FLETCHER C. PADDISON and KWANG YU

USE OF GEOTHERMAL ENERGY IN THE EASTERN UNITED STATES

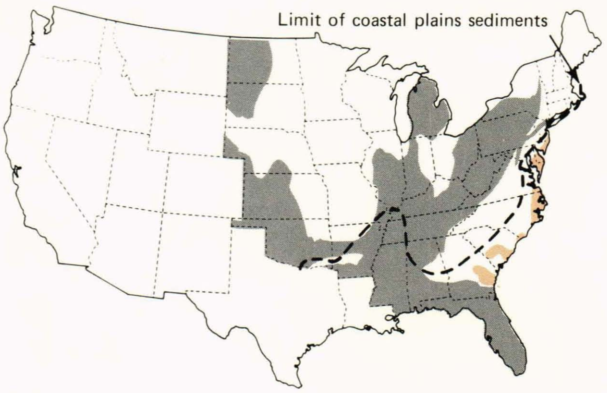
This article discusses the location of potential geothermal resources in the eastern United States, where the only confirmed hydrothermal field is located on the edge of the Delmarva Peninsula. The manner and economics of the field's use to heat a high school in Crisfield, Md., the pros and cons of extending the use of the resource to community heating, and institutional considerations are also discussed. It is concluded that the use of hydrothermal resources with greater than normal thermal gradients in the eastern United States appears promising if system design is optimized and capital costs are minimized.

INTRODUCTION

This article discusses the potential use of the moderate-temperature hydrothermal resources found in the sedimentary basins and coastal plains of the eastern United States. The depths and temperatures of the groundwater, the productivity of the extraction and reinjection wells, and the local geology dictate the economics of application. The effects of these variables on the cost are indicated, together with a quantitative description of well productivity. In the Atlantic Coastal Plain, Crisfield, Md. is the only location for which such data are available. Accordingly, this article outlines the engineering and economic considerations to use in applying the hydrothermal resource available at Crisfield to the space heating of a single structure, the local high school. Other potential uses in the Delmarva area and Department of Energy (DOE) initiatives to encourage further development are discussed. The financial, legal, resource management, and environmental issues that must be resolved by state and local governments prior to extensive development are summarized.

HYDROTHERMAL RESOURCES IN THE EASTERN UNITED STATES

Thick sedimentary deposits of noncrystalline rock that are saturated with water and possess high permeabilities (so that water can be removed without unreasonable expenditure of pumping energy or drilling costs) are potential hydrothermal resources. Figure 1 shows the location of such sedimentary basins and sedimentary coastal plains in the United States east of the Rocky Mountain States. These areas and their approximate depths have been delineated over a period of time through both geologic and geophysical studies and scattered prospecting for oil and natural gas. The thermal and hydrologic characteristics of the deep sediments are now being given increasing attention as a result of the recent sharpening of awareness of hydrothermal reservoirs as a potential energy source.



■ Basement depth greater than 4000 ft below surface. (Contours adapted from map of North America - 1967)

🟧 Approximate areas of thermal anomalies under investigation by Costain et. al. of VPI&SU. (From Gruy Federal report DOE/NVO/1558-7, Dec 1979)

Fig. 1—Coastal plains and interior sedimentary basins with potential for hydrothermal resources.

The American Association of Petroleum Geologists (AAPG) and the U.S. Geological Survey (USGS) have together produced a series of regional maps and a combined map of the thermal gradients for the North American continent. References 1 and 2 were compiled from bottom hole temperature measurements made at the time of drilling for oil and gas. Many states, under DOE sponsorship, are compiling detailed thermal data.[3]

The Virginia Polytechnic Institute and State University (VPI&SU) is targeting, locating, and assessing areas along the Atlantic Coastal Plain whose thermal gradients are greater than average.[4] Although not conclusive, models of the size and location of granitic plutons, some of which may possess higher than average concentrations of radioactive material, were developed, and estimates were made of the potential heat production together with the conductive heat flow from the surrounding rock. Further assumptions were made regarding the insulating properties of the sedimentary cover, and thermal gradients above these plutons were calculated. In 1979, a series of 1000 ft deep holes was drilled from New Jersey to North Carolina to confirm these predictions. This series of test drillings will be extended in 1980 to the Georgia-Florida border. Figure 2 shows the study area on the coastal plain. High gradients of 19.5 to 24.8°F/10^3 ft were recorded in the region from Wallops Island, Va., to Crisfield, then 26°F/10^3 ft across the Chesapeake Bay at Smith Point, Va.[4] These may be due to granitic plutons (as VPI&SU suggests), but the observed thermal gradients are more or less in the high end of the range of normal values. Since the nearest known pluton to Crisfield is over 20 miles away, it is unlikely that this pluton contributes in any significant manner to the 135°F temperature found at Crisfield at the depth of 4200 ft. This supposition is clearly indicated since the thermal impedance over a distance of 4000 ft is negligible compared to that over more than 20 miles, either by conduction or by the fluid transport mechanism. (Typical natural ground water transport velocity is about 3 ft per year.)

In 1979, DOE authorized the drilling of a deep (4200 ft) confirmation well near Crisfield. (Figure 3 shows the drilling rig in operation.) From this well, an extensive body of geologic and hydrologic information has been obtained. For example, an aquiclude[5] (low permeability horizon) was found, from 2000 to 2700 ft, that appears to be an effective separator of the fresh (potable) groundwater at shallower depths from the saline waters of deeper layers. Three potentially promising saline-water-bearing sand/sandstone layers were found immediately above the basement rock (4225 ft) (Table 1).[6]

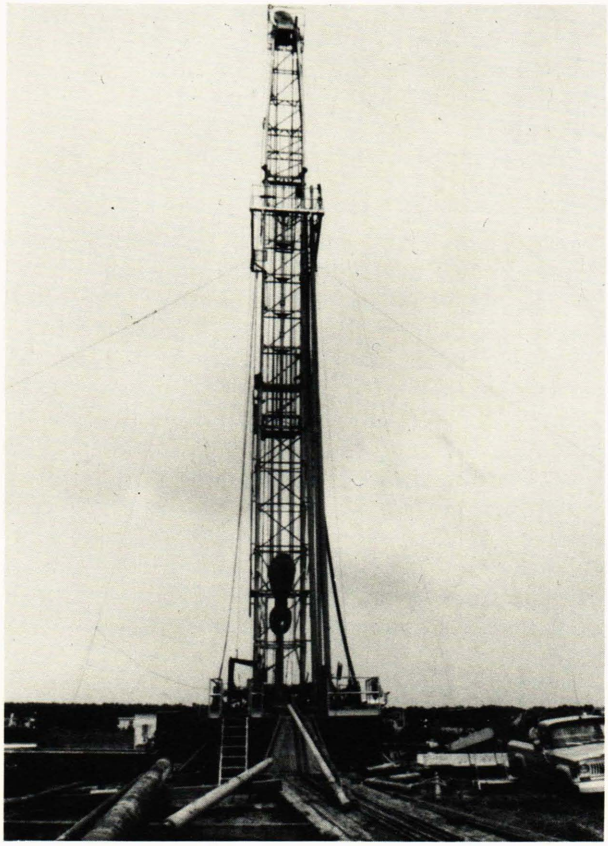


Fig. 3—Drilling rig in operation at Crisfield.

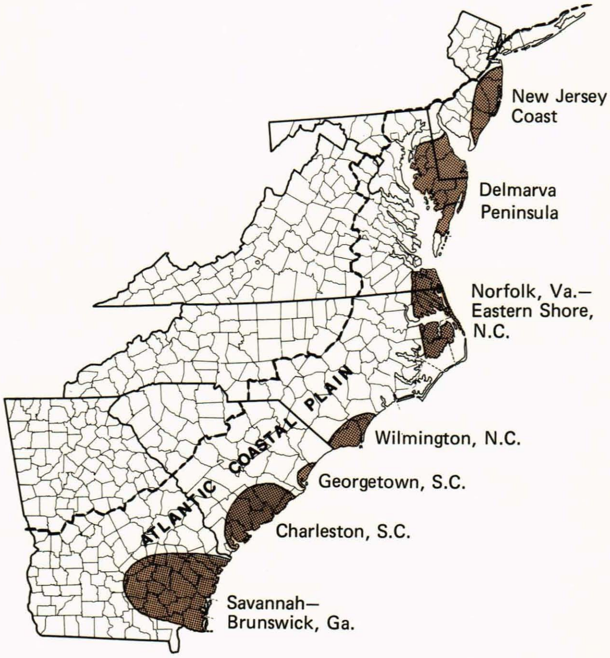


Fig. 2—Areas on the Atlantic Coastal Plain being studied in detail by the DOE to locate, assess, and evaluate utilization of hydrothermal resources.

This test well was completed with steel casing extending to the basement rock and cemented in place (for experiments to be performed for the DOE Hot Dry Rock program). Access to the hydrothermal test zones was obtained by perforating the casing. Because of technical problems, only the Zone 2 test produced a reliable set of hydrologic parameters, and this test was not continued long enough to infer the spatial extent of the resource. The parameters determined are:[7]

Table 1

WATER-BEARING PERMEABLE SANDSTONE AT CRISFIELD

Zone	*Depth (ft)*	*Net Thickness (ft)*	*Water Temperature (°F)*	*Salinity (ppt)*
1	4148 – 4223	62	135	67.9
2	3901 – 4032	86	133	68.9
3	3798 – 3846	44	128	68.4

Permeability	110 md (millidarcys)
Transmissivity	0.50 cm^2/s
Storage coefficient	3.9×10^{-3}
Size	>2000 ft
Salinity	68.9 ppt
Water temperature[8]	133°F

Groundwater Movement

Before discussing the use of hydrothermal resources, we will briefly review some of the features of groundwater movement. For more detailed information, see Refs. 9, 10, and 11.

The movement of groundwater in this area involves the flow of water through porous media. Items of interest are the characterization of the porous media (porosity and permeability) and the laws governing the groundwater movement.

Porosity — We will define the porosity of a medium as the ratio of "void" (i.e., nonsolid) volume to the total volume, with the assumption that the medium under consideration consists of a solid matrix or skeleton through which the water may flow.

Porosities may range from near zero to over 50%, depending on the materials and degree of compaction. Typical values are shown in Table 2.[12]

Table 2

REPRESENTATIVE POROSITY RANGES FOR SEDIMENTARY MATERIALS

	Porosity (%)
Soil	50—60
Clay	45—55
Silt	40—50
Medium to coarse sand	35—40
Fine to medium sand	30—35
Gravel	30—40
Gravel and sand	20—35
Sandstone	10—20
Shale	1—10
Limestone	1—10

Permeability and Darcy's Law — Although porosity is a measure of the water-bearing capacity of a medium, it is not a good measure of the ease with which water may flow through a porous medium. For example, coarse sands with angular or rounded grains may have a porosity considerably less than clay but may make an excellent aquifer, while clay is generally the opposite, i.e., a good aquiclude.

To describe subterranean water flow quantitatively, the concept of permeability is necessary. Originally, it was found in the experiment of Darcy[13] that the flow rate through a cross section A normal to the flow is proportional to the hydraulic gradient driving the flow, a situation similar to Poiseuille's pipe flow. This is often expressed as

$$\vec{v} = -\frac{k}{\eta}\nabla p, \qquad |\vec{v}| = \frac{Q}{A}, \qquad (1)$$

where Q is the volume flow rate, v the flow speed, η the dynamic viscosity, and ∇p the pressure gradient. The proportionality constant k is called the permeability and has the dimension of area. In petroleum engineering, a unit called the darcy is used, which is equal to

$$0.987 \times 10^{-8}\,\text{cm}^2\text{, or } 1.062 \times 10^{-11}\,\text{ft}^2$$

This permeability value gives rise to a flow rate of 1 cm/s for a fluid having a viscosity of 1 centipoise (water at 20°C) under a 1 atm/cm pressure gradient.

Darcy's Law is an analog of Ohm's Law. With $|\nabla p|$ as the voltage drop per unit length and v playing the role of current density, the permeability is seen to be the analog of conductivity. To emphasize the analogy, one may introduce the concept of hydraulic conductivity, K, defined as

$$K = \frac{k\rho g}{\eta}, \qquad (2)$$

where ρ and g are the density of fluid and the gravitational acceleration, respectively, and K has the dimension of velocity. Typical ranges of k and K are shown in Table 3. Normally, hydrologists concerned with shallow wells regard k greater than 1 darcy as "good" and k smaller than 1 darcy as "poor" with regard to exploitable flow rates. However, for geothermal applications the aquifers tend to be deep, with the consequence that the sands often are compacted to a much greater degree than in shallower formations. Perhaps a better terminology in geothermal application is

Good	$k \gtrsim 0.3$ darcy
Moderate	$0.1 \lesssim k \lesssim 0.3$ darcy
Poor	$k \lesssim 0.1$ darcy

In discussing the productivity of an aquifer between two confining layers, a quantity called transmissivity, T, is used. Transmissivity is the product of the hydraulic conductivity and the aquifer thickness. Consequently, even with poor permeability, productivity can be high if the producing layer is thick enough.

Table 3

TYPICAL VALUES OF HYDRAULIC CONDUCTIVITY AND PERMEABILITY

	K (cm/s)	k (darcy)
Gravel	1 to 100	10^3 to 10^5
Coarse sand	10^{-3} to 1	1 to 10^3
Fine/clay sand	10^{-6} to 10^{-3}	10^{-3} to 1

Returning to the analogy with the pipe flow, the transition from laminar to turbulent flow is characterized by the Reynolds number expressing the ratio of inertial to viscous forces. However, unlike the case of pipe flow, the flow in porous media does not have a uniquely identifiable "characteristic length." But we may avoid these questions here because we are interested primarily in low velocity groundwater flows, which are essentially laminar.

Confined Flow — Most of the deep geothermal aquifers are of a confined variety where flow is assumed to occur between two confining layers. When the hydrodynamic and rheologic statements of the conservation laws (mass and momentum) are linearized, we obtain the equation of groundwater movement, which leads to a parabolic equation,

$$\nabla^2 h = \frac{S}{T}\frac{\partial h}{\partial t} \quad \text{(at equilibrium, } \nabla^2 h = 0\text{)}, \quad (3)$$

where h is the piezometric (or hydraulic) head and S is the so-called storage coefficient. S is a dimensionless constant that represents the amount of water released from a column of aquifer having unit cross section under a unit decline of head. Later we will consider an example of transient contained flow. For further considerations see Ref. 14.

Unconfined Flow — In unconfined flow, we obtain

$$\nabla^2 h - 2\rho g \beta \frac{\partial h}{\partial z} = \frac{S_0}{K}\frac{\partial h}{\partial t}, \quad (4)$$

where β is the isothermal compressibility of the fluid and S_0 is the specific storage coefficient (which has the dimension of $1/L$). Usually one may neglect the time derivative term. But in general, the solution is much more difficult because the location of the free surface is not known *a priori.*

However, for the moderate temperature hydrothermal resources of the eastern United States, the flow problems are often made easier since the aquifers are usually of the confined variety. This situation changes when aquifer recharge effects are significant as a result of extensive resource use or for other reasons. When such situations arise, it is necessary to model the entire aquifer system, including the natural recharge region where the flow is unconfined. We will restrict our discussion to the confined flow regime.

Head Loss — In the case of head loss due to pumping in a homogeneous, isotropic, confined, horizontal, infinite aquifer, the equation of water movement is considerably simplified (it is a simple one-dimensional diffusion case with cylindrical coordinates):

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial h}{\partial r}\right) = \frac{S}{T}\frac{\partial h}{\partial t}, \quad (5)$$

which can be solved for the initial condition $h(r, 0) = 0$, subject to the boundary conditions $h \rightarrow 0$ as $r \rightarrow \infty$ and

$$\lim_{r \rightarrow 0} r\frac{\partial h}{\partial r} = -\frac{Q}{2\pi T}, \quad (t>0), \quad (5a)$$

where Q is the water (volume) removal rate. Actually, the precise limit is $r \rightarrow r_w$, instead of 0. The solution is

$$h(r_w, t) = \frac{Q}{4\pi T} E_1\left(\frac{r_w^2 S}{4Tt}\right), \quad (6)$$

where r_w is the well radius and E_1 is the exponential integral of order 1.[15] This is often called the Theis solution.

In most practical applications, the argument of the exponential integral is much less than 1, and thus may be approximated as

$$E_1(x) \approx -\gamma + \ln x \quad (x << 1), \quad (6a)$$

where $\gamma = 0.57721$ is Euler's constant.

Pumping Energy Consumption — We wish to know how much energy is expended in pumping the water at a constant rate, Q, to the surface over a period Δ. For this purpose, we assume that the initial head is at ground level. If there are no loss mechanisms, the work done against gravity is

$$\epsilon = \frac{\rho g Q^2}{4\pi T}\left[(\Delta + B)E_1\left(\frac{B}{\Delta}\right) - \Delta e^{-B/\Delta}\right], \quad (7)$$

where

$$B = r_w^2 \frac{S}{4T}. \quad (7a)$$

Once this is known, loss mechanisms such as pipe frictional loss and pump efficiency can easily be incorporated.

Equations 6 and 7 or their variants are useful in estimating the geothermal system performance. Such an estimate is needed in the early phases of systems engineering.

ENGINEERING, ECONOMICS, AND SYSTEM OPTIMIZATION

Reservoir Characteristics and Utilization Considerations

In geographic areas where the extent of the hydrothermal resource is not well defined, it is necessary to conduct a technical program to establish the temperature as a function of depth; the depth to basement rock; the location, thickness, permeability, and chemistry of the water in the waterbearing sediments; the lateral extent of the hydrothermal resource; and the opportunity for disposing of the spent water. Crisfield is one of the few locations in the eastern United States where at least some of these data now exist. At Crisfield, the water temperature and composition are known, as are the aquifer transmissivity and storage coefficient to a radial distance of approximately 2000 ft.

However, much is unknown that may affect the final cost and system optimization. Some of these unknowns are

1. Isotropy, homogeneity, and extent of the reservoir;
2. Reservoir recharge mechanism;
3. Possible precipitation of carbonates or other chemicals that may lead to gradual changes in permeability;
4. Transmissivity of the reinjection area and possible changes with time due to aquifer damage from suspended solids in the reinjected water;
5. Extent (laterally) of the aquiclude;
6. Environmental effects of sustained water withdrawal and reinjection in different geologic formations;
7. Allowable rate of withdrawal to minimize temperature drawdown;
8. Dynamics of the potentiometric head of the production zone with extensive use of geothermal water (this may require reinjection at a distance of, typically, 1½ to 3 miles into the production aquifer); and
9. Experience with and costs of the production and reinjection wells in deep unconsolidated sands in the coastal plain.

We will illustrate a system designed to provide the base load of space heating for Crisfield High School. The system uses the existing fossil fuel boiler as a peaking subsystem and as an emergency standby. The use of the peaking plant provides a method of optimizing the geothermal water withdrawal rate from the production well, thereby reducing well drawdown and, accordingly, minimizing annual operating and maintenance costs. It allows the system designers to select the amount of the base annual load that the geothermal system supplies. For Crisfield High School, the optimum hydrothermal base load is about 97%, with the remaining 3% supplied by the peaking system. For each application and resource area, the optimum will vary.

The Geothermal Wells

Two wells are often required for geothermal energy use, one for production of the water and another for reinjection. Each well extends through one or more formations, one (the production well) removing the hot geothermal water and the other (the reinjection well) returning the cooled geothermal water to suitable acceptor strata. Both wells usually are constructed in a similar fashion, with a series of metal casings of decreasing size cemented in place as the hole deepens. Valves and fittings are mounted at the top of the well to control water flow and to direct it to the user. The piping is designed to accommodate the thermal expansion caused by the warm geothermal water. Also at the top of the well are a motor and pumps to remove the water and to circulate or reinject the water. The production well pump is usually inside the casing at such a depth that it is always below the drawdown level of water; it is connected to the surface through separate production tubing within the metal casing.

In wells where geothermal water is saline and corrosive, components used in water handling must be made of appropriate materials. In Maryland, double casings separated by cement are currently required when well pipe traverses formations containing potable water. At Crisfield, this double casing is required down to a depth of approximately 1500 ft.

The connections between the casing and the rock strata producing the geothermal water are of three forms: (a) an open hole in the rock, limestone, or consolidated sandstone that will not disintegrate as water flows into the well void (a simple screen catches any rocks or pieces of the formation that may break loose); (b) a cemented casing with perforations in the production zone (i.e., holes through the casing and cement made by bullets or shaped explosive charges); and (c) a screen and gravel pack in formations where particles of sand or other rock material may be produced along with the geothermal water. A packing of different-sized gravel, graduated in size, is placed between the producing formation and a cylindrical metal screen pierced with many small slots that permit the passage of water, without the accompanying sands, into the well bore. The gravel pack reduces the water velocity in the unconsolidated formation and thereby minimizes the washing out and the movement of loose sand particles to the screen. Finally, the slots in the screen act as a filter to prevent sand particles from entering the well bore. This type of construction is typical of water wells and some oil wells in poorly compacted materials. The open well is the least expensive form of construction.

Unlike oil wells, which generally have low pumping rates (to maximize oil recovery), a geothermal well is usually characterized by a relatively large pumping rate to compensate for the modest specific energy content of the fluid. Therefore, it is necessary to design the well for a high flow rate. Water-well technology applies especially where it is known that sediments are unconsolidated and, therefore, well productivity may be modest.

Since the few geothermal wells that have been drilled are located primarily in the western United States, they are not necessarily a good indication of the cost of future production and reinjection wells in the eastern United States. Most wells have been exploratory in nature, with much drilling, testing, and technical development that would not be required for production wells. Such extra work results in much higher costs than would be reasonable to spend on a production and reinjection well in an area where the resource quality and its long-term characteristics are known. Current oil and gas production well costs are a reasonable indication of minimum possible costs for production or reinjection wells in areas where lithology and aquifer hydrology are well known. The costs are nearly linear with depth to approximately 7000 ft at $25 per foot (1977 dollars).[16,17] However, in the case of new wells at Crisfield (to heat the high school), detailed well design and cost are yet to be established. Accordingly, we will assume $70 per foot (1980 dollars) as a conservative value.

Production Well Pump Costs

Although some deep aquifers in the eastern United States are artesian, water usually must be pumped to provide the desired removal rates. Two types of pump are available. One is a downhole pump and motor assembly, which becomes mandatory when the necessary lift exceeds 1500 ft. For lifts less than this, one may use a vertical turbine pump with a motor at the surface connected to the downhole pump by a long vertical shaft. With this choice, it becomes feasible to attach a variable speed device (located at the surface), but it is necessary to have a number of bearings along the long shaft that connects the motor and the pump. Figure 4 illustrates the two types of pump systems. The second arrangement is readily available from the groundwater irrigation industry.

A discussion of the sizing, initial costs, annual maintenance requirements, and cost of the submersible downhole pump/motor is available in Ref. 18.

For the surface motor system, the submerged pump portion is identical to the totally submerged system. Because the surface motor is not constrained in size and can operate with higher voltages in a cooler environment, its reliability and life expectancy are greatly improved. Although detailed operating cost documentation is unavailable, surface motor systems have been in continuous use in the hydrothermal wells in Klamath Falls, Ore., and in Iceland. The mean life of the motor/pump system is 15 years or more, the critical item being the bearings supporting the long shaft. Lubricated phosphor bronze material is used in Klamath Falls; in Iceland, Teflon inserts have been used. In any event, the annual maintenance cost is substantially lower than that for the totally submerged system.

The cost of a vertical turbine pump adequate for supplying 100 gal/min of water with a pressure equivalent to 700 ft is $52,000.[19] This includes a variable speed hydraulic coupling between the motor and the vertical shaft to the pumps. The 700 ft head provides pressure in excess of expected well drawdown to force water through the school building heating system and the well-head heat exchanger.

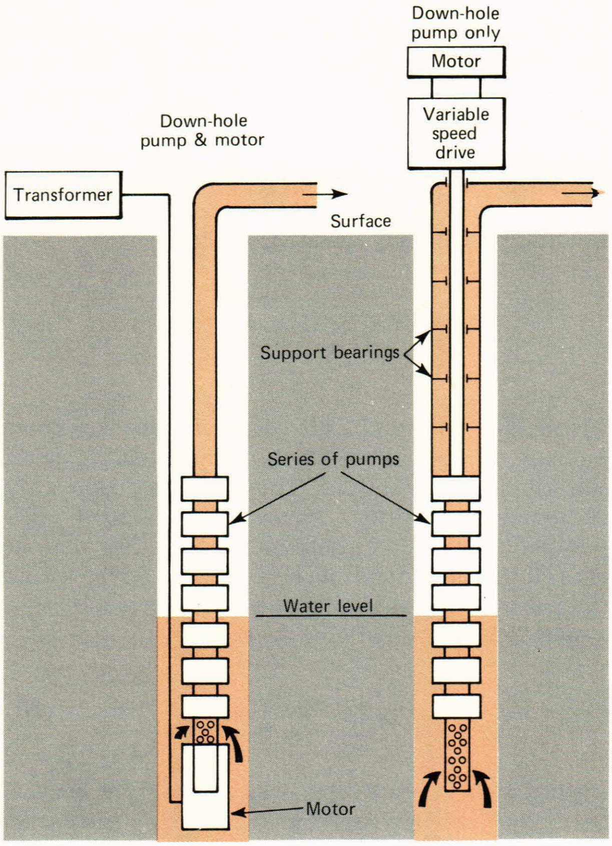


Fig. 4—Two motor/pump configurations to recover geothermal water.

Pumps of this type have had extensive use in handling moderate-temperature geothermal waters and, except for an annual removal from the well for inspection, require little maintenance. Annual costs are typically $2500 in Klamath Falls.

Drawdown, Production Cost, and Well Life

In many of the applications of hydrothermal energy, it is desirable to vary the pumping rate, Q, with time. This is particularly true in the case of space heating. In this case, Eq. 6 is replaced by

$$h(t) = \frac{1}{4\pi T}\left[Q_0\, E_1\left(\frac{B}{t}\right) + \int_0^t E_1\left(\frac{B}{(t-r)}\right)\, dQ(r)\right], \quad (8)$$

where Q_0 is the initial pumping rate. The associated energy expenditure in pumping from time t_1 to t_2 is, neglecting the loss mechanisms,

$$\epsilon = \int_{t_1}^{t_2} \rho g\; Q(t)\, h(t)\, dt\,. \quad (9)$$

For Q = constant, $t_2 = \Delta$, and $t_1 = 0$, this reduces to Eq. 7, as it should. Equation 9 gives the pumping cost (in energy units) incurred from t_1 to t_2. If reinjection is also necessary, the total pumping cost should be increased appropriately.

Since we are considering an extraction system operating cost, it is natural to ask when the energy expenditure rate becomes equivalent to the extraction rate. When they coincide, we have

$$\rho C_p (T_{out} - T_{inject}) = \rho g h , \qquad (9a)$$

where the left-hand side denotes the maximum amount of thermal energy extractable and C_p is the specific heat of the fluid. The right-hand side is the required pumping energy. Assuming the pump/motor system efficiency of $\approx 50\%$ and an electric power generation efficiency of 35%, we see that, for a rational operation of the geothermal system, we must satisfy the inequality

$$\left| \frac{dh}{dT} \right| < 136 \text{ ft/°F} . \qquad (10)$$

Inclusion of various other loss mechanisms reduces the right-hand side to about 100. Taking the energy expenditure in the reinjection and the circulation to be about equal to 1.5 times the production usage, the inequality becomes

$$\left| \frac{dh}{dT} \right|_{max} < 40 \text{ ft/°F} . \qquad (10a)$$

In view of Eq. (10a), one may define the well life as the time at which the left-hand side becomes equal to 40 ft/°F, due either to the increased drawdown or to the degradation of the thermal energy content of the geothermal water. Although each application will require that different temperatures be extractable from the geothermal water, a typical resource in the east is expected to provide a minimum temperature of 40 to 50°F, which is sufficient for space heating systems. For a well drilled into such a formation, the life may be taken as the time at which the drawdown is 1600 to 2000 ft.

In Figs. 5 and 6, we show the drawdown and the annual pumping energy consumption for a constant well pumping rate of 100 gal/min. Results for other (constant) values of Q can be obtained by scaling the drawdown linearly with Q and the pumping energy by Q^2.

Handling of Geothermal Water

The deep geothermal groundwater found in Crisfield had a salinity of 6.9% (about twice that of ocean water).[6] The concentrations of total dissolved solids will probably increase for wells at greater depths on the coastal plain and for the same depth in the interior sedimentary basins. Accordingly, a heat exchanger must be used to transfer the thermal energy from the well water to water whose chemical composition can be controlled, thereby minimizing the amount of plumbing exposed to the corrosive geothermal water. A compromise must be made between the efficiency and the size (i.e., cost) of the heat exchanger. The cost of the heat exchanger, piping between the two wells, a surface motor and reinjection pump, and structure to cover the wellheads (if required) at Crisfield High School were estimated in 1979 to be $100,000.

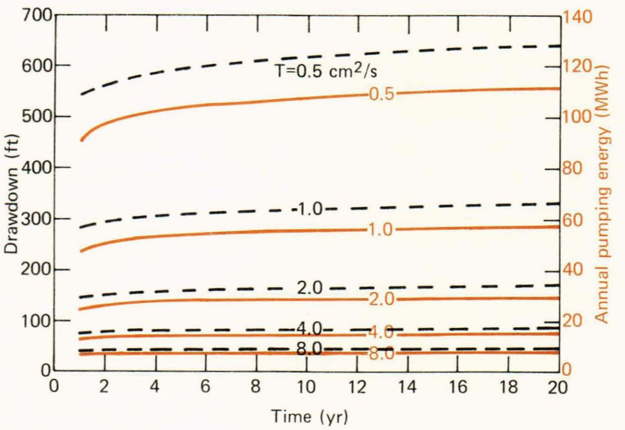


Fig. 5—Black curves show well drawdown as a function of time for constant utilization rate of 100 gal/min for several aquifer transmissivities. The other curves show annual electrical pumping energy (100% efficient motor and pump).

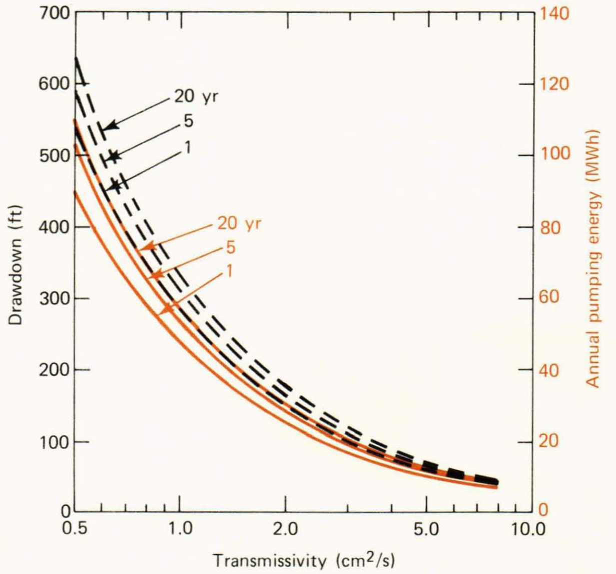


Fig. 6—Black curves show well drawdown as a function of aquifer transmissivity for three periods of continuous operation at a volumetric flow rate of 100 gal/min. The other curves show annual electrical pumping energy (100% efficient motor and pump).

The Peaking Plant

A standby fossil-fuel-powered peaking plant plays a most significant role in almost any geothermal application we have analyzed to date (Table 4). It can provide a small increment of temperature to the circulating hot water or it can be a completely separate, parallel system. It augments the geothermal system by increasing the peak heat rate capability needed for limited periods of time when the ambient temperature falls below a selected value. The annual load supplied by the peaking system is small (i.e., less than 10%). In the case of the conversion of an existing building, such as Crisfield High School, the existing fossil fuel boiler can be used as a peaking system. For a new installation, peaking plants are commercially available for a cost of approximately $16,000 per million Btu/h capacity (including building, controls, etc).

POTENTIAL USE OF HYDROTHERMAL ENERGY IN THE EASTERN U.S.

Space heating of residential, commercial, and industrial buildings uses a substantial amount of fossil fuel in the eastern United States. Any building located within the shaded areas in Fig. 1 probably could be heated with hydrothermal water, if available. The economics will, of course, vary in each locale depending upon the depth and temperature of the hydrothermal water and the transmissivity of the formations yielding the water. Groundwater at or below approximately 70°F can be used with water-referenced heat pumps for space heating. At temperatures above 70°F, geothermal water can be used for convective heating systems with large heat exchange areas. At temperatures above 110°F, geothermal water can be used with convectors of appropriate size, or its energy can be transferred to forced air. It is also practical to consider hybrid systems, as in France, where heat pumps recover thermal energy from partially cooled geothermal water prior to reinjection.[20]

Table 4

FUNCTIONS OF THE PEAKING PLANT

1. Matches user temperature requirements to resource
2. Allows system designer to select percentage baseload to be carried by geothermal
3. Can increase water temperature on demand
4. Provides emergency heat supply
5. Compensates for transmission and heat exchanger losses or variations in resource temperature or well productivity with time
6. Tends to standardize plant and residence heat exchanger
7. Provides method to optimize system
8. Allows system design to select well flow and thereby to limit well drawdown

There are many industrial, agricultural, maricultural, and other processes that require modest temperature sources. Only a very limited survey of these processes has been made in the eastern United States (Table 5).[21]

USE OF THE HYDROTHERMAL RESOURCE AT CRISFIELD

The hydrothermal resource near Crisfield, made accessible by the deep well 3.5 mi from town, provides salty water at 133 to 135°F. Withdrawal rates and duration of demand had to be scheduled to minimize well drawdown. Use of this resource to provide space heating of the high school (a 50,000 ft^2 building) illustrates the first application of a resource of this character. Limited use studies have been completed for growing shellfish[22] and for vaporizing liquefied natural gas.[23,24] DOE is soliciting proposals for use of the resource on Delmarva,[25] and many other applications will be developed.[26,27]

The High School

The number of heating degree-days in the Crisfield region is approximately 4000 (Fig. 7). The high school's oil-fired, circulating hot water heating system typically requires 57,000 gal/yr of heating oil to produce about 5×10^9 Btu/yr (at 65% efficiency) at a peak heating rate of about 3.6×10^6 Btu/h. The existing heating system is to be retained as a peaking system for use when the ambient temperature is below 30°F (Fig. 7). This tempera-

Table 5

INDUSTRIAL PROCESSES THAT CAN USE MODERATE-TEMPERATURE HYDROTHERMAL ENERGY

1. Vaporization of liquefied natural petroleum* (Refs. 23 and 24)
2. Scalding and clean-up water (130 to 160°F) for poultry eviscerating plant (Ref. 26)
3. Manufacture of fructose syrup from corn (125°F and up) (Ref. 27)
4. Preparation, cleaning, and cooking (120 to 220°F) in food processing (Ref. 21)
5. Drying of lumber and agricultural products (120 to 180°F) (Ref. 21)
6. Optimum salinity (20 to 35 ppt) and temperature control (70 to 80°F) for growing of shellfish and some other aquatic species (Ref. 22)
7. Alcohol distillation, either as a boiler preheat or direct distillation under limited vacuum (125°F and up) (Ref. 27)
8. Heating of greenhouses to grow cut flowers and vegetables (i.e., tomatoes and cucumbers) with appropriate heat exchange surface temperatures

*Temperature is not a primary requirement since thermal energy can be withdrawn from water down to near its freezing point; water availability is the critical parameter.

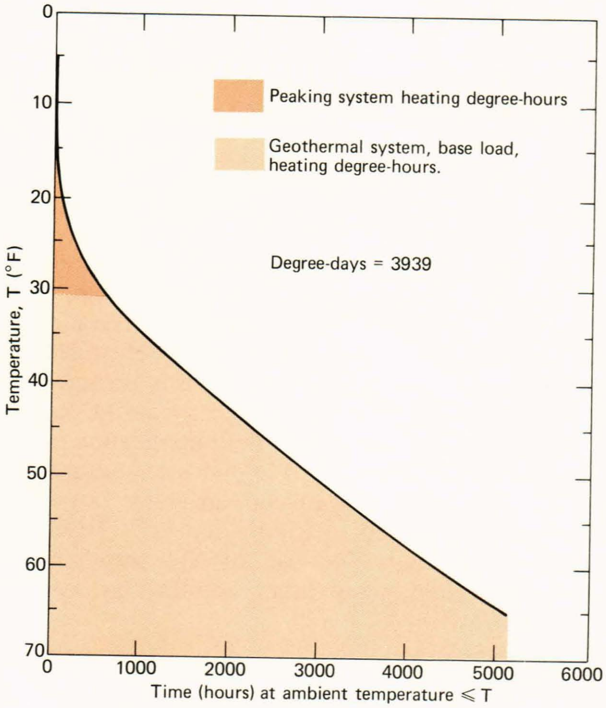


Fig. 7—Average annual temperature distribution below 65°F near Crisfield, Md.

ture was selected because, at that value, the geothermal well could supply the heat requirements with a volumetric flow rate of just under 100 gal/min, which results in a well drawdown of under 500 ft at the end of the heating season (Fig. 8). The well water level will almost recover its initial value before pumping is started again for a new heating season. Year after year, there may be a small residual drawdown, but this is not expected to exceed an additional 100 ft added to the annual pumping drawdown over a 20 year period. The selection of the design temperature to minimize drawdown allows the use of a reliable and long-life vertical turbine-type pump and motor, minimizing the annual cost of operating and maintaining the system. The capital costs of conversion of the school to geothermal energy can be financed out of the money saved from the fuel oil displaced minus the annual operating and maintenance costs. This new concept of financing will gain acceptance as the cost of fossil fuel increases.

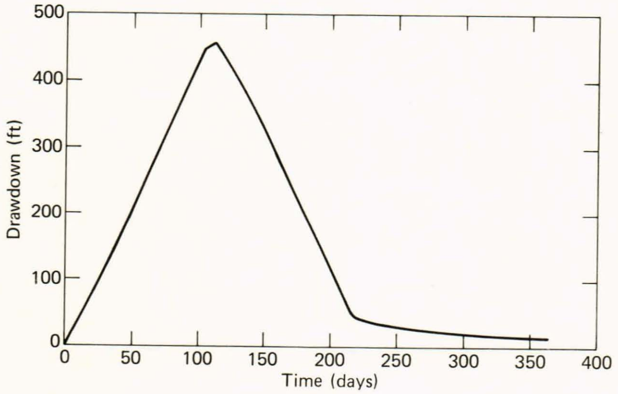


Fig. 8—Well drawdown as a function of time throughout the first year of operation at Crisfield High School.

A block diagram of the school heating system is shown in Fig. 9; included is a completely separate and parallel system using geothermal heat. The cost of the additional plumbing and its installation is estimated at $110,000.

Water well drillers are currently looking at the detailed designs and costs of geothermal production and reinjection wells in the Mid-Atlantic Coastal Plain. They estimate the cost of a 4200 ft production well and a 3000 ft reinjection well, complete with testing, to be under $500,000 (1980 dollars).

As stated previously, the vertical turbine pump, motor, and variable speed drive capable of providing a head of 700 ft are expected to cost approximately $52,000.

Capital Costs — Table 6 summarizes the capital costs for the conversion of Crisfield High School.

Annual Operating Costs — The electrical energy required to lift water against the well drawdown (Fig. 8) is $4500, with electrical energy at $0.05 per kWh.

The cost of annual inspection of the production well vertical turbine pump is estimated at $2500 per year.

Savings on Conversion to Geothermal Energy — The addition of a geothermal system to supply the base load of annual heating results in a substantial saving of oil. This saving can be considered to be a source of income to amortize the cost of conversion. The recent oil usage was 57,000 gal/yr. On conversion to geothermal heating, the annual oil

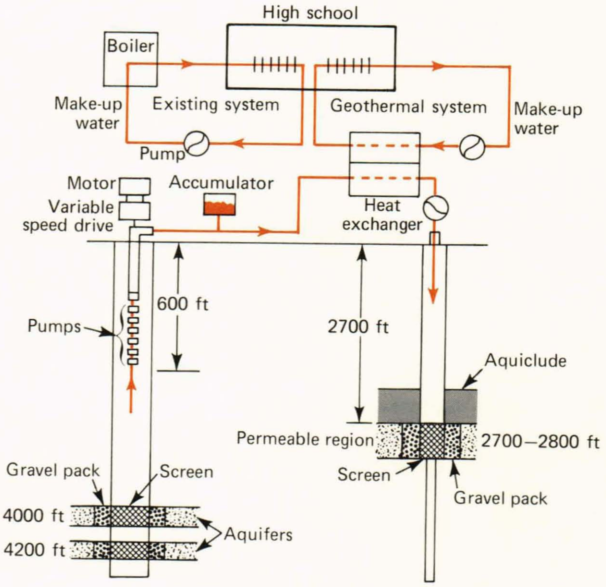


Fig. 9—Proposed schematic of a retrofit of the Crisfield High School heating system.

Table 6

CAPITAL COSTS OF GEOTHERMAL RETROFIT, CRISFIELD HIGH SCHOOL

	Dollars (thousands)
Additional radiators, plumbing, and installation	110
New geothermal wells, including 4200 ft production well, 3000 ft reinjection well, and testing	500
Heat exchanger, reinjection pump, well cover, etc.	100
Architect and engineering costs	70
Production well, pump motor, and variable speed drive	52
Total	832

use will drop to 1400 gal, saving 55,600 gal of oil. At a cost of $1.00 per gal and subtracting the annual costs of $7000, an annual saving of almost $50,000 is available to repay capital investments.

Payoff Period of Capital Investment — Figure 10 shows the number of years required to amortize the capital costs at Crisfield and the payoff period in years as a function of financial assistance that may be available (such as through the National Energy Act[28]) with the annual escalation rate of oil as a parameter. The curve is shown for the currently available interest rate of 7% for tax-free school construction bonds. As an alternative, 5% financing is available in Somerset County from the Farmers Home Administration.

The times to recover conversion costs are also shown in Table 7. The payback times assume that funds resulting from saved oil are used to amortize capital costs with no subsidy, assuming (a) a capital cost of $832,000 and (b) a conceivable 30% reduction in capital costs through improved design.

The influence of system cost reduction is profound in terms of a large reduction in the payoff periods. This indicates that, in the future, emphasis must be placed on reduction of the system cost, particularly for the moderate-temperature resources.

Table 7

PAYBACK PERIOD OF CONVERSION OF CRISFIELD HIGH SCHOOL TO GEOTHERMAL ENERGY HEATING

	Years of Payback Time			
	$832,000 *capital cost*		$582,000 *capital cost*	
Annual Escalation Rate of the Cost of Oil and Electricity (%)	5% *interest*	7% *interest*	5% *interest*	7% *interest*
0	36.6	—	17.9	25.0
10	12.1	13.5	9.1	10.0
20	8.4	9.0	6.7	7.1
30	6.7	7.1	5.5	5.7

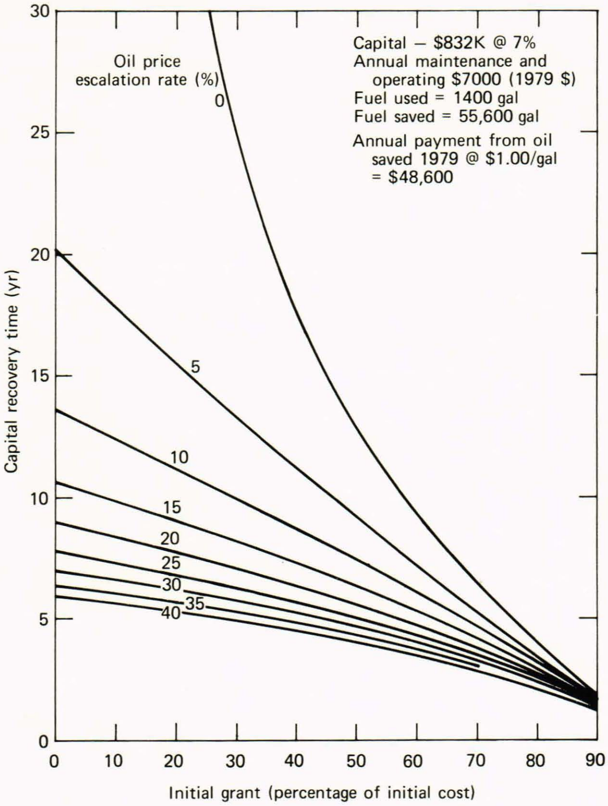


Fig. 10—Time to amortize a loan for the capital cost of the Crisfield High School retrofit using savings resulting from displaced fossil fuel. Escalation rate of the fossil fuel is a parameter. The effect of a grant or of aid to pay a portion of the initial capital cost is shown on the abscissa.

Community Heating System

For the moderately hot hydrothermal resources of the eastern U.S., a most promising use is expected to be residential or community heating, and one is naturally led to multiple-building heating systems. A community heating system requires a distribution system, which can add significantly to the initial capital expenditure requirement. Clearly, a high user density would reduce the per capita (i.e., per user) capital expenditure.

An element that adds a constraint on the system is the peak heating power required. For a single building, a design temperature near 30°F is usually adequate to ensure acceptable system characteristics (i.e., a moderate peak pumping rate and low overall system cost). Design temperature is defined as that temperature at which the peaking system starts to supply additional heat. For the community heating system, the production wells must provide enough geothermal water to meet a significant fraction of the total annual heating energy needs of the users. Since the maximum geothermal fluid production rate is limited by the hydrology of the resource, the reservoir characteristics become an even more important factor in the maximum rate of energy supply.

Evidently, the required heating energy is dependent on the number of users, the size of each building in the user complex, and the climate (or, more accurately, the expected annual temperature distribution). This leads to the dependency of the system on the annual heating degree-days of the locale.

We thus have a much more complex task in establishing the geothermal system feasibility, as well as sizing the total system. Resource characteristics, size of the buildings, user density, and annual degree-days now dictate the feasibility and optimization of the system design parameters. Clearly, the cost of the geothermal system (and, hence, the cost of supplied energy) would differ significantly for each set of parameters chosen. This problem is currently under investigation, and the preliminary results indicate a wide variation in the energy cost.

The mutual interference effect of two or more production wells can be significant.[24] An attractive way to reduce both well drawdown and expended pumping energy is to reinject the spent geothermal fluid into the same aquifer at a reasonable distance from the nearest production well. While this method would also reduce the risk of subsidence, it introduces a new problem, "thermal breakthrough." The cooled reinjected water will be reheated while flowing toward the production well primarily by extracting the heat energy stored in the aquifer skeleton (and the trapped water). The stored energy being finite, after some time a significant temperature drop will be experienced at the production well. This breakthrough time is proportional (a) to the ratio of the heat capacities (per unit volume) of the aquifer skeleton to the fluid, (b) to the square of the separation distance between the reinjection and production wells, and (c) to the inverse of the pumping rate. Reference 23 shows that, for a pumping rate of 100 gal/min and a well spacing of one and a quarter miles, the breakthrough time would be 640 years. It is thus seen that the reservoir engineering management and the community heating system optimization are intertwined.

INSTITUTIONAL CONSIDERATIONS FOR THE USE OF GEOTHERMAL ENERGY

Prior to extensive development of geothermal energy, legislative action must be taken by the federal, state, and local governments to define ownership, to establish environmental requirements, to enact permit-granting procedures and resource-use rules, and to provide regulations and management procedures. Furthermore, the costs and life expectancy of hydrothermal systems and their potential for displacing fossil fuel must be established in order to attract commercial financing.

Legal

Maryland, Louisiana, and Texas are the only states in the east that have enacted geothermal legislation.[29,30,31] The National Conference of State Legislatures, under sponsorship of DOE, is currently assisting Delaware, Virginia, and South Carolina in formulating geothermal legislation. Other eastern states' legislatures are expected to follow.[32] New legislation is required where existing laws preclude geothermal development. For example, in Delaware and Virginia, reinjection of water into the ground is currently prohibited.

The question of ownership of the geothermal energy resource must be carefully set forth in legislation and not left as ambiguous as it is in the current Maryland law. It may be that public ownership and allocation of the moderate-temperature geothermal resources will be necessary to promote their timely development and minimize their cost. The alternative is private ownership, where the geothermal resource is treated as a mineral resource. This is the type of ownership cited in most of the western and Gulf states, with geothermal laws requiring establishment of rules and regulations to determine the surface owners who share the geothermal resource, the royalty payments, and the rights to development of the resource. A similar problem in oil and gas field development is termed unitizing. (Unitization is the combination of adjacent oil leases for efficient operation, in which the value of oil, regardless of where the production wells are located, is allocated among the properties according to some reasonable formula.) Implicit in this definition of ownership are the costs to the potential developer that are not included in this paper, i.e., establishing the extent of the geothermal resource, lease or royalty payments, and contractual documents for area development (similar to the costs of commercial mineral exploitation).

Resource Engineering and Management

As discussed previously, these are separate but related functions that are crucial to the successful commercialization of geothermal energy. Resource engineering establishes the resource parameters sufficiently well to allow a prospective user to estimate the amount of energy recoverable at a given locale, the engineering details of the extraction and reinjection system, the life expectancy of the resource, and the cost of the energy extraction as a function of time. The costs of geophysical, geologic, and hydrologic engineering data to determine the engineering characteristics of the geothermal resource can be considerable, and they may be beyond the reach of the average potential user of the moderately hot water resources in the eastern United States.

The regulatory responsibility for the states is to ensure that a geothermal well temperature or drawdown with time is not adversely affected by the granting of licenses for sites that are either too close or too large in their withdrawal of thermal water. Geothermal energy development in the east is not analogous to oil field development where much of the reservoir engineering is done by oil companies. For moderate-temperature hydrothermal resources, the economic incentive is not great, and, accordingly, this function is best done by the individual states. It is suggested that the federal government provide aid and guidance for eastern states not conversant with oil and gas field development. To assist the states, DOE is developing a set of analytic tools for reservoir modeling and management[33] and is establishing state geothermal planning and resource assessment teams to adapt these techniques.[34]

Financial

Hydrothermal energy recovery systems are capital intensive since they may require deep, sophisticated, and expensive wells for water extraction and reinjection. In the application to space heating of a community with separate buildings, the cost of piping to distribute the warm water and to collect the cooled water can exceed the cost of the wells. However, if the costs of delivered energy (including maintenance and operating costs) are less than the cost of comparable energy delivered by fossil fuel, then financing can be made available. Reliable data on life expectancy of eastern hydrothermal resources and the probability of drilling successful wells in a given locale are the biggest unknowns. Except in France, Hungary, and Iceland, where geothermal energy has been in use for years, there is little systematic data available on hydrothermal well productivity and thermal history. The federal government either has in place or is planning incentives to limit the risk due to the lack of firm estimates of hydrothermal well drilling success and well life. These are in the form of a loan guarantee program[35] that indemnifies investors against well failures, either initially or prematurely. The Farmers Home Administration has a similar loan guarantee program for business and industry in rural communities and small cities.[36] DOE is currently initiating a user coupled resource confirmation program that will partially indemnify a prospective user if the hydrothermal well is not completely successful.[37] In the Delmarva area, a variant of this plan is currently available, termed the Eastern Geothermal Drilling Project.[25] To stimulate the development of additional geologic data on the resource and to encourage well development, DOE will pay a substantial portion of the cost of the geothermal wells and their testing if a user will install appropriate equipment and put wells to use demonstrating long-term viability and economics.

Environmental

The recovery of thermal energy from geothermal waters in the eastern United States is considered to have minimal impact on the environment. This is partly due to the fact that geothermal water is handled totally within a closed system from production to reinjection. Should some parts of the surface components get damaged, the production system can be readily deactivated to minimize the release of water at the surface. Further, in cases of significant water-removal rates, reinjections into the same aquifer at suitable distances will assure the limited head loss in the aquifer, thereby eliminating the possibility of land subsidence. Protection of potable water aquifers can usually be achieved by appropriate well design.

SUMMARY

The hydrothermal resource at Crisfield can displace fossil fuel and pay for itself in a reasonable time period if used for space heating. If used for industrial process heat (where the annual utilization factor can be more than twice that of space heating), the payback period can be proportionately shorter.

Since the resource at Crisfield is of the near-normal gradient type, similar resources would underlie essentially all of the Delmarva Peninsula, if water is present. As the depth to the basement rock and the thickness of the deep sand sequences increase toward the east, the wells will be deeper and possibly may produce greater quantities of higher temperature water. Thus, the increase in the well costs may be offset by the corresponding decrease in the production cost.

Since the required reservoir data in the eastern United States are so scarce, it is premature to pass a verdict on the merits of geothermal heating systems. It is expected, however, that in a significant number of areas, such geothermal systems will have acceptable qualities. Thus, one may look forward to resource exploration and assessment programs to provide the necessary data.

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