ENVIRONMENTAL PROTECTION AND INTEGRATED SUSTAINABLE MANAGEMENT OF THE GUARANI AQUIFER SYSTEM - GAS

GEOTHERMAL PROJECT COMPONENT

AN ASSESSMENT OF OPPORTUNITIES FOR GEOTHERMAL ENERGY UTILISATION

Organisation of American States
Contract No. R-20226

Petroleum Geology Investigators/Lars Tallbacka 10th July, 2001

CONTENTS **PAGE**

TABLES

FIGURES

ENCLOSURES

DRAWINGS

ANNEXES

GUARANI AQUIFER SYSTEM
GEOTHERMAL PROJECT COMPONENT

AN ASSESSMENT OF OPPORTUNITIES FOR
GEOTHERMAL ENERGY UTILISATION

1. INTRODUCTION

This report is presented pursuant to the Agreement executed on the 24th April, 2001 between the Organisation of American States, Washington D.C., USA (OAS) and Petroleum Geology Investigators/v Lars Tallbacka, Copenhagen, Denmark (Consultant). In accordance with the Agreement Consultant performed a mission in Argentina, Brazil, Paraguay and Uruguay during the 2nd-12th May, 2001 with the primary purpose to assess the technical basis upon which geothermal development(s) could be pursued as well as to acquire an understanding of the institutional and policy issues that need to be addressed in connection with such development. The outcome of Consultant's mission was summarised in a draft Aide Memoire that was submitted on the 16th May, 2001 to all parties met during the mission as well as to OAS and The World Bank (the Bank), Washington D.C. Consultant's draft Aide Memoire is enclosed in Annex 1 of this report.

An important issue for discussion in connection with Consultant's mission comprised the possibilities for the establishment of the Guarani Geothermal Task Force (the Task Force) with a view to provide a technical concept document upon which an investment operation could be launched aiming at the implementation of a geothermal energy utilisation demonstration programme within the Guarani Aquifer System (GAS). Draft terms of reference (TOR) with regard to the Task Force were prepared by Consultant and forwarded to OAS and the Bank, Washington D.C., on the 29th May, 2001. A copy of the draft TOR is furthermore enclosed in Annex 2 of this report.

A location map highlighting the extension of the area of investigation is shown in Drawing 1.

1.1. Underlying Data Base

In connection with the mission Consultant was provided with a number of recent publications on the Guarani Aquifer System with accompanying maps highlighting the structural, thickness and temperature characteristics as well as the potentiometric conditions within the region. Consultant also received a copy of the "Proposal for Project Development Funds" (PDF) and selected parts of the "Project Background Document" (PBD) from the Bank, later supplemented by OAS, Montevideo. The PDF and PBD together with the works published by Araújo et al (1999) provided the basis for Consultant's technical evaluation and assessments with a view to the introduction of the Geothermal Project Component.

In addition to the above Consultant acquired US Defence Operational Navigational Charts (ONC) and Tactical Pilotage Charts (TPC) in the scales 1:1,000,000 and 500,000, respectively. The projection and geographical grid as well as the locations of urban and rural areas shown in the Drawings accompanying this report are taken from the TPC maps. The same applies to any altitudes stated by Consultant in this report. Depths below ground level (GL) were based on Araújo et al (1999) combined with the altitude information in the TPC maps.

There is a vast number of publications and reports available on the Guarani Aquifer System and generally speaking, all pertinent aquifer parameters have been addressed and evaluated at various degrees of concept and detail. However, there exist serious inconsistencies and confusing features and there is a pronounced lack of adequate test data and evaluation in the data base. One particularly serious aspect in this context is the use of the term “Guarani Aquifer System”, i.e. implying the existence of one contiguous aquifer over an area of approximately 1,200,000 square kilometres. There is no support to the existence of such an aquifer system in the data perused by Consultant. On the contrary there is ample evidence for the existence of more than one aquifer system within the area, i.e. comprising stratigraphic correlation indices, reported variation with regard to pressure, volume and temperature (PVT) conditions as well as the variations in the chemical composition of analysed aquifer waters.

In view of the above it is recommended to change the term Guarani Aquifer System to “Guarani Aquifer Complex” for future reference. Misconceptions of the actual aquifer conditions could result in erratic water management (for any purpose) and deterioration of existing aquifer system(s) in the long term. In the following the term “Guarani Aquifer System” has been changed and referred to as the Guarani Aquifer Complex.

The systematic arrangement of the data retrieved from the aquifer complex and subdivision into aquifer systems and aquifer zones comprises one of the most important work assignments for the proposed Task Force. In this context it is emphasised that the access to detailed underground data may be attributed by various constraints in the four countries. For example all data on the sedimentary basins of Brazil are retained by the Agencia Nacional do Petroleo (ANP). Access to and utilisation of these data requires the previous authorisation of ANP (Ref. Section 10).

1.2. The Academicians’ Report

In connection with the mission’s visit in Montevideo, Uruguay Consultant was shown a copy of the “Academicians’ Aquifer Evaluation Report”, apparently considered of limited significance in the continued preparation of the overall aquifer management project. It is beyond Consultant’s ability to determine the overall strategic significance of this report. It is however recommended that the Academicians’ Report be regarded as a key document for the further preparation of the Geothermal Project Component.

1.3. Area And Population

As deduced at the aquifer formation boundary the Guarani Aquifer Complex extends over approximately 1,200,000 square kilometres and straddles the territories of four countries, i.e. Argentina (19%), Brazil (71%), Paraguay (6%) and Uruguay (4%).

Selected pertinent information concerning the distribution of the aquifer complex as allocated to the various provinces and states of the four countries is shown in TABLE 1 below.

TABLE 1 : Guarani aquifer complex, aquifer areal extent and distribution as deduced inside aquifer boundaries

	AREA, km^2	POPULATION	CAPITAL	URBAN/RURAL
1. ARGENTINA		To be provided by OAS		To be provided by OAS
Missiones			Buenos Aires	
Corrientes			Buenos Aires	
Entre Rios			Buenos Aires	
Total Argentina	**225,500**		Buenos Aires	
2. BRAZIL				
Mato Grosso	26,400		Cuiabá	
Goiás	55,000		Goiãnia	
Minas Gerais	51,300		Horizonte	
Mato Grosso do Sul	213,200		Campo Grande	
São Paulo	155,800		São Paulo	
Paraná	131,300		Curitiba	
Santa Catarina	49,200		Florianópolis	
Rio Grande do Sul	157,600		Porto Alegre	
Total Brazil	**839,800**		Brasilia	
3. PARAGUAY				
Eastern Territory	71,700		Asunción	
4. URUGUAY				
Northwest Territory	45,000		Montevideo	
TOTAL AREA	**1,182,000**			

The compilation in TABLE 1 clearly reveals the predominantly Brazilian proportion of the aquifer complex. The Brazilian dominant control of the aquifer becomes further accentuated in terms of geothermal energy. Hence as deduced at the 40°C isotherm as mapped at the top aquifer level (Araújo et al, 1999) Brazil's part of the aquifer complex increases from 71% (deduced at aquifer boundary level) to 81%. At the 60°C and higher isotherms the geothermal energy potential is more or less entirely confined within Brazilian territory. This must be taken into account when determining the nature and extent of contribution by the four countries in the continued preparation of the Geothermal Project Component.

The areal extent of the aquifer complex as deduced at the 25°C, 40°C and 50°C isotherms and corresponding percent distributed between the four countries are summarised in TABLE 2 below.

TABLE 2 : Guarani aquifer complex, areal extent and distribution of geothermal potential at top aquifer level

TERRITORY	25°C (772,500 km^2)	40°C (424,000 km^2)	50°C (213,200 km^2)
	AREA, km^2 (% DISTR.)	AREA, km^2 (% DISTR.)	AREA, km^2 (% DISTR.)
Argentina	93,500 (12)	71,500 (16.4)	49,000 (23)
Brazil	626,000 (81)	343,500 (81)	160,000 (75)
Paraguay	21,000 (3)	2,500 (0.6)	nil
Uruguay	32,000 (4)	6,500 (2)	4,200 (2)

A total population of approximately 15 million is confined within the areas occupied by the aquifer complex. An interpretation of the ONC and TPC maps indicates that most of this population, i.e. approximately nine million, is confined in a large number of rural areas (villages and rural developments). The remaining six million population is confined within an indicated 28 urban areas and developments (areas of primary energy demand). 24 of these urban areas are located in Brazil. Once again the requirement for major Brazilian content in the Geothermal Project Component becomes apparent.

1.4. Illustrations

Three types of illustrations accompany this report referred to as "Figures", "Enclosures" and "Drawings". Figures are illustrations directly copied from the published material and reports received by Consultant and enclosed with this report, Enclosures are illustrations taken from the same material however modified or combined by Consultant for the purpose of clarification, the Drawings are illustrations independently prepared by Consultant, basically addressing economic considerations, geothermal energy utilisation and the regulatory/legislative issue. All illustrations are separately enclosed following the main text of this report.

2. SALIENT DEPOSITIONAL AND STRUCTURAL FEATURES

2.1. Depositional Features

The Guarani Aquifer Complex is contained within the Paraná and Chaco-Paraná sedimentary basins extending northeast-southwest and subparallel with the major Andes Mountains towards the West. The basin complex measures approximately 2,000 kilometres along strike and 800 kilometres across (dip), i.e. covering 1,600,000 square kilometres (Ref. Fig. 1). The Guarani Aquifer Complex occupies 1,200,000 square kilometres, i.e. covering 75% of the combined basin area.

The basin fill comprises sedimentary and volcanic rocks of Cambrian-Recent in age with major unconformities at the top of Middle Silurian, Late Devonian, Early Triassic and Early Cretaceous sequence boundaries. Maximum depth to the crystalline basement ranges between 4,000m (Chaco-Paraná) to 6,000m, (Paraná). Major volcanic activity took place during early Cretaceous resulting in the extrusion of the extensive and locally thick plateau basalt referred to as the Serra Geral Formation (SGF). The SGF directly overlies the late Jurassic-Early Creactous eolian sandstones that represent the most important aquifer system of the Guarani Aquifer Complex.

A less significant aquifer system of Permo-Triassic age underlies the eolian sandstones however separated at the Late Permian-Early Triassic unconformity. The time span between the deposition of the two aquifer systems equals approximately 100 million years.

The stratigraphic succession of the basin deposits and lithostratigraphic correlation between the Paraná and Chaco-Paraná basins are shown in Figure 2. A corresponding stratigraphic compilation with regard to the Uruguayan portion of the Paraná Basin is shown in Figure 3. The geological map of the basin is shown in Figure 4.

For more elaborate descriptions of the depositional features of the basin areas reference is made to Araújo et al (1999), Milano & Filho (2000) and Montaño et al (1998).

2.2. Structural Features

The major structural feature comprises the two slightly displaced northeast-southwest trending Paraná and Chaco Paraná Basins, the displacement is possibly due to transcurrent movement along or at least related to the Rio Grande Arch in the south. Balanced subsidence and uplift along the basin margins resulted in extensive outcropping of the late Jurassic-early Cretaceous Botucatu/Tacuarembó sandstones with widths between 10-30 kilometres across that extend approximately 3,500 kilometres along the basin margins.

The basin areas are intersected by a number of northwest-southeast trending ridge like features referred to as "arches" in the literature. It is possible that these counter regional arch features represent a reactivated and uplifted archean grain of the predrift structural configuration of the area. Aquifer areas located adjacent to and along these arches could conceivably have increased geothermal gradients due to increased exposure to basement induced heat flow. Local Postjurassic tectonic inversion is indicated in areas of thick aquifer deposits at high structural position and vice versa.

The salient structural configuration of the aquifer complex area in its geographic framework is shown in Enclosure 1. The structural style of the Postpaleozoic section is highlighted in cross sections A-A' to C-C' in Enclosure 2. Further reference is made to the top aquifer structure map and the aquifer thickness map shown in Enclosure 3 and 4 respectively.

3. AQUIFER ROCK CHARACTERISTICS

3.1. Lithology

The aquifer complex consists of an upper sequence consisting of predominantly fine to medium grained, well sorted and subrounded eolian quartz sandstones of excellent aquifer quality, unconformably overlying a thick sequence of coarser, less differentiated subarkosic deposits and of lesser apparent significance as a candidate for initial geothermal development. This lower sequence is referred to as i.a. the Pirambóia and Buena Vista formations in the literature. The upper superior aquifer system comprises the Botucatu and Tacuarembó formations as confined within the Paraná Basin and the Chaco-Paraná Basin, respectively.

The separate mapping (structure, thickness, temperature) and detailed lithological evaluation of the above mentioned aquifer rock sequences are basic requirements for the continued preparation of the Geothermal Project Component. Conducting the related work and the systematic presentation of the results of this work are important work tasks for the proposed Task Force (Ref. Annex 2).

Additional aquifer rock sequences of Postbasalt origin are present in the late Cretaceous-Cenozoic section, i.e. represented by the Bauru Group in the Paraná Basin and by the Manano Boedo and Chaco Group predominantly sandstones in the Chaco-Paraná Basin (Ref. Fig 1). The utilisation of these shallower positioned rocks for heat and cold aquifer storage carries considerable economic significance in a continued geothermal development scenario.

A fourth potentially existing aquifer system comprises the basalts of the Serra Geral Formation. Although poorly described in the literature retained by Consultant, fractured basalt could prove important geothermal energy sources, both from the viewpoint of sustainable energy production as well as heat and cold storage for utilisation pursuant to seasonal energy demand (Ref. Section 5).

3.2. Petrophysical Characteristics

The petrophysical characteristics of the major upper (Botucatu/Tacuarembó) and the lower (Pirambóia/Buena Vista) aquifer systems were presented by Araújo et al (1999) and by Silva Busso (1999) and are summarised in TABLE 3 below.

TABLE 3 : Pertinent petrophysical characteristics

PARAMETER	UPPER AQUIFER	LOWER AQUIFER
Gross aquifer thickness, m	nil-500	25-770
Porosity, %	17-30	14-24
Permeability, Darcy	8-17	2
Transmissivity, Darcymetres	2-550	not available

The depth at top aquifer ranges between ground level (GL) and 1,800 metres below mean sea level (MSL). Maximum elevation at ground level is located in the State of Santa Catarina, Brazil where the outcropping Botucatu sandstone is located at 800 metres above mean sea level (aMSL). Maximum depth at top aquifer is located in the southwestern Saõ Paulo State, Brazil, i.e. corresponding to 1,800m (MSL) or approximately 2,225m (GL).

The top aquifer structure and isopach map adjusted to the geographical framework are shown in Enclosures 3 and 4.

As for the lithological evaluation (Ref. Section 3.1) separate petrophysical evaluations and assessments are required for the upper and lower aquifers for each individual project considered, also comprising petrophysical assessments for the Postbasalt potential aquifers and the Serra Geral Formation, as applicable.

3.3. Volumetric Assessment

The isopach map as presented by Araújo et al (1999) was planimetered and an area versus thickness plot was prepared, shown in Drawing 2. Based on this exercise and applying an average porosity at 20% for the Guarani Aquifer Complex the gross and net aquifer rock volumes as well as the water volume contained in the pore space were calculated. The result of this volumetric assessment is shown in TABLE 4.

TABLE 4 : Volumetric assessment

PARAMETER	VOLUME
Gross aquifer rock volume	368 x 10^{12} m^3
Water-in-place at porosity 20%	92 x 10^{12} m^3
Net aquifer rock volume	276 x 10^{12} m^3

The above assessed water-in-place volume exceeds the volume quoted in the PDF by 52 x 10^{12} m^3 or 130%. This is serious and stresses once again the requirement for the Task Force. As for the lithological and petrophysical evaluations separate volumetric assessments are required for the upper (Botucatu/Tacuarembó) and lower (Pirambóia/Buena Vista) geothermal aquifer systems.

3.4. Temperature

Temperature data from 322 deep wells located within the aquifer complex area were used by Araújo et al (1999) and an isothermal map at top aquifer level was presented, shown in its geographical framework in Enclosure 5. The map reveals top aquifer temperatures ranging between 25°-70°C. An average geothermal gradient has been reported at 2.9°C/100m, however locally as low as 2.0°C/100m. This low gradient is believed to be the result of the cooling effect due to the annual surface water recharge of the aquifer. Other areas have a considerably higher geothermal gradient, e.g. in the northern Paraná Basin (State of Goiás) where the geothermal gradient has been recorded at 5.5°C/100m and believed to be due to high heat flow from the crystalline basement directly underlying the aquifer in this area (Ref. Encl. 2, cross section A-A').

The above implies that produced geothermal water temperatures would be considerably higher than the top aquifer temperature in areas of thick aquifer deposits. Two such areas are present in the aquifer isopach map (Ref. Encl. 4), i.e. one area located adjacent to Campo Grande in Brazil with a maximum aquifer thickness of 600 metres and one area located in the Chaco-Paraná Basin straddling the Corrientes and Entre Rios provinces in Argentina as well as part of the western State of Rio Grande do Sul, Brazil with a maximum aquifer thickness of 800 metres (i.e. indicating a difference between top and bottom aquifer temperatures of nearly 25°C).

The above reveals the requirement for the preparation of additional isothermal maps at top lower aquifer level and at the bottom of the Guarani Aquifer Complex, consideration should also be given to the preparation of maps showing the geothermal gradient distribution and the regional heat flow in the area.

3.5. Pressure

There is an apparent lack of reported actual aquifer pressure measurements in the literature. However a potentiometric surface map (pressure surface map) has been presented by Araújo et al (1995 and 1999). The potentiometric surface represents the static head of the aquifer water and is defined at the level to which the water will rise in a well. The pressure surface map in its geographical framework is shown in Enclosure 6, also depicting the trajectories of cross sections A-A' to C-C' (Ref. Encl. 2).

Assuming datum at MSL the pressure surface map reveals that the static water level ranges between 50m-800m (aMSL) in the area and that pressure balance is principally controlled by the major recharge areas located along the eastern basin margin and the discharge areas predominantly located along and between the major Uruguay and Paraná rivers. The annual recharge of the aquifer is reported at 138 x $10^9 m^3$ (Araújo et al 1999)

For the most the aquifer pressure appears as hydrostatic or slightly underpressured, i.e. with a static geothermal water level located at or just below ground level. However artesian wells and gushers are locally present within the area, i.e. conclusively confirming that the pressure surface is locally located above ground level. Furthermore, indicated areas of potentially existing artesian conditions have been indicated in Araújo et at (1995). One such area of particular interest is the town of Presidente Prudente located in the southwestern State of São Paulo, Brazil. Here the potentiometric surface appears to be located above ground level in an area of maximum reported aquifer temperature (60°-70°C). Although the superior Botucatu sandstone aquifer has reduced thickness in this area (around 100m) the excellent permeability of this formation (Ref. Section 3.2) suggests that a sustainable geothermal energy production could be maintained at relatively low operating costs. In this context the production index (PI) for the Botucatu sandstone was assessed by Consultant to range between 52-148m^3/hr/bar as based on Silva Busso (1999). This implies that at a drawdown of 10 bars (100m) a geothermal water flow rate could be achieved ranging between 520-1,480m^3/hr/well.

The above reveals a requirement for detailed analysis of the pressure surface and available aquifer test data from wells previously drilled in the area, an exercise to be conducted by the Task Force.

It is suggested that comparisons between the potentiometric surface and ground level elevation should take into account the altitude information provided in the TPC maps.

3.6. Aquifer Water Composition

Based on the data evaluated by Consultant there is evidence for the existence of at least three types of aquifer water within the Guarani Aquifer Complex, i.e. a) typically fresh water with a total mineralisation not exceeding 0.25 g/l and confined within the Botucatu/Tacuarembó aquifer system(s), b) brackish-saline waters with a total mineralisation ranging between 1-10 g/l and confined within the Piramboia/Buena Vista aquifer system and c) alkaline, fluorine bearing waters of believed magmatic origin, confined locally in the predominantly lower aquifer systems.

For the purpose of simplicity and systematic arrangement of aquifer characteristics it is recommended that waters pursuant to points “a” and “b” above are referred to as geothermal water and that waters pursuant to point “c” be referred to as hydrothermal water in the future.

The difference in aquifer water composition suggest a reduced recharge impact with regard to the lower aquifer system(s) and furthermore imply that tentative geothermal development of the lower aquifer system should take place in doublet configuration (production-heat retrieval-injection) under closed system conditions.

The Botucau/Tacuarembó aquifer/recharge system is by far the most important candidate for geothermal development in view of the fresh composition of the geothermal water, hence carrying the opportunity for single well development and multiple utilisation of the water after heat energy retrieval. The increased salinity of the lower aquifer system(s) suggest reduced rates of recharge water and furthermore emphasises geothermal development in doublet configuration, hence without opportunities for utilisation of the water after heat energy retrieval.

4. GEOTHERMAL ENERGY POTENTIAL

An assessment of the geothermal energy potential of the Guarani Aquifer Complex has been carried out through volumetric calculations based on the aquifer thickness map by Araújo et al, 1999 (Ref. Section 3.3) applying average porosity and temperature values for the aquifer at 20% and 40°C, respectively. Specific heat capacity values for rock matrix and aquifer water were estimated at 2.2 and 4.5 Megajoules per cubic metre and degree centigrade ($MJ/m^3/°C$). In this report heat energy is consistently expressed in Joules, electric energy (power) is expressed in kilowatt hours (kWh), as applicable. Effect is calculated assuming maximum constant energy off take during 8,500 hours per year. Useful energy conversions are shown in TABLE 5 below.

TABLE 5 : Useful energy conversions

TO FROM	Btu	Cal	Joule	kWh
Btu	1	252.0	1,055	2.93×10^{-4}
Cal	0.00397	1	4.186	1.16×10^{-6}
Joule	9.48×10^{-4}	0.2389	1	2.78×10^{-7}
kWh	3,413	$8.60\ 10^5$	3.60×10^6	1

kilo (k) = 10^3, mega (M) = 10^6, giga (G) = 10^9, tera (T) = 10^{12}, peta (P) = 10^{15}, exa (E) = 10^{18}

4.1. Heat-in-place

Based on the pertinent parameter values quoted in Section 4 above the geothermal heat-in-place (the geothermal heat resource) was calculated and allocated to the four countries participating in the project in accordance with the percentage distribution shown at the 40°C isotherm in TABLE 2. The result of this exercise is summarised in TABLE 6.

TABLE 6 : Geothermal heat-in-place and allocation to Argentina, Brazil, Paraguay and Uruguay

PARAMETER	**TOTAL**	**ARGENTINA**	**BRAZIL**	**PARAGUAY**	**URUGUAY**
Rock volume, 10^{12}m3	276	45	233	2	6
Water volume, $10^{12}m^3$	92	15.1	74.5	0.6	1.8
Heat-in-place, EJ	41,000	6,724	33,210	246	820

The total heat-in-place value at 41,000 EJ corresponds to approximately 1,000 billion tons fuel oil equivalent (toe) assuming a heat value for fuel oil at 41 GJ/ton. The natural gas equivalent value equals to approximately 1,200 x 10^{12} normal cubic metres (1,200 trillion cubic metres) assuming a heat value for natural gas at 35 GJ per thousand normal cubic metres (tcm).

4.2. Heat Reserves

Heat reserves comprise the portion of the heat-in-place that could be retrieved at surface and can be subdivided into technical and economical heat reserves. Technical heat reserves are simply calculated as a portion of the heat-in-place assessed, the economical heat reserves can only be calculated pursuant to known surface energy demand and to type of utilisation and preferred technological solutions for the related heat based energy supply. An assessment of economic heat reserves can not presently be carried out, the technical heat reserves are shown in TABLE 7 below based on heat recovery at 30% of the heat-in-place together with the allocation to the four countries involved.

TABLE 7 : Technical geothermal heat reserves and allocation to Argentina, Brazil, Paraguay and Uruguay

PARAMETER	TOTAL	ARGENTINA	BRAZIL	PARAGUAY	URUGUAY
Heat-in-place, EJ	41,000	6,724	33,200	246	820
Technical heat reserves, EJ	12,300	2,017	9,963	74	246
Fuel oil equivalent, 10^9 toe	1,000	164	810	6	20
Natural gas equivalent, $10^{12}m^3$	1,170	192	948	7	23

The heat reserves were calculated in terms of oil equivalent and volume natural gas equivalent for the purpose of establishing a basis for the calculation of the economic energy asset value, attributed to the geothermal heat reserves as allocated to the four countries.

A preliminary weighted average potential energy content within the area of the 25°C isotherm was assessed at 8 PJ/km^2 or, as expressed in terms of effect, at 260 MW/ km^2.

4.3. Economic Heat Energy Asset

Most companies and organisations operating within the field of exploitation of underground energy resources regard such resources as an economic asset. In this report the economic asset value was calculated based on the conversion of the technical heat reserves (Ref. Section 4.2) into tons fuel oil equivalent with a heat value at 41 GJ/ton and applying a fuel oil price assessed at USD 120/ton. The result of this exercise is summarised in TABLE 8 below and further highlighted in the composite area versus temperature plot in Drawing 3.

TABLE 8 : Economic asset values for technical heat reserves in Argentina, Brazil, Paraguay and Uruguay

PARAMETER	TOTAL	ARGENTINA	BRAZIL	PARAGUAY	URUGUAY
Heat reserves, EJ	12,300	2,017	9,963	74	246
Fuel oil equivalent, 10^9 toe	300	49	243	2	6
Asset value, 10^{12} USD	36	5.88	29.16	0.24	0.7
Population, million	204	35	160	5	4
Asset value per capita, USD	176,400	168,000	182,000	48,000	175,000

The economic asset values shown in TABLE 8 above only serves the purpose to highlight the importance of the Guarani Aquifer Complex as a national energy resource and should not be directly applied in national economic considerations without previous and critical scrutiny. However it is Consultant’s considered opinion that the enormous thermal energy resource of the Guarani Aquifer Complex carries a vast economic impact in the future in view of expected increased greenhouse effects and ozone layer deterioration.

5. THERMAL ENERGY UTILISATION

In connection with the performance of this contract Consultant met with and discussed the current state of the art with recognised expertise in the field of geothermal energy utilisation. Based on these discussions it can be concluded that ample opportunities exist for geothermal energy supply within the entire temperature range of the aquifer water (20°-80°C).

A basic requirement for the tentative geothermal development is that implementation of the underground development predominantly takes place in doublet configuration, i.e. implying the construction of both production and injection wells and the establishment of geothermal water loops as closed systems. Any diversions from this scenario is pending conclusive and properly documented existence of an effective recharge system as well as the environmentally acceptable composition of any geothermal aquifer water produced.

Heat retrieval is principally limited to heat exchange and the utilisation of heat driven absorption pumps (chillers).

5.1. Sustainable Utilisation Of Geothermal Energy

Major sustainable supply of geothermal energy could be applied in the fields of district heating and cooling (including the provision of air conditioning and ventilation), provision of hot tap water, provision of heating and cooling for industrial processes and finally, the provision of power.

The aquifer water temperature required for the provision of air conditioning and power generation, i.e. the driving heat for absorption pumps and the heat for the driving of steam turbines, must exceed 50°C and preferably be in the range 80°-100°C(+). As mapped at the top aquifer level (Ref. Encl. 3) the geothermal temperature does not exceed 70°C, hence implying the requirement for boosting the aquifer water temperature at surface prior to heat retrieval. This boosting of the temperature could be achieved through utilisation of oil or gas driven hot water or steam boilers. A preferred solution in this context comprises however the utilisation of solar energy for the purpose of boosting the geothermal water temperature prior to heat retrieval. Ongoing research with regard to the utilisation of solar energy for the driving of absorption heat pumps is performed through the International Energy Agency (IEA), Paris, France. Reference is made to www.iea-shc.org, search for Task 25.

It is beyond the scope of this report to go into further detail with regard to solar supported air conditioning and power generation systems or “geosolar” energy combi systems. Consultant retains however *ad hoc* arrangements with leading expertise connected to the IEA and could therefore readily provide in-depth evaluations and proposals for practical applications regarding solar energy supported geothermal demonstration or pilot projects.

5.2. Auxiliary Utilisation Of Geothermal Energy

Excess heat or cold resulting from the sustainable geothermal development discussed in Section 4.1 can be utilised for the provision of heating and cooling for a considerable number of applications requiring phased temperature regulation and ventilation due to seasonal variation. Such applications comprise *i.a.* cold storage, greenhousing, fish farming, tourist facilities, crop drying, balneotherapy etc., none of which could justify an investment for geothermal development on its own merits. However possible multipurpose applications combined with thermal energy storage (aquifer and/or borehole storage) could present future prolific opportunities for development. In this context it is of paramount importance to assess in detail the climate conditions attributed to areas of interest for potential auxiliary geothermal development. The same applies to the sustainable scenarios (Ref. Section 4.1).

A composite synopsis summarising the opportunities for geothermal energy utilisation as discussed in Section 5.1 and 5.2 above is shown in Drawing 4.

5.3. Constraints

There are some apparent constraints related to the readily introduction of sustainable geothermal energy supply in the region, basically due to the climatic conditions combined with the relatively low aquifer temperature which prevents an effective utilisation of geothermal energy for the supply of cooling and air conditioning. Further constraints are related to the general absence of energy demand in areas of superior geothermal aquifer conditions as well as the lack of existing infrastructure for heating and cooling (air conditioning) supply and distribution in areas suitably located within the aquifer area.

However, existing artesian conditions and an effective recharge system combined with requirements for multipurpose utilisation of geothermal heat provide ample opportunities for environmentally sound and economically viable development of the aquifer. Although such development carries unconventional and partly unique technological solutions, the economic significance and importance of the Guarani Aquifer Complex as an energy source is beyond doubt, in Consultant's opinion. The above mentioned constraints merely accentuate the requirement for a careful and balanced approach with regard to the continued preparations for the Geothermal Project Component.

6. ENVIRONMENTAL AND SOCIAL ECONOMIC BENEFITS

Environmental and social benefits are related to the substitution by geothermal energy for thermal energy alternatively generated through the burning of fossil fuels with resulting atmospheric emissions of predominantly CO_2, SO_2 and NO_x gasses as well as the outlet of solid particulates in connection with the incineration process. The reduced emissions are calculated in tons per year and given monetary values in accordance with rates previously provided by the Bank (and GEF). The following calculation (Ref. TABLE 9) is based on the assumption that 500 TJ of geothermal heat is supplied annually into an established heating/cooling system from a tentative geothermal pilot plant.

TABLE 9 :Environmental and social economic benefits related to the substitution of fossil fuel by geothermal heat supply at 500 TJ p.a

PARAMETER	FUEL OIL	NATURAL GAS	COAL
Heat value	41 GJ/ton	35 GJ/tcm	24.4 GJ/ton
Efficiency	0.85	0.9	0.8
Gross heat production	588 TJ	555 TJ	625 TJ
CO_2 emission	78 kg/GJ	57 kg/GJ	95 kg/GJ
SO_2 emission	0.5 kg/GJ	nil	1.2 kg/GJ
NO_x emission	0.2 kg/GJ	0.1 kg/GJ	0.3 kg/GJ
Annual CO_2 emission	45,864 tons	31,635 tons	59,375 tons
Annual SO_2 emission	294 tons	nil	750 tons
Annual NO_x emission	118 tons	56 tons	188 tons
Particle outlet	0.03 kg/GJ	nil	n.a.
Total particle fallout	18 tons	nil	n.a.
CO_2 emission cost	USD 7/ton		
SO_2 emission cost	USD 600/ton		
NO_x emission cost	USD 250/ton		
Particle fallout cost	USD 1,000/ton		
Environmental benefit (CO_2 + fallout)	USD 339,048	USD 221,455	USD 475,625*
Social benefits (SO_2 + NO_x)	USD 205,900	USD 14,000	USD 497,000

* Includes ash disposal cost at USD 60,000.

The environmental and social economic benefits are credited in the economical analysis for the purpose of the assessment of a project's economic rate of return (ERR) on capital expenditure (investment).

Other social economic benefits are related to the locationing or relocationing of heating or cooling requiring industry that may be attracted by the availability of "green" and cheap energy for its production or manufacturing processes. This could furthermore contribute to the off loading in other areas of the strained hydropower supply system. Needless to say a sustainable supply of air conditioning (and heating) and hot and cold tap water would improve the residential comfort and sanitary conditions, hence carrying improvements in the health sector.

7. COST ASSESSMENT

The following assessment of costs was made for the tentative implementation of a geothermal pilot project located within the area of maximum aquifer temperature (Ref. Encl. 5). This area is principally located within the southwesternmost State of São Paulo, Brazil. Maximum temperature at top aquifer is reported at 70°C, the total aquifer thickness is around 300 metres with depths to the top aquifer located between 1,400m-2,000m (GL). Flowing well head temperature was reported by the Departamento de Aquas e Energia Elétrica at 63°C from a well drilled to a total depth of 1,800m (GL) at the town of Presidente Prudente in the 1980's. Whether this well could be re-entered and used in connection with a pilot project is not known, neither is the well configuration or current well status.

The cost assessment assumes the construction of two vertical geothermal water wells (one producer and one injector) connected by a flow line at surface, geothermal energy is primarily retrieved via heat driven absorption pumps, heat required for the driving of the absorption pumps is provided by fuel oil driven boilers, excess heat and cold is stored in the aquifer(s). The geothermal water flow rate is estimated at 320 m^3/hr and maintained by a downhole submersible production pump and surface installed injection pump(s). The net annual geothermal energy production equals 500 TJ.

7.1. Capital expenditures

The capital expenditures (CAPEX) are summarised in TABLE 10 below.

TABLE 10 : CAPEX for geothermal plant supplying 500 TJ p.a. from aquifer at 1,600m (GL)

ITEM	DESCRIPTION	COST, USD thousands
1	Well construction (2)	3,600
2	Clean up and testing	500
3	Plant and flowline	2,200
4	Production/injection pumps	450
5	Absorption heat pumps	1,300
6	Cables and electric equipment	280
7	Mechanical/electric installations	540
8	Control and regulation system	110
9	Filters and miscellaneous	310
10	**Sub total**	**9,290**
11	Heat/cold distribution system	6,000
12	**Grand total**	**15,290**

The above budget is based on "Western" costs and carries considerable reductions pending geothermal water composition and recharge system as well as the opportunity to use solar heat for the driving of the absorption heat pumps. Hence production of fresh geothermal water would reduce item 1 to USD 1.8 million, item 2 to USD 0.25 million and remove the requirement for flowline and injection facilities (total around USD 0.7 million) and reduce items 6-9 by 50%, i.e. a total saving of USD 0.62 million and bring item 10 down to USD 6.72 million. The opportunity to use an already existing well entirely removes item 1 from the budget (a further deduction of USD 1.8 million) however changing item 2 to "Re-entry and geothermal completion" which would probably bring the cost for item 2 back up to USD 0.5

million. Hence pending fresh water composition of the aquifer combined with the utilisation of an already existing well would bring item 10 down to USD 5.2 million.

The budget does not reflect equipment required for the driving of the absorption heat pumps (boilers or solar heat). However if all heat required for the driving of the absorption heat pumps was to be provided from boilers a corresponding budget item would be to the tune of USD 0.8 million.

The cost estimate for a distribution system assumes the establishment of 5 km of main line at USD 0.66 million per kilometre plus USD 2,500 per household for the required connections comprising approximately 1,000 households. A potential reduction of these costs is pending local cost levels.

7.2. Operating Cost

The operating cost (Opcost) for the geothermal plant as outlined in Section 7.1 above would range between USD 700,000-900,000 p.a. based on experience from elsewhere and pending the cost for power required for pumps and electric equipment. As the cost for boilers was excluded in the CAPEX the Opcost does not include fuel cost for boilers.

8. PILOT PROJECT(S)

In view of the constraints related to the readily geothermal heat utilisation for other sustainable applications besides heat and hot tap water supply (Ref. Section 5.3) areas for preferred pilot project implementation are restricted to areas of sustainable heat demand. It appears reasonable to assume that such areas would tend to be located within the southernmost part of the aquifer area. Towards the north the overruling demand would comprise cooling and air conditioning requirements and for which the utilisation of the Guarani geothermal heat resource becomes questionable due to the relatively low aquifer temperature and related thermodynamic constraints. However solar supported air conditioning and power generation systems combined with thermal storage could be of interest for application in the northern area. Thermal aquifer storage in this context may not necessarily involve the utilisation of the Guarani aquifer.

Based on Consultant’s best judgement in light of this assessment two areas of primary interest for tentative geothermal development could be considered, i.e. the town of Presidente Prudente, Brazil for the predominately supply of cooling and air conditioning and the areas of the towns of Salto, Uruguay and Concordia, Argentina for the predominantly supply of heating and hot tap water.

The locations of the above two areas for tentative pilot project implementation are shown in Drawings 6 and 9 in the proposed regulatory framework (Ref. Section 9).

A third area that could be of interest with regard to pilot development could be the city of P.N. Iguazú located at the triple border junction between Argentina, Brazil and Paraguay within the central-western part of the aquifer area. Here the temperature at top aquifer level is reported between 30°-40°C (Ref. Encl. 5) at a top aquifer depth of 400m (MSL) or between 600m-700m (GL). The reported aquifer thickness is 300m (Ref. Encl. 4).

The size of a pilot project and related capital expenditures can be scaled down based on the discussion in Section 7 above.

The tentative pilot areas are highlighted in the composite maps shown in Enclosures 1 and 3-6 and furthermore in Drawings 1 and 5.

9. REGULATORY FRAMEWORK

A regulatory framework for the Geothermal Project Component is proposed to be in compliance with the geographical grid in accordance with the TPC maps (scale 1:500,000). The framework consists of 22 concession block areas covering 2° latitude x 2° longitude each and are defined in the southwest corner in latitude/longitude (west Greenwich). Each concession block has been subdivided into quadrants (roman I-IV) measuring 1° latitude x 1° longitude which have been further subdivided in 16 "leases", each measuring 15' latitude x 15' longitude and covering an area of approximately 688 square kilometres, i.e. representing a potential geothermal energy asset of 5.5 EJ (134 x 10^6 toe).

The proposed regulatory framework is shown in Drawing 5, four selected concession block areas were furthermore prepared based on the TPC maps and depict the systematic subdivision as well as the population density within these concession block areas (Ref. Drawings 6-9).

The areas considered for tentative pilot project implementation (Ref. Section 8) are included in these maps, i.e. Lease No. 2352/II-03 (Ref. Drawing 6), Lease No's 3359/I-08 and 3359/II-05 (Ref. Drawing 9) and Lease No's 2755/I-06 and I-10 (Ref. Drawing 8).

Legislative requirements pursuant to the overruling water management of the Guarani aquifer are not addressed in this report although it is Consultant's impression that such legislation could be adopted from the State of São Paulo, Brazil. Geothermal legislation issues should be addressed in connection with the preparation of a geothermal model concession upon which decisions on legislative requirements could be based. It is believed that such requirements could partly be based on available hydrocarbon exploration and production legislation.

10. INSTITUTIONAL ARRANGEMENTS

It may be considered pre-mature to enter into time consuming institutional arrangements for the Geothermal Project Component until conclusive evidence can be presented justifying the regional and economically viable development of the Guarani Aquifer Complex. In view of the uncertainties attributed to sustainable heat and hot tap water demand in the region and the currently unexploited opportunity for solar energy supported cooling and air conditioning systems a balanced approach is recommended with regard to the continued preparation for the Geothermal Project Component.

In view of the above it appears reasonable to scale down the Task Force, say only to comprise the three tentative pilot areas discussed in Section 8. Although this would not affect the content of the work tasks it would considerably reduce the time and cost frames, i.e. from 10 months and USD 500,000 to say three months and USD 150,000, respectively. The balanced approach would also tend to defer the requirement for the addressing of the "heavier" policy issues, hereunder the declaration of priority by the four countries concerning the utilisation of geothermal energy. A second issue in this context concerns the question of focal point for the Geothermal Project Component. As relevant underground data and information is controlled by the energy authorities and as the primary aim of the Geothermal Project Component is to utilise geothermal energy and not the water it could be considered whether the focal point for the major water management project and the Geothermal Project Component should be the same.

Institutional arrangements in the short term are proposed to comprise although not necessarily be limited to a) the entry by the four countries of a Task Force Agreement including the commitment to comply with the recommendations to be provided by the Task Force, b) the acquisition of permission of access and utilisation of all relevant underground data required for the Task Force assessment and c) the preparation of a geothermal model licence upon which future legislative requirements could be based.

A further issue for consideration in the short term could be to establish a group of experts with the purpose to assess the current and forecasted sustainable heating and cooling demands in the region, to provide detailed assessments of related climatic conditions and to establish contact and possible cooperation with institutions and organisations involved in the field of solar support for the driving of absorption heat pumps and related models for thermal energy storage.

11. THE TASK FORCE

With a view to perform the Geothermal Guarani Project Assessment (GUAPA), it has been recommended by Consultant to establish a Task Force that could carry out this assessment within the same premises and within previously determined time and cost frames.

The Task Force is defined as a group of geoscientists comprising one Member from each country plus a Coordinator who shall be responsible for all extramural contacts and communications required by the Task Force during its performance of GUAPA.

The primary objective of GUAPA comprises the detailed evaluation and systematic arrangement of available underground data and information and the presentation of the results in a previously agreed upon regulatory framework (Ref. Section 9).

Draft terms of reference (TOR) for the Task Force were previously forwarded to OAS and the Bank, Washington D.C. and are furthermore enclosed in Annex 2 of this report. Issues related to the Task Force in connection with Consultant's Mission No. 1 are further summarised in the Aide Memoire enclosed in Annex 1.

The findings of this report reveals a high degree of complexity attributed to the Geothermal Project Component, strengthening the requirement for a careful and balanced approach to the further preparations with regard to this component. In this context a scaling down of the currently proposed extent of GUAPA, i.e. only to comprise the tentative pilot project areas discussed in this report (Ref. Section 8) is recommended. The pilot areas were chosen in order to satisfy the multinational participation in the project as well as to provide a diversified basis for considerations on preferred solutions for geothermal energy retrieval.

12. REFERENCES

Araújo L.M., França A.B. and Potter P.E. Aquifero gigante do MERCOSUL no Brasil, Argentina, Uruguai e Paraguai; Mapas hidrogeológicos dos Formações Botucatu, Pirambóia Rosário do Sul, Buena Vista, Misiones e Tacuarembó. Univ. Fed. Paraná, Bibl. Ciênc. Tecnol., Centro Politéc., Curitiba (1995).

Araújo L.M., França A.B. and Potter P.E. Hydrogeology of the Mercosul aquifer system in the Paraná and Chaco-Paraná Basins, South America and comparisions with the Navajo-Nugget aquifer system, USA. Hydrogeol. Journ., No. 7 (1999).

Forlin M. and Rosa Filho E.F. Mapa de isotermas do Aquifero Guarani. From PBD (2000).

Milani E.J. and Filho T. Carta estratigráfica das bacias do Paraná e Chaco-Paraná. From PBD (2000).

Montaño J., Tujchneider O., Auge M., Fili M., Paris M., D'Elia M., Pérez M., Nagy M.I., Collazo P. and Decoud P. Sistema Aquifero Guarani. Univ. Nac. del Litoral, Arg. (1998).

Paulipetro. Mapa geológico simplificado da Bacia do Paraná. From PBD (2000).

Silva Busso A.A. Geologic and hydrogeologic aspects of the thermal aquifer system in the Argentinean eastern Chacoparanense Basin. PNTAS, Inst. Aqua y Ambiente Arg. (2000).

Project Background Document (PBD). Received from World Bank (2001).

Proposal for project development funds (PDF).Received from World Bank (2001).

Environmental Protection and Integrated Sustainable Management of the Guarani Aquifer System - GAS.

Geothermal Project Component
Aide Memoire

Consultant's Mission No. 1, 2nd-12th May, 2001

INTRODUCTION

1. Pursuant to Contract No. R-20226 executed on the 24th April, 2001 between the General Secretariat of the Organisation of American States (GS/OAS), Washington DC., USA and Lars Tallbacka (Consultant), Copenhagen, Denmark, Consultant visited Brasilia and São Paulo, Rio de Janeiro, Buenos Aires, Asunción, Montevideo and Brasilia between the 2nd-12th May, 2001 (the Mission) with the objective to investigate the opportunities to launch a geothermal component under the major project entitled "Environmental Protection and Integrated Sustainable Management of the Guarani Aquifer System" (GAS). The GAS is being executed by the Governments of Argentina, Brazil, Paraguay and Uruguay, with GS/OAS acting as regional executing agency and the International Bank for Reconstruction and Development (the Bank) as implementing Agency. Funds for the GAS are being provided by the Global Environment Facility (GEF). The terms of reference (TOR) and the actual schedule of activity for the Mission are enclosed in Attachment 1.

2. In connection with the Mission Consultant met with representatives of the governments and relevant local authorities of the countries visited as well as representatives of the GS/OAS, Consultant wishes to express its appreciation for the cooperation, hospitality and courtesy extended to Consultant during the Mission. A list of participants that attended the various discussions and meetings held during the Mission is enclosed in Attachment 2.

3. The primary objective of the Mission is to highlight and promote the utilisation of geothermal generated heat as an indigenous, environmentally sound and cost effective source of energy with particular emphasis on the technical/economical and financial/institutional aspects attributed to geothermal development under recognised legal/regulatory framework(s).

4. A further objective comprised the establishment of a geothermal task force and agreed upon TOR with a view to the preparation and presentation of a concept document upon which an investment operation could be launched for the implementation of a geothermal demonstration operation, comprising relevant geothermal pilot project(s).

5. The contents of this Aide Memoire was discussed and agreed upon in principle in connection with wrap-up meetings held in Montevideo, Uruguay and Brasilia, Brazil on the 9th and 11th May, respectively between Consultant and representatives of the GS/OAS and the Governments of Uruguay and Brazil.

6. This Aide Memoire is subject to final confirmation by the GS/OAS and the Bank in Washington, D.C. upon Consultants return to Copenhagen.

PROJECT COMPONENTS AND DESCRIPTION

7. Main topics for discussion focused on:

a). alternative scenarios for utilisation of the geothermal heat reserves, currently assessed at 2,100 Exajoules (50 billion tons oil equivalent).

b). the establishment of a Geothermal Task Force (the Task Force) for the continued preparation of the Geothermal Project Component, hereunder the performance and completion of the Geothermal Guarani Project Assessment (Geo-GUAPA), including staffing requirements and arrangements for office facilities and support etc., required for an orderly and time effective completion of the Geo-GUAPA.

c). The presentation of TOR for the Task Force together with proposed scope of work and schedule of activity, as applicable.

8. The potential opportunities for utilisation of geothermal energy within the region as based on currently available documentation and state of the art were highlighted. The characteristics of the geothermal aquifer water reveal temperatures ranging between 20°-70°C, hence excluding high enthalpy application, e.g. geothermal power generation. Consultant mentioned however ongoing research with a view to boosting the temperature of the produced geothermal water at surface prior to heat retrieval through utilisation of solar energy, an application requiring further investigation and evaluation.

9. Currently considered application for utilisation of geothermal heat is limited to the agricultural sector (irrigation, drainage of various crops, soya and mushroom production etc.,), food manufacture and processing (chicken and pig farming, beer and beverage production), the tourist sector (spas and recreation activities) and the health sector (balneotherapy).

10. Other applications include the provision of residential hot tap water, substituting currently power generated residential hot water supply and improving comfort for potentially large groups of population, the pre-heating of make-up water used for the supply of industrial heat (steam) hence substituting part of the currently used fossil fuels (oil, gas) for steam generation. Pending the boosting of the geothermal aquifer water temperature at ground surface through utilisation of solar energy carries the opportunity for provision of air conditioning and cool storage.

11. All parties engaged in the discussions acknowledged the importance attributed to a balanced development of the geothermal heat resource. In this context experimental geothermal activities planned pursuant to GAS at existing artesian occurrences (e.g. Salto, Uruguay) shall be carefully monitored and considered for application in a continued geothermal development.

12. A total of 15 million population is confined within the area occupied by the Guarani aquifer system. Assuming that five million people could benefit from the advantage of the aquifer heat at a rate of heat demand at say 200 Gigajoules *per capita per annum* would suggest the requirement for a geothermal heat supply to the tune of one Exajoule *per annum*, i.e. corresponding to less than one *per mille* of the currently assessed geothermal heat reserves. One Exajoule of energy corresponds to the energy generated from the incineration of 25 million tons fuel oil. The economical significance of the Guarani geothermal heat resource becomes apparent.

13. The launching of the Task Force Project has been suggested by Consultant and was furthermore endorsed by both the Bank and the GA/OAS. The project is expected to take 10

months to complete and shall be performed by a coordinator and one member each from the countries under GAS. The works shall comprise although not necessarily be limited to the compilation, evaluation and assessment of relevant surface and aquifer information as well as the identification of areas of interest for geothermal development and recommendations for geothermal pilot project(s) implementation.

14. Constraints and perspectives related to the Task Force were discussed with representatives of the governments and relevant *ad hoc* organisations in the four countries visited during the Mission. All four countries expressed their interest in principal to establish and proceed with the Task Force as presented by Consultant and as briefly described in the above.

15. In connection with the Mission Consultant met with representatives of Petrobras in its head offices located in Rio de Janeiro, Brazil. The opportunity of locating the Task Force at the Petrobras premises in Rio de Janeiro would carry considerable benefits to the geothermal project component in view of Petrobras's internationally recognised skills with regard to underground development as well as the benefit of access to Petrobras's in-house expertise required for a credible assessment of the Guarani aquifer (system). An agreement by Petrobras to participate in the Task Force is pending an official request by the Brazilian Minister for Mines and Energy and the subsequent approval by Petrobras' Board of Directors.

16. It is envisaged that all four countries participating in the GAS shall commit to compliance with the recommendations by the Task Force, such commitments to be submitted in writing in due time prior to the initiation of the project.

17. Uruguay expressed concern with regard to Petrobras potentially significant involvement in the Task Force and emphasised the importance for a balanced approach, i.e. reflecting the circumstance that a mere five per cent of the aquifer occupies nearly 50% of Uruguay whereas 70% of the aquifer confined within Brazil only occupies ten per cent of its total territory.

18. It was unanimously agreed that the Task Force shall constitute a dedicated technical project to be performed and completed without bias or disturbance of institutional or political character.

ESTIMATED PROJECT COST

19. At this preliminary stage the total outlay for the performance of the Task Force is estimated at USD 500,000.00, i.e. including salaries, office facilities and expenses for the Task Force Coordinator and Members as well as costs related to the reprocessing of geo and petrophysical data in connection with the Task Force and the preparation and submittal of the final concept document presenting the Task Force findings and recommendations for geothermal pilot project implementation.

FINANCING

20. The financing of the Geothermal Project Component (including the Task Force) is expected to be provided by the GEF.

INSTITUTIONAL AND POLICY ISSUES

21. It was agreed between the four countries under GAS and the Mission that appropriate institutional and policy arrangements need to be considered with a view to support and sustain the long term objectives of the Geothermal Project Component, *i.a.* comprising the cost effective development of the indigenous geothermal energy resources and the reduction of the emission of greenhouse gasses through the substitution of fossil fuels with geothermal energy. All parties also recognise that comprehensive and meaningful arrangements would have to be defined based on acquired experience from the geothermal demonstration operation (the pilot projects).

22. Arrangements to be considered in the short term (in parallel with the Task Force) should comprise the declaration by the four countries concerned with regard to the development of the indigenous geothermal resource as a Priority under the National Energy Strategies.

23. Given the national importance of the Geothermal Project Component an action plan is required that establishes the institutional and policy arrangements addressing the allocation of responsibility for:

a). the time and cost effective implementation of the geothermal demonstration operation.

b). the future promotion of the new technology and its benefits.

c). mechanisms which would secure the financial strength of the implementing entity(s) and its commercial success as based on appropriate and recognised pricing policies.

ENVIRONMENTAL AND LEGISLATIVE ISSUES

24. The implementing entity(s) shall be prepared to submit licence application(s) for geothermal development to relevant National Authorities (Ministry of Environment, Ministry of Energy) in order to acquire environmental clearance and permission for geothermal heat production and utilisation. The application(s) should comprise the principal project design concept, specification of project site(s) and a description regarding the removal of environmental problems as applicable.

25. Clarification is required with regard to the exemption of taxes (state tax, VAT etc.,) and customs fees related to the implementation of geothermal pilot projects financed through the GEF or The World Bank.

Environmental Protection and Integrated Sustainable Management of the Guarani Aquifer System - GAS

Guarani Geothermal Task Force
Terms of Reference

I. BACKGROUND

1. Pursuant to Contract No. R-20226 executed on the 24th April, 2001 between the General Secretariat of the Organisation of American States (GS/OAS), Washington D.C., USA and Lars Tallbacka (Consultant), Copenhagen, Denmark. Consultant visited São Paulo, Rio de Janeiro, Buenos Aires, Asunción, Montevideo and Brasilia between the 2nd-12th May, 2001 (the Mission) with the objective to investigate the opportunities to launch a geothermal component under the major project entitled "Environmental Protection and Integrated sustainable Management of the Guarani Aquifer System" (GAS). The GAS is being executed by the Governments of Argentina, Brazil, Paraguay and Uruguay, with GS/OAS acting as regional executing agency and the International Bank for Reconstruction and Development (the Bank) as implementing Agency. Funds for the GAS are being provided by the Global Environment Facility (GEF).

2. A draft Aide Memoire with regard to the Mission was issued by Consultant on the 16th May, 2001 and forwarded to all parties met in connection with the Mission as well as to GS/OAS and the Bank, Washington D.C.

3. An important issue for discussion during the Mission comprised the proposal for the establishment of the Guarani Geothermal Task Force (the Task Force) for the performance of the Geothermal Guarani Aquifer Assessment (GUAPA).

4. Agreement in principle was reached between Consultant and the Governments of Argentina, Brazil, Paraguay and Uruguay to establish the Task Force consisting of one Coordinator and four Members (one Member for each country participating in GAS).

5. It has furthermore been unanimously agreed that GUAPA shall constitute a dedicated technical project to be performed and completed without bias, interference or other disturbance of institutional or political character.

6. It is envisaged that all four countries participating in GAS shall commit to compliance with the recommendations by the Task Force.

7. The Task Force Coordinator and Members should be selected with a view to represent recognised professional skill and integrity of their respective countries.

8. The Task Force shall be supported without limitation by the governments participating in GAS and their relevant *ad hoc* organisations, local authorities and consultants as well as by international consultants within the field of geothermal development and energy supply.

9. It is envisaged that the Task Force shall result in the establishment of local corps of expertise required for the future, continued economic development of the geothermal energy resource stored in the Guarani Aquifer System.

10. The opportunity of locating the Task Force at the premises of Petróleo Brasileiro S.A. (Petrobras) in Rio de Janeiro, Brazil would carry considerable benefits to the project in view of Petrobras's internationally recognised professional skills with regard to underground development as well as the benefit of access to Petrobras's in-house expertise in the fields of geoscientific evaluation and assessment.

II OBJECTIVES

11. The primary objective of the Task Force is to prepare and present a concept document upon which an investment operation could be launched for the implementation of a geothermal energy demonstration programme, comprising relevant geothermal pilot project(s).

12. A second although equally important objective comprises the establishment of effective routes of liaison and communication between the Task Force and relevant government and local authorities, consultants etc., required for the time and cost effective performance and completion of GUAPA.

13. Institutional and national policy issues for an effective implementation of the geothermal demonstration programme should be addressed in parallel with the Task Force by relevant national authorities assisted by international consultant(s) with previous experience of such activity.

III SCOPE OF WORK

14. The performance of GUAPA by the Task Force is expected to take ten months to complete with a planned date of issue for the final report (the concept document) two months later. Assuming a Start Date on the 2nd October, 2001 would hence indicate a Completion Date around the 2nd October, 2002.

15. GUAPA can be subdivided into five basic components, i.e. comprising a) the predominantly geo-scientific evaluation and assessment of geothermal heat-in-place and reserves for selected areas of tentatively considered geothermal development, b) the predominantly technical evaluation and assessment of potential possibilities for utilisation of geothermal heat and related technological solutions including the presentation of the basic design and heat production forecasts for such solutions, c) the performance of financial and economical analyses based on assessments of environmental and socio-economic benefits and capital expenses and operating costs for tentatively considered geothermal development (pilot projects), d) the rating and ranking of identified areas for tentatively considered geothermal development and recommendations for further work and e) the preparation and issuing of required project reports.

15.1. Underground assessment

Major work tasks comprise:

i. Geological (stratigraphic and lithologic) compilations and descriptions of the aquifer formation(s).

ii. Petrophysical compilations and descriptions, based on wireline log, core analyses, temperature and test data from previously drilled wells in the region.

iii. Hydrochemical and physical compilations and descriptions of aquifer water composition and physical properties.

iv. The preparation of relevant location maps in the scale 1:500,000 highlighting a) the position, areal extent and population of urban areas, industrial complexes and agricultural areas for potential geothermal development and b) the position of previously drilled wells that penetrated the aquifer indicating well designation, year drilled, total depth below ground level (GL) and top and bottom of the aquifer in metres (GL) together with the location of available seismic data within the region.

v. The preparation of detailed structure maps at top aquifer level in the scale 1:500,000 for areas of tentatively considered geothermal development, depth contours in meters (GL).

vi. The preparation of aquifer zone isopach maps in the scale 1:500,000 for areas of tentatively considered geothermal development, recommended contour interval is 10 metres.

vii. The preparation of isothermal maps in the scale 1:500,000 at the top and bottom aquifer levels for areas of tentatively considered geothermal development, contour interval in °C to be decided.

viii. The preparation of relevant geothermal cross sections, preferably extending along structural dip through areas of tentatively considered geothermal development, clearly revealing depths (GL) and temperatures at top and bottom of aquifer.

ix. The preparation of anticipated sections for the construction of geothermal wells (producers and injectors) for areas of tentatively considered geothermal development, clearly indicating stratigraphic succession and lithostratigraphic subdivision, main lithologic composition, suggested casing programme, proposed wireline logging programme and short descriptions of testing and completion procedures.

x. The description of conceptual pilot project development and the preparation of composite project panels for areas of tentatively considered geothermal development.

15.2 Surface development

Major work tasks comprise:

i. Description of past and current utilisation of geothermal heat and/or aquifer water within the region.

ii. Description of current state of the art with regard to the development of low enthalpy geothermal energy resources and proposed scenarios for surface heat retrieval and utilisation scenarios for areas of tentatively considered geothermal development.

iii. Assessment of current and forecasted heat demand for areas of tentatively considered geothermal development, based on information provided by the UNPP's pursuant to questionnaires issued by the Task Force.

iv. Description of unique and novel applications for utilisation of geothermal energy, hereunder a) the heating of excrements from major areas of pig and chicken farming for the purpose of recycling methane gas and subsequent power generation and b) the boosting of the produced geothermal water temperature at surface through the utilisation of solar energy for the purpose of driving absorption heat pumps and generation of air condition (and cool storage facilities) and possible steam generation and subsequent power production.

15.3 Financial and economical evaluation

Major work tasks comprise:

i. Compilation of current heat and power production costs as well as heat and power tariffs for residential and industrial utilisation, based on information provided by the UNPP's pursuant to questionnaires issued by the Task Force.

ii. Assessment of environmental and social economic benefits related to the reduced emissions of CO_2, SO_2, and NO_x due to substitution of fossil fuels (oil, gas, coal) by geothermal energy, monetary values for gas emissions to be provided by GEF or the Bank.

iii. Assessment of capital expenditures and operating costs related to areas and design for tentatively considered geothermal development.

iv. The performance of financial and economic analyses based on points "i"-"iii" above and the calculation of the financial and economic rates of return (FRR and ERR) for areas of tentatively considered geothermal development.

15.4 Rating, ranking and recommendations

The major work task comprises the assessment by the Task Force of procedures for rating and ranking of identified areas for tentatively considered geothermal development that can be unanimously agreed upon by the four countries participating in GAS.

Pending the availability of unanimously agreed upon procedures for rating and ranking the Task Force shall provide a set of conclusive recommendations leading to an investment operation for the implementation of a geothermal demonstration programme within the region of the Guarani aquifer system.

15.5 Reporting

Reporting activities shall comprise the preparation and issuing of four bimonthly progress reports (items “i”-“iv”), a draft final report (item “v”) and the issuing of the final report (item “vi”) around the 2nd October, 2002.

IV. SCHEDULE OF ACTIVITY

16. It is somewhat premature to present the detailed timing and phasing for the activities to be undertaken by the Task Force. However, based on an assumed Start Date on the 2nd October, 2001 a preliminary Schedule of Activity for the major work pursuant to Section 15 in the above is shown below.

ITEM	ACTIVITY	COMPLETION DATE
15.1	**Underground assessment**	**02/07/2002**
15.1.i	Geological compilations	15/11/2001
15.1.ii	Petrophysical	15/12/2001
15.1.iii	Hydrochemical and physical	15/12/2001
15.1.iv	Location maps	15/12/2001
15.1.v	Structure maps	02/04/2002
15.1.vi	Isopach maps	02/04/2002
15.1.vii	Isothermal maps	02/04/2002
15.1.viii	Cross sections	02/05/2002
15.1.ix	Anticipated well sections	02-05/2002
15.1.x	Concepts presentation	02/07/2002
15.2	**Surface assessment**	**15/06/2002**
15.2.i	Description	15/11/2002
15.2.ii	Utilisation	15/04/2002
15.2.iii	Assessment heat demand	02/05/2002
15.2.iv	Novel applications	15/06/2002
15.3	**Financial/economical**	**02/08/2002**
15.3.i	Costs and tariffs	02/07/2002
15.3.ii	Environmental/social benefits	02/07/2002
15.3.iii	Capex and opcost	02/07/2002
15.3.iv	Financial/economical analyses	15/07/2002
15.4	**Rating/ranking and recommendations**	**02/08/2002**
15.5	**Reporting**	**02/10/2002**
15.5.i	Progress report 1	02/12/2001
15.5.ii	Progress report 2	02/02/2002
15.5.iii	Progress report 3	02/04/2002
15.5.iv	Progress report 4	02/06/2002
15.5.v	Draft final report	02/08/2002
15.5.vi	Final report	02/10/2002

17. The diversity of the various project items of the Schedule of Activity carries an inherent circulation of Task Force Members during the performance of the project. In this context the Task Force shall never exceed four members. The balanced national composition of the Task Force shall remain unchanged for the entire duration of the project.

V. COST

18. A total budget for the performance of the Task Force is currently estimated at USD 517,000.00 allocated as follows:

SALARIES	**US dollars**
One Coordinator and four Members, ten months	250,000.00
EXPENSES	
Travel, accommodation	60,000.00
Reprocessing, seismic and petrophysical	35,000.00
Core and water analyses	15,000.00
Local consultants	25,000.00
Translation services	10,000.00
Extramural computer services	10,000.00
Drafting services and reproduction	35,000.00
Transportation and communications	20,000.00
Miscellaneous	10,000.00
Sub total	**470,000.00**
Contingency (10%)	47,000.00
Grand total, Task Force	**517,000.00**

19. The contingency budget is primarily to cover the extra costs attributed to circulation of Task Force Members during the project.

PARTIES AND PEOPLE MET

1. ARGENTINA ,BUENOS AIRES

NAME	ORGANISATION	POSITION
Maria J. Fioriti	MoECO	Executive Secretary
Victor Pochat	MoECO	Head of Department
Jorge N. Santa Cruz	INAA	Coordinator
Ignacio Mendez	SdEN	Coordinator
Abel H. Pesce	SGMA	Head of Department
José A. Repar	ENARGAS	Vice President

MoECO : Ministry of Economy, Subsecretaria de Recursos Hidricos
INAA : Instituto Nacional del Agua y del Ambiente
SdEN : Secretaria de Energia
SGMA : Servicio Geologico Minero Argentino
ENARGAS : Ente Nacional Regulador del Gas

2. BRAZIL

2.1. SÃO PAULO

NAME	ORGANISATION	POSITION
Nelson da Franca Ribeiro dos Anjos	OAS	Coordinator
Claudio Vidal	CPRM	Associate
José C. Ferreira	CPRM	Superintendent
Armando T. Takahashi	CPRM	Manager
Omar Y. Bitar	IPT	Director
José L.A. Filho	IPT	Geologist
Renato L. Prado	IPT	Geophysicist
José D.F. Gallas	IPT	Geophysicist
Aldo da Gunha Rebouças	-	Consultant

2.2. Rio de Janeiro

NAME	ORGANISATION	POSITION
Edison J. Milani	PBR	Manager
Laury M. Araújo	PBR	Geoscientist
Nelson da Franca Ribeiro dos Anjos	OAS	Coordinator
Claudio Vidal	CPRM	Associate

2.3. BRASILIA

NAME	ORGANISATION	POSITION
Julio T.S. Kettelhut	MoENV	Director
Luiz Amore	MoENV	Coordinator
Ivaldo Frota	MoENE	Assessor
Emanuel T. de Lueirox	MoENE	Coordinator
Luis A.S. Villalba	MoPCC	Deputy Minister
João Salles	CPRM	Director
Nelson da Franca Ribeiro dos Anjos	OAS	Coordinator

MoENV : Ministry of Environment
MoENE : Ministry of Energy
MoPCC : Ministry of Public Construction and Communications
PBR : Petróleo Brasileiros S.A. (Petrobras)
CPRM : Companhia de Pesquisa de Recursos Minerais (Geological Survey)
IPT : Institutos de Pesquisas Tecnológicas, São Paulo
OAS : Organisation of American States

3. PARAGUAY, ASUNCIÓN

NAME	ORGANISATION	POSITION
Fabio Lucantonio	MoENE	Head of Department
Pablo Flugfelder	MoPCC	Director
Rafael Franco	MoPCC	Geologist
Daniel H. Garcia Segredo	-	Consultant
Wilson Rojas	-	Interpreter

MoENE : Ministry of Energy
MoPCC : Ministry of Public Construction and Communications

4. URUGUAY, MONTEVIDEO

NAME	ORGANISATION	POSITION
Luis E. Loureiro	MoTPC	Director
Carlos A. Arcelus	MoTPC	Director
Enrique M. Segui	UGS	Agroengineer
Luis Silveira	UOR	Professor, Agriculture
Pablo Decoud	AOSE	Director
Lourdes Rocha	-	Consultant
Jorge M. Xavier	-	Consultant
Roberto E. Kirchheim	OAS	Consultant

MoTPC : Ministry of Transportation and Public Construction
UGS : Uruguayan Geological Survey
UOR : University of the Republic
AOSE : Administratión de las Obras Sanitarias, Montevideo
OAS : Organisation of American States