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STUDIES OF GEOTHERMAL POWER AND PROCESS HEAT APPLICATIONS IN ST. LUCIA AND GUATEMALA

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ABSTRACT

Many countries have the potential to use geothermal energy for both power production and process heat applications. Two Los Alamos programs have studied the most effective use of geothermal energy in St. Lucia and Guatemala. The general objectives are (1) to reduce oil imports; (2) develop employment opportunities; and (3) make products more competitive. The initial St. Lucia studies emphasized power generation but a number of applications for the power plant's residual heat were also found and costs and systems have been determined. The costs of geothermal heat compare favorably with heat from other sources such as oil.

In Guatemala, the development of the nation's first geothermal field is well advanced. Process heat applications and their coordination with power generation plants are being studied at Los Alamos. Guatemala has at least two fields that appear suitable for power and heat production. These fields are close to urban centers and to many potential heat applications.

INTRODUCTION

One of the programs at the Los Alamos National Laboratory has as its goal the assisting of Central American and Caribbean Basin countries with their energy problems. Because a number of these countries have promising geothermal resources, one facet of the program is concerned with the development of this type of energy resource both for the generation of electricity as well as for directly using this same source of energy to provide process heat.

Although many developing countries have substantial indigenous energy resources, these resources are frequently not developed because of the lack of either the necessary technical expertise or the needed capital. Consequently these countries depend upon the importation of petroleum to satisfy their energy needs, which in turn aggravates balance-of-payment problems. Thus the goals of the author's portion of the program are to investigate the substitution of geothermal (indigenous) heat for imported oil, the reducing of energy cost, and possibly the introduction of new industries providing local employment.

The investigation for St. Lucia was initially concerned with the generation of electricity, but the heat remaining in the geothermal fluid after the generation of electricity was found to be still useful for process heating. In the investigation for Guatemala the primary interest of the authors was in the direct application of geothermal energy to provide process heat. However, the generation of electricity can provide an excellent method of load leveling so again a combination of energy uses is proving of interest.

ST. LUCIA

St. Lucia is in the Windward Island Group of the Lesser Antilles of the West Indies; its location is shown in Fig. 1. A more detailed map of the island is presented in Fig. 2 which shows the location of the capitol, Castries, the industrial park area at Vieux Fort, and the location of the geothermal area at Sulphur Springs near Soufriere. A comprehensive survey of the magnitude and detailed location of the geothermal resource was carried out by the Los Alamos National Laboratory with the use of geologic, geophysical, and geochemical studies. The encouraging results led to the conclusion that a large geothermal reservoir with temperatures in excess of 250°C lies approximately beneath the Sulphur Springs area at a depth between 1000 and 2000 meters. At least three locations near Sulphur Springs were considered worthy of further drilling. Figure 3 shows the geothermal area in greater detail and includes the three sites recommended for drilling [1].

LUCELEC, the St. Lucia Electric Utility Co., now generates electricity with the use of 2.6 MW Diesel powered generators. At the time of the study the average electric power consumption was about 8 MW, with a peak of 12 MW. Although the maintenance is excellent, many of these units are approaching the end of their useful lifetime.

With the conservative assumption of a 2.5 MW capacity for each successful production well a schedule was devised for the introduction of the geothermal electric power. This schedule is designed to make the capacity factor of each new well-generator system high enough to make its use economical and also to make the total generation capacity compatible with the growth of electricity consumption as predicted by LUCELEC. The resulting schedule is shown in Fig. 4 which also indicates the continued use of Diesel powered generators to provide peaking power. Although it is believed that the capacity of the geothermal field can be higher, the cost estimate for the electricity produced from geothermal energy was based on a total capacity of 30 MW [2].

In order to estimate the cost of generating electricity it was necessary to consider a specific system. Figure 5 shows the system used for the cost estimate and in Table I the values of some of the system parameters are listed.

The cost estimating was done, not only for the electricity produced from geothermal energy, but also for other generation methods such as the continued exclusive use of Diesel engines, the use of Diesel engines only for peaking power, an oil-fired power plant, and a coal-fired power plant. To make this comparison consideration must be given to the fact that each plant requires a different costing schedule, some requiring a large initial investment followed by a smaller operating expenditure, while others have a low initial investment followed by a larger, continuing expense for fuel. Along with this the effects of inflation, interest on construction, and return on investment must also be considered. To make a fair comparison a Los Alamos computer code, BICYCLE, was used. The BICYCLE code keeps track of the investments as they are made as well as the revenue from the plant production and then computes a levelized life-cycle cost (LLCC) per unit of production (kWh in this case). The LLCC is given in constant, base year dollars for each of the methods considered, and the comparison of these LLCC's then gives a fair method of comparing the cost of two different processes for producing the same product. The BICYCLE code input includes a schedule of construction costs as well as the operating cost for each year of plant operation. Some other inputs are the interest to be paid on construction loans and the expected rate of inflation over the life of the study period. For this study a well drilling cost of $1000 US per meter of depth and a well depth of 2000 m were assumed. Typical of the construction costs to be included are the site preparation, drilling rig shipping, buildings, well drilling costs, generation equipment, piping and valves, and instrumentation and controls. Operating costs include fuel and electricity costs, equipment maintenance, salaries for operating personnel, well maintenance, and drilling of replacement wells at the end of their 20 year assumed lifetime.

With these assumptions and a number of others it was possible to compute LLCC's for the above mentioned methods of electricity generation, and the results are given in Table II where it can be seen that the geothermal electricity ($0.06 US per kWh) is the least expensive. The cost for the Diesel generation ($0.09 to $0.10 US per kWh) was in good agreement with the existing cost in St. Lucia for Diesel generation ($0.10 per kWh). With total electricity generation according to the schedule shown in Fig. 4 and with the costs shown in Table II it can be seen that over the 30 year lifetime of the study a monetary saving of $94,000,000 US can be made. During this same period a saving of 10^9 liters (231,000,000 imp. gallons) of Diesel oil can also be realized by St. Lucia. [2,3]

In the study of the generating system shown in Fig. 5 it was noted that a great deal of energy still remained in the geothermal fluid being reinjected into the ground. For the conditions assumed (see Table I) the liquid stream leaving the steam separator still contains about 4.7×10^{10} J/hr (44,600,000 Btu/hr). This is referred to as "residual heat." If one were to consider dedicating a well with the same flow rate for the direct use of process heat (no electricity production), then 10^{11} J/hr (95,600,000 Btu/hr) would become available. This is referred to as "primary heat." It then became of interest to see whether this quantity of heat was at the proper temperature level to be useful to either existing industries or to industries which would be appropriate for St. Lucia's economy.

In Soufriere, about 2.4 km from the proposed well sites there is a copra processing plant that is now using bunker C petroleum as the source of its process heat. The required temperature level is compatible with the 160°C temperature of the fluid leaving the steam separator, and the plant manager was very interested in obtaining the geothermal heat as soon as possible. Another existing possibility is the use of the residual hot water to provide hot water for the tourist hotels near Soufriere. Unfortunately these two industries could utilize only a very small portion of the residual heat from one well that is being used to produce electricity, see Table III. More of the available heat could be used either by a longer delivery system that could transport the heat to the industrial park area at Vieux Fort (about 21 km away) or by creating additional industries in the Soufriere area. At Vieux Fort one industry that could utilize the geothermal heat is the brewery. Possibilities that appear worthy of more detailed examination include such new industries as production of banana chips from the portion of the banana crop that is not exported, the drying of timber, or the production of fuel alcohol from sugar. Although not directly using heat the production of dry ice from the carbon dioxide in the geothermal fluid would make it possible for St. Lucia to have export frozen fish, and the condensate from the steam turbines would produce appreciable quantities of fresh water which is currently expensive. These possibilities plus several others are listed in Table III.

As with the electrical system it is advantageous to have a specific system model in mind in order to estimate the cost of the heat that the system can deliver. It is also of interest to investigate the effect of the capacity factor at which the system can operate. In this case the quantity of heat available is large compared to the industrial capacity to use it. Therefore studies were made to determine heat costs for both a 100% utilization as well as a 10% utilization of the heat available from a single well. A schematic representation of the system envisioned for the use of a residual heat system is given in Fig. 6, and a primary heat system is shown in Fig. 7. In both cases the spent geothermal fluid is reinjected into the ground. Flow rates and expected temperatures are shown on the figures.

Although costs were not estimated for the establishment of these new industries, costs were estimated for the delivery of the geothermal heat to industries either in Soufriere or Vieux Fort. The costs can vary over a wide range depending upon the capacity factor of the total system, the distance to the use site from the wells, and the fraction of the heat available that is actually used. Figure 8 gives several costs for geothermal heat at the plant site either in Soufriere or Vieux Fort, either for primary or residual heat, for two plant operation schedules, and for either 100% or 10% of well capacity being used. Also shown are the costs for oil and natural gas process heat in the US, and from Fig. 8 it can be seen that the costs for the geothermal heat are competitive in all cases. Only in the case of delivery of primary heat to the farther delivery point with the smaller well capacity and at the smaller plant capacity factor does the heat cost exceed that of the cost of natural gas in the US. All costs are less than that of oil in the US.

GUATEMALA

The work in Guatemala is a cooperative program between Los Alamos and the two Guatemalan organizations: Ministerio de Energia y Minas de Guatemala (MEM) and Instituto Nacional de Electrificacion (INDE). MEM participants have included Leonel Lopez Rodas, Carlos A. Avalos Ortiz, and Rolando Yon. INDE participants have been primarily Hugo Rolando Bethancourt and Edgar Tobias.

Guatemala (see Fig. 9) has a land area of 42,000 mi^2 and a population close to 8 million. Its economic base is agricultural but the industrial sector is significant.

Since early 1985, Los Alamos has been assisting with energy developments in Central America. There are different program components in Guatemala, El Salvador, Honduras, Costa Rica, and Panama. Similar to the St. Lucia program that was previously described, the major objectives are to create new employment opportunities and improve the balance of trade by reducing oil imports. All types of indigenous or renewable energy sources are of interest but for Guatemala most of the Los Alamos work to data has concentrated on the use of geothermal energy and involves the applications of geothermal energy as process heat in agricultural, industrial, or commercial enterprises. However as was found in St. Lucia, it is often not as useful as it might otherwise be to study only heat applications without also considering electric power generation from the same geothermal resource.

Geothermal Resources in Guatemala

In general, Central America is heavily endowed with geothermal energy. In Guatemala alone there are 35 volcanos, including three that emit volcanic materials at frequent intervals (Fuego, Santiaquito, Pacaya).[4] The volcanic highlands, where the geothermal resources are located, are in the southern and southwestern parts of the country. In eleven areas that have been studied, the estimated reservoir temperatures range from 140 to 300° C. The field with the highest temperature is called Zunil I and is located about 8 km south of Quezaltenango and near the small village of Zunil. This field has been given the highest development priority by the Guatemala Government. Zunil II, adjacent to Zunil I, may become another favorable geothermal field but its exploration is still in the early stages. Another promising field is called Amatitlan and is located about 25 km south-southwest of Guatemala City and mostly to the southeast of the city of Amatitlan. Slim holes have been drilled but no full-size production wells exist. A maximum reservoir temperature of about 250°C is predicted for the Amatitlan land field. Preliminary indications are that this area is an excellent resource capable of supporting a large power plant development.

The geothermal resources in Guatemala range from hydrothermal to steam-dominated. To generate electric power initially from the high temperature resources, conventional steam turbine conversion systems are planned. For exploitation of lower temperature resources in the future, the use of binary cycle power systems might be most viable.

A fact worth noting is that Guatemala has the theoretical potential to use hydroelectric facilities to meet all of its electricity demand. However, there are some serious practical impediments to the achievement of that condition. One factor is that the initial costs of hydro facilities are very large, requiring scarce foreign exchange equal to hundreds of millions of US dollars. This economic constraint may prevail for many years.

Another factor is that there is a marked seasonal variation in rainfall which means that supplemental power could be and in fact is required during dry periods. At this time, all of the supplemental power is generated in thermal (oil) plants. Guatemala's largest hydro project, Chixoy, went on line in 1983 and the total national capacity was almost 700 MWe. Of the total, 60% was generated by hydro and 40% by thermal plants. In the future, as in 1983, it is expected that the supplemental power requirement will always be substantial. However, the supplementary power could be generated by other means besides thermal, e.g., geothermal.

Survey of Existing Process Heat Applications

The Guatemala based organization, Instituto Centro-Americano de Investigacion y Technologia Industrial (ICAITI) was subcontracted to make a survey of process heat users in the Amatitlan and Zunil regions. Data on 28 different users were compiled. Using data from 20 of the most representative type users it was determined that the average plant used 10,500 x 10^6 Btu/year which would require burning the equivalent of about 80,000 gal/yr of bunker or distillate fuel. The average capacity factor was 0.67. The availability factor for the geothermal piping and production system was estimated as 0.94. Combining the latter with the previously noted capacity factor of 0.67 results in an overall average capacity factor of 0.63. Our previous studies in St. Lucia showed that capacity factors greater than about 0.50 should result in favorable costs of heat delivered to a factory assuming that other factors such as pipeline length and efficiency of heat utilization at the factory are reasonable.

A map of the Amatitlan area is shown in Fig. 10 with the location of the factories that might use geothermal heat. The potential users to the south of Amatitlan are the most likely users. The location of production wells with temperatures suitable for process heat will probably be to the southeast of Amatitlan and south of the lake. The area just southeast of the city has the potential to become an industrial park and Guatemala industrialists appear to be quite interested in that idea. However, further exploration with additional exploratory boreholes are required before this geothermal resource can be fully exploited.

Figure 11 shows the locations of the existing plants in the Zunil vicinity that use process heat at temperatures compatible with geothermal heat. Unfortunately none of these are very near to the Zunil I field. However, the future Zunil II field is expected to lie to the northwest toward Quezaltenango and many new geothermal heat applications might develop in the future. Quezaltenango is the second largest city in Guatemala and its agricultural and industrial enterprises are growing.

There are six full scale production wells at Zunil I and we are planning to install the first small-scale demonstration facilities at that location. The surrounding area, including the steep slopes of the adjacent Santa Maria volcano, produces many of the vegetables used in Guatemala and neighboring El Salvador. Therefore, we feel that the use of the geothermal heat for processing fruits and vegetables could be very useful.

Near-Term Plans for Zunil

A fruit and vegetable processing center near the Zunil field is conceived as including freezing, blanching, drying, sterilization, and cooking. There is a ready market in the US for frozen produce. A substantial amount of energy is required for the freezing process. Figure 12 illustrates the concept now being studied for attaining the necessary freezing temperatures. It is an organic Rankine cycle "binary" system providing shaft power to drive compressors. A small amount of electric power can also be generated as needed by the processing plant. The processes requiring steam or direct heating will use a residual heat system such as was described previously (Fig. 6). Figure 13 illustrates the components in a full scale processing plant. Construction of such a plant will have to wait until some of the major processing steps are demonstrated in smaller facilities. The first small demonstrations are planned for later this year.

Benefits from Geothermal Energy Applications

We have already discussed the way that geothermal electric power plants could displace oil-fired power plants and be beneficially integrated with Guatemala's hydro capacity. Benefits can also be obtained from the use of geothermal heat in place of oil-derived heat in industrial processes. First, cost per unit heat quantity (e.g. $\$/10^6$ Btu) is important. The costs are site specific and different scenarios were assumed in order to estimate the cost of delivering heat to factory boundaries. Our cost estimates range from about $1.50 (US) to $5.00 (US)/10^6 Btu over heat transportation distances of 1 to 7 km. These costs are competitive with oil-derived heat costs.

When evaluating oil displacement and how effective geothermal direct heat applications are compared to geothermal power generation we found that direct heat can be more effective. Table IV illustrates this point. The comparison is made for equal flow rates of geothermal fluid on an hourly and an annual basis. We assumed that the oil power plants being displaced have a heat rate of 10,200 Btu/kWh and the plant capacities are 0.63 for the direct heat applications and 0.85 for the geothermal power plants. Three geothermal resource temperatures were evaluated: 165, 200, and 250°C. We have been evaluating direct heat at temperatures up to 200°C in Guatemala but have also included 250°C as one case listed in the table. The 250°C temperature represents an excellent geothermal resource and for generating power, steam turbines would be used. At 200°C, one might economically use either a steam turbine or an organic Rankin cycle type plant. At 165°C, the latter type plant would be most appropriate.

The second row of Table IV shows the more important comparison that the geothermal direct heat applications can displace approximately twice the oil that geothermal electric power can. Thus the use of geothermal energy for process heat can be worthwhile--even if geothermal electric power is displaced. Of course, this in no way implies that geothermal power should not be developed because the total energy quantities for a nation's electricity generation is almost always much greater than that required for process heat.

REFERENCES

1. M. Ander, F. Goff, R. Hanold, G. Heiken, F. Vautaz, K. Wohletz, "Evaluation of the St. Lucia Geothermal Resource - Geologic, Geophysical, and Hydrogeochemical Investigations," Los Alamos National Laboratory Report No. LA-1023-MS (Aug 1984).

2. "Evaluation of the St. Lucia Geothermal Resource - Summary Report," Los Alamos National Laboratory Report No. LALP-84-26 (April 1984).

3. J. H. Altseimer, F. J. Edeskuty, W. B. Taylor, K. D. Williamson, Jr., "Evaluation of the St. Lucia Geothermal Resource - Engineering Investigation and Cost Estimate," Los Alamos National Laboratory Report No. LA-10209-MS (August 1984).

4. Hugo Rolando Bethancourt, "Desarrollo Geotermico En Guatemala Aprovechamiento De La Energia," Instituto Nacional De Electrificacion, INDE, Guatemala (1985).

TABLE I

BASE-CASE ASSUMPTIONS AND OPERATING CHARACTERISTICS
OF A STEAM TURBINE ELECTRIC POWER SYSTEM IN ST. LUCIA

- Well depth : 1000 to 2000 m
- Reservoir-fluid temperature : 250°C (482°F)
- Fluid-saturation pressure : 4.0 MPa (580 lb/in^2 abs.)
- Pumping is by flash-boiling action in the well.
- Steam-separator pressure : 0.62 MPa (90 lb/in^2 abs.)
- Steam-separator temperature : 160°C (320°F)
- Residual water : 98,600 kg/h (217,400 lb/h)
- Total steam generated : 24,267 kg/h (53,510 lb/h)
- Steam through turbine : 23,040 kg/h (50,800 lb/h)
- Turbine inlet pressure : 0.52 MPa (75 lb/in^2 abs.)
- Turbine efficiency : 0.80
- Steam-condensation temperature : 46°C (115°F)
- Steam-condensation pressure : 10 kPa (1.5 lb/in^2 abs.)
- Surface condenser cooled by ocean water is assumed.
- Coolant temperature into condenser : 15.6°C (60°F)
- Coolant temperature out of condenser : 43.3°C (110°F)
- Coolant-flow rate : 474,000 kg/h (1,045,000 lb/h)
- Gross power : 2,865 kWe
- Net power : 2,500 kWe

TABLE II

COST COMPARISON--ELECTRICITY FROM GEOTHERMAL ENERGY
AND FROM ALTERNATIVE TECHNOLOGIES

System	LLCC ($US/kWh)	Savings[a] ($US M)
1. Geothermal	0.063	94
2. Diesel (peaking)	0.102	---
3. Diesel (total)	0.090	0
4. Oil-fired steam	0.086	2
5. Coal-fired system	0.071	62

[a]Savings represent difference in total expenditures over a 30-yr period between 100% diesel generation and using diesels for peaking only plus geothermal systems for base-load.

TABLE III

TYPICAL PROCESS-HEAT DELIVERY RATES

Activity	Work Schedule (8-h shift/ days/wk)	Production	Average Heat Consumption (million Btu/h)
1. Coconut-oil production	3/5	3300 Imp gal/day	2.7
2. Timber drying	3/7	15,000 brd ft/ 20 days	0.4
3. Concrete-block production	2/5	650,000 blks/yr	0.4 to 1.2
4. Beer production	3/7	6,000 bottles/day	1.0
5. Alcohol/gasohol from sugar cane	3/5	482,300 US gal/yr	4.0
6. Dry-ice production	3/5	1,270 metric tons/yr	5.5
7. Banana-chips production	3/5	10.3 million lb/yr	2.1
8. Tourist & other commercial hot-water applications	3/7	2/3 of 256 room hotel's annual needs	0.3 to 1.1
9. Alumina production	3/7	28,500 metric tons/yr	66

TABLE IV

COMPARISON OF OIL DISPLACED BY TWO GEOTHERMAL APPLICATIONS: DIRECT HEAT VS POWER GENERATION

	Geothermal Resource Temperature (°C)		
	165	200	250
Oil displaced per hour by direct heat / Oil displaced per hour by power generation =	2.9	2.6	2.4
Oil displaced per year by direct heat / Oil displaced per year by power generation =	2.1	1.9	1.8

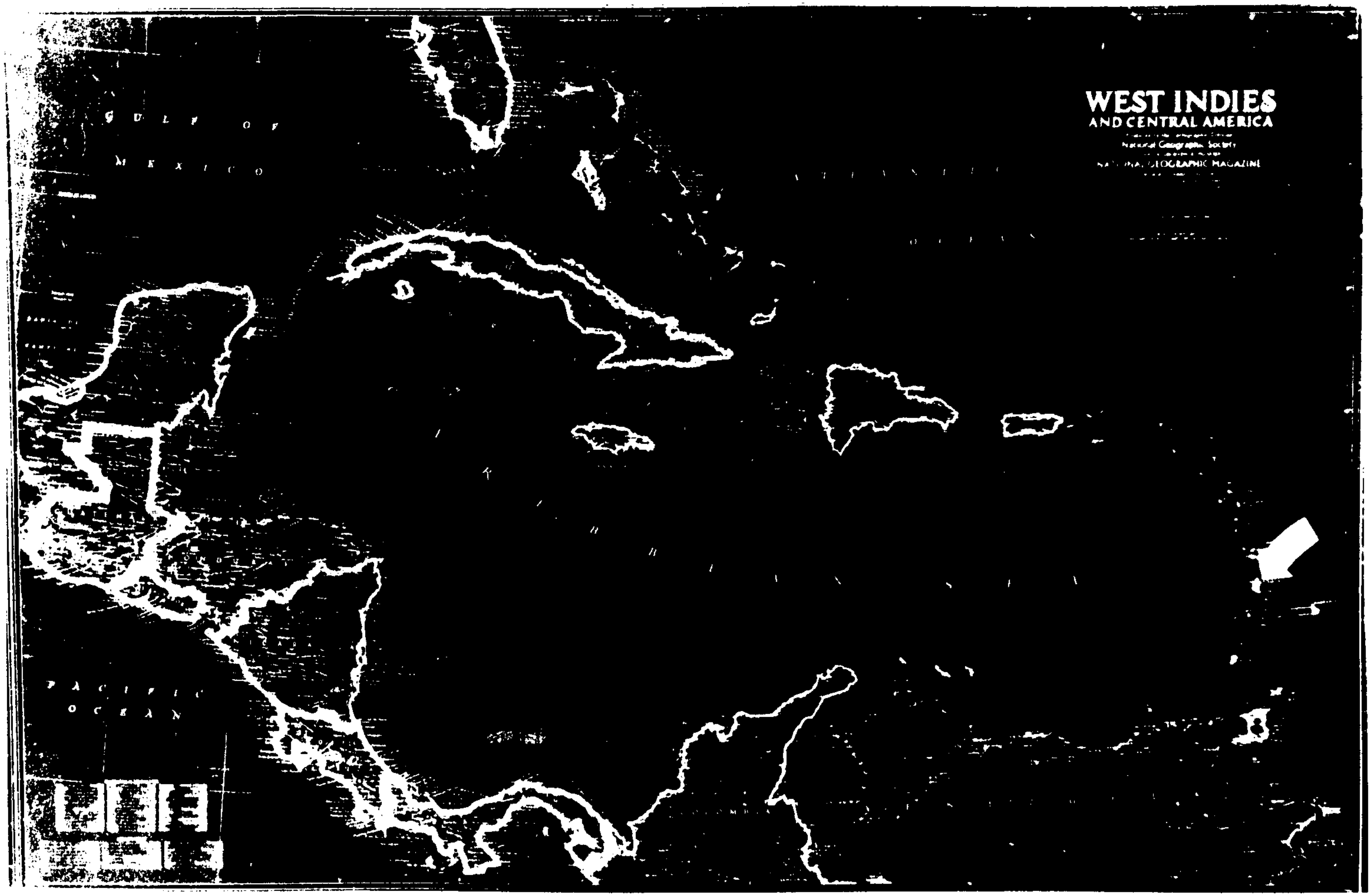

Fig. 1: West Indies and Central America. Arrow shows the location of the Island of St. Lucia.
Source: National Geographic Society

St. Lucia

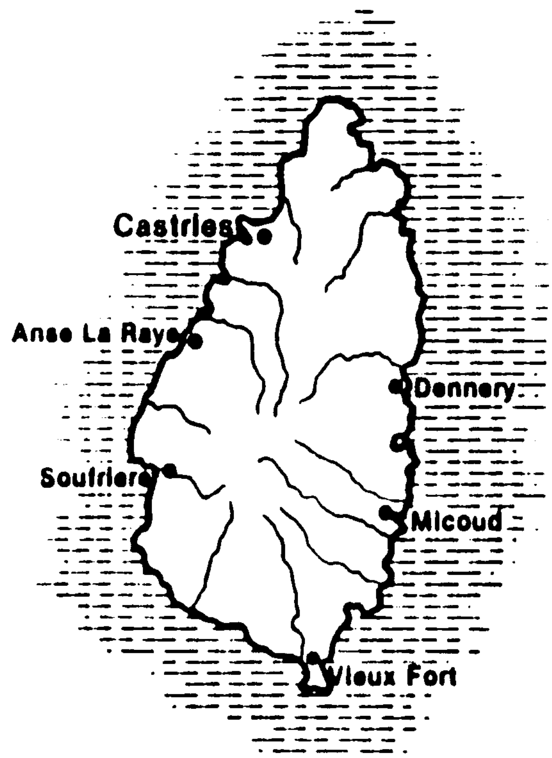

Fig. 2: Major population centers in St. Lucia. The geothermal field is a short distance east of Soufriere.

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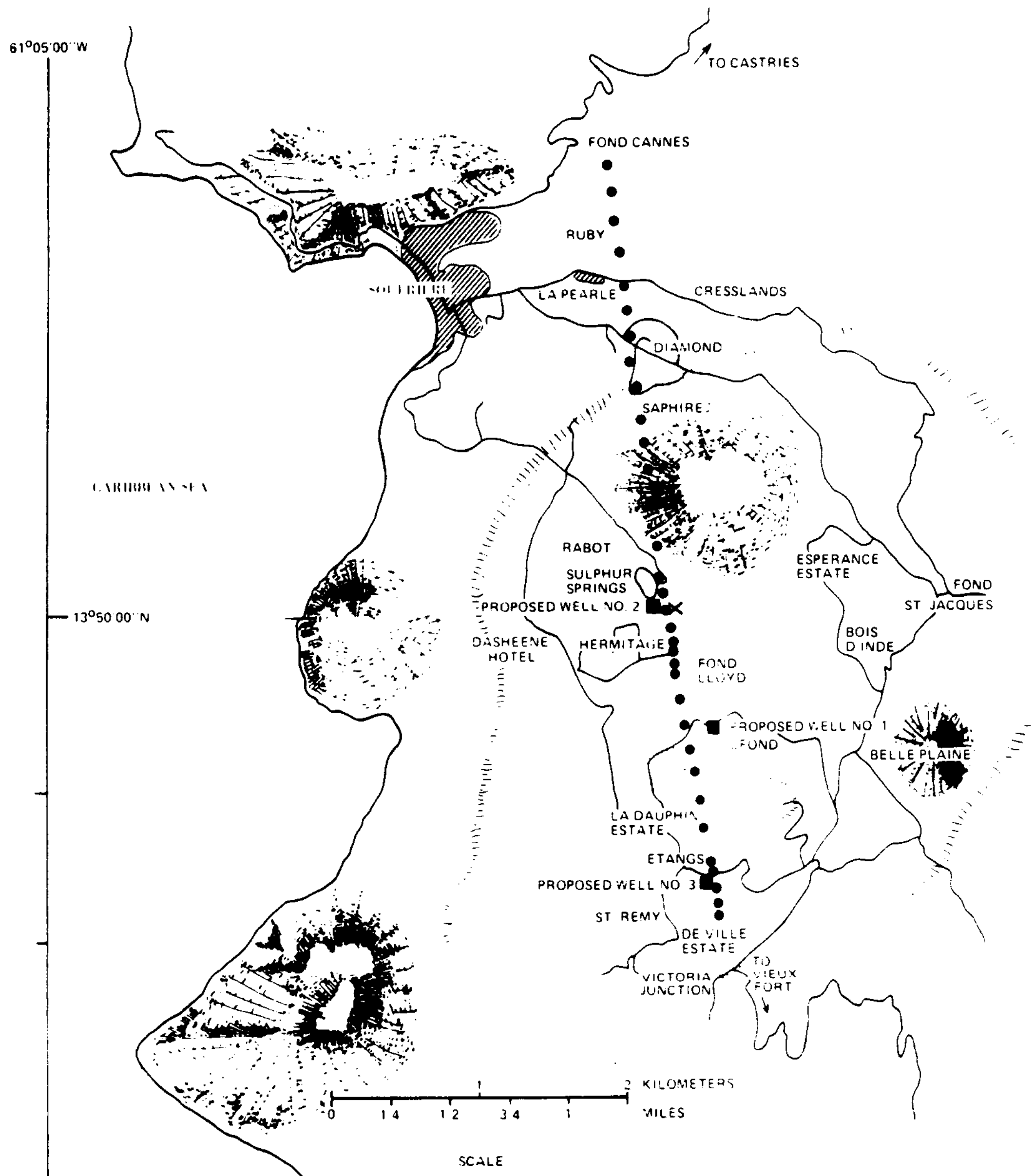

Fig. 3: The geothermal field in St. Lucia. The dots locate the electric resistivity measurement stations made through the caldera area. The proposed well drilling sites are noted.

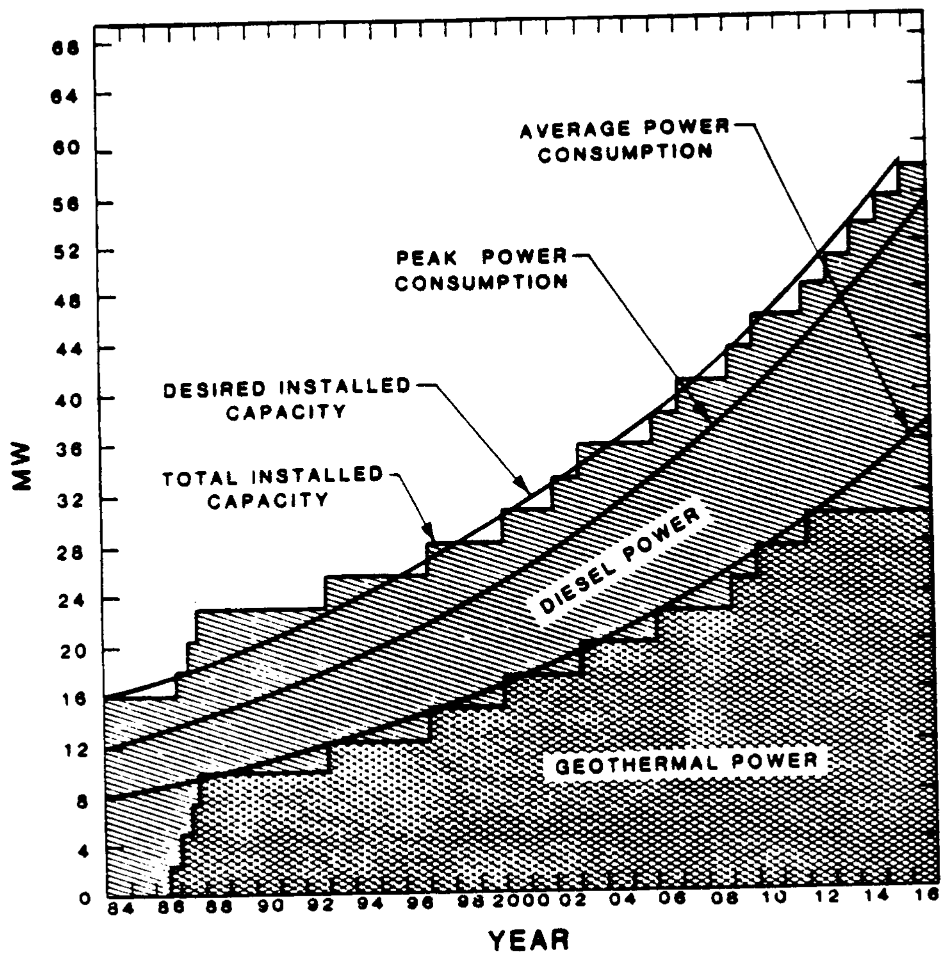

Fig. 4: A scenario for the introduction of geothermal electric power in St. Lucia.

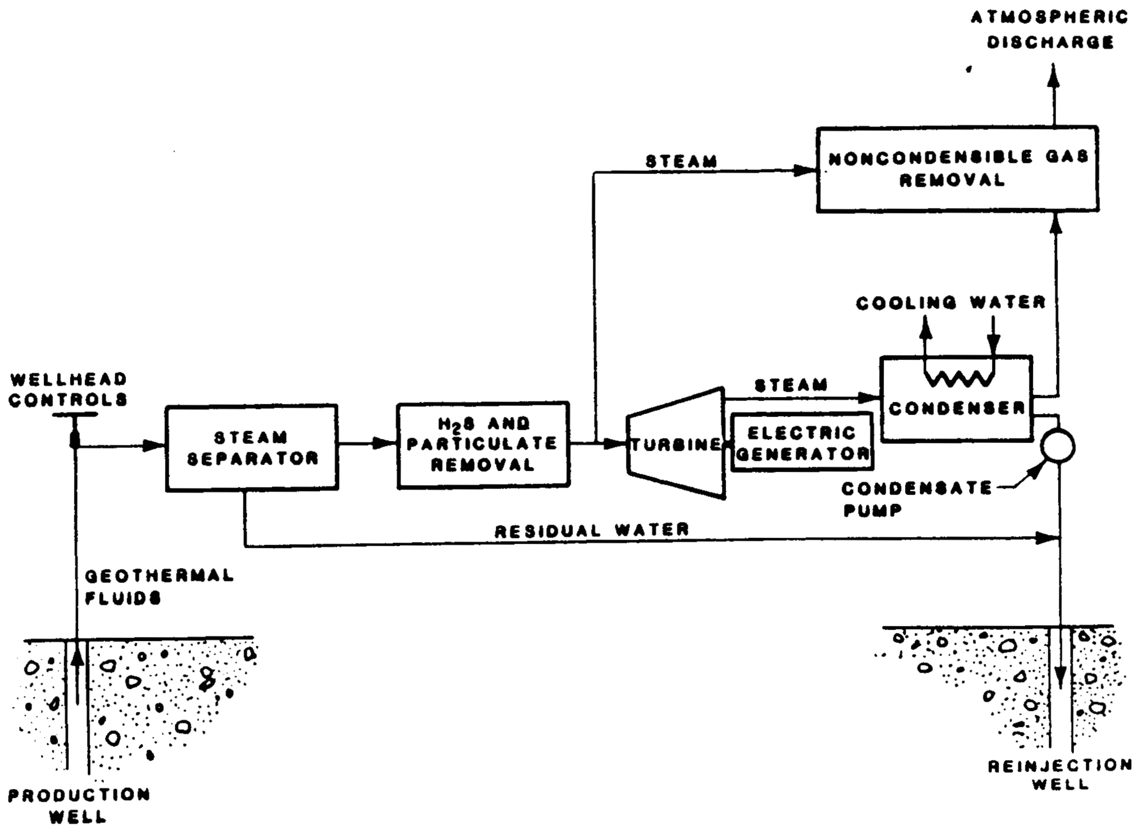

Fig. 5: Power generation components used for performance estimates.

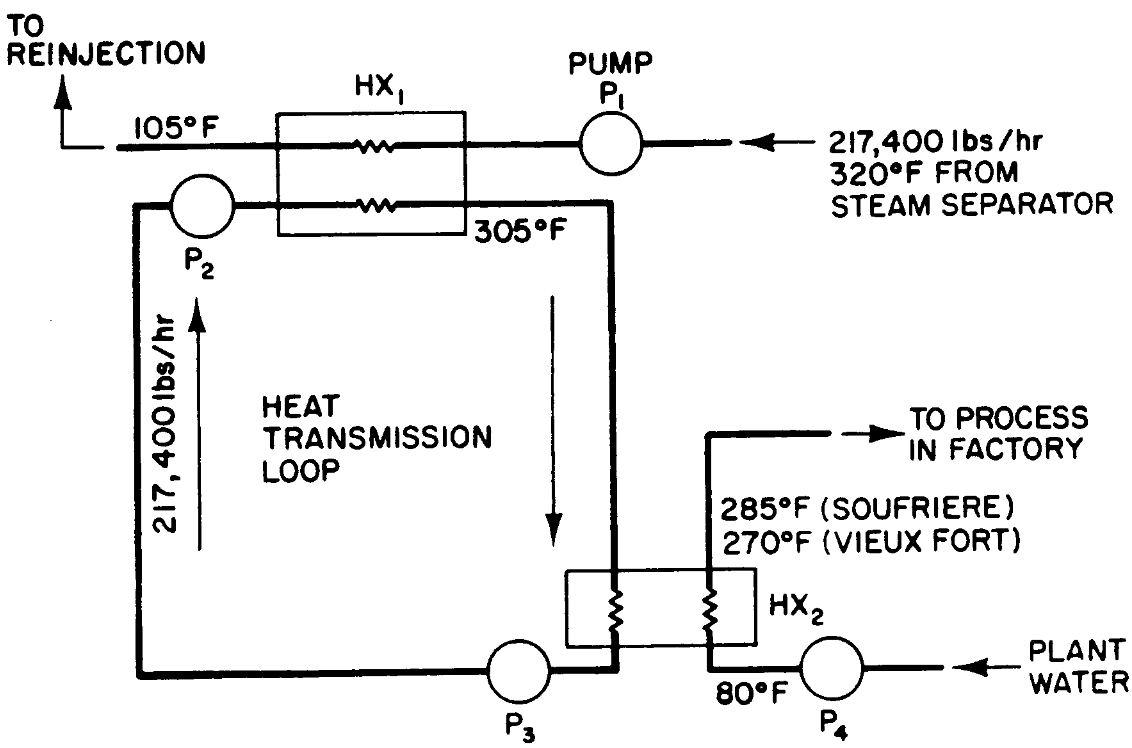

Fig. 6: Simplified schematic of a "residual heat system."

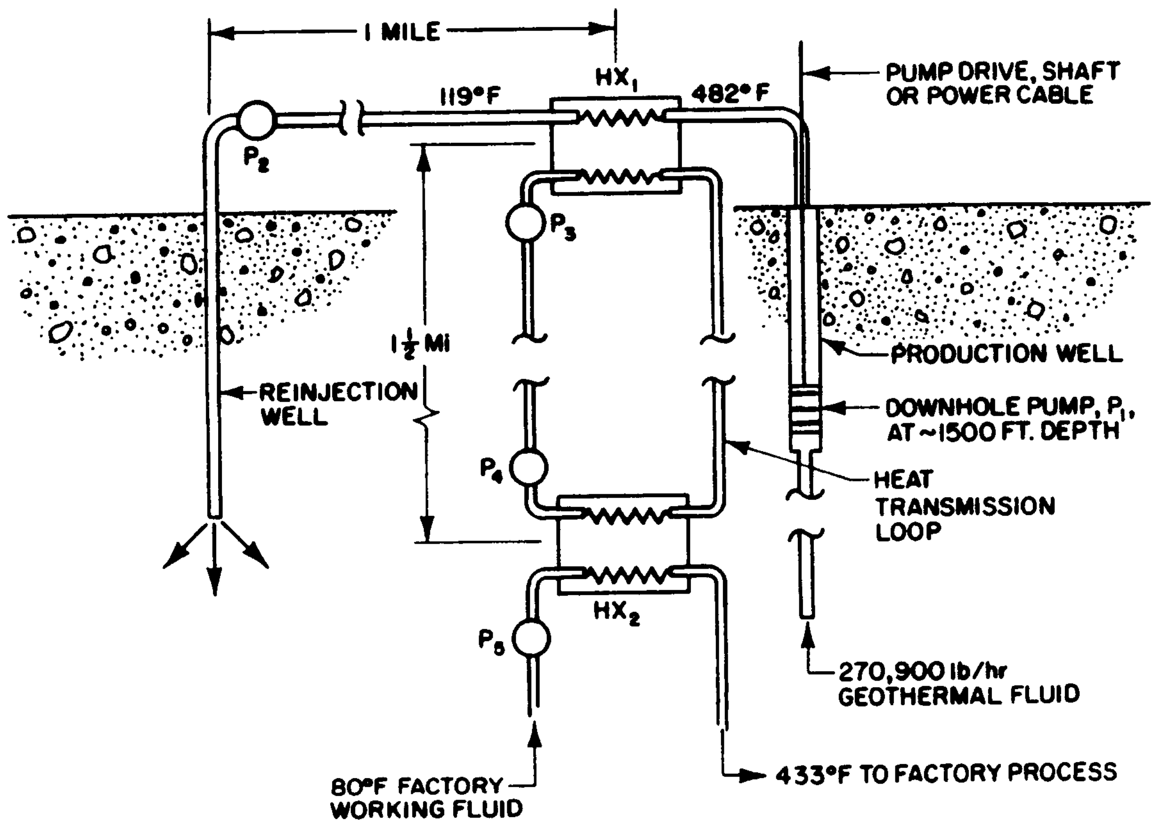

Fig. 7: Simplified schematic of a "primary heat system."

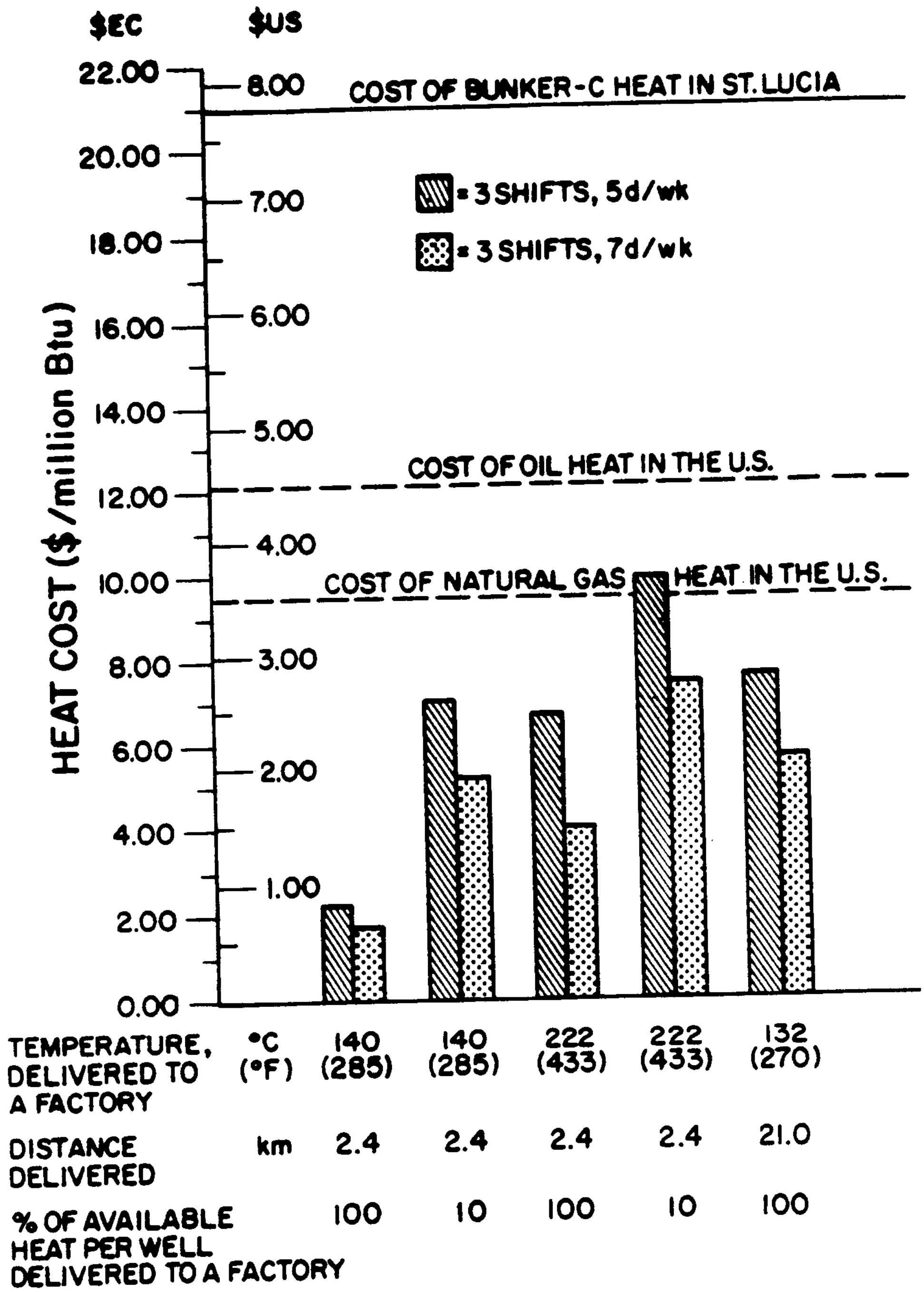

Fig. 8: Summary of process heat cost estimates from St. Lucia studies.

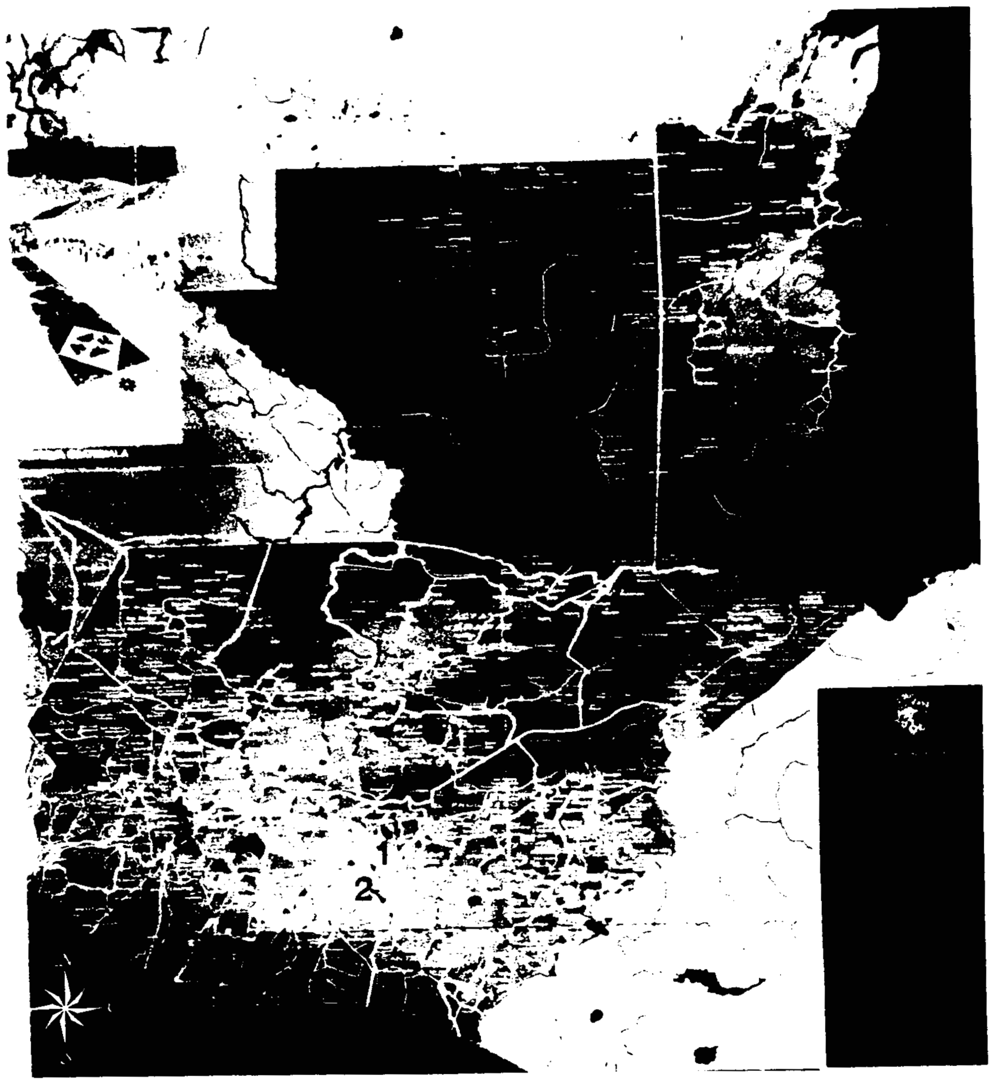

Fig. 9: Map of Guatemala showing: (1) Guatemala City, (2) Amatitlan, (3) Zunil, and (4) Quezaltenango.

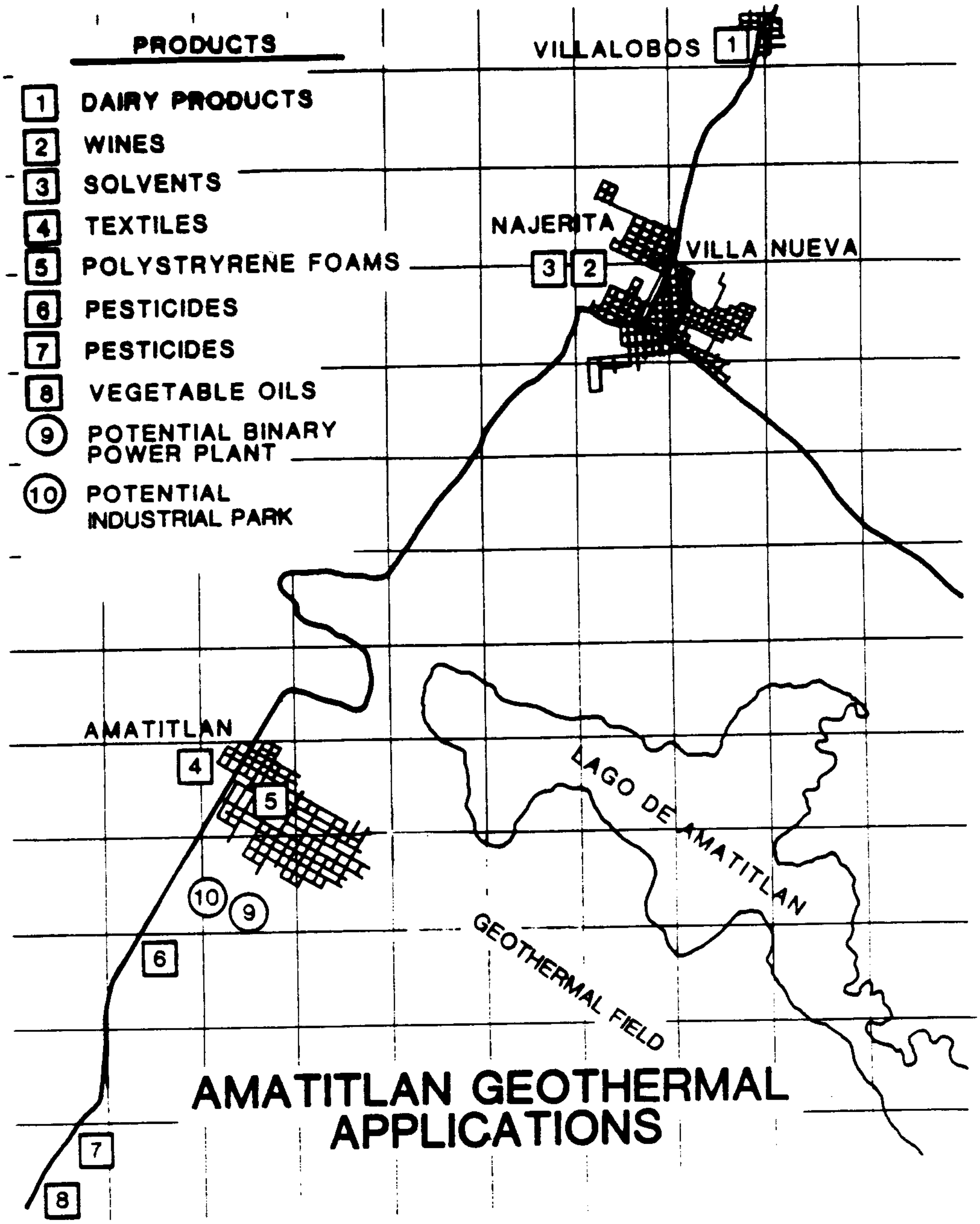

Fig. 10: The locations of existing and potential users of geothermal heat in the Amatitlan area. The most interesting application concept seems to be that of an industrial park, noted at (10). Electric power will probably be produced somewhere in the area at the lower right corner of the map. Each square has 1 km sides.

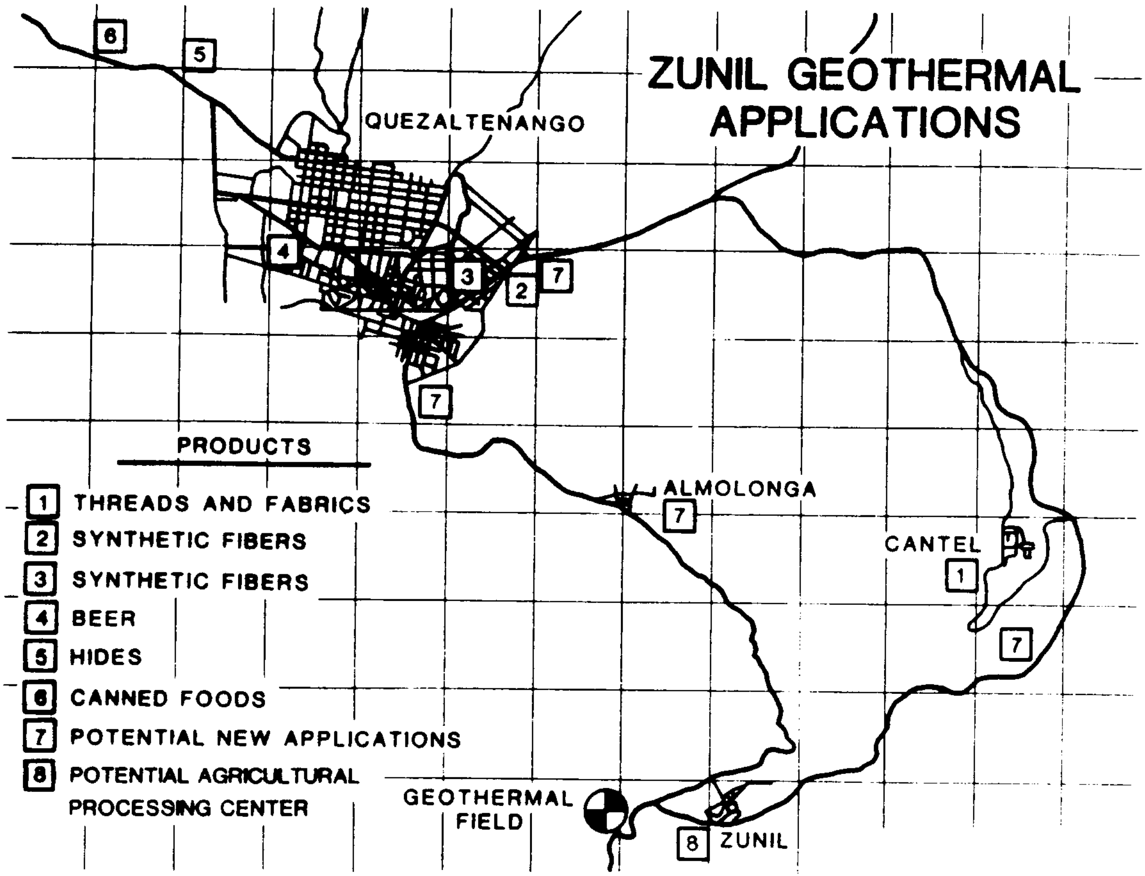

Fig. 11: The location of existing and potential users of geothermal heat between Zunil and Quezaltenango. The geothermal field noted is Zunil I. Each square has 1 km sides.

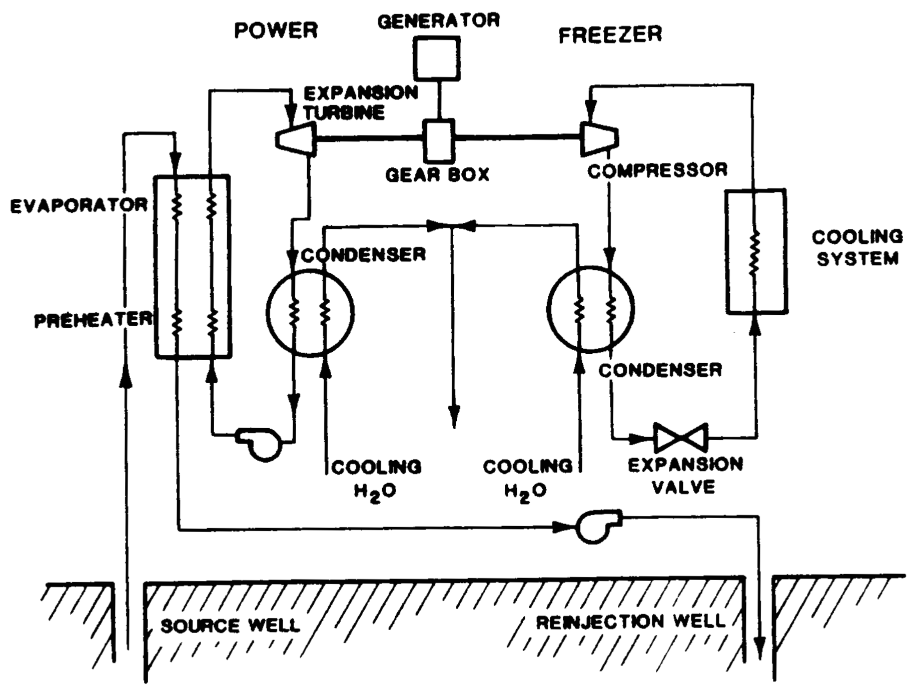

Fig. 12: Thermally driven freezer system using an organic Rankine power cycle.

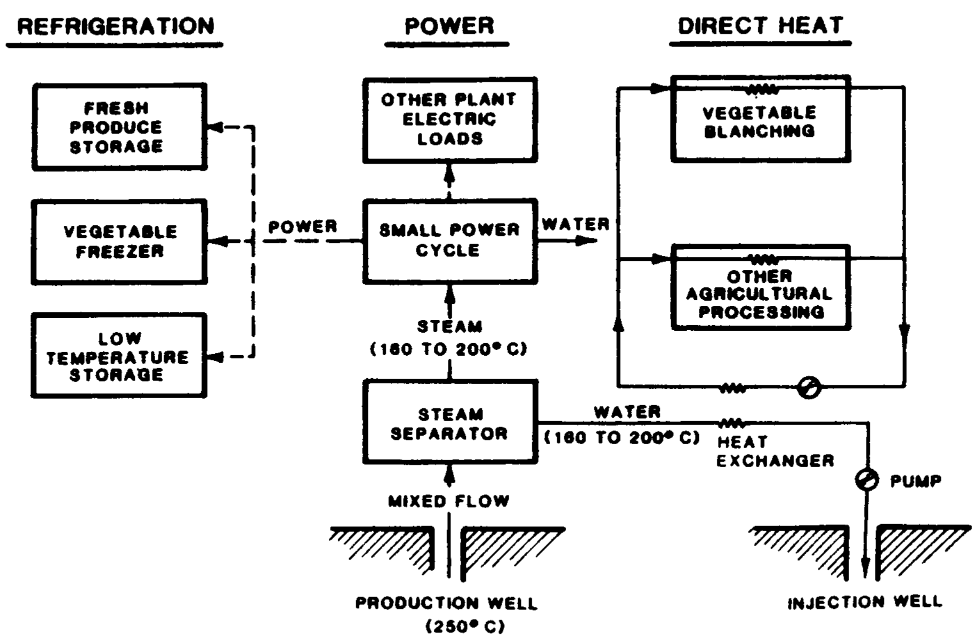

Fig. 13: Zunil "Agricultural Processing Center" Plant.