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ST. LUCIA GEOTHERMAL REPORT REVIEW

for

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Leland L. Mink, PhD

Kuna, Idaho

EXECUTIVE SUMMARY

Los Alamos National Laboratory conducted an investigation of the geothermal potential for the island of St. Lucia in 1983-1984. The results of the study indicated St. Lucia has a potential geothermal resource which may exceed 250°C in the Qualibou caldera area near Soufriere. Potential sites for development include Belfond, Sulphur Springs, Etangs, and Diamond areas.

The Sulphur Springs area appears the most promising since the existence of a 212°C system has been shown through earlier drilling. The area is highly fractured and the data indicate a dry steam system may exist beneath this site. The Belfond area also indicates a high temperature system exists at depth but is capped by an impermeable layer of rock. Siting a well in the Belfond area should consider intersecting the regional faulting to get the fracture permeability for fluid production. The other areas rate a lower priority because they either do not exhibit fracture potential or are of lower predicted temperature.

Engineering and economic studies indicate a definite cost savings of geothermal over conventional electrical generation for St. Lucia. The concept of developing the geothermal in 5 MW_e or 10 MW_e increments may be better justified.

Non-electric development should be secondary to electrical development. The only industry on the island which appears feasible to utilize the geothermal brine is the sugar processing industry. This is an established industry and would require no new training or imported materials.

Introduction

An evaluation of the St. Lucia geothermal resource was conducted by Los Alamos National Laboratory (LANL). The objective of the study was to determine geothermal development potential of the islands. Historically, electrical energy in St. Lucia has been derived from diesel generation. This fuel must be imported which results in a heavy burden on the people of the island. If geothermal energy can be developed it would be a great stimulus for the base economy of the people of St. Lucia.

The following summary is an overview of the four LANL documents evaluating the St. Lucia geothermal resource.

- Geologic, geophysical and hydrochemical investigations
- Engineering evaluation and cost estimate of the development of the geothermal resources in St. Lucia
- Macroeconomic model for the development of the geothermal resources in St. Lucia
- Evaluation of the St. Lucia geothermal resource summary report

Geologic and geophysical investigation

Geologic investigations were conducted in the fall of 1983 and included geologic mapping, volcanic stratigraphy and structural interpretations. The report is quite detailed for the area of the Qualibou caldera located in the southwest portion of the island of St. Lucia. No information was presented reguarding the potential of the remainder of St. Lucia for geothermal energy. This was rather disconserting since the title indicates a complete assessment of the island's potential. Other investigation indicate older volcanic activity is known to have occurred to the north which may contain some residual heat for direct use applications.

Geologic information from other investigators, Aquater (1982) and Williamson (1973), was used as a basis for the geologic work presented by Los Alamos. The Los Alamos investigation, however, did place more emphasis on integrating the results of the geologic work with the other disciplines of geochemistry and geophysics. This made for a much stronger report.

Stratigraphic correlations indicate a sequence of volcanic activity occurred prior to the collapse of the volcano forming the Qualibou caldera. The work by Los Alamos and others also correlates the ages of Qualibou eruptions relative to other volcanic activity both pre and post. This data gives evidence the volcanic activity was extensive over a rather long period of time. The geologically youthful nature of the most recent activity provides evidence a substantial heat source is present beneath the island.

The geologic description presented did not discuss in sufficient detail the hydrothermal alteration of the volcanics. The alteration products give an indication of the thermal history of the system. It also provides valuable information on the circulation system and rock-water interaction for resource evaluation. I feel more detail on the hydrothermal alteration products would have been useful in the evaluation.

The structural setting is dominated by the faulting and associated fracturing resulting from the formation of the Qualibou caldera. This type of faulting is generally shallow and often does not extend to great depths. Regional faulting is evident in the caldera area and is thought to be the major conduit for upwelling of high temperature geothermal fluids. The major structural feature are two NE-SW trending faults which transect the caldera. This deep structure is evidenced by the occurance of volcanic vents, domes and recent extrusives along the fault trace. This in turn provides good evidence the structure intersects the magma chamber beneath St. Lucia.

The importance of the shallower caldera faults lies in their creating secondary permeability. The ring fractures along the margin of the caldera provide conduits for the circulation of ground waters to the depths necessary for contact with the high temperature rocks beneath the caldera. This mechanism allows for drilling of successful production wells in a volcanic environment. The nature of the sediments welded tuff, ash flows and volcanic breccias do not have sufficient primary permeability to transfer fluids so adequate production must rely on secondary permeability from faults and fractures.

The low permeability of volcanic sediments does not support the conceptual model presented by Los Alamos in Figure 5. This shows a lateral flow of 2-3 Km with upwelling in the center of the caldera. I feel the upwelling will be associated with deep faulting/fracturing with lateral flow occurring only for short distances of less than 1 Km before the cooled fluid begins to sink to recharge the system. This results in smaller convection systems with the higher temperatures in the center of the cells. To gain optimum production one must drill to intersect the major fractures to attain maximum permeability. The discussion relating to the system hydro-geology was insufficient to adequatly describe the variable mechanisms which control the hydrothermal circulation within the caldera system.

The geophysical section is very weak. Geophysical studies conducted by other investigators were not correlated with the Los Alamos findings in sufficient detail. Only briefly were the studies by the London Institute of Geological Sciences mentioned. Also no mention was made of the audiomagnetotelluric and gravimetric survey of the Qualibou caldera conducted by Aquater in 1982. The geophysical work does indicate areas of potential high temperature fluids. This data has assisted in interpretation of the potential target areas for drilling although I feel it has not been folded adequately with the geologic setting.

Hydrochemistry

The hydrochemistry section was very complete. This section did a good job of evaluating the past data and comparing it to information collected during the Los Alamos investigation. From the geochemistry of the waters near the Qualibou caldera it appears there is a substantial resource on St. Lucia.

The chemistry of the fluids in Sulphur Springs is very typical of active high temperature steam systems. Also there exists substantial hydrothermal alteration changing the host dasitic volcanic rocks to a cristobalite-kaolinite product. One steam vent is reported at 171°C which is of extremely high temperature for a surface manifestation. The pH and high sulfates in the area indicate the presence of an acid-sulfate system.

The problem I note is the fact the conventional geothermometers (Si and Na, K, Ca) give a lower temperature than observed in temperature gradient boreholes, calculations based on gas analysis, and temperatures inferred from isotope and enthalpy calculations. This could be caused by one or a combination of phenomena other than those mentioned in the report. Significant mixing of colder ground waters could be occurring as a result of precipitation infiltrating and mixing with the geothermal fluid. Another reason could be the achieve circulation system which discharges as thermal springs at the surface has not reached depths necessary for the high temperatures. The higher temperature fluids may be in a deeper system.

There was no information as to the producability of the existing drill holes to check this theory against. It may be a possibility the rocks at depth have been hydrothermally altered to the point they have lost permeability. As a result the active deep hydrothermal system cannot flow to the surface except in areas of deep regional fracturing. It is in the areas of the deeper fractures where production of the higher temperature fluids could occur. This would also account for

the existence of anomalous high temperature surface manifestations within an area of cooler waters.

In summary I feel the geologic, geochemical and geophysical report was an excellent assessment of the resource. There are a few unanswered questions but to gather the answers would require an extensive, deep exploratory hole program. The completeness and integration of the data set definitely supports the concept that a substantial potential for a high quality geothermal resource exists beneath the Qualibou calders.

I feel the priorities defined by Los Alamos are valid except the proposed site for the Belfond well. This site should be reviewed so the well would intersect the regional fault/fracture system which crosses the northeast side of the Belfond area. This would provide a better chance of intersecting a higher permeability system so adequate fluids could be produced. Resistivity data indicate drilling would have to take place to depths greater than 900 m to intersect the low resistive system in the Belfond area.

The first well should be located in the Sulphur Springs area. This area has essentially been proven to contain high temperature fluids. The major factor in location of a well would be to accurately target the fault/fracture system so maximum production potential will occur. This well would then be followed by a well in the Belfond area. The third site should be re-evaluated after deeper drilling has occurred at the first two priority sites and the conceptual model of the Qualibou caldera re-evaluated.

The Etangs area looks good from the geophysical and geochemical viewpoint but lacks evidence of faulting/fracturing which provides the permeability for fluid production in this type of volcanic setting. The Belle Plaine area contains two intersecting regional structures which would provide adequate potential for secondary permeability but does not show the high temperature potential as determined by geophysical and geochemical surveys. This is also true for the area

north of Terre Blanche where faulting and an active hydrothermal system are evident but data does not support a high temperature resource. As a result the third site should not be drilled until the system has been re-evaluated based on deep exploratory drilling or unless high risk step-out wells are justified.

Macroeconomic models

The macroeconomic model used to describe the St. Lucia economy utilizes 1970 to 1982 economic data. It appears that St. Lucia possesses a good economic data base with most of the variables required for the models equations having at least 10 years of base data. The data on investment population and employment can be considered representative but one would prefer a better data base for this type of modeling. The sources of the population and employment data varied by the time period and some years had no data reported at all. Consumption and investment data were not available so assumptions were made that these variables equaled imports.

In general, the type of variables used in the model are adequate to describe the general economy. The time period for the data base 1970 to 1982 is adequate for the evaluation. Also, the quality of the base data appears adequate for an accurate macro model of St. Lucis's economy. Better data on investment would be useful for both modeling and nonmodeling reasons.' Assumptions regarding investment being equal to imports is adequate for the purposes of macroeconomic modeling but does not consider potential for domestic investment. Differentiating the type and source of investments could provide valuable insite into who, why and what kind of investors are attracted to St. Lucia.

The models are comprised of several equations estimated by ordinary least squares analysis. These equations describe consumption, production, foreign trade and investment. Several key variables were identified that influence the level of output in St. Lucia. Macroeconomic models of output are generally dependent

upon capital and labor. In the St. Lucia case, the data base on employment was incomplete and little data was available on investment. This is the fundamental weakness in the St. Lucia macroeconomic model. The model does not have a production function. Instead, it uses a value estimate of output for certain available data. The lack of investment data limits the model's insight of the economy. This limits the model's ability to predict output. Thus the model only forcasts the economy's general ability to grow. The macroeconomic model does not forcast the ability of the economy to form capital for new investments.

Nonlinear optimization model

The nonlinear programming model was used to forecast growth in consumption and Gross National Product and to estimate energy cost and investment through the year 2012. The model is a standard optimal growth model. This type of model is well suited for forecasting economic growth but limited in its capability to evaluate detailed issues of specific growth sectors. The trends forecasted in a nonlinear programming model can be used to predict trends in demand for energy based on economic growth as defined by the macroeconomic model. The basic requirement of this model is to integrate the forecasted economic trends of the macroeconomic model into a long range forecast of energy demand.

The critical factor involved is to forecast a realistic price of oil and demand for energy. The model does have an inelastic relationship between the price of oil and demand for electricity. Under the higher oil price scenarios one would expect an elastic relationship which radically effects demand when prices increase. Given the simplicity of the St. Lucia economy and confidence level of the data base, a satisfactory model of electricity demand and capacity was developed.

The basic conclusion that energy cost as a percentage of GNP is decreased by geothermal development is sound if the geothermal costs are accurate.

Geothermal electricity system

The study assumes a maximum 30 MW_e geothermal production limit based on forecasted demand and the ability to add incremental geothermal capacity to meet base demand through the year 2012. The use of 2.5 MW_e units over the life of the project is questioned. The initial installation should be two 5 MW_e or a single 10 MW_e unit. The economics of scale dictate a reasonable investor would want to initially install larger units to capture as much of the base load as possible. Also, available equipment from worldwide procurement will play a pivotal role in size of the unit. Because there are no wells and, thus, no confirmed reservoir conditions, it is difficult to project the unit size that would be most optional. The 2.5 MW_e unit seems to have been selected because it best fit the incremental growth curve.

Temperature and flow considerations will be the major factors used in selecting the type of unit. Ormat Units provide for a wide range of temperatures. 120°C to 190°C and units in the 1 to 2.5 MW_e range are available. Biphase provides a 1.5 MW_e unit while radial flow turbines also are available in 1 to 2.5 MW_e units. The factor ignored by the study is the possibility of larger capacity for the initial installation. Initially [illegible] MW_e of capacity could be installed thereby matching the power consumption curve for St. Lucia for 1985-86. This could readily be accomplished with a single 10 MW_e flash unit or two 5 MW_e flash units. Mitsubishi currently sells a 4 MW_e unit as well as 5 MW_e and 10 MW_e units. Toshiba and GE also are selling 5 MW_e units. Reliability considerations may require two 5 MW_e units instead of a single 10 MW_e installation.

It is also more reasonable to expect that a developer would increase capacity in 5 MW_e increments. The excess geothermal capacity would be used as spinning reserve or peaking power. The primary objective is to keep the diesel power plants off line while utilizing the geothermal units as base load units.

The capital cost estimate does not contain sufficient detail to adequately

evaluate the estimate. Several items seem to be missing. The condenser cost and cooling water supply system will be a major equipment item and should be a line item cost. If sea water is used for cooling, the pipeline cost will be significant as will the parasitic load for pumping. The effect of parasitic load on net output is not discussed in the plant cost, sizing and demand curves. The report does discuss the elevation effects on pumping and parasitic cost. Explanation of these factors should be a major concern to this study. Also, the efficiency of such a tower could have been addressed and compared to an ocean water cooling system with very little effort. Parasitic loads for each could have been estimated and shown in the report.

The cost of interconnection to the regional power system is also not addressed. The simple assumption that the power will be sold to existing systems is unrealistic There will be approximately 5 to 8 Km of transmission line required to interconnect the plant to the existing grid. Also, there may be requirements for reinforcement of the grid and interconnection between the existing electrical systems. These costs are directly related to the concept of a new power plant. These types of transmission related costs have been [illegible] projects in North America.

The engineering economic report evaluated costs on the basis of a power plant being located in the northern part of the Qualibou caldera near Soufriere. Since the recommended primary sites for drilling the production wells are listed as Belfond, Sulphur Springs and Belle Plaine, the cost of either additional power transmission lines or additional piping costs would have to be factored in. It is a general consensus the power plant be located near the resource because heat loss and pipeline costs in a steam or brine distribution system are important considerations.

Diesel generated electricity costs were reasonable and representative of continuation of the present system. Both oil-fired and coal-fired steam plant

electricity costs were reasonable except for the possibility that the price of coal may go down in the future when the Cerrejon Coal Mine in Columbie begins to export coal in 1986. This mine will be a major exporter of coal to North America and Europe and will undoubtedly affect the price of coal in the Carribean region.

Thermal systems

It is apparent by the level of detail shown in the report that considerably more emphasis was placed on evaluating direct use applications than electrical power options. Cooling systems for a power plant was not discussed in as much detail as the concepts for the utilizing of waste heat from a power plant. The conceptual evaluations for direct heat applications are adequate and the capital cost estimates are realistic, given the level of detail and base data. The concept of industrial use of geothermal heat from the power plant warrants further investigation. Because geothermal resources are site specific, and fluid piping costs usually quite extensive, careful examination should be given only to those industries in close proximity to the potential well field or industries that could relocate near the power plant.

The possibility of attracting new industry to St. Lucia to utilize inexpensive geothermal energy was examined in some detail. The concept of locating industries at geothermal sites cannot be based on attractive energy prices alone. Industries will be most likely attracted to St. Lucia to take advantage of available labor, low labor cost, and domestic products. Low energy cost will be an added incentive but taxes, cost of land, and political stability are just as significant considerations. Further studies should only examine those industrial applications which can readily use local resources such as raw products and labor. It is not reasonable to base long term economic benefit on possible direct heat applications. Only two industries, coconut-oil and sugar cane, appear to be able to benefit immediately by low cost geothermal process heat. Any additional industrial applications may take other development incentives in addition to low cost energy.

Summary

The Los Alamos investigation of the geothermal resource poetntial of St. Lucia involved researching published information; supplementing this information with field data and engineering studies; and conducting economic calculation. The investigation appeared well organized and approached the study in a logical fashion. The field data collected appeared to adequately supplement existing data to the extent an exploratory drilling program could proceed.

The conceptual model of the flow system as presented by Los Alamos does not take into account the full extent of fault and fracture control that was described within the geologic and geophysical sections. The fracture permeability of the caldera could modify the horizontal flow system proposed for the shallow thermal waters. The importance of intersecting fractured rock with the production holes was mentioned but not emphasized. As a result, the final drilling sites should be located such that the well will target a regional fault/fracture system at depth to maximize fluid production potential. I do not feel there will be any problem with getting the temperature predicted by Los Alamos but fluid production could be a problem if secondary permeability were not found. The sites of Sulphur Springs and the crater area in the north eastern portion of the Belfond area appear to be the best drilling targets. The other sites, Belle Plaine, Etangs and Diamond Spring/Migny River Valley area need additional specific site work on the structural setting prior to drilling.

The engineering/economic evaluation appears adequate for the purpose of the report. Additional work on the size of units to be constructed and schedule of power on line to meet the demand needs additional thought. Also the cost of power lines and piping from wells to the power plant to the electrical grid was weak. The discussions on direct utilization of geothermal appeared to out weigh the section on electrical generation. The thrust of development should be for electrical potential to eliminate the dependence on oil imports for diesel

generation. The only nonelectric use I feel should be studied in detail is sugar cane processing since this is an on-going industry on the island so imported raw material would not be necessary.

The economic model used appears to be good considering the data base available at present. Until the actual reservoir has been drilled so good engineering numbers can be obtained on the cost of a power plant, a more extensive economic evaluation is not warranted.

Recommendations

- Proceed with confirmation drilling at Sulphur Springs and Belfond areas
- After drilling conduct flow test to determine reservoir characteristics (i.e. flow, temperature, chemistry, noncondensable gas, enthalpy)
- Conduct preliminary engineering evaluation to select plant cycle for cost estimating (i.e. process flow diagram and material balance disposal options)
- Identify optimal cooling cycle for power plant
- Identify transmission requirements and cost
- Obtain vendor quotations for skid mounted equipment packages
- Estimate capital and operating cost based on data listed above
- Determine base case delivered cost per kw/hr to the grid
- Establish an economic model of geothermal power cost to evaluate various forms of project financing, royalties, taxes and other economic variables
- Use the economic model to justify financing to lending institutions other than USAID for capital cost of field development and power plant construction