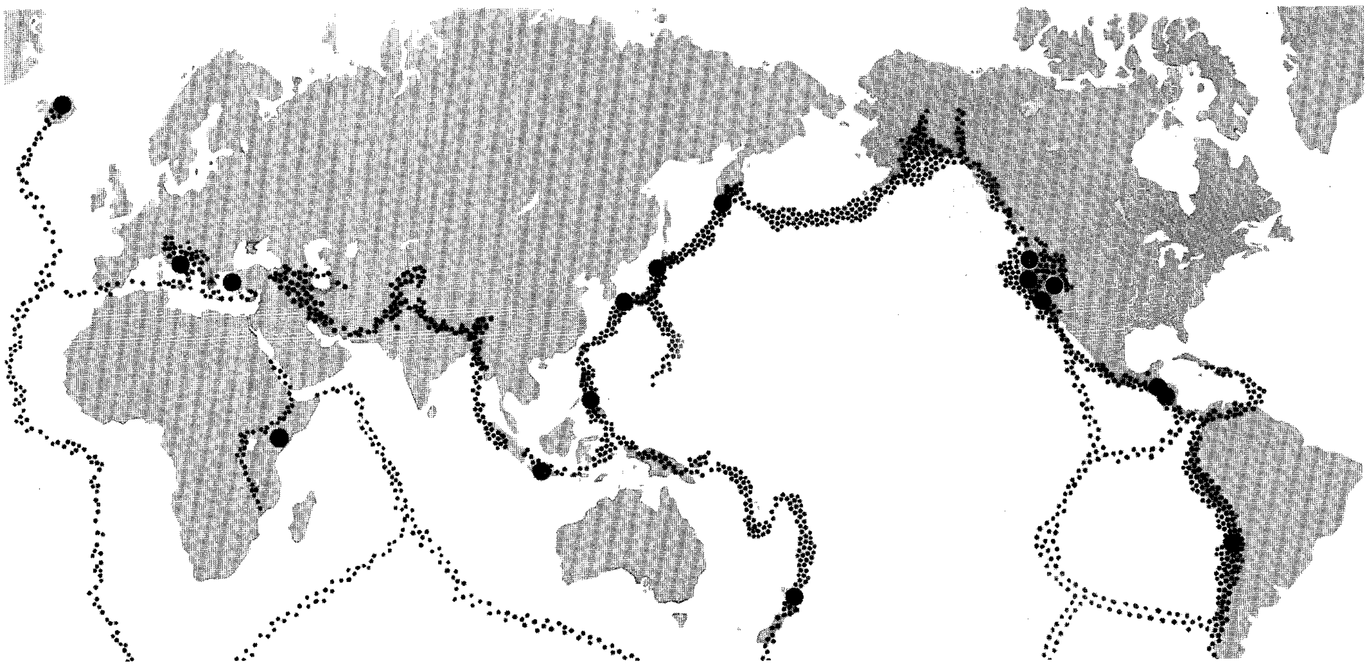


Areas of geothermal potential and location of geothermal developments around the globe.

Developing Our Geothermal Energy

by Carel Otte

In the late 1960's, the United States entered into a critical period of energy supply. No longer able to be self-sustaining, we became dependent on large volumes of imported crude oil. By the time of the Arab Oil Embargo in 1973, we were importing over 30 percent of our oil. The nation should have learned an important lesson in 1973, but in spite of government efforts to conserve, and industry efforts to bring forth new conventional and alternative energy supplies, the United States today must import some 50 percent of its petroleum. And, with the Iranian crisis, the country is faced once again with curtailment of supplies and increased cost for its foreign oil.

The mandate to develop all the available new energy technology is clearly upon us. Of all the new types of energy from which to choose, geothermal energy is the one resource that is a viable commercial reality today. Geothermal is on the line — producing electricity. We know it works, and works well.

Geothermal energy is, in the broadest sense, the "natural heat of the earth," but as a practical matter this heat is not directly available to us for capture. Normally we think of geothermal energy in terms of the fluids that are in contact with hot rocks. It is these heated fluids that can be captured and from which energy can be extracted.

The temperature within the earth is considerably higher than at the surface, and this difference causes heat to flow toward the surface — a flow that occurs everywhere, though we are not normally aware of it. The normal geothermal gradient is about 1.5 degrees F per 100 feet, so at a depth of 15,000 feet the temperature is about 250 degrees F. This temperature is too low to be useful and too deep to capture. However, in certain areas, molten rock or magma, formed at great depths in the crust, succeeds in working itself very close to the surface, causing a sharp steepening of the geothermal gradient, which may be ten times the normal gradient, or more.

The areas of above-normal heat flow and steepening of the geothermal gradient occur in zones or belts that extend around the world. These are zones of crustal weakness, and they are characterized by such phenomena as high seismicity, evidence of volcanic activity, and geologically young mountains. One such belt extends from the tip of South America through Central and North America, Alaska, and around the Western Pacific, through Kamchatka, Japan, and the Philippines to Indonesia. Another belt extends from Indonesia along southern Asia into southern Europe. According to the newest theory of plate tectonics, these zones mark the borders of the stable, but moving, continental plates.

In these mobile areas of weakness, magma ascends closer to the surface. If groundwater is adjacent to these magmatic bodies or is mixed with hot gases and steam emanating from the crystallizing molten rock, the water will be heated and begins to rise toward the surface, sometimes causing hot springs, geysers, and fumaroles.

Hot water in a continuous column is subjected to the pressure of its own weight, raising the boiling point of water progressively with depth. For instance, at a depth of 1,000 feet, water boils at a temperature of about 420 degrees F. If a well is drilled deep into a fissure that is bringing thermal fluids to the surface, the hot water can be relieved of its overlying pressure; it will begin to boil, and then will flash into steam. The higher the temperature, the higher the ratio of steam to water when it comes to the surface. If the original heat content of the rocks is high, or the formation fluid pressures are below normal, the fluid may occur in super-heated form and be all in the steam phase, and from the well it can be directly piped into the generating plant. In case of flashed hot water a steam separator is required. The excess water is then disposed of on the surface or by reinjection. It is thought that the hot water geothermal reservoirs will be by far the most abundant.

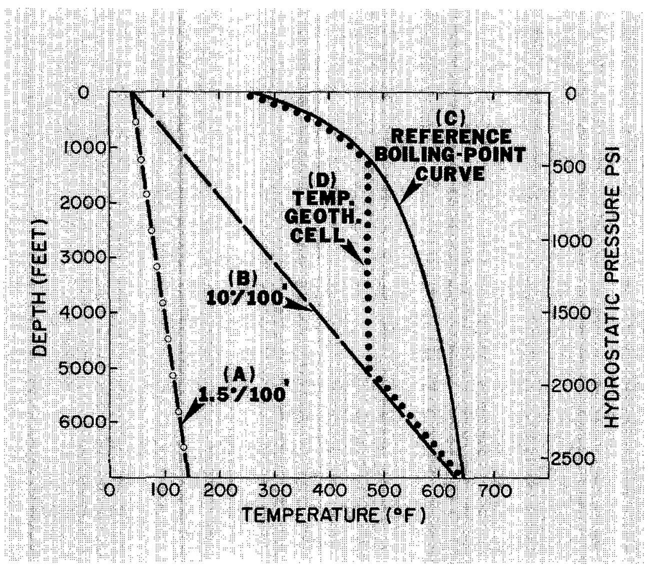
It is important to realize that it is *heat* that we are attempting to produce by means of fluids in the ground — either in the form of steam or hot water — not the direct heat of the magma itself. This, in turn, means that the rocks need to contain adequate void space so that they contain hot water or steam and that they are sufficiently permeable to yield these fluids.

Finally, the fluids should possess relatively suitable chemical composition so that they do not corrode or scale up the casing and piping systems. This is an important aspect of geothermal development; we need to locate a resource with all the suitable attributes.

The temperature of geothermal systems is normally in the range of 450 to 600 degrees F, which is considered low-quality heat by fossil fuel standards. For this reason, the most efficient utilization of the energy would be for the purpose of "process heat" in industrial applications. But the distance over which the energy can be transported is very limited — approximately one mile. Beyond this, there is too much heat or pressure loss. For this reason the utilization for process heat calls for a unique set of circumstances bringing the resource and the industrial application together in one single geographic setting. There are only a few such unique developments — for space heating in Iceland and in such towns in the United States as Klamath Falls, Oregon, and Boise, Idaho, and for the paper industry in New Zealand.

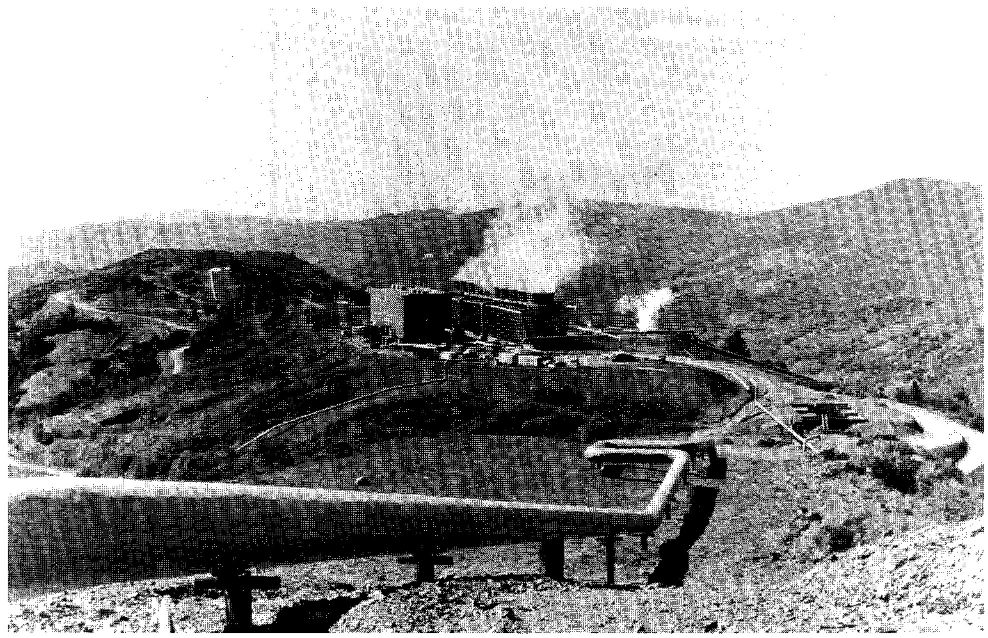
By far the largest application today of geothermal energy is for the generation of electric power. A pound of steam coming from a man-made boiler fired by conventional fuel or from the earth's boiler is undistinguishable, and the steam turbine does not know the difference. Accepting then that electric power can be generated, and transported over a transmission system, the development of a geothermal deposit will depend solely upon the available load centers requiring the energy. In the United States a dense power grid now brings every geothermal deposit within reach of such a load center, so good deposits will see ready development. In other areas of the world, however, the transmission cost to take the energy to the market is an additional factor in comparing the feasibility of

Geothermal Gradient



(A) depicts the normal geothermal gradient in the earth's crust of the stable areas, such as central North America and central Asia. (B) shows the gradient in geothermal areas. Curve (C) depicts the boiling depth curve, the temperature-versus-pressure relationship for boiling water. The field to the left of the curve delineates the liquid phase, to the right, the steam phase. Curve (D) is the temperature distribution in a typical geothermal cell.

Developing Our Geothermal Energy



Specially insulated pipelines carry geothermal energy to a 100-Mw electrical generating plant in The Geysers field in northern California.

geothermal power with an alternative source of electric generation such as coal, nuclear, or oil, where the fuel can be transported to its point of utilization at the generating plants.

In the United States, geothermal power is now developed in increments of 50 to 100 Mw (megawatts), which appear to be optimum blocks of power for the number of wells required, the pipeline distance, and the size and cost of the turbine. At increments of 100 Mw, geothermal power is economically competitive with energy produced by fossil fuel and nuclear plants of about 1000-Mw size that enjoy the advantage of economy of scale.

Many developing countries cannot handle such large increments to their installed capacity as 1000 Mw, and smaller blocks of fossil power are uneconomic. This makes geothermal power a very attractive form of power generation in those countries that have the geologic potential. Some 50 countries around the world are now active or interested in geothermal exploration.

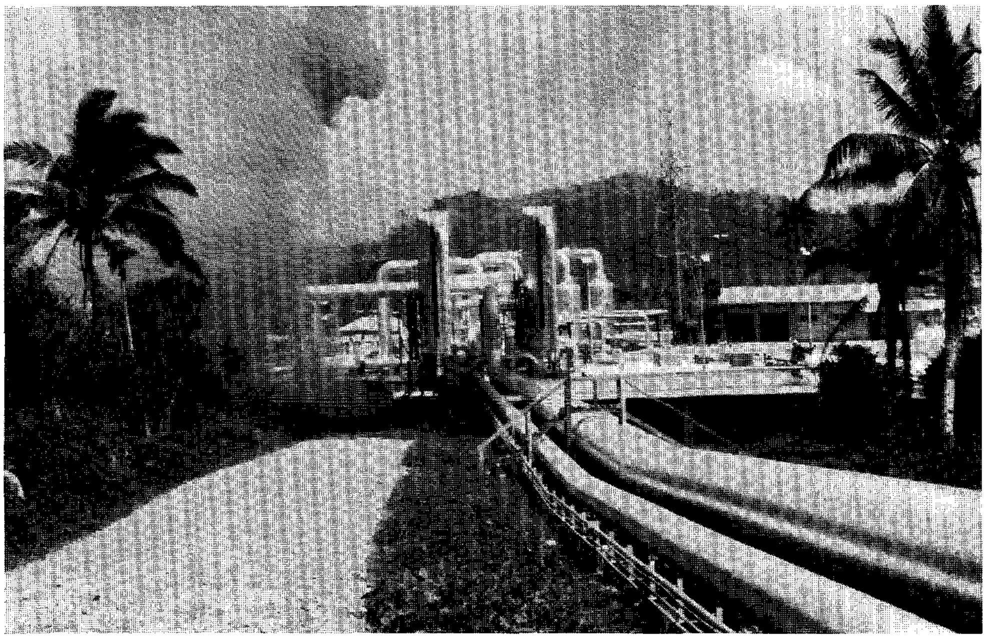
In the United States, the best areas for geothermal potential are found in the states west of the Great Plains from Canada to the Mexican border, and along a geopressured zone extending along the Gulf Coast.

Our major geothermal development is The Geysers project in Sonoma County, California, the largest geothermal project in the world. This development began in 1957, and by 1960 it was producing enough steam to power a 12.5-Mw generating plant. Today, enough steam is produced to power a generating capacity exceeding 630 Mw, which is sufficient to supply *all* the electrical requirements of a typical city of over 600,000 people. Currently, an additional 330 Mw of generating capacity is under construction, to be on line by 1980, bringing the total generating capability of the field to over 900 Mw.

The Geysers field is an example of a steam field, with water occurring in the vapor phase underground and ready to be used directly in the turbines when brought to the surface. The fact that this particular resource can be used so directly and efficiently has been a key element in the successful development of The Geysers to its current size.

Another area with the potential for major development is the Imperial Valley of California. Current activities there are a resumption of an effort that began in the early 1960's in the Salton Sea area to develop hot geothermal brines for their potash and heat content, for both electric and non-electric application. However, the fluids found there were so highly corrosive they proved impossible to handle with the equipment and technology available to industry at that time, and so the efforts were suspended. A renewed exploration effort started in the early 1970's, stimulated by the Mexican geothermal power production just south of the American border.

Test wells have indicated a decreasing amount of dissolved solids in fluids found southward from the Salton Sea approaching the Mexican border, and discoveries have been made in the Brawley, Heber, and East Mesa areas. Working in the Brawley area, Union Oil has drilled ten wells and is now conducting extensive tests to evaluate the



High- and low-pressure steam pipelines carry geothermal energy to a power plant in Tiwi, Philippines, equipped with a double inlet turbine; the scrubbers in the background eliminate moisture and dissolved constituents from the steam before delivery to the plant.

productive capacity and control the corrosion and scaling tendencies. Union has entered into a contract with the Southern California Edison Company to build a 10-Mw pilot generating facility to demonstrate the feasibility of utilizing the resource. If successful, this unit will be followed by units of 50- to 100-Mw size.

In the Heber area the problems are not so much technical as economic. Early drilling by Magma Power and Chevron, followed by Union, delineated a relatively low temperature deposit of about 350 degrees. A deposit with this low a temperature requires the drilling of many more wells to recover the needed quantity of heat energy. If the plans for cooperative field development between the resource producers are realized, commercial development could start soon. Edison has announced plans jointly with Chevron for the installation of a 50-Mw double flash steam unit by 1982. There are also test operations under way in the East Mesa field where Magma Power is installing an 11-Mw binary cycle power plant for completion in April 1979, and Republic Geothermal has announced plans for a 48-Mw facility under the Federal Loan Guaranty Program with the 10-Mw portion scheduled for completion in 1980. Like the Heber field, this is also a low-temperature deposit, and Magma and Republic are planning to pump the wells under back pressure to prevent flashing. Magma will heat-exchange the geothermal fluids against isopropane and isobutane that will drive the turbo-expander. Thus the name "binary cycle." Republic's plants will be steam-turbine type.

In 1976, San Diego Gas and Electric, jointly with the Department of Energy (DOE), resumed activities on the Salton Sea brines with the installation of a small unit for research and testing purposes — the Geothermal Loop Experimental Facility — utilizing brines from wells drilled by Magma Power. Recently, Union joined Edison and Southern Pacific Land on acreage in the same area. Four wells are being drilled and tested, and Edison has agreed to install a 10-Mw power plant to demonstrate that the technology has been developed to utilize the resource.

With all this activity in the Imperial Valley, solutions to the technical problems should be forthcoming soon, and this area should take its place as one of the major geothermal developments in the United States.

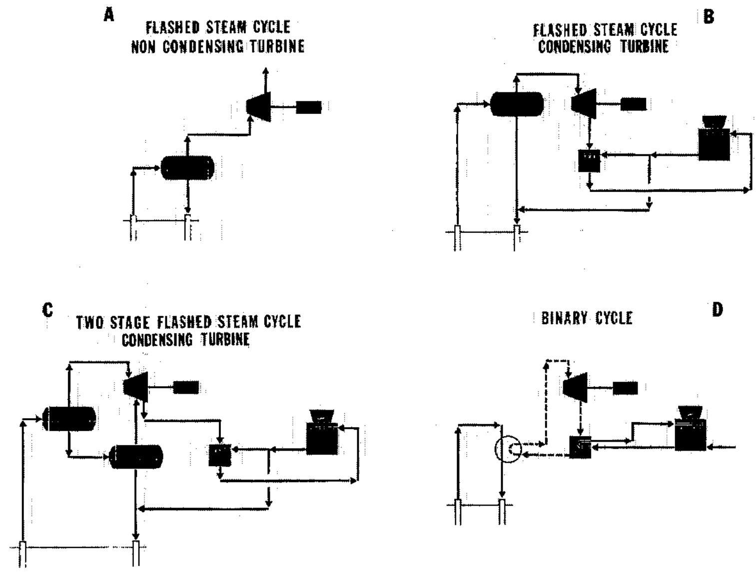
Outside California, Union and the Public Service Company of New Mexico have been selected by DOE to install a 50-Mw flashed steam demonstration plant in the Jemez Mountains 60 miles northwest of Albuquerque as the first step in what could become a major development of the resource that has been identified there.

In Utah, Phillips Petroleum has a hot water discovery in the Roosevelt area near Milford, and a 50-Mw plant is being planned jointly with Utah Power and Light.

A 10-Mw binary cycle unit is being planned in Raft River, Idaho, to operate on waters of approximately 300 degrees F, which should determine whether fluids of such a low temperature can be developed commercially.

These research and development activities, and the near-commercial demonstration facilities, add up to an-

Developing Our Geothermal Energy



Geothermal Power Cycles

Geothermal Power Cycles A, B, and C are examples of flashed steam cycles of increasing complexity, cost, and efficiency in heat recovery. In Cycle D, the geothermal fluid exchanges its "heat" against a secondary (binary) fluid that is contained in a completely separate and "closed" system. This cycle can be employed in relatively low temperature ranges of 300 to 400 degrees F.

nounced plans for nine geothermal power projects at seven sites with a total generating capacity of almost 300 Mw. The importance here is the number of sites involved, because the first power plant on a newly discovered resource is the most significant step in its development, as it demonstrates technical and commercial feasibility.

In addition to all these developments there is also exploration in Nevada, Utah, Idaho, and other places in California that should result in additional discovery of resources. Phillips Petroleum, for example, has apparently already located significant geothermal resources in western Nevada.

Special mention should be made of the very large geopressured water resources of the Gulf Coast, which are of an unusual nature because of the elevated temperature and the dissolved methane gas. Experiments are currently being conducted with DOE funds primarily for the recovery of methane and to identify the technical, environmental, and economic problems associated with the development of these resources.

Finally, mention should be made of the Hot Dry Rock (HDR) Program carried out by the Los Alamos Scientific Laboratory.

The resource base is considered to be immense, and consists of hot rocks devoid of fluids. LASL has drilled several wells in such rocks in New Mexico and established communication by artificial fracturing between two of them. The objective is to circulate water down one bore hole and through the formation, and then up the other well — "mining" the heat contained in the rocks in the process. If this can be carried out on a routine basis commercially, these resources can make significant contributions to our energy base.

On a nationwide scale, experts believe that there is a geological opportunity to produce enough geothermal energy to supply 20,000 Mw of generating capacity in the next two decades, which is equivalent to about 700,000 barrels of oil per day, or 8.5 percent of today's crude oil production in the United States. As technological advances are made, there is the potential for several times this capacity in succeeding decades.

All these activities indicate that the development of geothermal resources is now a reality. The resource is coming of age. The question now is, what size is the industry going to be and at what rate will it grow? The factors holding back development fall into two areas, technical and institutional. Technical problems play an important role in impeding geothermal development. Of the many technical problems, I would like to single out two areas of research where improvement of technology can make significant contributions to reduction of the investment costs associated with geothermal developments. One is in the area of drilling, the other in well or reservoir stimulation. Success in these areas could result in resource development cost savings of up to 50 percent.

The drilling of geothermal wells can be plagued with many problems — unusually hard and tough rocks, crooked holes, and abnormal formation fluid pressures that can cause lost-circulation conditions of the drilling fluids, for example. The elevated temperatures affect the drilling fluids and drilling tools, and the naturally occurring gases (such as carbon dioxide and hydrogen sulfide) can lead to corrosion of the steel drill pipe and other equipment. Consequently, geothermal wells are commonly twice as expensive to drill as oil and gas wells of equivalent depths. DOE has now joined industry on a program of improving drilling technology, equipment, and tools, and the program appears well formulated and closely coordinated with industry. DOE is also sponsoring a parallel program in the development of logging tools.

Increasing the productivity of wells by subsurface stimulation of the reservoir — mechanical, explosive, or chemical — would reduce the number of wells needed to provide the necessary steam of a power plant, reduce the cost of resource development, and make production of geothermal energy more cost competitive. Fracturing of rocks should be tested in known hydrothermal systems where the subsurface geology is well understood and success in increasing permeability can be immediately observed. Perfection of these technologies is very much needed to make existing systems economically viable.

LASL's work in the Hot Dry Rock (HDR) Program should be coordinated with the program on reservoir stimulation, the first priority being to prove that we can develop already known hydrothermal systems that have natural but inadequate fractures associated with them; then we can embark on exploring for new HDR resources. Such exploration has associated costs and risks that require major technological developments and that additionally require a water source for underground circulation in the areas of the Western states where water is normally scarce.

Of course, scaling and corrosion problems associated with certain geothermal developments can be serious. Positive results from industry's efforts in the Imperial Valley would stimulate geothermal developments in general because the technology would be transferable.

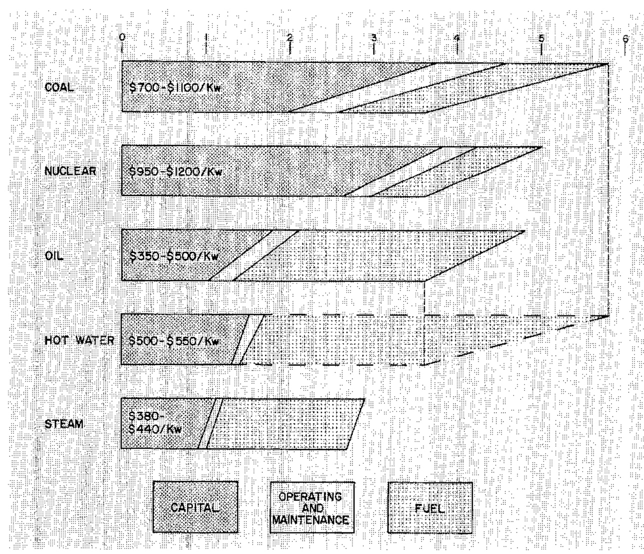
However, all our exploration successes and possible solutions to technical problems will be in vain if we do not resolve the institutional issues that are currently a great obstacle to geothermal development. One way the state and federal governments can take positive action is by reducing procedural red tape from government. Duplication of jurisdiction should be removed, and permitting processes should be streamlined. Federal and state environmental laws have become formidable obstacles, particularly in the hands of special interest groups. I fervently believe that we can proceed with development while protecting the environment, but I believe we must spend less money on studies and more on actual environmental improvements.

For example, the original plan for The Geysers project as a whole was to reach a generating capacity of 16,000 Mw by 1980. This would result in a savings of 18,400,000 barrels of low sulphur fuel oil per year that would *not* be needed to generate electricity, and a foreign exchange savings of about $280 million each year by reducing oil imports by that amount. But because of governmental red tape this goal will not be reached until 1990 — 10 years behind schedule.

Contrary to what many think, geothermal developments are very costly, calling for high and extensive investments and long lead time. Years of delay because of bureaucratic red tape adds to the costs of the development and adversely affects the economics.

The projected costs for achieving the national goal of producing enough geothermal energy to power 20,000 Mw of electrical generating capacity by 1990 illustrate the whole economic problem. To find and develop this capacity will require the drilling of at least 1,200 exploratory wells and 8,000 development wells at a minimum average cost of $825,000 per well or a total of $7.6 billion in 1978 dollars in drilling costs alone. Investment in hookup facilities will add another $4 billion, bringing the total investment requirement to about $11 billion, plus the necessary cost of capital itself. Moreover, a like investment will be required for replacement production wells and facilities through the approximately 30-year operating life of each

New Electrical Power Generation Costs ¢/KWH



Ranges of comparative electricity costs for new electrical power generation based on published cost information. The graph suggests the cost range for hot water geothermal that would make it competitive with conventional energy sources.

development as the resource depletes.

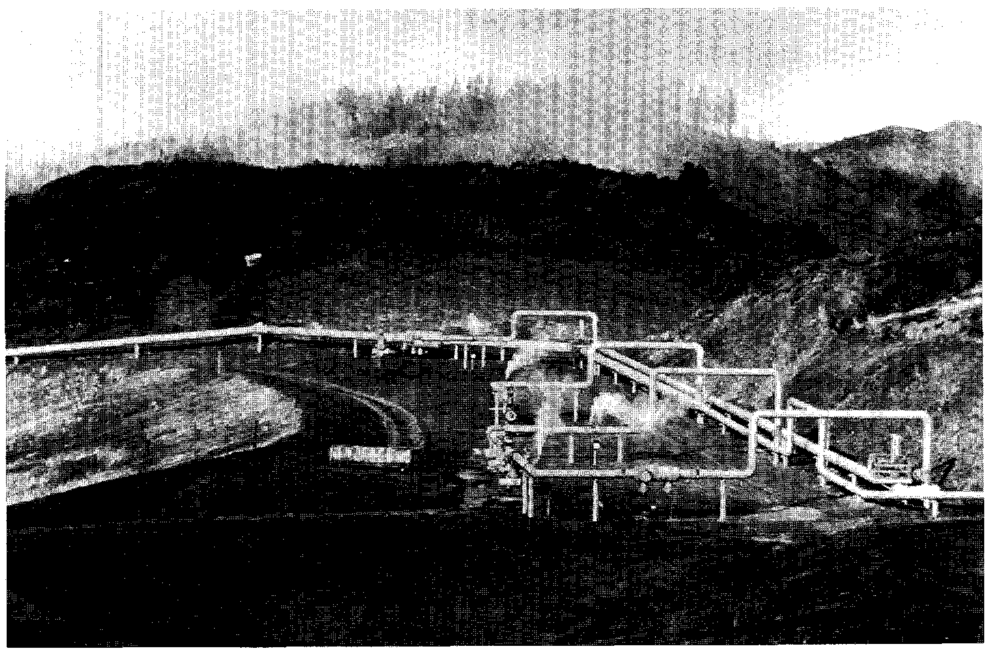
In this regard, the threat of forced divestiture has discouraged large energy companies from entering the geothermal business and thus has been counterproductive in fostering the growth of the industry. These investment requirements are awesome sums of money, and I fail to see where they will come from if not from the energy companies. Outside financial sources do not come forth if technical expertise is not also available. Fortunately, this threat appears to have subsided in the last year.

There is no doubt that geothermal development can be a significant factor in the effort to change our current energy consumption patterns. We burn too much valuable oil and natural gas in utility boilers, and in so doing starve other uses such as transportation, residential heating, and petrochemicals. By backing oil and gas out of the boiler feed stream for central station power generation, we achieve a double gain of reducing both imports and domestic oil and gas consumption. For instance, the 20,000 Mw of geothermal generating capacity that could be developed in the next two decades would be equal to almost 700,000 barrels of oil per day — more than the amount the nation will attempt to save by conservation in an agreement reached with the major industrial nations of Europe and Japan as a result of the recent Iranian crisis. Furthermore, development of this amount of power would result in a foreign exchange savings of about $4.0 billion annually for us.

While the industry has had — and still faces — frustrating conditions, there are some encouraging efforts at the federal and state levels to deal with some of the institutional barriers. On the federal level the President made a commitment to Congress that "the Departments of the Interior and Agriculture will streamline leasing and environmental review procedures to remove unnecessary barriers to development of geothermal resources." To carry out this mandate, an Interagency Geothermal Streamlining Task Force was formed to identify sources of delay in existing procedures and make recommendations for change. For many years the federal income tax treatment of geothermal well costs and production was in doubt, acting as a disincentive on development; in the face of uncertainty there is inaction. However, this uncertainty has now been resolved as part of the National Energy Act of 1978.

A state of California joint legislative and administration task force has also made detailed assessments of the obstacles to geothermal development in the state, and in late 1978 two bills were enacted that will accelerate the permit-approval process for energy production and power plants. Ideally, local government will cooperate with these federal and state initiatives and follow suit in reducing red tape burdens.

If the United States is to carry out its commitment to become more energy self-sufficient and protect itself against future international petroleum crises, alternative sources of energy such as geothermal must be allowed to grow. This will require cooperation between industry and government, not confrontation, and practical approaches to protecting the public interest must be adopted. □



A cluster of wells directionally drilled from one pad at The Geysers in northern California