopia may have an exploitable geothermal potential sufficient to meet the present need for electric power for the whole of Africa. There are in addition other areas in Ethiopia that are believed to have a geothermal potential of similar magnitude.

At this stage it is impossible to estimate the magnitude of the exploitable resources of geothermal energy that lie hidden under our feet in the earth's crust. The world's energy needs and exciting recent discoveries, however, certainly warrant a great effort of exploration for this ready-made store of energy.