GEOTHERMAL ENERGY

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Geothermal energy, as the name implies, is the energy derived from the natural heat of the earth. Earth heat has been utilized by man to a limited extent since he first noted the warmth available from natural hot springs. In some areas of the world it was found that shallow wells gave temperatures as high as 300° to 500° F. The first turbine generator attached to one of these wells was at Larderello, Italy in 1904. Development at Larderello continued over the years, and today the field has a capacity of 380 megawatts and contributes a small but important part of the electric generating capacity of Italy.

Technology soon by-passed geothermal power development as it became more desirable to mine fossil fuels, transport them to the load centers, and produce the electricity near the site at which the electricity was to be used. Ten or fifteen years ago it seemed to be the natural progressive step to utilize the heat of the atom to generate the steam to spin the turbines, but in recent years, an environment-conscious society has taken a critical look at the energy industry -- including electric utilities -- and has forced many changes. One of these changes is a re-evaluation of geothermal energy as a possible power source.

Misconceptions About Geothermal Energy

Misconceptions about geothermal energy are rampant, and I would like to discuss these briefly.

I am sure that most of the people in the audience here today have heard it said that geothermal energy is in the same stage of development as the oil industry was a hundred years ago. That just isn't true; we know a great deal more about the earth, its processes and resources, than we did 100 years ago, or even 20 years ago. We have had some experience in geothermal exploration, many years experience in the utilization of geothermal resources, and have gained a vast knowledge of petroleum exploration, which utilizes techniques that are also applicable to exploring for geothermal fluids.

There is a widely publicized opinion that geothermal resources are limited to a few places - mainly those areas where it is being produced today. Actually, geothermal resources can be expected to be present under large segments of the earth and will be found under many conditions, just as oil and gas, uranium, and many other minerals have been found in areas not previously considered to have potential. The presence of usable geothermal energy depends upon the presence of three things: heat, water, and a geologic trap which consists of relatively impermeable rocks overlying a more permeable reservoir rock.

It is repeatedly claimed that geothermal power development will require significant technological break-throughs to be effective. Actually, 75 to 80 percent of the electricity produced today from geothermal sources comes from the simple, well-developed process of taking steam out of the ground directly from well bores and running it into a turbine. The only pre-treatment required is the removal of particulates by centrifugal separators. This well-proven method makes it possible to bring plants into production within a year or two after the steam is discovered.

There is a common assumption that the type of geothermal field producing electricity in the United States today -- that is, the dry steam or vapor intensive field as represented by The Geysers in California -- is unique on the West Coast. In fact, some say The Geysers is the only "dry-steam" field in the United States. Let me point out that the "uniqueness" of dry-steam fields is an opinion, not a fact. A classic example of this type of thinking was the discovery of oil in the mountains of Pennsylvania and West Virginia in the 1840's when it was generally accepted as fact that oil was unique to this region. The cry then was, "There will never be oil found west of the Alleghenies" - then it was "West of the Ohio" - then it was

"West of the Mississippi." The same thing happened with uranium. The experts said it was unique to a few places in the world, but exploration showed it to be far more widespread than anyone anticipated.

An Important Supplement to Energy Supply

I believe the idea of scarcity will turn into a realization of abundance for geothermal power whenever exploration can begin. But until we can start serious exploration, this abundant and cleanest of all sources of energy will remain a novelty. The key to the development of geothermal resources is not to spend massive amounts of public funds or tie up large blocks of acreage for special interest study but to make public lands available for exploration and development by industry under approximately the same guidelines as other energy sources are developed. As the Interior Department's rules and regulations are now written, there are far more restrictions on geothermal development than on the other energy sources. Such excessive regulation serves only the interests of those who benefit directly by the production of energy from other sources because it discourages a competitor who can produce geothermal energy at lower cost both monetarily and environmentally.

No single energy resource, including geothermal, can solve the energy crisis, but geothermal energy is available in Oregon and other western states; with proper incentives for exploration and development it can be brought into use to supplement fossil and nuclear fuels.

The Earth as a Heat Engine

It is only in recent years that the theory of crustal plate tectonics has been refined to the point where we begin to understand the processes that have produced and localized geothermal energy. The concept of crustal plate tectonics has revolutionized geologic thought including exploration for oil, gas and metallic minerals. Figure 1, a map of the world, shows where crustal plates have been either pulled apart or pushed together in recent geologic time. Pulling apart, or rifting, forms new crust by allowing vast flows of lava to pour out of the earth through fissures or erupt from volcanoes, as is happening in Iceland today. Pushing together causes the collision of one plate with another and is probably the more important process in development of geothermal resources. Along the zone of collision, one plate tends to dive under another plate and be subducted (or pulled down). Above the subduction zones are areas of intense geologic activity: mountain building, volcanism, earthquakes, and intrusion of magmas. The

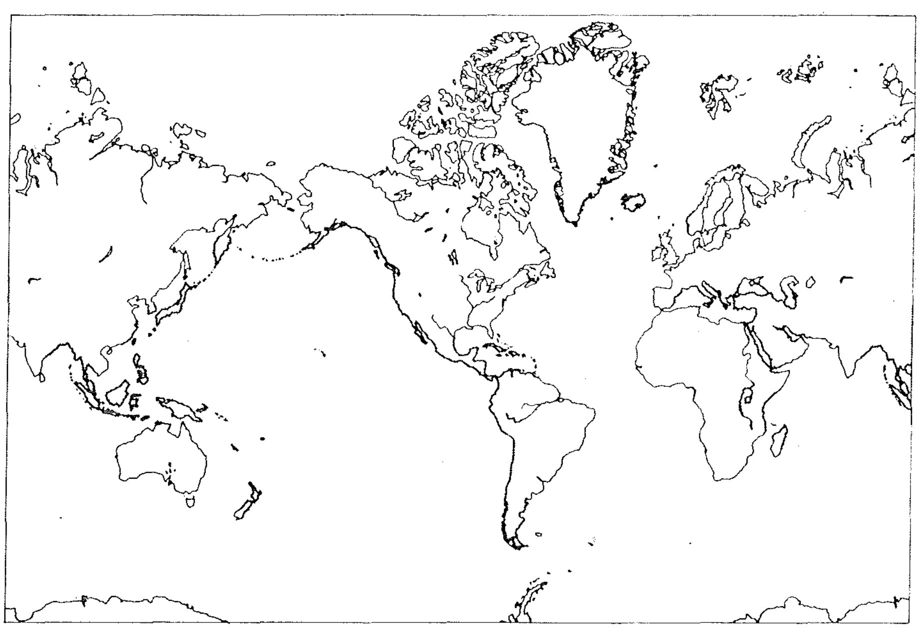

Figure 1. Shaded areas show volcanic belts associated with volcanic ridges or crustal plate boundaries.

Ring of Fire that surrounds the Pacific Ocean--the area in which we are most interested--is a subduction zone in some places and a rift zone in others.

The earth is a tremendous heat engine that accomplishes work. The motivating force is the decay of radioactive minerals deep within its heart, the work is the movement of the gigantic plates, and the product is the waste heat radiated out into space.

A few simple calculations will show that the amount of heat energy contained within the outer 10 kilometers (6 miles) of the earth's crust is greater than that believed to be in all of the fossil fuels on the earth. Scientists in the past realized the presence of this vast amount of energy but felt that most of it was too diffuse to utilize. The theory of crustal plate tectonics has changed this concept and has shown that most of this energy is contained in relatively restricted areas.

Temperature increases with depth at an average rate of about 30°C/km (1.6° F/100'). This gives a lot of heat in storage, but because of its relatively low temperature it is quite diffuse and not very usable. But in possibly 10 percent of the land surface, the gradient is about 60° C (3.2°F/100'). It is believed that most of Oregon from the west edge of the High Cascades to the eastern border of the State falls within this zone, and it is here that our high-temperature geothermal resources lie. From our present state of knowledge, it seems reasonable to believe that within about 10 percent of the high-heat flow zone, or 1 percent of the land surface of the earth, the geothermal gradient is in the neighborhood of 80° C/km (4.4°F/100'), and throughout eastern Oregon we have found many readings of this order or greater.

The amount of heat localized in that one percent of the land surface to a depth of 6 miles and at a temperature greater than 190°F is about 17×10^{25} Btu's. We can get a better understanding of the magnitude of these resources by comparing the energy resource base to that of coal, our most abundant and best identified energy resource. Within the United States, coal reserves of 3.2 trillion tons have been calculated to a depth of 3,000 feet, the general limit of economic mining. This volume would have a total energy content of about 7×10^{19} Btu's , or one ten millionth of the heat energy contained in the geothermal areas. An even better perspective of the enormity of these numbers is obtained by comparing them with the total consumption of energy in the United States, which in 1970 amounted to 6.8×10^{16} Btu's, or about one thousandth of our identified coal resources.

Geothermal Reservoirs

There are two basic types of geothermal reservoirs: hot water and dry steam. These constitute the drilling targets in which the geothermal resource is localized sufficiently for utilization. Our knowledge about these reservoirs is quite limited, but some ideas and theories are starting to develop. One important theory to explain the origin of the dry-steam reservoir suggests that through time the hot-water reservoir self-seals, blocking out incoming water. Then a lowering of the water level by leakage creates an expansion chamber in which steam can flash and eventually form a dry-steam reservoir.

It is interesting to note here how the geothermal reservoir, particularly the dry-steam reservoir, resembles a recently discovered phenomenon called the "heat pipe." The heat pipe is a very effective device for transferring large amounts of heat. It accomplishes this by using the generation, circulation, and condensation of steam to move the heat energy. Heat pipes have replaced other methods of forced cooling of devices that need to dissipate heat, such as large computers. Also, heat is transferred in industrial processes using this principal. The geothermal reservoir is a natural heat pipe.

Oregon's Potential

Now that we have an idea of what these geothermal reservoirs are, let's turn to Oregon and, by using the techniques developed for estimating resources and reserves in the petroleum industry, estimate what we might expect for Oregon. The technique is to estimate the amount of petroleum present and extractable in unknown areas by using experience from known regions.

In the Western United States about 1,200 hot springs are known. These could represent 600 geothermal systems or reservoirs. Let me mention here that many of the persons working in the field of earth heat flow believe exploration will reveal more geothermal systems that lack surface expression than those that can be seen at the surface--experience in the petroleum industry has shown this to be true. World-wide experience so far has shown that about 12 percent of the geothermal systems discovered produce all or significant amounts of dry steam. Using that experience number, we should expect 72 dry-steam systems in the Western U. S. Using The Geysers as a standard where we do have some experience, let's assume the following:

25% are the size of The Geysers at 4,000 MWe	= 72,000 MWe
25% are 1/4th size of The Geysers	= 18,000 MWe
50% are 1/10th the size of The Geysers	= 14,000 MWe
	104,000 MWe

Let me point out here that I am talking only about the so-called dry-steam fields that can be developed with present technology; no technological break-through or massive research effort is needed. Such fields are similar to the Larderello and The Geysers fields, which have operated for many years. If 12 percent of these geothermal fields are of the dry-steam type, the other 88 percent will produce hot water that can be used for many purposes including production of electricity with only minor improvements in the existing technology, as is presently done in Mexico, Japan, New Zealand, and Russia.

In Oregon, we have about 200 hot springs, or 1/6th of those known in the United States, and in addition we probably have about 1/2 of the recent volcanism. This illustrates there is a great amount of heat underlying our State. I believe it is reasonable to estimate that we could expect to find at least 20,000 MWe of dry-steam geothermal energy in Oregon.

Cost of Operation and Production

Many years of world-wide experience in the production of electricity from geothermal resources show that the costs involved can be considerably less than for other types of thermal plants, and even less than for some hydroelectric plants. This is because of the over-all simplicity of the geothermal power-production cycle. Costs of finding and bringing a geothermal field into production can be estimated from numbers developed in petroleum exploration and from experience records in a producing geothermal field.

Costs to develop a prospect will range upward from a minimum of $50,000, but $250,000 is probably a reasonable figure for 2,000 to 20,000 acres, enough to be considered a good prospect. At least two wells are needed to evaluate the prospect, and these at a cost of approximately $350,000 each. This means spending a million dollars to put together and evaluate a prospect. Out of ten evaluated prospects, at least one and possibly two geothermal fields can be expected. That amounts to 10 million dollars and a lot of money, but let's put it into perspective. If it costs 10 million dollars to strike usable steam, then exploration costs, with amortization at 15 percent per year, would be 0.187 mills/kwh for a 1,000-MW field. Not a very significant figure considering that fuel costs have been escalating at 1 to 2 mills per year. Experience at The Geysers indicates that in order to produce sufficient steam for 1,000-MW plants (and this would probably consist of a mix of 100-and 200-MW stations), 150 to 175 wells would have to be drilled at an average of $150,000 each for a total investment in wells of about $25,000,000. Steam transmission lines could be expected to cost $15,000,000 and roads and landscaping $5,000,000. This would mean a total investment in the field of about $55,000,000.

Assuming amortization at a rate of 15 percent a year, fixed charges would amount to $8,250,000 per year, royalty to landowners, at 0.5 mills/kwh, would be $4,000,000 per year, and up to $6,000,000 would probably be necessary for field operating and maintenance costs. That gives a total energy cost of about $17,000,000 to $18,000,000 a year for 8,000 hours of operation, or 2.2 to 2.5 mills/kwh.

The costs for developing the steam field and the costs of steam per kilowatt hour of electricity produced are tabulated on the following page.

TOTAL STEAM COSTS
1,000 MWe Geothermal Field

Exploration	$10,000,000
Developmental wells (150-175 wells at $150,000)	25,000,000
Steam transmission lines (at $15/kwh)	15,000,000
Roads, landscaping, etc.	5,000,000
	$55,000,000

STEAM COST PER KWH
1,000 MWe Geothermal Field

	mills/kwh
Fixed charges $55,000,000 at 15% = $8,250,000/year $ 8,250,000/8 x 10^9 kwh	1.03
Royalties to landowners	.5
Field operating and maintenance costs $5,500,000/8 x 10^9	.67
	2.2

Pacific Gas and Electric is currently paying about 3.5 mills at The Geysers, but new contracts are being negotiated in the range of 5 mills for steam delivered to the power plant.

The question most frequently asked by those not familiar with geothermal development is "What is the life of the field?" That can best be answered by explaining what we know about geothermal fields and from experience developed in petroleum reservoir technology. That is, that steam in the reservoir behaves according to the same physical laws that apply to natural gas. This became apparent at The Geysers when developers were faced with the problem of proving sufficient steam for PG&E to amortize its plants over the normal 30-year period. The early practice had been to drill all the wells necessary to supply the proposed plant and to run lengthy tests to see how much draw-down was caused by the freely flowing wells. When it was found that the steam behaved like natural gas, this original practice was discontinued.

Now the procedure is to drill two wells in the region where a new plant is planned, and from that information ascertain the size and character of the reservoir. No longer is it necessary to put so much capital into numerous wells before starting plant construction; instead, production wells can be drilled while the power plant is being built.

Experience has shown that the wells decline with time but that the individual wells last 10 to 20 years. When production declines to the point where those wells can no longer produce all the steam required by the plant, new wells are drilled between the original ones, thus restoring production. It is now the practice at The Geysers to drill wells on a 40-acre spacing with the intention of filling in as production declines. All of the work to date shows this decline is predictable and the fields will last 30 to 50 years, long enough to allow amortization of the plants.

Environmental Factors

The potential environmental problems arising from geothermal developments are similar to those of any other industrial operation. The construction of roads, drilling of wells, and installation of pipelines and power plants all contribute to the changes in land-use patterns for the particular site. The effects on the land vary, dependent upon the type of fluid and utilization.

There is less environmental impact from producing electric power from a geothermal plant than from other types of thermal power plants, and in many instances less than from a hydroelectric plant when the dislocations caused by massive construction are considered. In geothermal power production, all of the steps of the fuel cycle are localized at the site. Other types of thermal power plants require considerable industrial support in the form of mines, transport facilities, and processing plants; thus the environmental impact of the fuel cycle for these operations extends far beyond the bounds of the power generating plant.

The "dry-steam" or vapor-intensive type of geothermal electric power plant has a long history of production experience based on the Larderello, The Geysers, and Matsukawa fields. For these areas, the only continuing environmental abuse has been the release of hydrogen sulfide gas, which has an unpleasant odor even in small amounts. The odor of hydrogen sulfide from a geothermal plant is more objectionable than the odor of sulfur dioxide from a coal-fired plant; however, the amount of sulfur released per unit of power generated is less. The Environmental Protection Agency limits sulfur emission from fossil fuel plants to 1.2 pounds per million Btu's. The Geysers releases less than a quarter of the EPA limits.

Because of the remote location of geothermal plants and the relatively small size of the operation, the release of hydrogen sulfide gas has not been considered a serious problem. However, as the size and number of plants increase it will be of greater concern, and studies are under way to alleviate it.

At The Geysers, Pacific Gas and Electric is conducting an emission abatement program that is expected to scrub 90 percent of the hydrogen sulfide out of the noncondensible gases. The company plans to start adding this equipment to the new installations and begin a program of retrofitting on the older equipment.

The major gaseous release from geothermal plants is carbon dioxide, but here again the release per unit of power is much less than from any fossil fuel plant. Moreover, the geothermal plant releases no oxides of nitrogen, smoke, fly ash, or other aerosols.

Some routine operations in geothermal steam fields are extremely noisy. In the past the process of well clean-out and testing generated large amounts of noise, sometimes continuing for long periods. At present the major noise is episodic and occurs only during the initial testing period when a productive well is first opened to clean the rock and other debris from the well bore. The noise normally lasts for only a few hours; as soon as the well stops throwing out the debris, further testing is done through silencers. Uncontrolled blow-outs are also very noisy but these are infrequent.

The "hot-water" or liquid-intensive geothermal field has problems of a different nature. It takes from 100 to 150 pounds of hot water (in contrast to 16 to 20 pounds of steam) to produce a kilowatt hour of electricity. The handling and disposal of these large quantities of water per unit of power cause most of the environmental problems of the "hot-water" geothermal plant.

Thermal waters carry dissolved solids ranging from a few hundred to hundreds of thousands of parts per million. The presence of these dissolved chemicals usually precludes intermingling the geothermal waters with other surface waters, and in the United States necessitates their injection into the ground.

Because of the fear of ground subsidence from the removal of large quantities of water and possible seismic effects due to reinjection, no hot-water fields have been developed in the United States. Such fears, however, are not founded on fact. Detailed studies have shown that subsidence from geothermal fields would not occur in most areas. Where it presented a potential problem it could be alleviated by reinjection, as practiced in the oil fields. Induced seismic activity relating to injection of fluids into the ground is shown to be proportional to injection pressures. Because the reinjection of geothermal fluids involves only a return of fluid to the reservoir at hydrostatic to sub-hydrostatic pressures, there is no reason to believe seismic activity would be induced.

Geothermal plants do not require a supplementary source of cooling water when using natural steam or the flashed cycle. The steam, after passing through the turbine, is condensed, piped to the cooling towers, and then recirculated to cool the condenser. By this method, the field at The Geysers produces about 20 percent more condensate than is evaporated. This surplus is then returned to the reservoir where it originated, thus prolonging the useful life of the field. A geothermal plant is the only type of thermal power plant that does not compete with other uses for our dwindling supplies of water.

The environmental impact of any power-production system is reflected in the number and complexity of the steps in the fuel and production cycle. Because geothermal power plants utilize naturally occurring steam, they need no complex steam-generating equipment or extensive mining, processing, storage, or transportation facilities, as do other thermal power plants; but, because all the power production steps are localized within the bounds of the geothermal field, it may appear that the geothermal plant has considerably more effect on the environment. As a practical matter, development of a geothermal field will displace other land uses in the area. However, after the initial construction period, most of the area within the geothermal field can return to pre-existing land-use patterns compatible with geothermal developments. An example of this is the Larderello field in Italy where development has stabilized. Most of the area occupied by the geothermal field is covered with farms, orchards, and vineyards, with the wells, steam transmission lines, and power plants occupying only a small percentage of the land.

Utilizing Geothermal Waters

Of local importance but largely overlooked on the national scene is the use of geothermal energy for direct application, such as space heating or for heat needed in industrial processes. For this purpose, waters of much lower temperature than is necessary for electric power production can be used, greatly broadening the resource base. Probably the best known example is Reykjavik, Iceland, where a large district heating system provides nearly all the space heating for this city of 85,000. Extensive use is made of geothermal waters in Hungary, where in Budapest alone 5,600 flats are supplied with natural hot waters. Some of the most imaginative uses of geothermal waters occur in New Zealand. Aside from electric power production and space heating for homes, businesses, and industries, geothermal energy is used for cooling via absorption refrigeration and for process steam in a large paper mill. In the United States, the largest utilization of natural hot water is in Klamath Falls, Oregon, where several hundred homes and numerous schools use geothermal waters for heating. Several other cities in the West make some direct use of this energy source.

Utilization of geothermal fluids for space and process heating may involve little more than the drilling of a well and circulating the fluids through a radiator in the home. In some cases, heat exchangers are used, and in others it is necessary to make minor changes in the chemistry of the waters to keep minerals from plugging the pipes. The disposal of these fluids is handled in different ways, depending upon the region and quality of the fluids; some are put directly into surface streams and some underground. Often the spent fluids are of sufficient quality to be used directly for irrigation or stock watering. If aquifer conditions are appropriate, there is no need to bring the geothermal fluids to the surface; instead down-hole heat exchangers can be used and clean secondary fluids circulated to the surface installations. All of these techniques are practiced in some areas; nowhere has it been necessary to resort to complex techniques of effluent capture and disposal.

The direct use of geothermal energy has been largely unheralded because it lacks the glamour and large revenue aspects of the production of electric power. However, the total amount of energy produced for direct use exceeds that for electric power production from geothermal resources today. The direct use of geothermal fluids for space heating is particularly attractive in arctic and sub-arctic areas where winter heating is a major economic burden and where the winter high-pressure weather systems often create a pall of lingering smoke and fog from the burning of fossil fuels. There should be a major effort in those areas where geothermal resources are available to build district heating systems on the pattern of Reykjavik to lower the overall pollution and decrease the use of and dependency on fossil fuels.

Conclusion

The use of geothermal energy has a long history of successful operation. Seventy years of operating experience at Larderello and 20 years at Wairakei have shown geothermal systems to be economically and environmentally successful. It is known that geothermal energy exists in vast quantities; its resource base is second only to solar energy. But how much geothermal energy is sufficiently concentrated to be utilized economically is not known and can only be answered by serious exploration to locate and develop geothermal reservoirs. Unfortunately, delays and harassments are discouraging the exploration for geothermal energy in the United States at a time when the world most needs this clean supplemental energy to help reduce environmental degradation and offset the rapid depletion of fossil fuels.