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THE FUTURE OF DIRECT UTILIZATION OF GEOTHERMAL ENERGY

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ABSTRACT

The future of direct utilization of geothermal energy in the United States is addressed from quantitative and qualitative viewpoints. A possible nonelectric geothermal energy applications scenario based upon development at 38 preselected sites is presented. This scenario was constructed without the benefit of real market factors, demography, local weather data, etc. It does, however, represent a first effort at estimating the possible growth of nonelectric usage in this country. The total annual energy consumption represented by this scenario is disappointingly low, even though the individual developments are relatively large scale when compared with some of the DOE sponsored ongoing studies. This result points to the need for serious consideration of studies for very large applications. Finally, some very preliminary calculations are given for the main supply system for a city of 100,000. The temperature losses, pumping energy costs, and supply system costs, other than wells and land, are shown to be quite low for transport up to ten miles.

BACKGROUND

An overview of the historical energy consumption patterns in the United States shows the cyclic nature of our consumption of three major energy resources, wood, coal, and petroleum, with the clear implication of the periodic need for development of new resources. To further reinforce this, attention is directed to one predictive method of evaluation of our future supply of petroleum. Assuming a bell-shaped depletion curve wherein increased usage and consumer demand forces and availability factors for an exhaustible resource exist in a free market, a widely held model is one in which maximum usage or supply coincides with the point of one-half depletion of the resource. Coupling this with estimates of the total petroleum resources originally on this planet, which range from 1.74 to 2.0 x 10^{12} barrels, the worldwide use rate and knowledge of past cumulative consumption enables us to estimate the point in time when we will have used half of this resource. The result is easy to obtain and sobering --if we could sustain the historic eight percent worldwide energy growth rate, we would esstentially deplete the world's petroleum by the year 2000! Clearly this will not happen. Market forces will moderate usage, and petroleum will undoubtedly be available, albeit at increasingly higher real cost, considerably beyond the turn or the century.

Turning our attention to American production of petroleum together with our imports for the decade 1965-1975, we find that domestic production peaked in 1970, which may indicate one-half depletion of our domestic resources. Also, our imports continued to increase markedly during this period except for the decline due to the Arab oil embargo in 1973.

Given this future petroleum availability problem, the obvious question is how much of our present energy requirements are now being satisfied with this resource? Examination of our present domestic energy use pattern indicates that our usage naturally falls into three main categories, residential and commercial space conditioning, industrial processing and transportation. The first two of these are slightly larger than the last, but roughly speaking, each category represents one-third of our national need in the near-to-intermediate time frame, since transportation requirements have recently been increasing more rapidly than the other two.

Oil and natural gas supply roughly 75 percent of our residential and commercial space conditioning energy, approximately the same percentage of our industrial processing energy, and essentially all of our transportation energy at present. This picture, coupled with the rather dismal future for petroleum, highlights our problem. In addition, it points to the areas in which we can focus attention on satisfying our needs with other resources. Clearly, the technology exists for meeting many of our non-transportation energy needs with other energy resources, particularly with geothermal energy.

Before turning to nonelectric geothermal possibilities, it is important for us to have a grasp of the magnitude of our national energy needs and overall energy resources for the near-to-intermediate time frame, say at least until the year 2000.

Our total domestic energy requirements for the period 1975-2000 are estimated to be from 2400 to 2900 quads. Estimates of recoverable domestic resources are:

Gas	1,030 quads
Oil	1,100 quads

Geothermal	3,434 quads
Oil Shale	5,800 quads
Coal	13,300 quads
Uranium	
Light water reactors	1,800 quads
Breader reactors	30,000 quads
Fusion	3×10^{12} quads
Solar	43,000 quads/years

The major points germane to our discussion center on the time frame appropriate to each of these energy sources. Given the present administration's position toward the LMFBR program and the required development time, we must rule out this as a possible contributor for the time frame of interest. Clearly, the present status of the fusion program and the very long projected lead time for its development indicate that this is also not a possible contributor for the time of interest. Thus, we are left with

- natural gas
- oil
- geothermal
- oil shale
- coal
- light water reactors
- solar

as major contributors. The only one of these theoretically capable of meeting all of our future energy needs is solar energy. The practical limitations on its development, however, are very well known and will not be discussed in depth here. As a simple illustration of this problem, current state-of-the-art technology for solar heating of an 1800 square foot residence in a southern U. S. city with 4000 degree-days of annual heating requirement dictates the use of approximately 600 square feet of flat plate collector surface costing about $7,800 for the collectors (not installed). This, coupled with the installation, energy storage system and control system costs, typically results in an estimated system cost of $15,000-$20,000. And the solar system would also require an auxiliary heating system for extended inclement winter weather (beyond three days)!

Clearly, of the available near-term resources, geothermal is the largest and the most readily suitable, other than oil, gas, and coal, for extensive commercialization. Many of our geothermal resources are better suited for direct thermal use than for production of electricity. This is a simple result of the temperature being so low as to preclude economical conversion to mechanical work due to the very low Carnot cycle efficiency. On the other hand, these same low temperature resources, especially hydrothermal ones, are ideally suited temperature-wise for many industrial, agricultural, aquacultural and space conditioning needs. Indeed, the use of a very high temperature resource of any type to satisfy a low-to-moderate thermal need is a serious waste of our national resources! A direct corollary to this idea is that the attempt to use a low temperature resource of any kind to generate mechanical work in order to obtain electricity is also a serious waste of resources due to the very low overall efficiency.

NONELECTRIC APPLICATIONS SCENARIO

The most likely early nonelectric uses of geothermal energy are space conditioning of residences and businesses, industrial processing, and heating of greenhouses and other agri-aquaculture applications. To examine the possible rate of adoption of geothermal energy, the Division of Geothermal Energy has outlined the steps required to develop over 350 modular heat-using facilities or units that were postulated for 38 prospective geothermal sites [1] *. A scenario that describes these developments has been prepared based upon a schedule of additions of new thermal energy on-line from the present through the year 2013. Sequenced scheduled activities of landowners, supply use contractors, and governmental agencies that would participate in the development of each unit of energy on-line by year were thus developed. It should be emphasized that this is a first-cut exercise, and that it was undertaken without the benefit of local demographic, market factor and weather data. It is planned to refine this effort through DGE's operations research regional contractors.

The preliminary study was based on available heat capacity and very tenative possible application information for each of the 38 sites. The sites chosen are distributed geographically as follows:

Region	Number of Sites
1. California, Hawaii	9
2. Gulf of Mexico	1
3. Northwest	16
4. Southwest	11
5. East	1

Heat Load Assumptions

The following assumptions were used for all sites:

1. Space Heating/Cooling Development. The smallest applicable unit was assumed to consist of 600 homes plus the commercial equivalent of 150 homes. This would require a peak heat production rate of 45 million BTU per hour (MBtuh). The largest installations (near a large city for example) were assumed to be twice as large, requiring a peak heat demand of 90 MBtuh.

2. Industrial Development. The average size of an industrial unit was assumed to result in a peak demand of 35 MBtuh in the absence of specific heat load information.

3. Agricultural/Aquacultural Development. For a large agricultural application, the peak thermal load was assumed to be equivalent to that of a typical industrial unit, 35 MBtuh. The peak

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*Numbers in brackets denote references at the end of the text.

demand for smaller, more prevalent applications such as greenhouses and aquaculture was assumed to be that required for three typical greenhouses, and this results in a peak demand on the order of 0.5 MBtuh for a small agriculture unit.

Timeline Assumptions

The total development of a particular site was assumed to proceed until a predetermined site capacity for nonelectric development was reached. From the start of development at a residential/commercial, industrial, or agricultural prospect at time T_O, developmental activities for the first three units and for units four and beyond were postulated to be as shown in Table I which is taken from reference 2. All times are shown in years.

TABLE I

NONELECTRIC ACTIVITY SCHEDULE
(All Time in years)

Activity	Units 1-3		Units 4 and Beyond	
	Timeline	Milestone	Timeline	Milestone
Process leases and environmental assessment report	T_o-1.25yr		T_o-1.00yr	
Lease land		1.25yr		1.00yr
Geophysical exploration and resource assessment	1.75-4.00		1.50-3.00	
Exploratory drilling--final decision		2.50		2.00
Drilling and reservoir characterization	2.50-4.50		2.00-3.00	
Thermal supply system development--final decision		4.50		3.00
Prepare environmental data statement--certify facility--obtain permits--process EIS	4.50-5.75		3.00-4.00	
Field development, including drilling and production tests	5.75-6.75		4.00-5.00	
Construction--energy supply system	5.75-7.75		4.00-5.50	
Construction--utilization system	5.75-7.75		4.00-5.50	
Direct heat application on line		7.75		5.50

The time intervals between the start of development of the first unit at a given site and the start of the second unit at that site, and so on, were assumed to be as given in Table II, adapted from [2], for "typical" and "extended" rates of initiating development. The "Extended Starting Time Interval" column of this table is applicable to only three sites postulated for slower paced development.

TABLE II

TIME INTERVALS IN INITIATING NONELECTRIC UNITS
(A SINGLE SITE)

UNIT	TYPICAL STARTING TIME INTERVAL (YR)	EXTENDED STARTING TIME INTERVAL (YR)
1-2	2	3
2-3	1	2
3-4	1	2
4-5	1	1
5-6	1/2	1
6-7	1/2	1
7-8	1/2	1
8-9	1/2	1
9-10	1/2	1/2
10-11	1/2	1/2
11-12	.	.
.	.	.
.	.	.

Additional Assumptions and Procedures

- The development of each site was assumed to start in either 1978 or 1979 in the absence of specific information to the contrary.
- A graphical format was used to depict the development of each site and complete results are given in reference 3. This shows all major activities, including those by Federal agencies, required for sequenced development of the entire site.
- Thermal peak power was assumed to be the sum of the design maximum capacities for all units at a site.
- Peak residential thermal heat loading was assumed to be 60,000 Btu/hr per home. The average thermal loading, however, is probably in the 15,000-20,000 Btu/hr range.
- The more demanding space cooling requirements to be handled were assumed to be equivalent to the cold climate heating energy requirements. Even though measured cooling degree-days are usually less than heating degree-days, the absorption refrigeration systems are less efficient than heating systems.
- Some of the nonelectric prospects are situated in the same region with prospective geothermal electric sites, however, combined cascaded usage is not assumed because of concern with operating interactions.
- Small agricultural applications (units of 0.5 MBtuh) were combined with the higher residential/commercial heat demands in all cases where both types of applications were postulated at a given prospect.

- The preliminary scenario is based on the premise that DOE/DGE R & D activities will be required for only the initial unit to be developed at each of the 38 prospective sites.

Scenario Summary Results

Using the preceding thermal load, timeline and other assumptions, a possible nonelectric thermal development in integral units of Residential/Commercial Space Conditioning, Industrial and Agricultural/Aquacultural applications was prepared for each of the 18 preselected sites. Site-estimated thermal capacities ranged from a low of 85 MBtuh to a high of 3,400 MBtuh. Development of the smaller sites was achieved with as few as two units, whereas some of the larger sites required tens of units with development extending from 1978 until 2013.

Figure 1, adapted from [2], graphically illustrates the summary results of this scenario. This is a plot of cumulative peak power on line between 1980 and 2013. In 1990, for example, the combined Residential/Commercial/Agricultural installed applications represent a peak thermal power demand approaching 5200 MBtuh. Altogether, this indicates a peak power demand of about 10,000 MBtuh for the year 1990. The maximum peak demand occurs at the completion of development in the year 2013, assuming all units to remain fully operational, and this is shown to be 17,000 MBtuh.

Annual Nonelectric Energy Usage

Using the peak installed thermal power for each site and suitable capacity factors for each type of application permitted estimation of the annual energy consumption by site. The following simplified approach for estimation of capacity or load factors was employed.

For Residential/Commercial/Agricultural units, the load profiles for either heating or cooling were assumed to represent an average power demand of one-fourth the peak magnitude during the seasonal period of utilization. Furthermore, the heating or cooling loads were each estimated to last a half-year, with no overlap. Also, one-third of the installations were assumed to be used for both space heating and cooling (or some other combined usage), and the remaining two-thirds were considered to employ heating or cooling only. The resultant capacity factor was thus estimated as:

$$\left(\frac{2}{3}\right)\left(\frac{1}{4}\right)\left(\frac{1}{2}\right)+\left(\frac{1}{3}\right)\left(\frac{1}{4}\right)1 = \frac{1}{12}+\frac{1}{12} = \frac{1}{6}$$

For Industrial applications, the average load during periods of thermal utilization was estimated to be maintained at a level nearer the maximum, assumed to be 80 percent of the peak. Also, the average thermal utilization time (duty cycle) was estimated to be 50 percent. This will vary considerably from industry to industry: For example, some plants will use process heat full time;

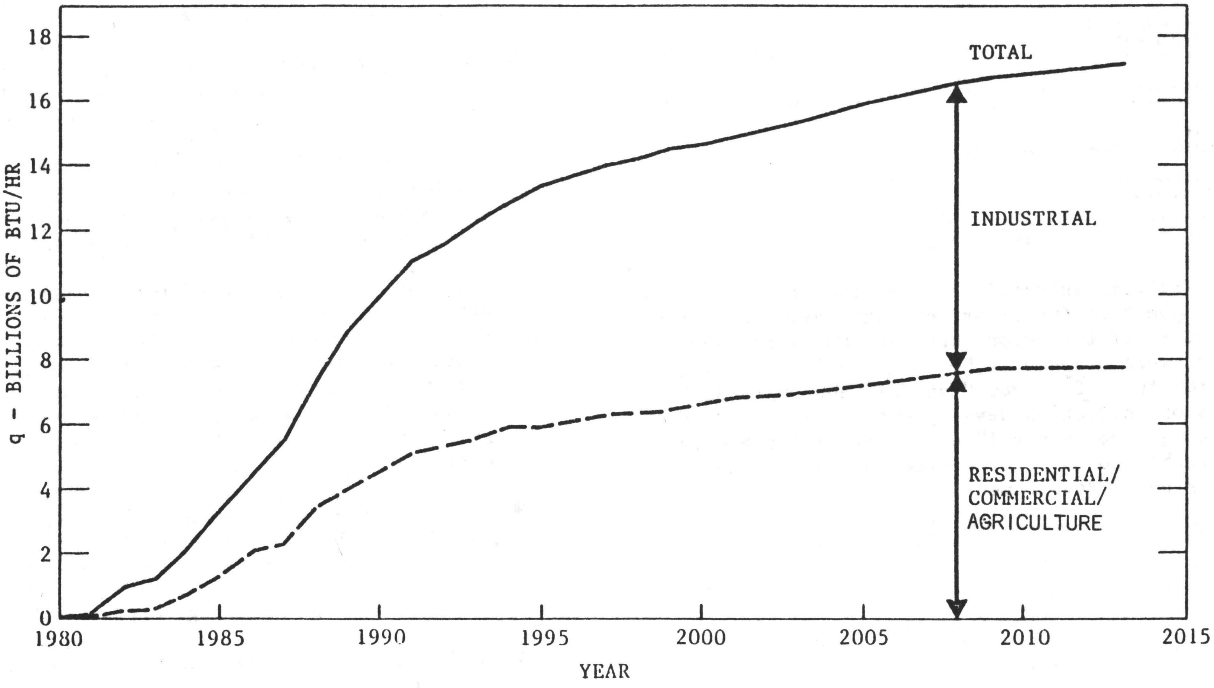

FIGURE I - CUMULATIVE PEAK THERMAL POWER ON LINE others will operate only during a 40-hour work week; some will function at full load during the day and reduce to fractional load throughout the night; and some will require energy on a short seasonal basis, (e.g., crop drying). In addition to these periodic thermal load demands, industries will experience varied scheduled/unscheduled outages for maintenance. The resultant typical capacity factor used for the spectrum of industry was:

$$(0.50)\ (0.80) = 0.40$$

Table III, adapted from [2] summarizes the annual nonelectrical heat energy estimated to be supplied by geothermal resources to Residential/Commercial/Agricultural (R/C/A) and Industrial (Ind) users. One observation is the relatively low cumulative annual energy demand imposed by nonelectric geothermal users at the 38 specified sites, only 0.04 Q per annum in year 2000. Moreover, the growth shown in succeeding years is small. Thus, further efforts to sustain growth in non-electric uses of geothermal energy should be pursued.

TABLE III

ANNUAL NONELECTRICAL HEAT ENERGY FROM GEOTHERMAL SOURCES

	Nonelectric Energies			
	Year			
	1985	1990	2000	2010
Peak Installed Thermal Power (MBtuh):				
R/C	1391	4854	6970	7960
Ind	1870	5123	7915	9060
Annual Peak Energy (Trillion Btu):				
R/C	12.19	42.52	61.06	69.73
Ind	16.38	44.88	69.34	79.37
Annual Avg. Energy (Trillion Btu):				
(R/C) x 1/6	2.032	7.087	10.176	11.622
(Ind) x 0.4	6.552	17.951	27.734	31.746
TOTAL	8.584	25.038	37.910	43.368
	0.009	0.025	0.038	0.043
Million Bbl. Oil, equivalent*	1.64	4.80	7.26	8.31

* Crude oil heat value = $5.8 \times 10^6 \frac{\text{Btu}}{\text{Bbl}}$ x 0.9 combustion efficiency.

PRELIMINARY RESULTS FOR A LARGE APPLICATION

As a simple example of the feasibility of pumping geothermal fluid a significant distance for a large-scale application, the case of supplying a peak load of 3.25×10^9 Btuh from a resource at 180°F for heating a typical city of 100,000 in a climate resulting in a 4000 degree-day heat requirement was considered. The design selected resulted in:

Design Heat Load	3.64×10^9 Btuh
No. of supply pipes	3
Pipe diameter	36 inches
Flow Reynolds number	5×10^6
Pumping distance	10 miles
Pressure drop, frictional	69 psi
Pumping horsepower, total	2445
Pipe Insulation, fiberglass block	6 inches
Temperature loss, well head to city, for 12°F outside temperature	0.43°F

These engineering factors appear to be very promising; consequently, a preliminary cost estimate was undertaken. The main supply system, exclusive of wells, land acquisition, and right-of-way costs, was estimated to be $31,359,000. This figure consists of costs for a pumping station, main transport pipes, storage tanks, pipe insulation, and an auxiliary heating plant. The storage tank was sized for 20% of the peak daily city load, and the auxiliary heating system, fossil-fueled, was sized to supply up to 1.5×10^9 Btuh for meeting severe weather heat loads.

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