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A Survey of Geothermal Process Heat Applications in Guatemala

An Engineering Survey

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EXECUTIVE SUMMARY

Guatemala is developing its geothermal energy resource for the generation of electricity, scheduled to be on line in the early 1990s. Simultaneously the use of direct energy to provide agricultural, industrial, or commercial process heat is being investigated. For temperature requirements of 160 to 200°C (320 to 392°F), this process heat could be supplied either by the liquid geothermal fluid discharged from steam separator subsystems of a geothermal electric power plant or by primary heat from wells flowing by means of downhole pumps. Higher processing temperatures would require primary fluid from the hotter wells, which sometimes have reservoir temperatures up to 300°C (572°F). Although conceptually possible, primary heat extraction operations at 300°C (572°F) have never been demonstrated. For temperatures less than 160°C (320°F), the heat delivery systems are easier to construct and many processing applications can also be found.

There are at least 23 geothermal areas of interest in Guatemala; many of these are promising, and 2 have been investigated in some detail. Investigation of the Zunil geothermal field (about 7 km south of Quezaltenango) has progressed to the point where six production-size wells have been drilled. Four of these wells appear to be capable of useful production. A second promising field being explored lies about 25 km south of the city of Guatemala in the vicinity of Lake Amatitlán. Although the exploratory work is not yet completed, sufficient investigation has been done to indicate that an excellent resource exists along the south shore of Lake Amatitlán.

Because of the relatively high initial cost of a geothermal heat distribution system, prefeasibility and feasibility studies of such a project must be made to show that it is technically, economically, and environmentally feasible. Preliminary system designs must be made, system costs must be estimated, and these, along with operating costs, can be used to predict levelized life cycle costs (LLCCs) of heat delivery to a processing plant. Some operating scenarios have been devised resulting in generalized systems. The LLCC depends heavily upon such factors as the distance the heat must be transported, the capacity factor of the system, and the required processing temperatures. Cost calculations made from preliminary system designs have been encouraging, ranging from US\$0.80 to US\$5.00/MBtu--favorable compared to the cost of oil heat, about US\$8.00/MBtu at the beginning of this investigation. Even at the current

depressed oil price of US\$5.00/MBtu, the low end of this range is still favorable. And even with no monetary savings, a reduction of petroleum imports is still a desirable goal.

Surveys made of existing industries in the vicinities of Zunil and Amatitlán indicate that a number of industries already exist with process heat requirements that could be satisfied by geothermal heat. In addition, the area between Zunil and Quezaltenango has been referred to as the "Salad Bowl of Central America," indicative of the potential for agricultural processing in this area. Such applications as food drying, food freezing, and food storage are obvious possibilities.

The Amatitlán field is near a relatively active industrial area and would be a favorable source of process heat for a geothermal industrial park. However, the Amatitlán field is still in the early stage of exploratory drilling. Any serious plan to develop a geothermal industrial park there will have to be delayed until suitable geothermal production wells become available.

Eleven general categories of new applications for geothermal heat were evaluated, and the following nine appear favorable enough for further economic feasibility studies. The list is by no means exhaustive.

1. Agricultural processing and other agriculturally related activities
2. Final stage of salt refining
3. Amatitlán thermal power plant using heat augmentation of the plant's steam generation cycle
4. Water pumping for the city of Guatemala using heat to generate mechanical power for pumping
5. Hospital/hotel heating and cooling
6. Steam curing in concrete block production
7. Production of anhydrous ethyl alcohol from sugar cane molasses
8. Production of polyethylene from ethanol
9. Geothermal integrated heat and electric power production systems to increase the overall energy utilization efficiency

Considering (1) the extensive geothermal resource in Guatemala and its initial development at Zunil, (2) the dominance of agriculture in the economy, (3) the existence of a relatively large industrial base already using moderate-temperature process heat supplied by imported petroleum fuels, (4) the potential new enterprises that might make beneficial use of geothermal energy, and (5) the requirements of an economically feasible geothermal heat delivery system, we

recommend that as a first development, the utilization of geothermal heat be directed toward the development of commercial-scale agricultural processing plants to be located close to the geothermal resource at Zunil. Over the longer term, an industrial park at Amatitlán, designed to use the heat in the most optimal manner, should be planned, and other applications, such as municipal water pumping, could be developed and be beneficial to the national economy.

A SURVEY OF GEOTHERMAL PROCESS HEAT APPLICATIONS IN GUATEMALA

AN ENGINEERING SURVEY

by

John H. Altseimer and Frederick J. Edeskuty

ABSTRACT

This study investigates how process heat from Guatemala's geothermal energy resources can be developed to reduce Guatemala's costly importation of oil, create new employment by encouraging new industry, and reduce fuel costs for existing industry. This investigation was funded by the US Agency for International Development and carried out jointly by the Guatemalan Government and the Los Alamos National Laboratory.

Two sites, Amatitlán and Zunil, are being developed geothermally. Amatitlán is in the better industrial area but Zunil's geothermal development is more advanced. The industry around Zunil is almost exclusively agricultural and the development of an agricultural processing plant (freezing, dehydration, and cold storage) using geothermal heat is recommended. Similar developments throughout the volcanic zones of Guatemala are possible. Later, when the field at Amatitlán has been further developed, an industrial park can be planned. Potential Amatitlán applications are the final stage of salt refining, a thermal power plant, hospital/hotel heating and cooling, steam curing of concrete blocks, production of alcohol from sugar cane, and production of polyethylene from ethanol. Other special developments such as water pumping for the city of Guatemala and the use of moderate-temperature geothermal fluids for localized power production are also possible.

I. INTRODUCTION

The Los Alamos National Laboratory (LANL) is being funded by the US Agency for International Development (USAID) in a program to assist Central American

and Caribbean countries with the development of indigenous energy. One of the projects in this program and the objective of this study is concerned with the application of the geothermal energy resource to provide agricultural, industrial, or commercial process heat in Guatemala. By utilization of Guatemala's geothermal resource, it is hoped that the amount of imported petroleum in that country can be reduced. Also, a less expensive source of process heat will encourage new industries, creating both additional employment in the country and a more favorable economic situation for the industries involved. This project is a joint effort being carried out by the Guatemalan Government [through the Ministerio de Energía y Minas (MEM) and the Instituto Nacional de Electrificación (INDE)] and the Central American Program of the Energy Technology Office of LANL.

II. OBJECTIVES OF THE PROGRAM

The primary objectives of the direct-heat program are the following:

1. Reduce the importation of petroleum
2. Create new employment by encouraging new industry
3. Improve the financial basis of existing industry by providing a less expensive source of energy

This phase of the program is a survey to determine the potential for using geothermal energy (either the primary geothermal heat or the residual heat after generation of electricity) to meet agricultural, industrial, or commercial process-heat requirements.

III. DIRECT-HEAT PROGRAM PLAN

The program was initiated with a survey of existing potential consumers of geothermal heat for agricultural, industrial, and commercial purposes. In addition, potential new applications of the heat were evaluated. (The results of these studies are included in this report.) Then, a promising application was selected for an early demonstration of a heat supply system and a typical process-heat application. Agricultural processing was selected as an appropriate application for demonstration, and a small agricultural dehydration facility is now being constructed at the Zunil geothermal field. After the facility has been used to demonstrate how geothermal heat can be utilized for

processing, it is expected that over the long term the plant will be used as a research laboratory for new agricultural products and as a training center for both government and private-sector personnel who will be involved in future applications of geothermal heat.

Another long-term goal is the building and operation of a commercial-size agricultural processing plant at Zunil by private operators. Early phases of a prefeasibility study for such a plant are already under way. An even longer term goal is the development of an industrial park at Amatitlán to use geothermal energy for industrial processing as well as for generating electricity to meet the park's demands. The major efforts at present are being applied to building and operating the small demonstration facility.

The demonstration project is a food drying facility that is being designed and constructed jointly by INDE and LANL. INDE will provide the hot geothermal fluid from an existing exploratory well. The design of the heat supply system and the drying facility will be performed by LANL. The purchase of the material for the construction of the complete facility will be funded primarily by LANL whereas INDE will provide the labor for the basic construction of the facility and the operation of the heat supply system. LANL will also purchase equipment and machines in the US, when such are not available in Guatemala, and provide for their installation. MEM will participate in the technology transfer meetings, the initial operation of the dehydration facility, and the promotion in the private sector of the direct-heat concept. Private sector industrialists will participate in the agricultural facets of the project.

The agricultural processing plant is a more costly undertaking that requires the completion of a prefeasibility study before it can be described in detail. However, the processes now being considered include those for food freezing, food drying, cold storage, and the generation of electricity or mechanical power with a binary generation system to power the agricultural processing plant. The technical feasibility will be evaluated by LANL and INDE and includes such components as energy source, energy balance and heat transfer, plant design, equipment selection, and operating plan. The economic feasibility will be evaluated on the basis of foodstuff availability, market demand, construction and operating costs, product costs, marketing requirements and costs, and financing and will be evaluated jointly by LANL, its subcontractors, and MEM. The consideration of environmental feasibility is being addressed by MEM.

and INDE. The prefeasibility design of a full-scale processing plant will be subcontracted by LANL to a qualified private engineering firm.

IV. THE GEOTHERMAL RESOURCE IN GUATEMALA

Figure 1 is a general map of Guatemala, which borders on the Pacific Ocean on the "Ring of Fire" where frequent volcanic events and earthquakes occur. Thus Guatemala is richly endowed with geothermal energy. This is evidenced by 35 volcanos, including 3 that frequently emit volcanic materials (Fuego, Santiaquito, and Pacaya).¹ In Guatemala a volcanic chain approximately 40-km wide extends from west to east between the borders with Mexico and El Salvador. Geothermal areas occur on both sides of this volcanic chain. Figure 2 shows locations and data for 20 of the most interesting areas. The geothermal manifestations are fumaroles, hydrothermal alterations, and hot springs with temperatures up to the boiling point at atmospheric pressure. For comparison purposes, typical chemical constituents in the hot water from four geothermal fields in Central America are shown in Table I. The Zunil, Guatemala water purity compares favorably with the other samples shown.

TABLE I
TYPICAL CHEMICAL COMPOSITION OF GEOTHERMAL FLUIDS IN GUATEMALA
AND OTHER NEARBY AREAS IN CENTRAL AMERICA

Sample Location	pH	TSD	Ns	K	Ca	Hg	C ₁	SO ₄	HCO ₃	As	SiO ₂	B
BERLIN (El Salvador)	6.6	19 000	5 650	1 125	260	2	10 325	23	19	11	890	194
MOMOTOMBO (Nicaragua)	7.8	7 800	2 500	480	86	0.07	4 476	30	50	1.2	720	45
AHUACHAPAN (El Salvador)	7.5	19 000	5 800	1 000	425	0.09	10 600	31	35	11	577	147
ZUNIL (Well ZCQ-3) (Guatemala)	8.2	3 100	890	200	10	0.1	1 550	16	103	8	480	37

Figure 1. General map of Guatemala. (The site of the Zunil geothermal field, the most developed field in Guatemala, is also indicated.)

Source: Instituto Nacional de Electrificación.

According to previous studies,^{1,2} Guatemala is divided into four physiographic provinces (Fig. 2):

1. Plataforma Sedimentaria (low land of Petén--Cretaceous and Tertiary deposits)
2. Complejo Cristalino Metamórfico (central mountain range--sedimentary and crystalline)
3. Provincia Volcánica (volcanic--Tertiary and Quaternary)
4. Planicie Costera Del Pacífico (coastal plateau--volcanic, alluvial, and detritus)

According to the geological and stratigraphical conditions, Guatemala's Provincia Volcánica zone provides favorable conditions for the formation of productive geothermal fields.

A geologic depression, which starts in Nicaragua and continues to El Salvador, is not observed in Guatemala because it is covered there by volcanic ash. From a geographic study made in 1960 by the Instituto Geográfico (now Instituto Geográfico Militar), one can infer the presence of a basement depression 300 km in length and nearly 10 km wide. Because it is oriented in the same direction as the line between the city of Guatemala and Quezaltenango, it has been called the Guatemala-Quezaltenango Depression. This depression is closely related to the tectonic phenomena that have taken place between the Pacific Plate and the Continental Plate.

Ninety percent of the known geothermal fields are located on both sides of the Guatemala volcanic chain, and those located to the south are distinguished by high underground temperatures such as those measured in deep exploratory wells in Zunil and Amatitlán. At Zunil, a temperature of 297°C (567°F) has been found at a depth of 1 km, and at Amatitlán, 174°C (345°F) has been found at a depth of 0.5 km.

The planned use of the geothermal energy is principally for the generation of electricity where the temperature is greater than 175°C (347°F). However, this heat could also be utilized for high temperature direct heat for industrial processes. Another option is to use the heat in the residual water discharged from steam separators. In addition, geothermal fluid with low-to-medium enthalpy can also serve to provide some industrial heat. In the 11 areas that have seen some investigation, the estimated reservoir temperatures range from 140 to 300°C (284 to 572°F).

Below is a discussion of the geothermal fields of Guatemala.

A. Zunil

In the Zunil geothermal field, INDE has carried out all of the geoscientific studies at a detailed regional level sufficient to permit the evaluation of the feasibility of the first geothermal electric power plant to produce 15 MW². At this field there exist six geothermal wells drilled to depths between 812 and 1310 m; five of these produce geothermal fluid (see Fig. 3). The temperatures at the bottom of these wells range from 220°C (428°F) in well ZCQ-2 to 297°C (567°F) in well ZCQ-6. Wells ZCQ-2, ZCQ-3, and ZCQ-6 produce a mixture of steam and hot water ranging from 15% to 40% steam whereas wells ZCQ-4 and ZCQ-5 produce dry steam. Wells ZCQ 3 to 6 are planned to supply steam to the 15-MWe power plant, but more wells are required and are planned (see Fig. 3).

Geoscientific studies are being continued in order to define the boundaries of the field and increase the knowledge of its potential.

B. Amatitlán

The geothermal field at Amatitlán (see Fig. 4) is one of the most promising, according to the investigations carried out by INDE. The geothermal manifestations are distributed over a surface area of approximately 60 km². There are abundant hot springs on the south shore of Lake Amatitlán, and a bottom temperature greater than 200°C (392°F) is indicated.

Geologically the field at Amatitlán is in the extreme south of the city of Guatemala graben, bordered on the west by the Mixtán Fault, on the east by the Santa Catarina Fault System, on the north by the Jalpatagua Fault, and on the south by the complex volcanism of the Volcano de Pacaya. The Quarternary volcanic evolution in this zone ended with the formation of a series of domes with acidic composition that indicates a marked differentiation of magma and the presence of a magmatic chamber located at a relatively shallow depth (about 7 km). This chamber furnishes the source of heat for the geothermal reservoir. In this field, as in Zunil, there is an intrusive basement granite upon which is deposited a thick section of andesites with a Tertiary majority where the principal geothermal reservoir is expected.

The younger system of fractures that exists in the area is oriented north and south, and the principal surface manifestations and hydrothermal alteration of the rocks are associated with this fracturing. The most significant hot

Figure 4. The geographic location of Amatitlán.

springs are found where the fractures disappear under the surface of the lake. Prospecting for the appearance of radon gas corroborates the activity of this structural system, and phreatic activity generally associated with volcanic activity is indicated.

INDE has drilled five small-diameter exploratory wells with depths from 125 to 542 m. In well AM-2, located over a complex dome, a temperature of 174°C (345°F) was measured at a depth of 490 m. Also in the well named Bloteca, a temperature of 140°C (284°F) was measured at a depth of only 85 m.

This geothermal system has potential aquifers with fluid of low-to-medium enthalpy connected laterally to a principal geothermal reservoir of high temperature. The industrial development of the zone is due to its proximity to the capital city, which makes the existence of this natural energy source even more important.

Prefeasibility studies are being continued prior to the drilling of additional exploratory wells to determine the practicality of developing this field.

C. Other Areas

Finally, geological, geophysical, and geochemical investigations have been carried out at a preliminary level in the zones of San Marcos in the west of Guatemala and in Tecuamburro and Moyuta in the east. The investigation results are extremely favorable and indicate the presence of important geothermal aquifers of low and medium enthalpy.

V. SURVEYS OF DIRECT-HEAT APPLICATIONS

Two independent surveys of the possibilities for industrial application of geothermal process heat have been made by MEM and Instituto Centroamericano de Investigacion y Technologies Industrial (ICAITI), the latter under contract to LANL. These surveys cover 37 industries in the Amatitlán and Zunil areas and were concerned only with existing industries. Many of these industries utilize only small quantities of heat in the temperature range that can be provided by geothermal energy. It is recognized that the most advantageous application of direct geothermal heat will be with large users of heat located conveniently close to the heat source, and applications of this type will be discussed later

(see Sec. VII). In providing heat to the somewhat dispersed existing industries, the heat cost would range from advantageous to competitive in price. Costing calculations will be discussed later (Sec. VI).

A. Amatitlán

The proximity of the Amatitlán geothermal field to Guatemala City as well as to a number of existing industries makes this area interesting for the development of geothermal process heat. MEM and ICAITI surveys indicate that several possibilities for application already exist. The MEM survey was performed as a Guatemalan contribution to the LANL Central America Program. The MEM and ICAITI surveys summarized in Table II found that there already exist 29 industries in the vicinity of Amatitlán, all utilizing process heat obtained mainly from the combustion of petroleum products. Although a detailed analysis of the heat consumption was not included, the temperature levels indicate that approximately 50% of the total of 2.7×10^{11} Btu/yr consumed by these industries could be supplied by geothermal wells. Although a prefeasibility study is needed, the above quantity appears to be economically compatible with the use of a full-size production well. All but 7 of the 29 existing industries could make use of some geothermal process heat. Four of these industries have temperature requirements too high to be provided by even the primary heat from a geothermal well. Three industries are able to provide the necessary process heat by burning coffee hulls. The most favorable industries are those needing heat at say 80 to 130°C (176 to 266°F). Examples of favorable heat applications are heating water, producing low pressure steam, and drying. It is possible that geothermal heat could be used by even the highest temperature processes, such as preheating; however, such applications have not been considered in the above estimate of heat usage.

Table II shows that for the industries in the Amatitlán area the average capacity factor is 42%. However, large deviations from this average exist, with the lowest being 15% and the highest 91%. The value of heat (or percentage of total product cost that arises from the heat cost) also varies over the range from 1% to 27%. The average annual heat consumption of the industries surveyed is 1×10^{10} Btu; however, consideration of the above-mentioned capacity factors shows that a maximum rate demand would be closer to two to three times this amount. Six of the industries, which would otherwise be good candidates, are fairly far from the geothermal field (5 to 10 km away). Some entries in Table

TABLE II
POTENTIAL GEOTHERMAL HEAT
APPLICATIONS IN THE AMATITLÁN AREA

Plant No.	Location	Product	No. of Employees	Heat Consumption (10 ⁶ Btu/year)	Temperature Range (°C)	Heat Application	Operating Hours per Year	Energy Cost to Product Cost (%)
1	Amatitlán	Oven	170	25	850	Surface baking ^a	---	---
2	Amatitlán	Wine Aluminum	33	2.3	80 to 94	Cooking, pasteurization ^b	---	---
3	Amatitlán	Fabricated parts	31	1.0	425 to 700	Smelting, tempering, extruding ^a	---	---
4	Amatitlán	Coffee	80	---	---	Drying ^c	---	---
5	Amatitlán	Coffee	25	---	---	Drying ^c	---	---
6	Amatitlán	Coffee	32	9.0	---	Drying ^c	1500 (3 mo/yr)	3
7	Amatitlán (9 km S)	Plastic Sheets	11	2.2	60 to 96	Reactor & water heating ^b	---	---
8	Amatitlán (12 km S)	Pesticides	40	1.4	40 to 75	Liquification ^d	---	13
9	Amatitlán	Coffee	20	2.2	45 to 90	Drying ^b	---	5
10	Amatitlán (3 km S)	Salt	12	2.0	150 to 160	Drying is final processing stage ^e	---	11
11	Amatitlán	Textiles	12	3.0	40 to 80	Ironing & scouring ^b	---	---
12	Amatitlán	Pesticides	180 to 240	0.8 to 2.0	60	Water heating ^b	2500	2

TABLE II (Cont)

Plant No.	Location	Product	No. of Employees	Heat Consumption (10 ⁶ Btu/year)	Temperature Range (°C)	Heat Application	Operating Hours per Year	Ratio of Energy Cost to Product Cost (%)
13	Amatitlán (10 km S)	Pesticides/Insecticides	22 to 33	0.02 to 0.30	90	Heating ^b	4000	5
14	Amatitlán	Textiles	350	39 to 56	130 to 210	Drying, Sanforizing, thermal fixing, printing, glueing ^f	8000	4-9
15	Amatitlán	Polystyrene foam	10	1.6 to 3.1	120	Low pressure steam ^b	2000	10
16	Amatitlán (8 km S)	Vegetable oils	30	3.1 to 7.7	50 to 150	Extraction, filtration, cooking, deodorizing, bleaching ^b	2800	10
17	Amatitlán	Hospital services	200	1.3 to 7.7	170	Sterilization, drying, kitchen, baking ^b	8000	6
18	Villa Nueva (10 km N of Amatitlán)	Dairy products	75	5.4	75	Pasteurization & packaging ^g	2000	2
19	Amatitlán	Essential oils	23	1.0	---	Distillation ^h	2200	1
20	Amatitlán	Wines	100	1.8	170	Equipment cleaning ^g	2200	5
21	Amatitlán	Ceramic sanitararies	130	45	500	High temp. heating ^a	8000	27
22	Amatitlán	Soaps & detergents	100	0.8	---	Dissolution, smelting & mixing ⁱ	2800	2
23	Amatitlán	Solvents	45	0.8	---	Distillation ⁱ	2200	1

TABLE II (Cont)

Plant No.	Location	Product	No. of Employees	Heat Consumption (10 ⁶ Btu/year)	Temperature Range (°C)	Heat Application	Operating Hours per Year	Energy Cost to Product Cost (%)
24	Palín (12 km S of Amatitlán)	Dairy products	100	4.2	100	Pasteurization ^g	2900	2
25	Esquintla (~20 km S of Amatitlán)	Vegetable oils	125	19.0	---	Heating, deodorizing ^j	2200	4
26	Amatitlán	Vegetable oils	180	23.0	---	Cooling, pressing, extraction ^j	2200	12
27	Amatitlán	Beer	112	18.0	65 to 170	Cooking pasteurization, sterilization ^j	7200	11
28	Amatitlán	Construction blocks	10	---	---	Block curing ^k	2000	1
29	Amatitlán	Construction blocks	25	8.1	120	Block curing ^b	3000	7

^aRequired temperature is too high.

^bGood application.

^cHeat provided by burning coffee hulls.

^dGood application. Strong interest on part of operator.

^eGood application but at upper end of geothermal processing temperature.

^fGood application but high temperature is required.

^gGood application but far from field.

^hMarginal and also far from field.

ⁱMarginal.

^jGood but very far from fields.

^kGood, now using solar energy.

II are given as ranges because the two independent surveys received conflicting information from the same plant. The large variation seen in a few cases is regrettable, but all data were reported, and an average of the two values was used where necessary.

It may be possible to provide geothermal heat to some of the existing industries at Amatitlán; however, as will be seen, the most favorable application is for higher capacity factors and closer distances. In some case it might be possible to relocate a potential user closer to the geothermal source; certainly new industries should be located nearby.

The Amatitlán area appears favorable for the establishment of an industrial park containing relocated existing industries or new industries and using geothermal energy to meet processing heat requirements. Markets exist in the city of Guatemala as well as in the port of San Jose and provide an incentive for the establishment of a new industrial complex. Inexpensive and reliable thermal energy should make the area even more attractive, and each new user added to an existing loop will result in an even lower heat cost. Figure 5 shows the location of some of the existing industries in the Amatitlán areas plus possible new plants producing, for example, purified salt or polyethylene from sugar cane. An industrial park area could be established either south of the city of Amatitlán or anywhere to the south of Lake Amatitlán, depending on the locations of future production wells.

In November 1985 a technical exchange meeting was organized by LANL, MEM, and INDE to call to the attention of Guatemalan industrialists the potential of geothermal energy as an inexpensive source of process heat. Industrialists interested in the Amatitlán area exhibited a great amount of enthusiasm over the prospects there. Three smaller technical exchange meetings were held in January and November of 1986, and the private sector participants continued to express interest.

B. Zunil

The Zunil geothermal field, approximately 7 km south of Guatemala's second largest city Quezaltenango, has been extensively explored, with the drilling of a number of exploratory wells, followed by the drilling of 6 production wells. Both steam and mixed-flow production conditions have been encountered. Four of the production wells are expected to contribute to the generation of 15 MW of electricity. The drilling of additional wells is planned.

Figure 5. Some of the industries near Amatitlán that might use geothermal process heat. Also shown are potential locations for an industrial park development and a binary power plant for the industrial park.

At Zunil process heat could be provided by either (1) the heat in the residual water left after the generation of steam, (2) the primary heat from an unused production well, (3) the heat from additional wells drilled on the outskirts of the main reservoir and intended primarily for a direct-heat application, or (4) the heat in a fraction of the steam from the field's steam-gathering system.

The Zunil location is also attractive because of its proximity to a large agricultural area, the Salad Bowl of Guatemala. There are some industrial facilities to the northeast, but none is very close to the geothermal field.

The results of the surveys of the Zunil area made by MEM and ICAITI are summarized in Table III, which shows there are eight existing industries in the Zunil - Quezaltenango area requiring process heat that could be generated by geothermal energy. These industries include a textile mill, food processing plant, brewery, hotel, and hospital. The total heat consumption is 1.2×10^{11} Btu/yr. Typical uses for the process heat are drying, dyeing, humidification, cooking, pasteurization, water heating, and sterilization. The temperature range requirement for these plants is from 65 to 250°C (149 to 482°F). For these eight industries, about 97% of the process heat required is in the temperature range that could be supplied by the Zunil geothermal field. The capacity factors of these plants range from 25% to 91%, with the average being 53%. The relative importance of heat cost can be inferred from the fraction of product cost being attributable to heat cost, which ranges from 2% to 19%. The total heat consumption that could be provided by geothermal fluid is 1.1×10^{11} Btu/yr. The plant capacity factor would indicate a maximum heat rate of about 3×10^{11} Btu/yr. Such a maximum heat flow could be furnished from the residual heat from three or four wells being used to supply primary heat for the production of electricity.

Unlike the case of Amatitlán where future locations of the production wells are not yet known, Zunil wells are already drilled so that a prefeasibility study can include an approximately correct distance from well to industry. An extension to the Zunil field is already planned, and this extension is expected to be in the direction of Quezaltenango, reducing the distances to several of the industries listed in Table III.

Figure 6 shows that the most interesting existing plants listed in Table III are not optimally located. The addition of new users closer to the geothermal field would effect an improvement, but a heat-loop that could service several existing industries might still be desirable (see discussion, Sec. VI).

VI. COST DETERMINATION AND OPERATING SCENARIOS

A. Cost Determination Considerations

In order to carry out a prefeasibility study for a project, it is necessary to know something about the construction, operation costs, and delivered heat cost. A computer code is available that computes the levelized life cycle cost (LLCC)³ of a product, and this code can be used to compute the cost of the process heat being supplied. Frequently the project's costs vary considerably

TABLE III
POTENTIAL GEOTHERMAL HEAT
APPLICATIONS IN THE ZUNIL AREA

Plant No.	Location	Product	No. of Employees	Heat Consumption (10 ⁶ Btu/year)	Temperature Range (°C)	Heat Application	Operating Hours per Year	Energy Cost to Product Cost (%)
1 ^a	Cantel (~ 7 km E/NE of Quezaltenango)	Threads & fabrics	780	44	---	Setting, dyeing, & drying	5200	2
2 ^b	Quezaltenango (east side)	Synthetics	126	14	105	Dyeing, humidification	4100	3
3 ^b	Quezaltenango (east side)	Synthetic wool, textiles	80 - 100	5.6 to 8.0	100 to 250	Dyeing, fixing, humidification	4100	3 - 7
4 ^b	Quezaltenango (west side)	Beer	150 - 200	39	65 to 170	Cooking pasteurization, sterilization	8000	10
5 ^c	Quezaltenango (3 km NW)	Hides	45	5.1	120	Tanning, drying	2200	4
6 ^c	Quezaltenango (4 km NW)	Canned foods	60	2.8	115	Precooking, pasteurization, sealing	2200	19
7 ^b	Quezaltenango	Hotel	50	2.2	80	Water heating, drying, kitchen services	2000	10
8 ^b	Quezaltenango	Hospital	325	2.5	170	Sterilization, drying, baking, water heating	8000	7

^aWorthwhile candidate, but may be too far from field and too isolated from other candidates.

^bGood, but far from Zunil I.

^cPoor location.

Figure 6. The Zunil field and the location of existing nearby industries. Possible sites of potential new plants are also shown.

during its lifetime. The LLCC gives an average cost in constant dollars (or local currency units) that can be charged for the entire lifetime of the project; thus the total revenue exactly equals the sum of the initial operating costs (including the return on investment). In doing this, account is taken of inflation and interest, and the calculation requires the knowledge of a schedule of expenditures over the study period. Hence, a preliminary design of the facility and operating plan is needed.

The survey of existing industries gives us a knowledge of the location and present energy demand from which a preliminary system design can be made so that equipment and piping costs can be estimated. Because of the spread of the location of the existing industries at both Amatitlán and Zunil, a heat transfer loop several kilometers in length would be needed. Also because most of the users are small, the heat losses are higher than would be the case if larger industries were to be located close to the heat source. The cost of the heat loop piping becomes excessive when the distances increase beyond a certain value. In

the present configuration, without additional closer industries, preliminary calculations yield heat costs from US\$2.00 to US\$5.00/10⁶ Btu. This compares with a current cost from petroleum-based fuels of about US\$5.00/10⁶ Btu. On the other hand, for larger favorably placed industries, heat costs less than US\$1.00/10⁶ Btu can be anticipated.

It is best if the geothermal heat costs can be less than the cost for competitive fuels. However, it must be remembered that even if the cost of competing fuels are equal, the geothermal heat is indigenous and decreases the need for petroleum imports.

B. General Scenario Considerations

There are a number of factors that can influence the feasibility of using the energy from geothermal fluid to provide process heat including the various parameters describing (1) the production of energy by the source well, (2) the heat requirements of the using industries, and (3) the relative location of the source to users.

1. Production of Energy by the Source Well. Of primary importance at the wellhead is the temperature of the geothermal fluid and its mass flow rate, parameters determined by the hydraulic and geologic characteristics of the resource system. The temperature levels available for process heat are also determined by the design of the surface equipment. Lower temperatures are obtained if the fluid is first used to produce steam for the generation of electricity. Higher temperatures can be obtained if the extraction of process heat is the first use of the fluid, achievable if use is made of a downhole pump to maintain pressure on the fluid to eliminate the cooling effects of vaporization as the fluid rises to the surface.

Well drilling cost is another factor that can be extremely variable, depending upon well depth and the condition of the overburden and the reservoir strata being drilled. Also, reinjection of the spent fluid into the ground is often necessary and costly because reinjection requires an additional well and pumping system. Reinjection may be necessary to safely dispose of the fluids, which may be highly saline and/or toxic, or to recharge the reservoir to prevent a rapid depletion of the fluid. In a new development, wells drilled specifically for reinjection might be required or in an established geothermal field, it is occasionally possible to use previously drilled wells no longer required.

for exploration or production purposes. In unfavorable circumstances, the cost of reinjection can be significant.

The chemical constituents of the geothermal fluid are also important. The higher the mineral content, the higher the low temperature limit to which the fluid can be cooled before reinjecting or disposing of it in order to avoid unwanted precipitation and consequent fouling of heat exchangers or pipes. An increase in this temperature limit reduces the amount of heat that can be delivered by the fluid.

There are other environmental considerations in addition to those of dissolved chemicals already mentioned above. Gases released to the atmosphere when geothermal fluids are vaporized can include hydrogen sulfide. The smell of hydrogen sulfide at low concentrations is obnoxious. At high concentrations it can be biologically fatal, and abatement techniques become an operational requirement. In some locations and circumstances noise abatement can also be required.

2. Heat Requirements of the User/Industries. The temperature at which the process heat is required by the user will determine the applicability and desirability of this application. Even for primary heat from the well, temperatures are limited to about 250°C (482°F), and for residual heat after the generation of steam, the limit is about 160°C (320°F). Lowering the temperature of heat used in the factory increases the quantity of heat that can be profitably removed from the geothermal fluid. For example, if water at ambient temperature is to be heated, it might be possible to use almost all of the heat in the heating water loop, down to perhaps 38°C (100°F).

The plant capacity factor is also important. Because the heat loop is a relatively simple system consisting only of heat exchangers, piping, a few valves, and a pump, the operational availability of the heat loop itself should be very high, perhaps 95%. The geothermal well will require some maintenance, perhaps two weeks per year, resulting in an availability factor of 96%. If multiple wells can be connected into a redundant supply system, geothermal heat could be available close to 100% of the time. Therefore, the capacity factor of the heat delivery system will be largely determined by the ability of the users to accept the heat. A plant operating one shift per day five days per week will have a capacity factor of about 25% whereas a three-shift operation for five days per week will have a factor of over 70%, economically much more desirable.

A third factor of importance is the quantity of heat required as compared to the total capacity of the heat delivery system, or alternatively, the total capacity and distance between a number of users sharing the same heat delivery system.

3. Relative Location of the Source to Users. The cost of the heat delivery system will depend greatly upon the distance over which the heat must be transported. In special circumstances, where the plant is located immediately adjacent to the well and the fluid is relatively clean, it can be possible to use the geothermal steam or liquid directly in an industrial process that can tolerate the raw geothermal fluid. However, when multiple processing requirements must be met, it is usually advantageous to transfer the thermal energy to multiple users through a closed water loop in which the energy is transferred into the loop at the well. In this fashion contamination from the geothermal fluid can be limited only to the wellhead portion of the loop system. The water in the heat transfer loop can be treated to be compatible with its containment piping and equipment. Also, a closed water loop can be routed over changes in elevation without incurring any increase in pumping work requirements over what would be the case for a horizontal system. However, the distance from source to user will still be important in determining pipe sizes, thermal insulation requirements, and pumping energy. Although each case must be examined on its own merits, practical applications will usually be limited to users within a distance of 10 km.

In summary, the most advantageous cases will be for large users operating at high capacity factors, requiring heat down to the lowest temperatures, and located close to source wells of moderate depths.

C. Typical Scenarios and Heat Costs at Amatitlán

A number of different scenarios for geothermal heat delivery systems were established, and the corresponding costs of heat delivered to user plants were calculated. The scenarios that are discussed below have been selected to cover a range of the important parameters such as geothermal fluid temperatures and flow rates, distances from the heat source, processing requirements, and plant capacity factors. An attempt was made to make conservative assumptions for all cases. Six scenarios applying to Amatitlán will be discussed below to illustrate the costs of delivering heat to industrial plants.

1. ALHEAT Scenarios (Nos. 1 - 4). The scenarios bearing the ALHEAT title simulate systems that might be established at Amatitlán exclusively for industrial process heat applications. Also considered are two slightly different scenarios, titled PPHEAT, which pertain to the possible use of the geothermal heat as part of the thermal cycle in an oil-fired electric power plant. Such an oil-fired power plant already exists on the south shore of Lake Amatitlán. The major assumptions pertaining to the scenarios considered for Amatitlán are discussed below.

Although the potential for a geothermal power plant at Amatitlán is excellent, probably none will exist for many years, and no wells exist that can be shared by both power production and direct-heat applications. Therefore new wells would have to be drilled to be used either exclusively for process heat or else for process heat in conjunction with wellhead power generators. Based on information and estimates from INDE, wells can be drilled in the western part of the main reservoir area to depths of approximately 700 m to achieve flow rates of at least 300,000 lb/h and temperatures from 165 to 200°C (329 to 392°F).

An industrial plant will want to be assured of a continuous and reliable source of heat throughout the year. Therefore we have assumed that two production wells will be needed, each with a 300,000 lb/h capacity, to provide a production well and a backup well. In actual practice both wells could be operated simultaneously at one-half capacity so that any degradation with time could be minimized.

In order to avoid surface disposal of spent geothermal fluid into nearby Lake Amatitlán, a reinjection well will also be required. From the knowledge gained by INDE from the initial exploratory wells drilled at Amatitlán, there appears to be an aquifer system at a depth of about 150 m, and this aquifer is independent of the near-surface water as well as from the expected production zone located at a depth of 600 to 700 m. Therefore it was assumed that the geothermal fluid can be reinjected into a 150-m deep well.

The above-mentioned assumption of two production wells to supply the equivalent production of one well is conservative. If the Amatitlán geothermal field develops into one supplying steam to a power plant generating 100 MWe of electricity as projected by INDE, then the large number of wells needed would result in a redundancy of thermal energy sources. Also, use could be made of the relatively large reinjection system that will be needed for the electric power generation system. Thus there could be available a reduction in the cost

of wells, and consequently the cost of the process heat would be reduced accordingly.

As a geothermal fluid rises in a well bore and the hydraulic head decreases, steam is formed. The total hydraulic head on the reservoir then decreases and the liquid/vapor mixture is forced to the surface. This self-pumping action is usually utilized to effect the well flow, especially when steam generation is desired. The vaporization reduces the temperature of the mixture, and if the well production is already marginal, the temperature and mass flow rates available to provide process heat might not be adequate. One way to maintain the desired temperature level at the surface is to install a downhole pump in the well to generate sufficient pressure to prevent vaporization and to pump the fluid to the surface in a liquid state. Special high-temperature pumps are commercially available, but they are expensive and increase operating costs. However, the benefits of the higher temperature may be worthwhile, and several scenarios using downhole pumps were evaluated.

The concept used to transfer heat from the wellhead to the industrial plant is to use a closed water loop, heated at the wellhead and cooled at the plant. By controlling the chemical content of the water in the loop, inexpensive steel piping can be used. Included in the loop system would be shut-off, fill, and drain valves, pressure regulators, a pump, the heat exchangers at the hot and cool end-points, and thermal insulation on the piping. Depending upon the specific operating conditions and requirements, a more direct and perhaps cheaper heat delivery system might be used. For example, concrete blocks might be cured by using geothermal steam that flows directly from the well to the plant, or buildings might be heated by the direct use of geothermal water as has been done for many years in Iceland. However, because of dissolved chemicals or toxic gases, geothermal fluids cannot always be used directly. Also, when a variety of processing requirements are to be met, e.g., in an industrial park, heat delivery through the closed water loop is probably easier to control. In addition, scaling problems caused by precipitation resulting from the cooling of the geothermal fluid can be minimized and localized with the use of the closed-water heat-transfer loop.

The high cost of production wells and surface piping make it imperative that the plants using the geothermal process heat operate at a high capacity factor. For our analysis it was assumed that capacity factors of at least 60% could be used. The plants that were considered in this survey (see Tables II

and III) have capacity factors that range from 25% to 91%. For a plant that operates two shifts per day for 7 days per week, the capacity factor is 67%. If we assume a geothermal heat delivery system availability of 94%, the overall capacity factor then is reduced to 63%, which is still an acceptable value.

When a plant can operate on a 24-h/day basis, capacity factors of 95% are possible. An example of such an operation is a geothermal binary electric generating plant in northern California that has been reporting capacity factors of at least 95% for the past 2 years. To obtain estimates of heat for the most favorable capacity factor, several Amatitlán cases with a capacity factor of 95% were included. Two other cases at 70% were also examined. If all other parameters are maintained constant, heat costs are inversely proportional to the capacity factors.

Table IV summarizes the assumptions made for the ALHEAT and PPHEAT scenarios. The results of the LLCC calculations for the ALHEAT No. 1 and 2 scenarios apply to a user plant 1 km from the geothermal heat source and operating at a maximum capacity factor, but limiting the minimum effective geothermal fluid temperature to 80°C (176°F). Initial temperatures of 165°C (329°F) and 200°C (392°F) resulted in delivered heat costs of US\$1.82/10⁶ Btu and US\$1.43/10⁶ Btu, respectively. If the capacity factors were to be lowered to 63% instead of the 95% value, the ALHEAT scenarios Nos. 1 and 2 would result in costs of US\$2.74/10⁶ Btu and US\$2.16/10⁶ Btu, respectively. If, at the same time, the final exit temperature for the latter cases were to be reduced to 50°C (122°F), the corresponding heat costs would decrease to US\$2.03/10⁶ Btu and US\$1.73/10⁶ Btu, respectively. Thus the potential costs for delivered heat are seen to range from about US\$1.43/10⁶ Btu to US\$2.74/10⁶ Btu for nearby plants using most of the heat produced by a two-production-well combination with a 300,000 lb/h total flow of geothermal fluid.

The ALHEAT scenarios Nos. 3 and 4 are the same as Nos. 1 and 2 except that the plants were assumed to be at a distance of 4 km from the heat source. The effect of the increased cost of the heat delivery system was to approximately double the cost of the heat to the user. This result indicates that it might not be economically feasible to connect the existing plant sites in the Amatitlán areas with a rambling heat loop. Rather the economical approach would be to concentrate the plants in a more carefully planned industrial park complex.

TABLE IV

TYPICAL SCENARIOS AND PROCESS HEAT COST ESTIMATES FOR AMATITLÁN

	Scenarios					
	ALHEAT #1	ALHEAT #2	ALHEAT #3	ALHEAT #4	PPHEAT #1	PPHEAT #2
<u>Assumptions</u>						
• Number of production wells	2	2		2	2	2
• Depth of production wells (m)	700	700	700	700	700	700
• Number of reinjection wells	1	1	1	1	1	1
• Depth of reinjection wells (m)	100	100	150	150	150	150
• Distance, wells to plants (km)	1	1	4	4	1	1
• Flow rate of geothermal fluid (kg/h)	136 000	136 000	136 000	136 000	136 000	136 000
• Well pumping by vaporization in well	yes	--	yes	--	yes	--
• Pumping with down-hole pumps	--	yes	--	yes	--	yes
• Geothermal fluid temperature at wellhead (°C)	165	200	165	200	165	200
• Geothermal fluid temperature after heat extraction (°C)	80	80	80	80	50	50
• Capacity factor of process heat plant	0.95	0.95	0.95	0.95	0.70	0.70
Levelized cost components (US\$10 ⁶ Btu)	1.82	1.43	3.74	2.88	1.83	1.54

2. PPHEAT Scenarios Nos. 1 and 2. For the PPHEAT cases it was assumed that heat would be used in an oil-burning electric power plant such as the already existing plant on the south shore of Lake Amatitlán. In this case the heat can be extracted down to 50°C (122°F) instead of to the 80°C (176°F) limit used for the ALHEAT cases. Another difference was the 0.70 capacity factor of the oil-burning power plant itself. For the cases of the 165°C (329°F) and 200°C (392°F) upper temperatures of the geothermal fluid, the heat costs were estimated as US\$1.83/10⁶ Btu and US\$1.54/10⁶ Btu, still attractive costs compared to that of using diesel or bunker fuels.

The costs shown in Table IV are for producing and delivering the process heat to a factory only. No attempt has been made to predict the amount of profit desired by the operating agency or any tax that might be charged to the user. Similarly, no attempt was made to estimate a cost to the user for factory modification other than including the cost of the heat exchanger at the factory end of the heat loop.

D. Typical Scenarios and Heat Costs at Zunil I

1. Background Information and Considerations. The geothermal field called Zunil I contains a number of small-diameter exploratory wells plus six production wells. Of the six, two may be used for reinjection purposes. Fluid not reinjected will be disposed of into the nearby Samalá River through a concrete-lined canal. Additional production wells will be drilled to support the operation of the future power plant. The locations of the power plant and its wells, as planned by INDE several years ago, are shown in Fig. 3. The wells designated as ZCQ-1 through 6 are in place. Those designated A, B, and C have yet to be drilled. Additional exploration studies are being conducted outside of the Zunil I area, and INDE has indicated that the geothermal resource may trend to the northwest toward the city of Quezaltenango. INDE has named the potential new resource field Zunil II.

The results of the survey of existing plants that might use geothermal heat in the Quezaltenango-Zunil area was discussed in Chapter V-B. The closest potential user is a large textile plant about 7 km from Zunil I at Cantel, with an average heat consumption of about 8×10^6 Btu/h. Even more distant and somewhat more difficult to run piping to are several plants in Quezaltenango.

Figure 6 shows the locations of the two paved highways between Quezaltenango and Zunil, the six largest existing heat-using plants, hypothetical heat users, and a possible agricultural processing center. The latter potential application is extremely promising because of the wide variety and quantity of produce grown there. In addition to the temperate climate crops grown locally, tropical crops from the low coastal plain not far south of Zunil could also be available for processing.

Our investigation shows that the few plants consuming large quantities of process heat are not favorably located. For example, the brewery in Quezaltenango (no. 4 in Fig. 6) is about 16 km by road from the Zunil field. The terrain is rugged and precipitous, and the route may have to follow the road. Furthermore, there would be many street and road crossings plus safety and security problems to solve, especially in Almolonga and Quezaltenango. The costs estimate for solving these problems prohibit the project. Further consideration of supplying heat to Quezaltenango will have to be put aside until Zunil II is developed. However, several other heat application scenarios for Zunil I will be discussed below.

2. ZUCANT No. 1: High-Grade Heat to Cantel. A pipe route between Cantel and Zunil appears more feasible than one linking Quezaltenango and Zunil. Therefore, an evaluation of the costs of delivering heat to Cantel was made, based on the following assumptions. A schematic of the system is shown in Fig. 7.

(a) Residual water from a steam separator is used to supply hot water at an initial temperature of 200°C (392°F) at a pressure of 15.5 bar (225 psia). The latter pressure is higher than is usual in a steam power plant, but it would result in the desired 200°C (392°F) fluid temperature for this scenario.

(b) Two production wells, 1100 m deep, will provide the steam supply for the 15-MWe steam power plant (a steam wellhead generator would be another option), heat to a binary power generator, and heat to Cantel through a hot water loop. The average flow for the two wells over a 20-year project life is 300,000 lb/h. The production well ZCQ-3 has produced about 300,000 lb/h during previous test periods.²

(c) The geothermal fluid is reinjected through the same system used by the 15-MWe power plant.

ZUNIL TO CANTEL 200° C LOOP

Figure 7. Schematic of ZUCANT Scenario No. 1 for delivering high-grade heat to Cantel.

(d) The residual heat is used at the Q_1 , Q_2 , and Q_3 rates shown in Fig. 7. The sum of Q_2 and Q_3 equals $35.7 \times 10^6 \text{ Btu/h}$, over four times that now consumed by the textile plant in Cantel. Additional plants would probably have to be built at Cantel in order to make the installation of a hot water pipeline economically feasible. Also, plant no. 2 would probably require high-temperature heat for generation of processing steam, and plant no. 3 requirements could probably be met with lower temperatures. Hence, the 188 to 70°C temperature utilization range from inlet to outlet of the Cantel plants was assumed. Also, an average plant capacity factor of 63% was used.

(e) In order to maximize the utilization of the heat, power is generated by a binary generator sized to use the remaining heat after demands of Q_2 and Q_3 are satisfied.

(f) For cost and design estimation purposes, it is assumed the same supply of cooling water used by the 15-MWe power plant will be available to the binary generator. The binary generator has a net generating efficiency of 14.6%.

(g) The heat exchangers in the binary generator and in HX-1 are designed for ease of maintenance to avoid or remedy severe fouling and precipitation in the geothermal fluid lines.

(h) The costs of the energy production components are apportioned according to the absolute quantities of energy used by each of the four application's: Q_1 , Q_2 , Q_3 , and steam to the 15-MWe power plant. Using the above ZUCANT No. 1 scenario, we estimated a heat cost at the Cantel plants of US\$4.60/10⁶ Btu. This cost compares to the minimum of US\$5.00/10⁶ Btu for oil fuels at the current price in Guatemala of US\$0.57/gal. The major cost item is the 7-km-long heat loop, 100% of which must be charged to the heat loop, and this amounts to 72% of the total capital cost. The total capital cost consists of fractional costs of the wells and associated surface facilities plus all of the heat loop costs.

3. ZUCANT No. 2: High Grade Heat to Users 2 km from Source. The same assumptions as for ZUCANT No. 1 were used except that the distance was decreased from 7 km to 2 km. This would locate plants 2 and 3 (see Fig. 7) close to the village of Zunil. The heat cost for this case was decreased to US\$2.90/10⁶ Btu. Still lower costs could be obtained by moving the plants even closer to the wells.

4. ZUCANT No. 3: Cost of Power from the Binary Generator. The same energy proportions and system assumptions described for ZUCANT No. 1 were used to obtain power cost estimates, and the estimate for power generation cost was about US\$0.06/kWh. The latter would probably be a competitive production cost, depending on the mix of hydro, thermal, and geothermal power being generated or planned by INDE.

5. Other Scenario Options. The above ZUCANT scenarios are, by no means, the only scenarios that could be studied as is illustrated by the options described below.

Option 1: Reduce the Residual Water Temperature. This option is similar to that schematically illustrated in Fig. 7 except that the separator pressure would be reduced to 105 psia, which corresponds to a saturation temperature of 166°C (331°F). The separator pressure is the pressure level that was originally selected for the INDE 15-MWe power plant design.² It is also close to that used

in many other geothermal power plants around the world. The actual value depends on an economic optimization study for each geothermal resource and its reservoir pressure.

The 166°C (331°F) temperature level would be quite satisfactory for an agricultural processing plant located near the source well; therefore it deserves serious consideration. An advantage of this scenario would be that the steam available for the 15-MWe plant would not be affected by the diversion of the residual heat to the direct-heat application. Binary generators also perform well (generating efficiency ~12%) at the 166°C (331°F) temperatures. In fact, in the US and elsewhere, binary generators working at considerably lower temperatures than 166°C (331°F) have been found useful for a variety of applications.

Option 2: Use New Wells on the Field Fringes. It should be possible to drill wells into 165 to 200°C (329 to 392°F) geothermal fluids at less than the ~1100-m depths used for the existing production wells. We already have a few examples of these conditions in the exploratory wells that were drilled at Zunil. Exploratory well Z-11, which is planned to be used for the dehydration pilot plant being built next to well ZCQ-3, has tapped into a fluid at an ~600-m depth that appears to have a temperature of at least 225°C (437°F). Another promising candidate is well Z-4, located between the main Zunil I field and the village of Zunil and showing ~200°C (392°F) at about 300 m. The small-bore exploratory wells would have to be redrilled to larger diameters to assure adequate flow rates. The advantages of Option 2 would be that (1) the exploration work has already been done, (2) the main Zunil wells would be close by to serve as temporary backup heat sources (e.g., production well ZCQ-3 could be backup for a new shallow well drilled at the exploratory well Z-11 location), (3) downhole pumps might be used to maintain a maximum usable temperature at the surface, and (4) the financing of a direct-heat project could be relatively independent of that for the 15-MWe power plant.

Option 3: Use Only Steam from the Zunil I Field. At present two of the Zunil I production wells are steam-dominant. It would be fortunate if all wells were to become steam producers, a possibility considered by INDE. Even then, enough steam and liquid separation operations would be required to generate the residual liquid that could be used as described in the ZUCANT scenario discussions. However, the extraction of heat from the steam would not create a serious problem. Indeed, the reduction in steam flow to the power plant would

reduce the power output accordingly, but the quantity involved to satisfy the needs of an agricultural processing plant would be small. Our previous estimates for such a plant were for a power level of 650 kWe for the freezing components and perhaps 5×10^6 Btu/h for the dehydration and other direct-heat components. The electric power could be generated by the steam power plant. The 5×10^6 Btu/h could be extracted from ~4500 lb/h of steam. The 15-MWe power plant would require ~270,000 lb/h of steam. Therefore the direct-heat part of the processing plant would require only about 2% of the power plant's steam requirements--certainly not a "make or break" quantity for the power plant. Also, it has been estimated that from an energy-utilization efficiency standpoint, use of energy for process heat can be twice as efficient as its use for generating electric power. Further, the economic and political benefits to be gained by the development of a new geothermal agricultural processing plant probably far exceed those derived from the generation of an additional 300 kW of electric power.

The list of options and their variations will not be expanded further in this discussion. The most optimal design and operational approach will not be known until more detailed prefeasibility studies are made. For a new application like agricultural processing at Zunil, however, there do not appear to be any serious technical obstacles.

VII. NEW APPLICATIONS

In Sec. V, we presented the results of our survey of the existing industries in the Amatitlán and Zunil areas of Guatemala that might be candidates for the use of geothermal heat for processing. In carrying out the survey of existing industries, a number of possibilities for new applications became evident. A list (see Table V) was developed from discussions between LANL and ICAITI, MEM, INDE, and private sector industrialists who permitted us to visit their plants and who also contributed ideas during several technical exchange meetings.

The new applications and the applications already existing are presented together as "new" possibilities that appear attractive from the standpoint of energy utilization and logistics because existing plants might find it advantageous to relocate where less expensive thermal energy would be available.

TABLE V
POTENTIAL NEW APPLICATIONS FOR GEOTHERMAL HEAT

- A. Agricultural Processing and Related Activities
- B. Sale Production and Refining
- C. Amatitlán Thermal Power Plant
- D. Water Pumping for Guatemala
- E. Heating and/or Cooling of Hospitals or Hotels
- F. Production of Concrete Blocks and Adobe Bricks
- G. Production of Anhydrous Ethyl Alcohol from Sugar Cane Molasses
- H. Production of Polyethylene from Ethanol
- I. Production of Bleached Pulp from Sugar Cane Bagasse
- J. Methanol Production From Wood Waste
- K. Combined Heat and Electric Systems

Of the application concepts shown in Table V, only 2 of the 11, items J and K, were discarded and those for reasons not directly related to the utilization of geothermal heat. The remaining concepts were considered promising enough to warrant further investigation. The list is not all-inclusive by any means: only those which appear promising are listed. Below we describe and evaluate each new concept.

A. Agricultural Processing and Related Activities

1. Introduction. In Guatemala, where agriculture is the dominant activity, many different agricultural applications of geothermal energy are immediately obvious. The best applications are listed below.

- o Sterilization
- o Cooking
- o Blanching
- o Partial dehydration
- o Almost 100% dehydration
- o Heating greenhouses
- o Above-freezing cold storage
- o Subfreezing processing and storage

The last two applications are not direct-heat uses, but they can be accomplished using geothermal energy. They represent related agricultural

activities that can be even more energy and cost intensive than the first six activities. They also fit well into the concept of an agricultural processing center.

The improvement of the agricultural industry in Guatemala and the development of new agricultural products for export is a major objective of the USAID program in Guatemala. The USAID personnel strongly urged LANL to concentrate on the use of geothermal energy for agricultural processing in such a way as to complement the USAID efforts already under way in the highlands areas. A number of freezing and cold storage plants that use electric power to drive their equipment have already been built in Guatemala. Canning is not considered a viable process in Central America because of the high costs of the importation and shipping of the cans. Some drying of crops is done, but no extensive development of dehydrated products appears to have taken place. The latter is a good application for geothermal heat. The development of the market for frozen products is considered by USAID to be promising even without geothermal energy. The use of geothermal energy to mechanically drive the produce freezing and cold storage refrigeration equipment in a freezing plant is technically possible but its economic feasibility still needs to be determined.

2. Characteristics of an Agricultural Processing Center. The variety of agricultural products available in the vicinity of Zunil indicates a need for different ways to process food including dehydration, cold storage, and freezing. Table VI lists a number of the agricultural products available relatively close to Zunil that could be processed both for local consumption as well as for export. A schematic representation of an agricultural processing center for food dehydration, cold storage, and freezing capabilities is shown in Fig. 8. The plant would use Zunil residual heat to generate its own electric or mechanical power to drive the refrigeration processes and to accomplish the required blanching and dehydration processes. Use of Well ZCQ-3 is arbitrarily shown, and it can be observed that less than half of its residual fluid is required.

The economic feasibility of such a venture will depend upon the quantities processed and the times that crops become available, the latter being the determining factor in establishing the capacity factor of the plant. It has been estimated that to be economically feasible, a dehydration facility would require a minimum production of 1 to 2 ton/day of dried product. A freezing plant, on the other hand would require a throughput of at least 20 ton/per day.⁴ However, to establish these minimum quantities more firmly would require a feasibility

TABLE VI
CROPS THAT COULD BE PROCESSED IN A ZUNIL PLANT

Freezing:

1. Broccoli	5. Green beans
2. Cauliflower	6. Cabbage
3. Brussel sprouts	7. Other specialty crops
4. Snow peas	

Dehydration:

1. Green beans	11. Zucchini squash
2. Cabbage	12. Parsley and chives
3. Asparagus	13. Beets
4. Celery	14. Carrots
5. Okra	15. Cardamom
6. Spinach	16. Citrus peel
7. Cucumbers	17. Mangoes
8. Onions and garlic	18. Papayas
9. Peppers	19. Pineapples
10. Tomatoes	20. Apples

Source: Informal reports by Fred Voit, Voit y Compania, Guatemala.

Figure 8. Schematic illustrating the major components of an agricultural processing center (Zunil).

analysis that includes both local supply conditions as well as the current market.

A typical dehydration plant could use a dehydration tunnel with an air flow with velocities of up to 305 m/min (1000 ft/min) at temperatures up to 66°C (150°F). Of course, there are other drying designs besides tunnels that are applicable to large dehydration plants, but these will not be discussed here. In addition there will be a need for bin dryers, food washing and blanching, sulfur additive devices plus various utensils for food preparation such as slicers, peelers, and packaging devices. The necessary heat to warm the input air can be extracted from primary geothermal fluid or from residual fluid.

A cold-storage room can be used to hold fresh food near its freezing point for longer periods of time before marketing or processing. As will be discussed later (see Sec. VII-E) the necessary cooling can be provided by absorption refrigeration systems with heat from the geothermal fluid as the energy input.

A food freezing plant will require colder temperatures than the above-mentioned cold storage room (near -29°C or -20°F). This temperature is too cold to be achieved with commercially available absorption refrigeration equipment. Instead, use is made of conventional Freon refrigeration-cycle machines that utilize compressors. Typically these compressors are driven by electric motors. Thus one option is to power the motors by electricity either purchased from INDE or generated in-plant by a binary generator (see Sec. VII-K). However, it might be advantageous to consider connecting the compressors directly to the binary system, eliminating the generator and electric motor. The elimination of the extra energy conversions should contribute a gain in efficiency of about 15%.

The basic operations of a frozen food plant capable of at least 20 ton/day of product consist of the following.⁴

1. Preparation cutting, trimming to size, sorting out undesirable product, etc.
2. Washing
3. Blanching: heating to 82°C (180°F) to inactivate the enzymes
4. Cooling: using water and/or air
5. Sorting and packing into containers
6. Freezing, which can include a continuous belt and or a freezing tunnel and or plate freezers
7. Final packing for storage

The required stainless steel machinery in a frozen food plant includes the following:

1. Belts for trimming operations
2. Washer
3. Blancher
4. Cooler
5. Packaging machinery
6. Freezing machinery
7. Packing machinery

Other components of the facility include the following:

1. Refrigeration equipment
2. Land--5 acres
3. Building 80' x 200', including cool room at 1°C (34°F) for 10 truck-loads and warehouse at -29°C (-20°F) for 20 truck loads
4. Office, laboratory, dry warehouse
5. Wells and waste disposal equipment
6. Mobile equipment: two trucks, two pickups, two cars, and one small bus

The cool room can be used to cool fresh shipped vegetables and fruits and for storage of peaches, apples, plums, and other fruits, including tropicals to extend the marketing season or improve the plant's capacity factor.

The freezing operation will require at least 200 factory employees. These can be drawn from the local population. Management can be selected from the many university-educated people.

3. Summary. The geothermal field is very close to a good supply of a number of food products that are good candidates for processing by dehydration, cold storage, or freezing. Furthermore, the elevations span close by of from sea level to more than 2745 m (9000 ft) results in a great variation in climate and growing conditions, thus affording the opportunity to expand the range of products.

The Zunil geothermal field has already been developed to the stage where production wells are available, and the energy available, even after the production of electricity, is quite compatible with this application. The present plan to develop a 15-MW electric power plant will assure more than sufficient

energy (residual or otherwise) at a suitable temperature level to drive a full-scale agricultural processing plant. Therefore, the further investigation of this application by carrying out a prefeasibility study is highly recommended.

B. Salt Production and Refining

1. Introduction. In Guatemala, as in other Central American countries, natural salt deposits do not exist, so salt is either imported or produced from sea water. Local salt production has climbed from 30% to 80% of total consumption in recent years, and the product is designated either as crude "solar" or "cooked" salt. Cooked salt, requiring considerable amounts of firewood, has resulted in deforestation of the coastal salt production areas. Although cooked salt is the preferred variety, solar salt has displaced it for reasons of economics and convenience and accounts now for 99% of production.

2. Crude Salt Production. During the 5-month sunny season, some 120 small operators and 30 large ones produce around 35,000 metric tons of crude salt. Their sites are scattered across the southwest coast of Guatemala, with the majority located near Sipacate de Escuintla. Each operates an interconnected chain of open evaporator ponds terminating with a final crystalization patio. Seawater is introduced into the primary pond from a supply canal, or estuary, when the tide is high. A 16-HP gasoline or diesel engine is located next to the canal or estuary for the purpose of pumping the seawater up into the primary pond. The water then passes successively through the pond system, becoming more concentrated at each step. Salt concentration is measured with a hydrometer in units of degrees Baume (Bé). Salt concentration increases from around 3 to 4° Bé in the seawater to around 18 to 21° Be in the final pond over the space of around 15 days. Sealife and sediment drop out of the water as salt concentration increases, yielding crystal-clear, high quality saltwater. In the final step the water is passed onto the evaporator patio where evaporation and crystalization processes are accelerated by solar energy. The salt is scraped into piles with wooden rakes, then scooped into plastic bags and carted to a nearby storage bin or roofed area. In cooked salt, the final crystalization is accomplished by cooking the saltwater in large metal vats made from metal barrel material.

Evaporator ponds are simple earthen tanks made by scraping the ground surface flat and forming the sides with the scrapings. Connecting gates are

usually made from wood. The accumulation of fine silt seals the ponds so that water losses are negligible.

Water is moved from pond to pond in a manner that causes the least turbulence. This allows for greater sedimentation, optimum water clarity, and resulting greater penetration of solar energy to the pond floor. The natural black color of the local sand and silt is beneficial as an absorber. The final evaporator pond is sometimes equipped with a gate valve that allows surface water to pass on to the patios without disturbing the pond floor.

The crystalization patios are of various construction. Some patios are made with tile (9" x 9") floors and brick walls. Others are made of concrete, which is usually of a dark color. Still others are formed of earth and lined with a black plastic film to serve as both container and solar absorber. In place of a single patio, operators usually divide them into four sections to optimize crystalization batching.

A typical operator has 12 to 16 evaporator ponds, each approximately 929 sq m by 1 to 2 m deep, plus a final evaporation patio of equal area. Seawater is pumped into the first pond, successively displacing water through each pond until the final pond receives the increase. Early in the day, final pond water is allowed to enter the patio to a depth of around 2 cm. This quantity of water evaporates within 4 or 5 hours to yield crude salt that is then harvested.

Around 4 cubic meters of seawater is required for the production of 100 lbs (1 quintal) of crude salt, with a yield of around 1.5 lbs per square meter per day from the patio. The typical small operator produces 1,200 to 1,500 lbs per day during January to mid-May. Crude salt production is quite labor intensive, requiring four or five workers to operate a typical "salina."

Crude salt is in the range of 90% NaCl, including also CaSO_4 , CaCO_3 , and a host of other minor salts and grit. Small bits of patio surface gradually erode to contribute grit, along with a small quantity of airborne matter. Raw salt is not consumed directly because of Guatemalan law requiring iodization, so it must first be treated. After iodization most people consume the salt at this unrefined stage, either directly or after grinding. Many industrial users are consumers of this product.

3. Refined Salt. The raw salt is passed through a refining process, either to upgrade the crude variety or to produce pure salt. The up-graded salt is treated with water to remove particulate matter and then dried and ground for

end use as table salt, food processing, etc. This salt still includes some sulfates, carbonates, and trace minerals, which are not harmful to persons.

About 10% of the crude salt eventually becomes "pure-refined" at a refinery at Amatitlán. There the crude salt is dissolved in water, iodized, then passed to the evaporators that crystalize the salt after precipitating the extraneous salts. A diesel/bunker boiler produces steam that serves the evaporators. The final drier is fired by propane gas to yield dry, pure refined salt that is fine-ground for packaging and distribution as top quality table salt.

4. Production, Importation and Costing of Salt. In 1985, Guatemala produced approximately 32,000 metric tons of salt and imported almost 9,000 metric tons for a total consumption of more than 40,000 metric tons. Projections are that total consumption will climb to 50,000 metric tons annually by 1990. The government has instituted a program aimed at helping local people to set up additional salinas along the coast. These new operations would enable Guatemala to both reduce its present salt imports and fill future increased demand.

The producer's price for raw salt has gradually risen over the last few years from Q8.5 to Q11.00/quintal. Of this production, approximately 80% goes for human use or consumption, with the other 20% going for animal or industrial use. The user's price varies between Q0.12/lb and Q0.20/lb in the capital to as high as Q0.30/lb in remote areas. The refined salt brings a retail price of Q0.25 to Q0.40/lb.

5. Summary. It appears that geothermal energy could be appropriately utilized in the refining process at Amatitlán. The refinery siting and transport network are already in place, and geothermal resources are potentially available. Further, the owner and operator of the Amatitlán refinery has, on several occasions, expressed a strong interest in operating the refining process on geothermal heat and has even thought of moving the present plant, if necessary, to accommodate the geothermal source location.

Assuming that the geothermal fluid temperatures are sufficient to economically and efficiently generate the necessary steam [150 to 200°C (302 to 392°F) fluid temperature should be satisfactory], the refining process requirements should be easy to meet. The petroleum-fired boiler and the gas-fired drier could be replaced by geothermal heat exchange units to deliver the quality and quantity of energy needed for all the processing from solution and evaporation through final drying. The geothermal resource heat could supply energy for (1)

the evaporators, (2) the dissolving process, and (3) the drying process in a cascading manner within the refining plant.

Although crude salt production takes place over a period of 4-5 months, the refinery could be sized to operate continuously for around 10 months of the year, allowing 2 months for maintenance, clean-up and repair. Salt refining appears to be an excellent application of geothermal heat, and a salt refining plant could be a component of an Amatitlán industrial park.

C. Amatitlán Thermal Power Plant

1. Introduction. Thermal (oil-fired) power plants have been, and will probably have to remain for many years, the primary back-up units to Guatemala's hydro power plants. One of the oil-fired thermal plants is a relatively large (40-MWe) plant on the south shore of Lake Amatitlán, adjacent to, or directly over the Amatitlán geothermal reservoir. The fortuitous location of the latter plant offers the opportunity of adding some low-grade (geothermal) energy to the high-grade (oil) energy now in use.

2. Reasons for Considering Power Plant Modification. A geothermal/oil combination can be effected by using the geothermal fluid to preheat the feed-water entering the steam generator. In this case primary geothermal heat would be utilized because the highest temperatures possible would be desired. The only additional equipment needed in the thermal plant consists of heat exchangers, piping, instrumentation, and controls. The use of this technique could result in oil savings of the order of 20% depending upon the actual operating parameters of the existing power plant. Studies of this concept in other locations have already shown its feasibility.

3. Summary. The inclusion of this power plant application has a great deal of synergism with the establishment of an industrial park at Amatitlán. The power plant could contribute the relatively constant load that would raise the average capacity factor of the industrial park to economic levels. The power plant is also a large user with the potential capability of consuming up to perhaps 8×10^7 Btu/h so that full-scale production wells could be effectively exploited. The above energy demand might require more than the production capability of a single well. The requirement for multiple wells dedicated to direct heat application could provide the desired redundancy for the heat supply of a nearby industrial park. These advantages plus the potential oil savings make this an application worthy of further investigation. The

actual design features of the thermal plant must be studied to ascertain whether geothermal heat components can be easily included into its system.

D. Water Pumping for Guatemala

1. Introduction. All large municipalities have substantial water pumping requirements, and the city of Guatemala is no exception. Local groundwater supplies can only meet a small fraction of the future municipal demands, and water will have to be pumped from surface sources over considerable distances. No studies of the use of geothermal energy to assist with pumping were found; therefore we made such a brief study. Although pumping is not a process-heat application, geothermal power and process heat applications can usually be integrated economically. Once a geothermal pumping plant is established, an integrated system would probably be developed over the long-term. For pumping, the basic concept would be to use geothermal energy to produce mechanical power to directly drive water pumps.

2. Previously Developed Plans. The municipal waterworks EMPAGUA of the city of Guatemala, using the services of the Tahal Consulting Engineers Ltd., has designed a Master Plan of Water Supply to the City of Guatemala (PLAMABAG). The primary objectives were to assess all possibilities of supplying water to the city and establish a program to cover water demand to 2010.

In order to evaluate water demand to 2010, a population projection was made within a geographic framework identified as the Central District, which encompasses an area of 470 km^2 and 3.942 million inhabitants. Per capita average water consumption was estimated at 286 liters per person per day. This corresponds to a total demand of $1.128 \times 10^6 \text{ m}^3/\text{d}$ and a net production of $13.1 \text{ m}^3/\text{s}$ instead of the present $2.6 \text{ m}^3/\text{s}$.

Water-bearing resources within the PLAMABAG framework included ground water in the Guatemala valley, the Alto Guacalate valley at Antigua, Guatemala, surface waters for Xayá-Pixcayá and Guacalate rivers, as well as the basins of Los Esclavos and Los Plátanos rivers on the east and the basins of the high and middle Motagua, Negro, and Cuilco rivers on the west. Lake Atitlán was studied as a natural reservoir, regulating water flow from the Madre Vieja, Yatzá and Nahualate rivers and then harnessing them together with the Santo Tomás Perdido and Monte María headwaters in an independent integral project. Lagoda Atitlán was also considered as a possible reservoir of water resources combined with the

Rio Motagua. The Laguna de Ayarza was considered as a regulating reservoir for the Tapalapa, Belen, and Pinula rivers, in the eastern part of the country.

In order to obtain a very approximate estimate of the future pumping requirements associated with the above flow rate of $13.1 \text{ m}^3/\text{s}$, let us assume that all of the water would have to be pumped to an average head of 300 m. Then the pump shaft power would equal 74,000 hp, or the electric power into the electric motors would be 61,000 kW. Using an 85% capacity factor, the annual electric power consumption would be $454 \times 10^6 \text{ kWh}$. If the Chixoy power plant is used to supply all of the pumping power, Chixoy would have to produce about 72,000 kW (assuming a 15% transmission loss) or 24% of the present Chixoy 300-MW capacity.

3. Possible Geothermal Pumping Applications. More work needs to be done on the concept of combining geothermal resources with water distribution systems. Two possible sites for development already exist, at Lago de Atitlán to the west of the city of Guatemala and Laguna de Ayarza to the east. Up to $4 \text{ m}^3/\text{s}$ of water could be extracted from Atitlán without any harm to the lake level. The required pumping head would be 568 m (1,860 ft). No data is available for water availability at Laguna de Ayarza.

At Lago de Atitlán and Laguna de Ayarza, there are possible geothermal resources with temperatures of 186°C (367°F) and 182°C (360°F), respectively.¹² Such temperatures would be applicable to the use of binary (organic Rankin cycle) power generators. Either direct-drive or electric-drive systems could be used depending on the economics for each situation.

Because the pumping stations will be located in rural areas, residual geothermal heat could also be used for agricultural processing or other useful purposes.

4. Summary. There are several advantageous features of this application.

- (a) The capacity factor would be high, resulting in low costs.
- (b) Other applications besides pumping could be developed at the same site.
- (c) The national electric grid could be used as backup to achieve high availability of the pumps.
- (d) No petroleum fuels would be required.

It is recommended that more studies and tests be initiated to investigate the feasibility of this potential application.

E. Heating and/or Cooling of Hospitals or Hotels

1. Introduction. The energy requirements for hotels and hospitals include both heating and cooling processes. Most obvious are heat requirements for space heating, cooking, drying, water heating, washing, and sterilization. Heat energy can also be used in an absorption refrigeration system for air conditioning cooling. In all cases the temperature level requirements are moderate, and this fact coupled with the generally high use factor makes this application favorable for the use of geothermal energy.

2. Typical Energy Demand. An example of the heat requirement for the operation of a hospital is given in Table II where the hospital in Amatitlán is shown to require from 1.3×10^9 to 7.7×10^9 Btu/yr. The hospital located in Quezaltenango (see Table III) has a thermal energy requirement of 2.5×10^9 Btu/yr. In both cases the very favorable capacity factor of 91% is also indicated.

Air conditioning is frequently a requirement even when outside temperatures are moderate because of internal thermal loads within a building. This air conditioning load can represent a very substantial energy consumption in modern large hospitals or hotels. Data on facilities located in mild climate areas are given below.

(a) The Ramada Hotel. A 12-story, 238-room Ramada Hotel in San Bernardino, California, was designed to use geothermal heat to provide cooling and heating. Air conditioning, totaling approximately 200 tons, as well as heating will be provided by 250 heat pumps ranging from 3/4 ton to 10 tons of cooling. (1 ton of air conditioning equals the removal of 12,000 Btu/h of heat) This entire heat pump system was designed to operate with input of 96 gal./min of geothermally heated water at 57°C (135°F). The hotel was also designed to heat its domestic water with up to 144 gal./min of geothermally heated water at 54°C (130°F) input temperature and 24°C (76°F) discharge temperature.

(b) The La Palapa Hotel. The La Palapa Hotel in Acapulco, Mexico, has 377 rooms and 343 tons of primary air conditioning plus a duplicate unit for stand-by use. These are compression type units, using freon as refrigerant. They represent the principal load in the hotel's consumption of approximately 400,000 kWh of electricity per month. In a favorable location, such a hotel would be a prime candidate for the use of geothermal energy.

(c) The Mount Vernon Hospital. The Mount Vernon Hospital in Fairfax County, Virginia, has two 450-ton centrifugal air conditioners, only one of

which operates at a given time. In addition, for use during hot weather with high humidity, the Hospital has a 350-ton absorption refrigeration air conditioning unit. Thus, this 250-bed modern hospital has a design air-conditioning capacity of 800 tons.

3. Equipment Availability. A wide range of cooling equipment of the absorption refrigeration type is commercially available. Examples of the equipment, listed in order of sizes manufactured, follow:

a. The American Yazaki Corporation (cooling capacity 1.3 to 10 ton). The American Yazaki Corporation of Farmer's Branch, Texas, produces and sells a line of small, single-effect absorption cooling units. These units are primarily intended for use as solar-heated air conditioning units, with solar energy heating water to 88°C (190°F) at a rate of up to 26.4 gal./min. Although modules can be combined to produce incremental capacities of up to 50 tons, this capacity would still be too small to service hotels and hospitals of the moderate size described above and would, therefore, be limited to small users.

b. The Carrier Corporation (cooling capacity 70 to 815 ton). The Carrier Corporation of Syracuse, New York, manufactures larger units than those of Yazaki. Their 15 standard models of absorption chillers can produce refrigeration economically in the 70- to 815-ton range, using either low pressure steam at 8 to 14 psig or hot water from 104 to 149°C (220 to 300°F). Under contract to NASA, Carrier developed a 130-ton solar-fired unit that began operation in 1981 at the Frenchman's Reef Hotel, St. Thomas, Virgin Islands. This unit now operates on water at 82°C (180°F) and generates 130 tons of cooling; however, increasing the water input temperature to 121°C (250°F) would generate over 200 tons of cooling.

c. The Trane Company (cooling capacity 101 to 1660 ton). Still larger absorption cold generator units are manufactured by the Trane Company of LaCrosse, Wisconsin, with 23 standard models. The single-stage units are rated from 101 to 1660 tons and the two-stage units are rated from 385 to 1000 tons. These units use either steam at pressures of 8 to 14 psig or hot water at 71 to 132°C (160 to 270°F).

4. Summary. The heating and cooling required in hospitals and hotels represent significant loads that have favorable capacity factors. Furthermore, the low-to-moderate temperatures readily available, even as residual heat from steam separators in a geothermal electric power plant, could meet these requirements.

However in the cases of Amatitlán and Quezaltenango the hospitals and hotels do not appear to be favorably located with respect to the production wells likely to be drilled in the near future. The situation at Amatitlán may become more favorable if an industrial park complex is developed there, allowing a low-temperature branch of the heat loop system to be extended to the local hospital.

F. Production of Concrete Blocks and Adobe Bricks

1. Introduction. LANL had already done an assessment on the island of St. Lucia of the use of geothermal heat to steam-cure concrete blocks.⁵ The result was favorable although St. Lucia has the nonenergy-related problem of not being able to produce its own cement; this problem does not exist in Guatemala.

The materials used to construct small commercial and residential buildings in Guatemala primarily consist of concrete blocks (combined occasionally with fired clay bricks) in urban communities and adobe bricks in rural areas. Use of wood for building is limited because of wood's use as a fuel. In the urban areas of Amatitlán, Palin, and Villa Nueva south of the city of Guatemala, the percentage of dwellings constructed of blocks and bricks, adobe bricks, and "other" are 41, 28, and 31%, respectively. The corresponding percentages in the more rural Quezaltenango/Zunil area are 24, 67, and 9%.

Because solar energy is free, the energy embodied in adobe brick construction is much less than in concrete block construction: in a typical residential wall, concrete blocks are 14 times more energy costly. Although energy cost is not a large consideration in the use of adobe bricks, other factors such as production limitations imposed by rainy weather might be improved by using geothermal heat to dry the adobes. The latter possibility was evaluated.

2. Production of Concrete Blocks. The raw materials used to produce concrete blocks are indigenous to Guatemala, but the blocks are expensive, nevertheless, because of the high energy costs. Only the use of oil or other fossil fuels can process the cement used in the blocks to the necessary high temperatures of 600 to 1000°C (1100 to 1800°F). However, curing of the blocks is done in commercially available equipment where steam at 15 to 125 psig is used to heat blocks stacked in closed rooms or autoclaves. This curing process is compatible with the use of geothermal energy.

The strength of blocks is improved by a hydrating process, which takes place at approximately 77 to 93°C (170 to 200°F). The usual process sprays

steam over blocks stacked in standardized kilns, which are available commercially. A less standardized approach is to immerse the blocks in hot water. To produce the low pressure steam that could be used in the steam kilns, it is estimated that the geothermal fluid should be at a temperature of at least 125°C (257°F); temperatures of 150 to 200°C (302 to 392°F) would probably result in improved technical and cost characteristics.

Temperatures close to 150°C (302°F) might be available from the residual fluids discharged from the steam generators at future Zunil or Amatitlán geothermal power plants. Also, relatively shallow wells using submerged pumps could be used to obtain useful temperatures ranging from 150 to 200°C (302 to 392°F). It's possible the geothermal steam could be used directly from a well, but this possibility would require an especially favorable set of circumstances. A few years ago, a concrete block plant at Amatitlán actually did use the steam from a shallow geothermal well to cure blocks, but the well's production deteriorated rather rapidly and the operation had to be terminated.

If concrete blocks were produced at Amatitlán, the weight of a truckload of concrete blocks is small enough to economically permit their transport over distances such as from the Amatitlán geothermal field to Guatemala City.

3. Production of Adobe Bricks. Traditionally, adobes are produced by digging the basic earth materials from nearby or at the construction site, mixing with water, pouring into forms, and drying in the sun. Our initial approach for using geothermal heat to produce adobe bricks was to dry the bricks in an enclosed shelter that would permit production even during the 6 months of winter rain. This concept was found to have several problems. First, the traditional production technique of pouring mud into wooden forms for the initial drying phase resulted in some undesirable handling requirements that would increase costs and production times. Second, the costs of transporting the relatively heavy bricks (~16 kg each) from Zunil or Amatitlán to the construction sites would be prohibitive. (For example, the cost of adobe bricks in New Mexico increases about US\$0.01 (2.6 centavos) for each transport mile.) Third, the traditional production technique is being replaced by a faster and more reliable process. Machinery is already commercially available in the US for pressing a dry mix of adobe materials into high-quality bricks that can be handled and installed immediately after production.

Because of the above considerations, the concept of using geothermal heat in the production process for adobe bricks was discarded.

4. Other Nongeochemical Considerations. In addition to the strictly geothermal considerations of the use of geothermal heat to produce concrete blocks or adobe bricks, our architectural consultant P. G. McHenry, Jr. also introduced some nongeochemical considerations. In a preliminary report to LANL, McHenry concluded that an expanded use of adobe bricks in Central America might still be worth planning for. His compelling arguments follow: (1) the materials are almost universally available, (2) bricks can be produced in the traditional manner by unskilled workers, (3) higher quality blocks can now be produced with new pressing machines, (4) the embodied energy in an adobe wall is significantly less than in a wall constructed with concrete blocks resulting in a savings of imported fuels (e.g. oil), (5) earthquake resistance can be comparable to that for concrete block construction when the proper design precautions are taken, (6) adobe homes in the US have been demonstrated to have excellent heating or cooling characteristics, and (7) the US experience with adobe homes has moved adobe from being looked at as a poor man's material to being looked at as a highly desirable material for even the most expensive residential projects.

5. Summary. The generation of steam for curing concrete blocks is a good application of geothermal heat. Geothermal fluid temperatures of at least 150°C (302°F) would be desirable for generating the required steam, and such temperatures are available at Zunil or Amatitlán.

The use of geothermal heat to dry adobe bricks is not recommended. Nevertheless, putting geothermal considerations aside, a renewed effort to increase the use of adobe bricks in Central America might be worthwhile as it would reduce the need to import oil to manufacture concrete blocks.

G. Production of Anhydrous Ethyl Alcohol from Sugar Cane Molasses

1. Introduction. The importation of petroleum for automobile fuel could be decreased by 10 to 20% by the local production of 99.6% ethyl alcohol (ethanol) to be used as an additive to gasoline. Also if excess alcohol were to be produced it could be another export product. Export to the US could utilize the advantage provided by the "Caribbean Basin Initiative."

It is estimated that gasoline consumption in Guatemala will increase from a total of 89 million gallons in 1986 to 109 million gallons in 2000. ICAITI estimates that annual consumption of ethyl alcohol as a gasoline additive within Guatemala could amount to 10 to 20 million gallons.

2. Project Engineering

(a) Plant Size. The standard of 120,000 liters/day--equivalent to 10 million gallons of anhydrous ethyl alcohol (ethanol)/year--is chosen for this study because that standard is above the minimum economic size; it is the maximum size allowed by the Guatemalan legislation; and it is believed to be compatible with raw materials availability.

In this concept it is contemplated that ethanol production from both molasses (the final syrup from sugar mills with 55% fermentable solids) and high-test molasses (the concentrated sugar cane solution from sugar mills and/or sugar presses, with 65% of fermentable solids) will be used.

For the production of 10 million gallons of ethanol, 66,700 tons of fermentable solids are required, equivalent to 121,000 tons of molasses or 102,000 tons of high-test molasses.

The production of molasses in Guatemala is in the order of 164,000 metric tons per year: part of this molasses is used as cattle feed and part for ethanol production. It is assumed that 50% of the fermentable solids needed for ethanol production would come from molasses and 50% from high-test molasses, corresponding to 60,636 metric tons or 11 million gallons of molasses and 51,308 metric tons or 9 million gallons of high-test molasses.

(b) Location. The plant may be located either in the area of Zunil or Amatitlán because both have the potential for generating steam at 20 psig that is required for processing, and both have access to the raw materials. However the Amatitlán area has the advantage of closeness to the fuel refinery, to the mixing centers for ethanol-gasoline from the South, and to the Atlantic exportation facilities.

(c) Process Description. In the ethanol production plant the molasses is diluted to a convenient concentration, 10 to 20% depending on the technology used, subjected to a sterilization process, and sent to the fermentators (see Fig. 9). In the fermentator a previously prepared yeast cultivation is added, which is mixed with the diluted molasses broth. The fermentation starts with the production of alcohol, carbonated gas, and heat. The heat is removed by circulating the broth past plate exchangers cooled with water. The carbonated gas is evacuated, stripped of alcohol, and sent to another plant for use. Fermentation continues and after 12-14 hours (depending on the technology used) the fermentation is completed and the fermented broth is sent to a centrifuge where the yeast is separated out, and either recirculated or processed for other

Description

1) Filters	10) Transfer pumps
2) Broth sterilizer	11) Cooling circulation pump
3) Juice mixer	12) Plate coolers
4) Dosifier pump	13) Gas cleaner
5) Nourishing tank	14) Yeast separators
6) Culture tank	15) Yeast cream deposit
7) Culture transfer	16) Yeast cream pump
8) Pre-fermenters	17) Fermented broth deposit
9) Fermenters	18) Fermented broth pump

Figure 9. Ethanol production plant, fermentation section.

purposes; the fermentable, yeast-free broth is sent to a multiple distillation column (see Fig. 10). To enrich the resultant 95% alcohol, it is subjected to an azeotropic distillation with benzene or gasoline, resulting in alcohol of 99.6%.

Description

1) Beer column	11) Partial condenser
2) Rectification column	12) Recuperation condenser
3) Heads concentration	13) Stillage cooler
4) Dehydration column	14) Raboiler
5) Solvent recuperation	15) Ethanol cooler
6) Beer preheater	16) Reflux tank
7) Vent condenser	17) Stillage pump
8) Heads partial condenser	18) Feed pump
9) Heads total condenser	19) Circulation pump
10) Partial condenser	20) Product

Figure 10. Ethanol production plant, distillation section.

3. Economic Evaluation. The total investment is summarized in Table VII and estimated production costs are given in Table VIII.

The average sale price of the alcohol is estimated to be about US\$1.10/gal., indicating profitability as shown in Table IX.

4. Summary. Less pressure steam is required in an ethanol production plant. Geothermal fluids at temperatures of 150 to 200°C (302 to 392°F) would be required for this application, and such fluids could be made available at either Amatitlán or Zunil. From a geothermal energy standpoint, this would be a good application. Another favorable aspect is that the plant does not now exist, and therefore, it could be designed to optimize the use of low-cost geothermal energy. More detailed studies of the cost of the final product and the potential favorable impacts of geothermal energy are recommended.

From an overall national standpoint, the establishment of ethanol production plants could have a very positive impact on transportation fuels and petroleum imports. Ethanol could also be used as a feedstock for polyethylene production (see Sec. H below).

TABLE VII

ETHYL-ALCOHOL PLANT INVESTMENT

<u>Item</u>	<u>Cost</u> <u>(millions of US\$-1986)</u>
Process equipment and auxiliary	1.6
Civil works, building and structures	0.7
Plant's installation	0.7
Project engineering and administration	0.3
Start-up	0.3
Contingencies	<u>0.6</u>
Total Fixed Investment	4.2
Total Working Capital	<u>2.0</u>
Total Initial Investment	6.2

TABLE VIII
ALCOHOL PRODUCTION COSTS

<u>Production</u>	<u>Cost</u> <u>(thousands of US\$)</u>	
Raw material ^a	6900	
Indirect materials	100	
Fuels and lubricants	100	
Electric power	432	
Steam ^b	275	
Repairs and maintenance	200	
Labor (hand)	40	
Fringe benefits	12	
Fixed capital depreciation	210	
Technical assistance	100	
Insurances and taxes	<u>200</u>	
Total for Production		8569
<u>Administration</u>		
Salaries	36	
Fringe benefits	12	
Fixed capital depreciation	10	
General expenses	<u>100</u>	
Total for Administration		158
<u>Distribution and Sales</u>		
Wages and salaries	12	
Fringe benefits	4	
Travel expenses	25	
Advertising and other	<u>25</u>	
Total for Distribution and Sales		66
<u>Financing</u>		
Interest and commissions, fixed capital ^c	340	
Interest and commissions, working capital ^d	<u>300</u>	
Total for Financing		<u>640</u>
Total for all		9433

^a Nine million gallons of high test molasses at US\$0.40 per gallon, and 11 million gallons of molasses at US\$0.30/gallon.

^b Steam at US\$3.00/1 million Btu, geothermal.

^c Calculated at 11% annually, 10-year term.

^d Calculated at 15% annually, 5-year term.

TABLE IX
ETHYL-ALCOHOL PLANT PROFITABILITY

	Profitability (thousands of US\$)
Sales income (10×10^6 gal./yr $\times$ 1.10/gal.)	11,000
Product total cost	<u>9,433</u>
Net profit	1,567

Simple Profitability (% of total initial investment from Table VII)

Before taxes	-	$\frac{1,567}{6,200}$	- 25%
After taxes	-	$\frac{1,567 - 752}{6,200}$	- 13%

H. The Production of Polyethylene from Ethanol

1. Introduction. Ethanol produced within Guatemala could be used as a feedstock for the production of polyethylene plastic, a major item for consumption in Guatemala. As was the case for the ethanol plant discussed in Sec. G, geothermal heat might be used at the upper temperature levels of about 150 to 200°C (302 to 392°F), levels which could be made available for processing purposes. Two important benefits might ensue from this application: (1) the use of geothermal energy would decrease production costs, and (2) the reduction in the importation of petroleum-derived fuels and polyethylene plastic would improve the nation's balance of trade.

2. Project Engineering

(a) Plant Size. The polyethylene plant meet the 1990s market demand, which will be in the order of 40,000 metric ton/yr and will require 42,000 metric ton/yr of ethylene, which in turn will need 112,000 metric ton/yr of hydrated (95%) ethanol. SEGEPLAN (a long-term economic plan for Guatemala) information,⁶ used to determine the size of the plant, reports that in 1978 the polyethylene resin consumption was 22,000 metric tons, projecting a 43,000-metric-ton consumption for 1990.

b. Location. The plant could be located at either the Zunil or Amatitlán geothermal area, both of which are 125 km from the existing ethanol production

center on the south coast. Nevertheless, the Amatitlán site is preferred because it is located closer to the main consumption center, the city of Guatemala. Alcohol produced on the south coast would be transported to the Amatitlán plant by tank trucks, the traditional means of transportation.

Eventually, with the installation of an ethanol plant in the Amatitlán area, production could supply raw materials to the proposed industrial park there.

c. Ethylene Production. The ethylene plant would use a process that flows vaporized ethanol making it pass through a fixed bed adiabatic reactor, with recirculation to a heat exchanger in order to recover the heat yielded in the reaction. The ethylene is produced in a gaseous state and cooled in a recuperation boiler, where the geothermal steam is superheated from 150 to 300°C (302 to 572°F). In a superheater furnace operated with a fossil fuel, the steam is additionally superheated to 468°C (874°F), which is the operating temperature in the exchanger that maintains the reactor's conditions. The ethylene at 350°C is cooled with sprayed water and then washed with caustic chemicals and dried. Finally, to obtain the polymer grade purity (99.9%) it must be distilled and stored (see Fig. 11).

Overall, 21,000 lb/h of geothermal steam at 150°C (302°F) will be required, equivalent to approximately 21×10^6 Btu/h or 210 gal./h of petroleum fuel oil used to generate the above quantity of heat. The latter oil usage would total 1.5×10^6 gal./yr if the plant capacity factor was 0.8.

d. Low Linear Density Polyethylene. Ethylene with 2% of a copolymer (n-butane) is fed to a reactor, along with a special catalyst and hydrogen to act as a blocking agent. This batch reactor operates at a medium pressure of 200 - 400 psig and a low temperature of 50°C (122°F), with a residence time of 1 to 2 h.

The product continuously leaves the reactor as a slurry that contains a resin content of about 33%. The slurry goes through a liquid-solid separator and then through a dryer from which it emerges ready for storing (see Fig. 12). A mixture of 0.7 tons of steam per ton of ethylene at 170°C (338°F) is used for this process, which means that the geothermal fluid being used to generate the above steam would have to be at a high temperature, e.g. 200°C (392°F).

3. Economic Evaluation

a. Initial Investment. Table X shows the estimated initial investment required for this project, which amounts to US\$44 million.

b. Production Costs. Table XI shows the production costs for ethylene from hydrated ethanol at the plant and also the polyethylene production costs.

The basic costs utilized are the following:

Figure 11. Schematic of an ethylene plant.

Figure 12. Schematic of the production of polyethylene from ethylene.

TABLE X

INITIAL INVESTMENTS FOR ETHYLENE-POLYETHYLENE PLANT COMPLEX

<u>Item</u>	<u>Ethylene Plant (millions of US\$)</u>	<u>Polyethylene Plant (millions of US\$)</u>
Installed Plant		
Process and auxiliary equipment	5.5	14.0
Transportation and insurances	1.0	2.0
Plant installation	1.0	2.0
Civil works, buildings	0.5	0.5
Spare parts and initial catalyst	1.0	1.0
Engineering and license	2.0	3.5
Other	<u>1.5</u>	<u>2.5</u>
<u>Total for Installed Plant</u>	12.0	25.5
<u>Total Working Capital</u>	<u>3.0</u>	<u>3.5</u>
<u>Total Initial Investment for Plant</u>	15.0	29.0

TOTAL INVESTMENT FOR INDUSTRIAL COMPLEX - US\$44 million
(Ethylene Plant + Polyethylene Plant)

TABLE XI

ETHYLENE AND POLYETHYLENE PLANTS--TOTAL PRODUCTION COSTS

<u>Production</u>	<u>Ethylene</u> <u>(thousands of US\$)</u>	<u>Polyethylene</u> <u>(thousands of US\$)</u>
Raw materials	33,000	38,555
Indirect materials	1,000	3,045
Fuels and lubricants	100	120
Electric power	600	100
Steam	---	---
Repairs and maintenance	500	500
Labor (hand)	100	100
Fringe benefits	30	30
Fixed capital depreciation	600	1,275
Technical assistance	500	500
Insurances and taxes	<u>500</u>	<u>500</u>
Subtotals	36,930	44,725
<u>Administration</u>		
Salaries	50	50
Fringe benefits	15	15
Fixed capital depreciation	10	10
General expenses	<u>100</u>	<u>100</u>
Subtotals	175	175
<u>Distribution and Sales</u>		
Wages and salaries	---	50
Fringe benefits	---	15
Travel expenses	---	25
Advertising and other	---	<u>25</u>
Subtotals	0	115
<u>Financing</u>		
Interest and commissions, fixed capital ^a	1,000	2,040
Interest and commissions, working capital ^b	<u>450</u>	<u>525</u>
Subtotals	<u>1,450</u>	<u>2,565</u>
Totals	38,555	47,580

^aCalculated at 11% annually, 10-year term.^bCalculated at 13% annually, 5-year term.

<u>Item</u>	<u>Cost (US\$/Unit)</u>
Fuel (gal.)	1.00
Electric energy (kWh)	0.05
Qualified labor (man months)	250.00
Unqualified labor (man months)	100.00

c. Profitability and Sale Price. If a simple profitability of 15% over the capital invested is agreed upon, the sale price would be the following:

	<u>Thousands of US\$</u>
Total product cost	47,580
Profit margin	<u>6,600</u>
(15% over US\$44 million capital investment)	
Total income requirement/year	54,180

	<u>US\$</u>
Product sale price per metric ton	1,354.50
Income from 40,000 metric tons	54,180,000.00
Product sale price per kilogram	1.35
needed at the plant	

4. Market

The product considered in this section is the low linear density polyethylene, LLDPE, (0.90 - 0.95 g/cm³) that serves as raw material for most of the various uses of the polyethylene in the manufacturing of plastic articles such as bags and packings, pipes, and other objects.

Guatemala itself can provide an adequate market, and the availability of raw materials is appropriate for this market.

5. Summary

Plant size	40,000 metric tons/yr.	
Investment required	Fixed assets	US\$36.5 million
	Working capital	<u>7.5 million</u>
Total	US\$44.0 million	
Location	Geothermal area of Amatitlán.	

Total costs US\$47.58 million/yr.

Profitability A profit of US\$6.6 million has been estimated before taxes, which is equivalent to a 15% yield on capital invested.

The production of polyethylene from ethanol appears to be a large and potentially profitable enterprise, and geothermal heat could make a contribution to its success.

I. Production of Bleached Pulp from Sugar Cane Bagasse

1. Introduction. ICAITI projects that the annual importation of pulp by Guatemala will increase from 15 metric tons in 1985 to over 24 metric tons in 2000. Approximately 30% of demand is for short-fiber, bleached pulp that is not produced in Central America (see Table XII).

The production of pulp at a competitive price and using indigenous materials and energy would have favorable balance-of-trade benefits. Steam at temperatures of 129 to 170°C (264 to 338°F) is used in a pulp processing plant, and heat from a high-quality geothermal reservoir, such as at Amatitlán, might be utilized to generate the steam. Therefore, an evaluation of a pulp processing plant is given below.

2. Project Engineering

a. Plant Size. Data was available from ICAITI for a pulp plant capable of producing 9750 tp/yr (tp = metric tons of air-dried bleached pulp), and this is the size of plant that was evaluated. The required raw materials are 68,250 metric tons of bagasse per year. The production rate of 9750 tp/yr would approximately satisfy the demand from Central America for the year 1990. As shown

TABLE XII

DEMAND FOR SHORT, BLEACHED FIBER
(thousands of metric tons)

<u>Year</u>	<u>Guatemala</u>	<u>Central America</u>
1985	4.5	8.2
1990	5.4	10.0
1995	6.7	12.4
2000	7.3	14.4

Source: ICAITI

in Table XII, the demand for the short, bleached fiber is expected to increase with time, but no shortage of raw materials for a pulp plant is expected.

The recent low sugar prices have caused the sugar mills to operate at about 70% of capacity. However, it is anticipated that the raw materials (68,250 metric tons of bagasse per year) to sustain the 9750 tp/yr in 1990 will be readily available from a rejuvenated sugar industry and from several alcohol plants now being installed in Guatemala. ICAITI estimates available bagasse waste of over 100,000 metric tons/year (waste from the alcohol plants is not included). Table XIII shows sugar cane milling data for 1975 to 1981. The data are from the major mills in Guatemala and represent 70% of the total Guatemalan production.

Because it will take at least 4 years from feasibility study to start-up, the plant size is based on the projected Central American demand for short-fiber production in 1992 and is estimated to be 11,000 tp/yr.

Furthermore, in relation to the surplus bagasse availability (see Table XIII), it should be considered that the sugar industry crisis resulting from the international price decrease has forced the industry to reduce the total milling to approximately 3×10^6 ton of sugar cane per year (70% of the installed capacity), of which 70% belongs to the sugar mills shown in Table XIII. Also, several alcohol plants are being installed, which means that the milling level will have to be increased to satisfy the necessities of both the sugar and alcohol industries. For this reason, it is possible that the milling level for the selected sugar mills for 1990 will surpass the average value for the years 1975-1981 of 3,700,000 ton/yr of sugar cane (corresponding to 1,000,000 ton/yr of bagasse). Therefore, it should be reasonable to assume that the level of available bagasse waste (not including what the alcohol industry utilized) could be approximately 100,000 tons of bagasse per year.

Thus it is reasonable to select the plant size of about 9,750 MT/yr (77,000 ton/yr of bagasse) and cover the total Central American demand for the year 1990.

b. Location. The geothermal resources at Amatitlán could furnish steam for the pulp production plant. A bagasse preparation and packing plant could be installed southeast of Amatitlán near the city of Escuintla, where it would be close to the major sugar mills of Concepcion, Santa Ana, etc. The bagasse plant and the sugar milling plants would fall within a 25-km radius, water and electricity are available, and highway CA-2 provides a nearby transportation route. The pulp processing plant would be installed at Amatitlán near the geothermal field.

TABLE XIII

SUGAR CANE MILLING IN THE MAJOR MILLS IN GUATEMALA IN METRIC TONS
(70% of total Guatemalan production)

<u>Sugar Mills</u>	<u>1975/1976</u>	<u>1976/1977</u>	<u>1977/1978</u>	<u>1978/1979</u>	<u>1979/1980</u>	<u>1980/1981</u>
Concepción	1,084,975	942,084	667,806	656,445	606,679	576,035
Pataleon	1,017,875	1,061,662	917,345	753,311	755,290	1,121,293
El Baul	279,371	275,915	255,093	256,123	211,510	232,807
Los Tarros	456,487	367,868	240,754	192,052	213,382	228,764
Madre Tierra	494,912	390,341	313,920	244,634	356,285	470,658
La Union	350,824	467,596	484,338	422,071	484,601	503,036
Santa Ana	703,943	821,243	559,311	531,422	557,485	677,794
Total Sugar Cane Milled	4,388,387	4,326,709	3,438,577	3,057,058	3,185,232	3,810,387
Total Bagasse Produced ^a	1,228,748	1,211,479	962,802	855,976	851,865	1,066,908
SUGAR MILLING AVERAGE ^b	= 3,701,058 metric tons					
BAGASSE PRODUCTION AVERAGE	= 1,036,296 metric tons					

^aA bagasse yield of 28% of the milled sugar cane weight is assumed.

^bThe milling average for the entire sugar industry (18 sugar mills) equals 5,172,670 metric tons.

SOURCE: Asociación de Azucareros de Guatemala.

c. Production Process. Packed bagasse at 50% moisture content coming from the storing yard is treated in the depitting plant in two stages: First, using a wet depitting process, most of the bagasse's medulla is eliminated; second, utilizing the suspension depitting process, the residual medulla water and impurities are eliminated. This stage produces clean bagasse fiber with 50% moisture content that can be packaged for transfer to the pulp plant. Additionally, the moist medulla coming from the first stage can be packaged and returned to the sugar mills to be used as fuel.

In the pulp plant the bagasse fiber is digested in the cooking plant using continuous soda digestors with steam at 7.5 atm and 170°C (338°F). The chemicals recuperation boiler can provide 70% of the steam, with the remainder provided by the geothermal energy source. The chemical pulp obtained is unloaded into the blower tank where it is diluted with black liquor and transferred to the washing plant to recuperate 97% of the cooking chemicals pumped to the recuperation plant. The pulp is washed and sent to the sieve plant where a thorough purification takes place in a way that only the washed fiber pulp of the right size is accepted to be sent to the bleaching plant.

The fiber rejected by sieving is recycled to the digestors. The bleaching plant continuously operates as follows: First stage--chlorination; second stage--alkaline extraction; and third stage--hypochlorite bleaching at 84°C (183°F). Finally, the bleached pulp enters the "fourdrinier" machine where the sheet is formed, drained, pressed and dried to 10% moisture content (utilizing 2.4 ton/h of low-pressure steam at 129 to 160°C (264 to 320°F). This steam could be geothermal steam. Later on, the dried pulp bagasse sheet is cut and packaged for shipping to the final product warehouse.

d. Civil and Auxiliary Works. The civil works consist, basically, of the following:

- Buildings
- Foundations
- Support structures
- Isolations
- Receptacles
- Pits
- Other

The auxiliaries relate to the following:

- Chemicals recuperation plant
- Storing and preparation plant (soda, bleach & hypochlorite)

- Water treatment plant
- Electric energy generation plant (steam)
- Auxiliary electric energy generation plant (diesel)
- Waste treatment plant
- Compressed air plant
- Laboratories
- Well system and/or geothermal steam distribution
- Electric equipment (transformers, engines, cables, etc.)
- Lightning, telephone, and alarm systems
- Maintenance shop
- Plant's general equipment (vehicles, fire-proof equipment, offices and administration, loading mechanisms, fuel tanks, etc.).

3. Economic Evaluation. The fixed investment charges including pulp plant, chemicals recovery plant, auxiliary services, electric equipment, transportation of equipment, insurance, and contingencies amount to an equipment charge of US\$14.2 million. The addition of plant installation, project engineering, land, spare parts, etc. gives a total fixed investment of US\$21.8 million.

Working capital is calculated as the amount corresponding to two months of sales costs, equivalent to US\$1.2 million making the total capital investment equal to US\$23.0 million.

a. Operation Costs. The operation costs were calculated for 325 operation days/yr under the following criteria:

<u>Item</u>	<u>Consumption Per tp*</u>	<u>Unit Price (US\$)</u>
a) Raw materials and indirects		
Bagasse	6.8 metric ton	9.68**
Caustic soda	0.08 " "	676
Gaseous bleach	0.064 " "	260
Hydrated lime	0.175 " "	30
Aluminum sulfate	0.003 " "	520
Packaging	20 units	0.075
b) Electric power cogenerated	400 kWh	0.04
c) Water pumping	250 m ³	0.04

d) Labor

Skilled, 375 operators at US\$250/man-month
Unskilled, 75 operators at US\$100/man-month.

e) Administration

1 Technical manager (US\$1,000/month); 4 plant engineers (US\$500/month);
15 personnel, various secretaries, accountants, laborers, etc.,
(US\$80/month).

f) Distribution and Sales

2 salesman (US\$300/month); 1 assistant (US\$100/month)

*tp - metric tons of air-dried bleached pulp.

**Includes sugar mills bagasse prices, bagasse transportation, and depitted bagasse transportation.

Use of the above costs results in the production costs detailed in Table XIV. Use of the production costs from Table XIV for a 9750 tp/yr plant results in a unit cost of US\$774/metric ton of bleached bagasse pulp.

4. Summary. The total unit cost of bleached bagasse pulp at an Amatitlán plant is estimated to be US\$774/ton. The price of competitive hardwood pulp at the Guatemalan port of Santo Tomás de Castilla is approximately US\$490/ton. This CIF price plus the additional shipping costs to Amatitlán gives a total estimated delivery cost of hardwood pulp to the plant as US\$515/ton. With a differential of US\$260/ton, it is clear that the production of pulp from sugar cane bagasse is not economically feasible.

J. Methanol Production from Wood Waste

1. Introduction. There are three possible market areas for methanol: raw material for the chemical and cosmetics industries, fuel for automobiles, and fuel for fuel cells. The automobile and fixed cell applications are not practical as they are not used extensively in either Central America or in more developed countries.

As a raw material, SEGEPLAN data⁶ projects an annual consumption of methanol of 1977 metric tons in 1990 and 2974 metric tons in 2000. These quantities correspond to 0.64 and 0.97 million gallons and do not indicate the need for a very large plant.

TABLE XIV
PAPER PULP FROM BAGASSE, PRODUCTION COST

<u>Production</u>	Cost (thousands of US\$)	
Raw material	642.0	
Indirect materials	770.0	
Fuels and lubricants ^a	75.0	
Electric power	160.0	
Water	97.0	
Repairs and maintenance	440.0	
Labor (hand)	1000.0	
Fringe benefits	350.0	
Fixed capital depreciation	1100.0	
Technical assistance	100.0	
Insurances and taxes	440.0	
Subtotal		5,174.0
<u>Administration</u>		
Salaries	50.0	
Fringe benefits	15.0	
Fixed capital depreciation	55.0	
General expenses	227.0	
Subtotal		347.0
<u>Distribution and Sales</u>		
Wages and salaries	8.5	
Fringe benefits	2.5	
Travel expenses	25.0	
Advertising and other	145.0	
Subtotal		181.0
<u>Financing</u>		
Interest and commissions, fixed capital ^b	1744.0	
Interest and commissions, working capital ^c	101.0	
Subtotal		1,845.0
Total		7,547.0

^aIncludes US\$25,000 as geothermal energy cost.

^bCalculated at 13% annually, 10-year term.

^cCalculated at 15% annually, 5-year term.

2. Project Engineering

a. Plant. A methanol plant would be located in the geothermal area of Zunil, where it would be close to a wood supply and at a reasonable distance from the main consumption center of the city of Guatemala.

According to the expected demand, the plant must produce 1 million gal./yr during the 1990s.

b. Technology. According to an evaluation done by Raphael Katzen Associates⁸ of various technologies, the Moore-Canada gasifier was selected. This gasifier uses wood waste. For this process, waste wood is transferred to the plant by truck, dumped into a ditch, moved to piles, and then to bins. From the bins the wood is sent to the gasifier where air and geothermally derived steam separates out the tar and removes it; in a later phase, the separated tars are returned to the gasifier. Two gasifiers, 2.9 meters in diameter, are required for this plant.

The raw gas is purified and separated from organic by-products. Once purified, the gas, which is a mixture of carbon monoxide and hydrogen is compressed to 400 psig for steam conversion, thus forming additional hydrogen so that the final mixture will contain the stoichiometric relation of carbon monoxide and hydrogen required for the synthesis reaction. The gas, containing two hydrogen molecules for each carbon monoxide molecule, is compressed to 2,500 psig and fed to the reactor. Approximately 95% of the gas is converted into methanol. This product goes through a distillation train to separate off all the impurities.

The plant would include a power installation for which some part of the gas produced would be utilized to produce electric power and high pressure steam not available from the geothermal wells. Geothermal heat could be used as part of the heat required to produce 400 psig steam. Geothermally driven binary mechanical power generators (see Sec. VII-K for a discussion of binary power generators) could be used to drive the high-pressure generators. The latter application of geothermal energy would probably be the most worthwhile.

3. Economic Evaluation. This evaluation is based on the Raphael Katzen Associates' data for a plant of 50 million gal./yr (50 times larger than the plant considered here).

a. Investments. The fixed investment has been estimated using Williams' rule,⁹ with a 0.6 exponent. In accordance with this method, the total fixed investment for the Guatemalan plant of 1 million gallons of methanol per year would be US\$10 million (1985). The working capital is estimated as US\$0.2 million, resulting in a total initial investment of US\$10.2 million.

b. Sale Price. An analysis of Guatemalan production costs resulted in a sales price equal to US\$3.35/gal.

The methanol price listed in the United States is about US\$0.45/gal., for which the imported product to Guatemala would be less than US\$1/gal. Thus this project would not be economically feasible.

4. Summary. The steam temperature and pressure requirements for the evaluated methanol plant are not very compatible with the Amatitlán or Zunil geothermal resources. The most likely application for geothermal energy would be to use geothermally driven binary power generators to directly drive gas compressors. However, this was not evaluated because other costs appear to result in a noncompetitive product price--regardless of the energy cost component. The estimated sales price of the methanol is US\$3.35/gal., or over 3 times the cost of imported methanol from the US. The costs would be even less favorable if the size of the evaluated plant were to be scaled down to meet only the demand of Guatemala (10^6 instead of 50×10^6 gal./yr).

K. Combined Heat and Electric Systems

1. Introduction. From the geothermal standpoint, there are two basic types of combined heat and electric systems: (1) a cogeneration system where electricity is produced at the high temperature end of the plant and residual heat is used for processing, and (2) other various combinations of heat extraction and electric power generation arranged to maximize the utilization of the energy flowing from a well or set of wells. In this section, we will describe typical heat/power combinations and their characteristics and then summarize our opinions on combined heat and electric systems.

2. Background Information About Geothermal Power Generators. There are two general types of power generators that can use geothermal heat.

a. Steam Turbines. Most of the geothermal electric power plants being operated in the world today use steam turbogenerators. The hot geothermal fluid begins to vaporize to steam as it rises in the wellbore. The resultant mixed flow then goes to a steam separator where the steam is bled off the top and the hot residual liquid from the bottom. With a reasonably good geothermal resource, the pressure in the separator might be 100 psia, corresponding to a saturation temperature of 164°C (327°F). Under such conditions, the cost of the geothermal-generated power is usually competitive with that from fossil-fueled plants. However, if the geothermal production pressure is low, then the resultant system operating pressures are low, the steam density decreases, and the

physical dimensions and the costs of piping, valves, turbines, etc. increase. The net result is that the produced-power costs can become noncompetitive.

Occasionally, in attempts to maximize the amount of generated steam, double flash systems have been used. However, the economics of the second, lower pressure flash system is usually unfavorable.

Another type of system, called the Biphase Rotary Separator Turbine, exploits the pressure energy embodied in the geothermal water in addition to obtaining power from a steam turbogenerator. If the pressure of the geothermal fluid is relatively high, then the overall generating efficiency can be greater than that obtained with the more conventional steam system. The Zunil field does not have enough pressure to drive the Biphase-type system.

(b) Binary (Organic Rankine Cycle) Power Generators. Figure 13 is a schematic of a binary cycle being used to directly drive a compressor refrigeration system. Heat is transferred from a hot geothermal fluid to an organic fluid such as Freon or isobutane. The organic fluid is vaporized and made to flow through a turbine to generate power. The power can be used to drive mechanical devices such as a compressor or used to generate electricity, or do both, as shown in Fig. 13.

The binary cycle is economically best suited to the use of geothermal fluids with temperatures of up to 180°C (356°F). Greater temperatures are usually considered more suitable to steam turbine cycles although each situation should be analyzed for its economic crossover point.

Binary cycles can be operated at much lower temperatures than are required for steam systems. During the 1970s, the US National Aeronautics and Space Administration built and successfully operated about 40 binary electric power generators capable of generating ~15 kWe and operating on solar-heated fluids at ~88°C (190°F).¹⁰ Advanced and enlarged versions of the above small generators are incorporated in two power modules located in California that operate on 109°C (228°F) geothermal fluid.¹¹ The two modules produce a combined net power of 600 kWe at competitive costs. In addition, the system operates in a cogenerator mode, and the geothermal fluid discharged from the power modules is used to heat greenhouses covering 1.6 hectares (4 acres). Such power modules are mobile and operate unattended. In Nevada, a significant number of modules designed to generate 1.2 MWe each are in use. In southern California, a binary plant too large to be modularized and capable of generating almost 50 MWe has successfully demonstrated power production.¹²

THERMALLY DRIVEN FREEZER SYSTEM

Figure 13. Schematic of a binary cycle power plant plus a refrigeration subsystem.

Most of the binary generators now being operated in the US are fed pressurized hot fluids pumped out of wells by downhole pumps. Pumps are available that will fit inside a casing with an ~23-cm (9-inch) i.d. at depths of ~365 m (~1200 ft).

3. Possible Electric/Heat Combinations. Four basic combinations of systems that utilize geothermal heat and also generate mechanical or electrical power, either continuously or intermittently, are described below.

a. Case 1: Power Plant in a Cogenerating Mode. The concept of a power plant in a cogenerating mode was briefly discussed above in Sec. VII-K.1. The residual fluid from the steam generation process in a conventional geothermal power plant might be at temperatures of ~160°C (320°F). This temperature level would satisfy many, but not all, of the usual industrial processing requirements (see Tables II and III). If a binary generator is used, the geothermal fluid will exit the power system at a temperature of about 66 to 82°C (150 to 180°F). The latter low temperatures would restrict the use of the residual geothermal heat to relatively simple applications such as greenhouse heating.

If the process heat is given priority over power generation, then it will be possible to obtain residual temperatures up to perhaps 200°C (392°F) by operating the steam separator at a pressure of 225 psia. Figure 8 illustrates such a high pressure and temperature system at Zunil. Early production data released by INDE² for Well ZCQ-3 showed a capability to operate at a 225 psia separator pressure. The corresponding 200°C (392°F) temperature would satisfy most of the processing applications using steam. Because the use of the relatively high separation pressure decreases the quantity of generated steam and consequently the quantity of electricity produced by a Zunil steam electric power plant, a more detailed analysis would be in order before the above operating arrangement is selected. The recommended analysis would be one that evaluates the synergistic effects and benefits of (1) developing a new competitive industrial activity, (2) reducing petroleum consumption, and (3) generating electricity.

b. Case 2: Surplus Heat, Stand-Alone Development, Moderate Geothermal Temperature

In Case 2, the capacity factor of the plant using the heat is not high, perhaps 0.2 to 0.5, and the heat produced by the well when the plant is shut down would be wasted. Once a steady state flow is established from a geothermal well it is usually not recommended that the well flow be stopped and started frequently, for example, on a daily basis. If in this case there are no other

wells to act as emergency backups, then the well fraction of the total facility cost can be high as one production well, one backup well, and one reinjection well might be needed. The relatively high well costs make it even more imperative that most of the produced heat be used for either industrial processing, power generation, or a combination of both. For moderate geothermal temperatures below 180°C (356°F), the binary generating systems would be applicable. The binary generator designs can permit operation over a reasonable range of conditions. It is conceivable that when process heat is required, electric power output could decrease; when the heat requirement drops to zero, the power production could be maximized. Also a power generator incorporated close to a process heat plant cuts electric transmission costs. Excess power could be sold or routed back into the national electric grid.

c. Case 3: Surplus Heat, Stand-Alone Development, High Geothermal Temperatures

The discussion for Case 2 on surplus heat and stand-alone development also applies to Case 3. If the geothermal fluid temperature is high, e.g. >200°C (392°F) then it may be necessary or desirable to exploit the steam-generating capability of the system. The steam might be directly used in an industrial process or it might be used in a steam turbine. Binary generators could be employed to utilize even more of the surplus energy available in the geothermal fluid.

d. Case 4: No Surplus Heat, Stand-Alone Development

In Case 4, of course, power could not be generated because the plant requires all of the heat from a basic heat source. However, if the plant also has a high power demand, it might be economically viable to drill another well to use for both electric power generation and for a heat-supply backup well.

4. Summary. Depending upon a plant's relative demands for heat and power, the concept of using geothermal energy to supply process heat in coordination with the generation of electric or mechanical power is a good one. The combined system can have greater economic viability than either of the system components by themselves.

Binary generators have been proven over a wide range of power capabilities and can operate efficiently at the lower temperature levels usually associated with process heat systems. Their use can result in greater flexibility in the design of the combined heat and power systems and also can increase the energy utilization efficiency.

VIII. CONCLUSIONS

The existing data on the geothermal resource in Guatemala shows that an ample supply of geothermal energy exists. The development of these resources is only beginning. Exploratory wells are being drilled at the Amatitlan field; the Zunil field already has production wells, and additional exploration is taking place. Indications are that both of these fields could be used to supply process heat either as primary heat or as residual heat after producing electric power.

Guatemala has a number of existing industries that could use geothermal process heat, but many need to be more tightly grouped for maximum economy of geothermal application. A geothermal industrial park at Amatitlan appears promising. Also an agricultural processing center at Zunil is worthy of further development.

The development of either field to the point where geothermal process heat becomes available will probably attract additional industries to these areas.

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