Presented at Short Course IV on Exploration for Geothermal Resources,
organized by UNU-GTP, KenGen and GDC, at Lake Naivasha, Kenya, November 1-22, 2009.

KenGen
Kenya Electricity Generating Co., Ltd.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

Geothermal Development Company

STATUS OF GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA

Solomon Kebede
Geological Survey of Ethiopia
Addis Ababa
ETHIOPIA
Solo450354@yahoo.com

ABSTRACT

Ethiopia is located in the Horn of Africa between 3.5° and 14°N and 33° and 48°E. Energy consumption in Ethiopia is still (a) low in per capita terms, and (b) underdeveloped by structure. The energy consumption comprises: (i) less than 1% from electricity, (ii) about 5.4% from hydrocarbon fuels, and (iii) the balance from traditional biomass fuels. Most of the hydrocarbon fuels are consumed in the transport sector. Household energy comprises primarily traditional biomass fuels. Specifically, about (a) 40 million tons of fuel wood, and (b) 8 million tons of agri-residue is consumed annually. In addition, an important source of rural fuel supply is animal droppings.

Records of the recent history of electric demand in Ethiopia show a dramatic rise because of rapid new investment growth in all spheres of the economy. To fill power gaps, the country has embarked on an aggressive program of hydropower development, although there inevitably remain concerns over the vulnerability of the system to long term hydrological conditions. Approximately 3GW of hydro capacity (5 projects) are in various stages of development. Geothermal and wind are the other sources of energy being considered for development to supplement hydro.

The sector policy and regulatory framework supports IPP development. Subsequent to the National Economic Policy (NEP) of 1991 that encouraged private sector participation in the economic development of the country, a number of Proclamations and reforms have been made, aimed at enabling private participation within the electricity sector. Development of renewable energy resources for power generation is now being encouraged through the establishment of feed-in-tariffs (FIT) for such sources. A draft law and regulations supporting FIT is soon to be passed into law.

Ethiopia started long-term geothermal exploration in 1969. About 120 localities within the rift system are believed to have independent heating and circulation systems. From these localities about two dozen are judged to have potential for high enthalpy resource development, including for electricity generation. Only two prospect areas have been subjected to exploration drilling to date. Currently geothermal exploration and resource assessment is being carried out in strategically selected prospect areas in the Ethiopian Rift Valley.

The strategic plan for future exploration and development of geothermal resources considers the development of the most explored geothermal localities (Aluto Langano and Tendaho) to be followed by other geothermal prospect areas (such as Corbetti and Abaya) that are only at the level of detailed surface investigations. The financial scheme for the development of geothermal resources considers: (i) the participation of independent power producers, (ii) Public private partnerships, (iii) Participation of international financial institutions, bilateral donors and development agencies and (iv) establishment of revolve funds. The completion of the works proposed in the strategic plan is expected to have significant impact on energy supply including improvement of the generation mix and thus diversification away from over-reliance on hydropower.

1. BACKGROUND INFORMATION

1.1 Physiography and climate

Ethiopia is located in the Horn of Africa between 3.5° and 14°N and 33° and 48°E. The country has an area of 1.14million km^2 made up of a broad plateau and low lands along its periphery. The highlands rise up to 4600m altitude while the most depressed lowlands reach 120m below sea level. The Ethiopian sector of the Great East African Rift bisects the plateau from the northeast to the southwest of the country. The rift in Ethiopia has created a conducive environment for the existence of geothermal resources and covers an area of about 150,000 km^2 that is close to 12% of the total land area.

Several rivers drain the plateau flowing, radially outwards, into the peripheral lowlands and onwards into the neighbouring countries. The average annual rainfall in the highlands is 1200mm in the northern half of the country and 1800mm in the southwest. The lowlands annually receive below 600mm of rainfall. About 70-80% of the rain falls during mid-June to mid-September. In the highlands, the maximum monthly average temperature ranges between 23 and 27°C and the minimum between 10 and 13°C. In the lowlands, these temperatures range much higher.

1.2 Energy situation

Energy consumption in Ethiopia is still (a) low in per capita terms, and (b) underdeveloped by structure. The energy consumption comprises: (i) less than 1% from electricity, (ii) about 5.4% from hydrocarbon fuels, and (iii) the balance from traditional biomass fuels. Most of the hydrocarbon fuels are consumed in the transport sector. Household energy comprises primarily traditional biomass fuels. Specifically, about (a) 40 million tons of fuel wood, and (b) 8 million tons of agri-residue is consumed annually. In addition, an important source of rural fuel supply is animal droppings.

The Ethiopian electric supply system comprises the Inter-Connected System (ICS) which represents about 98% of the energy sold, and the Self-Contained System (SCS) which accounts for the rest.

The SCS serves isolated load centres and comprises two small hydro schemes with an aggregate installed capacity of 5 MW and some 40 MW of diesel units running on imported fuel.

The ICS is currently supplied by 860MW of installed capacity (mainly hydro based) although only 250-300 MW of firm generation is available. The ICS is therefore currently suffering severe electricity shortages, to the extent that load shedding in the country for several months has been on an alternate-day basis. Currently this situation has improved due to change of the hydrological conditions in the rainy season.

Ethiopia has embarked on an aggressive program of hydropower development, although there inevitably remain concerns over the vulnerability of the system to long term hydrological conditions. Approximately 3GW of hydro capacity (5 projects) are in various stages of development.

Geothermal and wind are the other sources of energy being considered for development to supplement hydro. About 3 MW of geothermal is currently being generated in Aluto. No wind generation plants are currently operating. A 120 MW wind farm is being developed in Ashegoda in northern Ethiopia.

Records of the recent history of electric demand in the Ethiopian Interconnected System (ICS) show a dramatic rise because of rapid new investment growth in all spheres of the economy, industrial, commercial, agricultural, domestic and rural besides the internal growth within these spheres. An annual load growth of approximately 25% has been reported.

Besides, rural electrification forecasts are treated separately based on the government electrification target of increasing the existing low rate of electrification in line with the Universal Electricity Access Program. For currently unsupplied centres the high demand is developed from estimates of population, population growth, the level of interconnection and consumption per connection.

1.2.1 Energy policy

The sector policy and regulatory framework supports IPP development. Subsequent to the National Economic Policy (NEP) of 1991 that encouraged private sector participation in the economic development of the country, a number of Proclamations and reforms have been made, aimed at enabling private participation within the electricity sector. Development of renewable energy resources for power generation is now being encouraged through the establishment of feed-in-tariffs (FIT) for such sources. A draft law and regulations supporting FIT is soon to be passed into law.

The rapid increase in demand for energy and through the poverty eradication programme, the government devotes a lot of energy and resources to rural development for the purpose of enabling the large rural population to emerge out of subsistence production and become integrated within the national economy as surplus producers for trade and as a market for goods and services. The emphasis on agriculture aims at achieving food security, increased rural income, surplus generation and production for the agro-industry for export.

The government's Energy Policy is an integral part of its overall development policy. It aims to facilitate the development of energy resources for economical supply to consumers. It seeks to achieve the accelerated development of indigenous energy resources and the promotion of private investment in the production and supply of energy. Electricity supply, as an element of the development infrastructure is being advanced in two fronts: (a) the building up of the grid based supply system to reach all administrative and market towns, and (b) rural electrification based on independent, privately owned supply systems in areas where the grid has not reached.

1.2.2 Future energy plans

Ensuring the integrated development of a country could not be realized without paying sufficient attention to the energy sector. Being the power source of an economy, it provides many benefits by enhancing investment opportunities, expanding employment, supporting the other sectors and in all, reinforcing the economic development of the country. To this end, the strategic development plan of Ethiopia has accorded due attention to the energy sector. This plan recognizes not only the essentiality of energy as an input for growth of the modern sector but also its important role in rural transformation through underpinning the expansion of agricultural production, irrigation, education and health sectors. It is relevant to note that to break the "vicious energy poverty circle"; a Universal Electricity Access Programme (UEAP) is being implemented in the PRSP (Poverty Reduction Strategy

Programme) of Ethiopia. It targets the electrification of around 6,000 rural towns and villages, making energy available to some 24 million people, while increasing the electricity penetration to 50 % by the year 2015.

Aside from the expansion of new small and larger hydropower projects, other generation technology alternatives are being looked at so as to enhance the total generation capacity and to widen the energy mix. Geothermal power provides the second indigenous alternative energy resource in the country after hydropower. It is estimated that Ethiopia could generate more than 5,000 MWe from its geothermal energy resources. However, little has been done so far with regards to the development of this resource, since the early 70's where exploration of geothermal resources was initiated in Ethiopia jointly by the United Nations Development Programme and the Ethiopian Government.

This slow progress of Exploration (including deep drilling), and the development of geothermal has been due to two main reasons:

- The great demands of the pressing tasks in socio-economic development in the country impose equally heavy demands for budgetary allocation such that adequate resources could not be allocated to projects of essentially long-term impact, such as in geothermal resource exploration and development. As a result, the limited annual allocations that could be made enable only limited studies, mainly restricted to surface investigations. These are however insufficient to progress even the most attractive prospect areas to the stages where they could be investigated by drilling, and so they remain at levels of knowledge that are far below the threshold levels required to embark on resource development.
- During the past several decades, Ethiopia had faced repeated cases of impending or actual power shortages that could be responded to more expeditiously by resort to hydro-power development based on existing studies and rankings of known hydro-potential sites. On the other hand, no geothermal resource area has been studied to the full extent of its potential to allow consideration as an alternative means of satisfying the short-term power needs. The high cost and risk of drilling, the commonly longish project gestation period, unfamiliarity with the technology involved militate against maintaining required levels of investment over the required extended periods.

Over-reliance on hydro-power is exposing the Ethiopian power sector to the vagaries of periodic drought and the country to environmental concerns. As a result, Ethiopia now plans to (a) diversify power sources, and (b) to improve the power generation mix, and (c) to do so through the utilization of indigenous energy resources that would be economically competitive, reliable and with low environmental impact. According to worldwide experience, geothermal resources meet these criteria. In this context, the strategic development plan reflects the priority of the Ethiopian Government to support and facilitate the geothermal resources development in the Ethiopian Rift.

2. GEOTHERMAL EXPLORATION AND DEVELOPMENT IN ETHIOPIA

Ethiopia started long-term geothermal exploration in 1969. Over the years, an inventory of the possible resource areas within the Ethiopian sector of the East African Rift system, as reflected in surface hydrothermal manifestations has been built up. The inventory work in the highland regions of the country is not complete but the rift system has been well covered. Of the about 120 localities within the rift system that are believed to have independent heating and circulation systems, about two dozen are judged to have potential for high enthalpy resource development, including for electricity generation. A much larger number are capable of being developed for non-electricity generation applications such as in horticulture, animal breeding, aquaculture, agro-industry, health and recreation, mineral water bottling, mineral extraction, space cooling and heating, etc. (UNDP, 1973).

Since the late 1970’s, geoscientific surveys mostly comprising geology, geochemistry, and geophysics, were carried out at, from south to north, the Abaya, Corbetti, Aluto-Langano, Tulu Moye and Tendaho prospects (Teklemariam and Beyene, 2005). In addition, a reconnaissance survey of ten sites in the Central and southern Afar has been carried out, some of these being followed up by more detailed surface investigation. The prospects and fields discussed here are shown in Figure 1.

Due to various factors that determined where the first geothermal power plant would best be located, detailed exploration work was decided to commence in the Lakes area of the rift system during the 1970’s. The ICS was already being extended into this region of load growth. The best prospect areas from the technical point of view were located in the Afar which had then been poorly endowed with essential infrastructure and local load demand to support power development. The present circumstances however favor resource development also in the Afar region.

Exploration work peaked during the early to mid 1980’s when exploration drilling was carried out at Alutu. Eight exploratory wells were drilled with five of these proving productive. During 1993-98, exploration drilling was also carried out at Tendaho. Three deep and three shallow wells were drilled and geothermal fluids were encountered in the 200-600m-depth range.

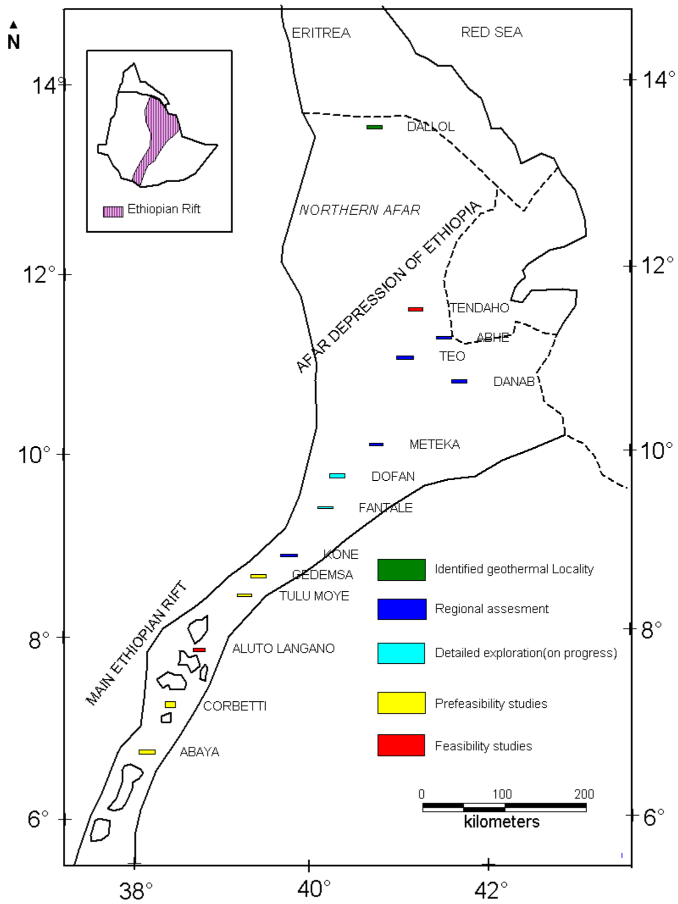

FIGURE 1: Location Map of the Ethiopian Rift and Geothermal Prospect Areas

Resource utilization was delayed until 1999. The 7.3 MWe net capacity pilot plant installed at Aluto has faced operational difficulties that are essentially due to the lack of the appropriate field and plant management and operation skills. At present, activities related to problem identification and putting the plant back into operation is being carried out at the Aluto-Langano geothermal field. The plant is partially rehabilitated and been put back into an operation of about 3 MWe.

During the three decades that geothermal resource exploration work was carried out in Ethiopia, a good information base and a good degree of exploration capacity, in human, institutional and infrastructure terms, has accumulated, ensuring that selected prospects can be advanced to the resource development phase much more rapidly than before.

The exploration work to date has been carried out by the Geological Survey of Ethiopia (GSE) but has benefited from a number of technical cooperation programs. The most consistent over the long term had been support by UNDP, which also helped in creating other technical capacities of the GSE. The European Development Fund financed the overseas cost of the exploration-drilling project that resulted in the discovery of the Alutu resource. The development cooperation program of the Italian Ministry of Foreign Affairs provided the funding for the offshore costs of the surface and drilling exploration of the Tendaho prospect. The reconnaissance survey of the Afar was spawned by the Petroleum Exploration Promotion project financed by IDA during the 1980’s. The IAEA is assisting the GSE in the isotope geochemical study of hydrothermal fluids and in the process is providing training and experience in the application of the technique in geothermal investigations. IAEA also provided technical advice and equipment. The German Geological Survey (BGR) assisted in Geophysical investigations (MT) of the Tendaho deep geothermal Reservoir during 2006-07. The specialized geothermal science and technology training programs in Japan, Italy, New Zealand, Iceland and Kenya (in cooperation with United Nations University- Geothermal Training Programme of Iceland and Kenyan Generating Power Company) contributed in human resource training and development.

2.1 Exploration drilling

Only two prospect areas have been subjected to exploration drilling to date.

2.1.1 The Aluto-Langano geothermal field

Detailed geological, geochemical and geophysical surveys were carried out in the Langano area during the late 1970's and early 1980's. Results showed the existence of an underground fluid at high temperature with evidence of long time residence in zones occupied by high temperature rocks (ELC, 1986). The objective then was to locate an economically exploitable geothermal reservoir.

Two wells (LA3 and LA6) drilled on the Aluto volcano produced 36 and 45 t.p.h. geothermal fluid at greater than 300^{O}C along a fault zone oriented in the NNE-SSW direction. Two wells drilled as offsets to the west (LA4) and east (LA8) of this zone respectively produced 100 and 50 t.p.h. fluid with a lower temperature. LA5, drilled in the far SE of the earlier two wells was abandoned at 1,867m depth due to a fishing problem but however later showed a rise in temperature over an extended period of time. LA7 was drilled in the SW but could discharge only under stimulation, being subject to cold-water inflow at shallow depth. The earliest wells drilled in the prospect were drilled outside the present limits of the reservoir area, to the south (LA1) and west (LA2) of the area drilled later.

A 7.3 MWe pilot geothermal plant was installed in 1999 utilizing the production from the above exploration wells. The plant has not been fully operational due to reasons that have to do with the lack of operational experience. But now the plant is partially rehabilitated and put back into an operation of about 3 MWe.

2.1.2 The Tendaho geothermal field

Geothermal exploration was carried out in the Tendaho area with economic and technical support from Italy between 1979 and 1980. Between 1993 and 1998, three deep (about 2,100m) and three shallow exploratory wells (about 500m) were drilled and yielded a temperature of over 250ºC. The Italian and Ethiopian governments jointly financed the drilling operation in the geothermal field. A preliminary production test and techno-economic study indicated that the shallow productive wells could supply enough steam to operate a pilot power plant of about 5 MWe, and the potential of the deep reservoir is estimated about 20 MWe.

Based on this and further studies, the Ministry of Mines and Energy is currently working on Tendaho for progressing it towards development. The recent upgrade of a trunk highway through the Tendaho area will help facilitate such exploration and development. In addition, the Ethiopian government plans to extend the country's main 230KV transmission line to Semera, which is within ten km of the drilled wells at Dubti.

2.2 Surface exploration

Over the years, a number of prospects have been subjected to surface investigation: geology, geochemistry and geophysics and the shallow subsurface has been investigated by drilling at a few of the prospects. They are mostly located in the MER, especially in its most recent zones of tectonic and magmatic activity, the different sectors of the discontinuous WFB. These prospects are enumerated below, from south to north. The more important areas are Abaya, Corbetti, Tulu Moye, Dofan and Fantale.

2.2.1 The Abaya geothermal prospect area

Abaya is located on the northwest shore of Lake Abaya, about 400 km south by road from Addis Ababa. The Abaya prospect exhibits a widespread thermal activity mainly characterized by hot springs, fumaroles and altered ground. Spring temperatures are as high as 96 °C with a high flow rate. Integrated geoscientific studies (geology, geochemistry, and geophysics) have identified the existence of a potential geothermal reservoir with temperature in excess of 260°C (Ayele et al., 2002). Further geophysical studies including drilling of shallow temperature gradient wells are recommended here.

The 132 KV transmission line to Arba Minch to the south starts at the Wolayta Soddo substation located about 40 km distance to the NNW of the prospect. This raises the prospect for development of the resource once it is adequately explored, including by drilling.

2.2.2 The Corbetti geothermal prospect area

The Corbetti geothermal prospect area (Figure 1) is located about 250 km south of Addis Ababa. Corbetti is a silicic volcano system within a 12 km wide caldera that contains widespread thermal activity such as fumaroles and steam vents. Detailed geological, geochemical and geophysical investigations conducted in the Corbetti area indicate the presence of potential geothermal reservoirs with temperatures exceeding 250°C. Six temperature gradient wells have been drilled to depths ranging from 93-178m (Kebede, 1986). A maximum temperature of 94°C was recorded. No further work has been carried out since then. The data shows the probable existence of a deep reservoir with temperatures exceeding 250 °C.

A 132 KV power transmission line passes within 15 kms of the prospect and is the main trunk line to Southern Ethiopia, to towns along the two branches of the highway to Kenya.

2.2.3 The Tulu Moye geothermal prospect area

The area is characterized by volcanism dating from Recent (0.8 –0.08 Ma) to historical times. Volcanism involved the extrusion of per alkaline felsic lava associated with young tensional and transverse tectonic features dating from (0.1 –1.2 Ma) with abundant silicic per alkaline volcanic products (Di Paola, 1976) in the Tulu Moye-Gedemsa prospect area (Figure 1). This suggests the existence of a deep seated magma chamber with a long residence time. The area is highly affected by hydrothermal activity with the main hydrothermal manifestation being weak fumaroles, active steaming (60-80°C) and altered ground. The drawback of the hydrothermal manifestations is related to the relatively high altitude of the prospect area and the considerable depth to the ground water table. During 1998-2000, integrated geological, geochemical and geophysical studies including shallow temperature gradient surveys (150-200m) , confirmed the existence of potential geothermal reservoirs with a temperature of about 200°C (Ayele et al., 2002) and delineated target areas for further deep exploration wells.

This prospect area is located close to the koka and Awash II and III hydro-electric power stations, the associated 230 and 132 KV substations and transmission lines.

2.2.4 The Dofan geothermal prospect area

Geological, geochemical, and geophysical investigations in the Dofan geothermal prospect (Figure 1) show that the area is characterized by a complex volcanic edifice that erupted a considerable volume of pantelleritic lava from numerous eruptive centres between 0.5-0.2 Ma (Cherinet and Gebreegziabhier, 1983). The presence of several hydrothermal manifestations (fumaroles and hot springs) within the graben, together with an impervious cap, needs to be regarded with high priority for further detail exploration and development (Teclu, A, 2002/2003).

The area is located about 40 km from the high voltage substation in the Awash town.

2.2.5 The Fantale geothermal prospect area

The Fantale geothermal prospect is characterized by a recent summit caldera collapse, felsic lava extrusions in the caldera floor and widespread fumarolic activity, suggesting thereby the existence of a shallow magma chamber. Active tensional tectonics form fissures up to 2m wide near the volcanic complex. Ground water discharge to the system is assured by the proximity of the area to the western escarpment. The results of an integrated interpretation of previous data suggest that the area is potentially prospective for future detailed geothermal resource investigations. Therefore, due to the presence of an impervious cap rock, the western part of the prospect particularly deserves to be investigated during a more detailed geothermal exploration programme. In this view, the Geological Survey of Ethiopia has carried out detailed geological, geochemical and geophysical investigations in order to delineate and select target areas for deep exploration wells.

2.3 Prospects at reconnaissance stage

The strategic exploration and development plan deals with a total of six geothermal project areas which had been selected on the basis of proximity to areas of economic activity and the national power grid. However, past work has shown that there are several other attractive prospects that are suited for pursuing in the long run.

During the 1980's, reconnaissance geological, geochemical and geophysical investigations have been conducted at Dallol, Kone, Meteka, Teo, Danab and L. Abe areas that are found in a zone extending between the southern and northern Afar geological provinces. Meteka and Teo hold promise for the discovery of economically exploitable geothermal resources at high temperature and warrant detailed surface investigation, followed by exploration drilling. The Lake Abe area warrants further investigation in a wider exploration context that encompasses areas in the eastern part of Tendaho graben and the Lake Abe prospect in Djibouti. These resource areas are not included in this proposal as their large distances from electricity load centres and the national grid accord them lower priority. With advancing economic activity in southern and central Afar as well as in the eastern part of the country, these prospect areas should prove useful for power supply both within the region and to the national grid in the longer-term.

The prospects that have been dealt with under reconnaissance stage are located to the north of 12°N latitude and comprise terrain that is at the most advanced stage of rift evolution in the eastern Africa region and holds a much greater potential for geothermal resources than any other region of equivalent size. This region should be considered as a prime target area for future exploration and development. With the improving availability of the economic development infrastructure in the region, the power-supply system in the load growth areas of northern Ethiopia would benefit from geothermal power generating facilities located in this part of the country.

From these long-term points of view, reconnaissance and preliminary surface evaluation works should commence in the not too distant future in the regions of southern and central Afar, north of 12°N latitude, in order to raise the available level of knowledge regarding the resource areas and to provide the necessary information that is required for long-term planning.

3. CURRENT GEOTHERMAL ACTIVITIES AND FUTURE STRATEGIES

3.1 Current activities

Currently the following geothermal activities are being conducted in Ethiopia:

- A three year project entitled Strategic Geothermal Resource Assessment in the Ethiopian Rift Valley has started in 2009. The target areas of assessment are Tendaho, Aluto Langano, Corbetti and Abaya. Geoscientific studies including: (i) geological, (ii) geochemical, (iii) geophysical (MT, TEM, Gravity and Magnetics) and (iv) Reservoir Engineering studies are being conducted in these areas. The objectives of the project are to locate and identify areas (sites) for deep drilling by acquiring data that can supplement the already available ones, and upgrade and synthesize all existing information in order to establish a geothermal exploration conceptual model for future feasibility studies.

- Ethiopia and Japan signed a memorandum of understanding in June 2009 to generate geoscientific and reservoir engineering data that can be used for expansion and further development of the Aluto Langano geothermal field. Under this framework, the main activities conducted in August 2009 are magnetotelluric (MT) and Audio magneto telluric (AMT) survey on 40 selected stations. During this survey, while experts from Phoenix company of Canada conducted the MT study under contract for West Jec of Japan, Ethiopian geophysicists took part in the field survey with the aim of obtaining hands-on experience in MT data generation and processing.

3.2 Future strategies

During the past several decades, Ethiopia faced repeated cases of impending or actual power shortages. Reliance on hydro-power has exposed the Ethiopian power sector to the vagaries of periodic drought as it limited the power that could be generated. Consequently, it is planned to diversify the power generation mix. Specifically, this will be done through utilizing indigenous energy resources that are economically competitive, reliable and have a low environmental impact. According to worldwide experience, geothermal resources meet these criteria. Indeed, geothermal is known to be a cheaper energy source. Besides, in Ethiopia it is more intensively studied compared to other renewable resources.

Currently, the desire to increase geothermal development and utilisation in Ethiopia is on account of the:

- Critical role of energy in socio-economic development of the country
- Energy demand growth
- Rural Electrification focus
- Increasing world oil price
- Vulnerability to drought of the hydro power (currently, the main energy supply)
- Availability of a Clean Development Mechanism (CDM)
- Opportunity to use Risk Mitigation Fund (RMF) of the World Bank through the ARGeo programme
- Growth of interest of private investors (REI, JAPAN etc)
- Readily available local qualified geoscientists and engineers and equipment (Deep drilling Rigs etc..), for geothermal exploration and development
- Existence of identified potential geothermal prospect areas

The planning aspects of exploration and development of selected geothermal prospects comprises the following elements:

- Review of existing information on a prospect;
- Detailed surface exploration (Geology, Geochemistry, Geophysics (Particularly MT coupled with TEM));
- Exploration drilling (Except for Aluto-Langano) and well testing (a minimum of 3 wells);
- Appraisal drilling (a minimum of 6 wells) and well testing;
- Feasibility studies;
- Production drilling, power plant design, environmental impact assessment and reservoir evaluation;
- Power station construction and commissioning; and
- Reservoir Management and further development.

The possible strategies of each geothermal prospect area are developed in terms of:

- Additional work required to fill the knowledge gap;
- Estimated time to complete the work
- Estimated potential (MWe) of the field; and
- Required input to implement the project (Human resource, Finance, equipment).

3.2.1 Criteria for prioritization of geothermal prospect areas

The main criteria for prioritization of various prospect areas for undertaking further exploration and development are: (i) State of advancement of exploration level (Technical); (ii) The relative strategic location (proximity to the existing National grid as an economical factor), and; (iii) Population density of the areas (GSE and EEPCO, July 2008).

Based on these main criteria, the following geothermal prospect areas have been selected (in order of priority) for further exploration and development:

- Aluto-Langano
- Tendaho
- Corbetti
- Tulumoye-Gedemsa
- Dofan
- Fantale

4. CONSTRAINTS AND OPTIONS

The constraints for development of geothermal resources in Ethiopia were largely related to prioritization, lack of funding and institutional set up (Teklemariam, 2009).

A national energy mix is the solution to the drought prone region of ours. Apart from hydro, geothermal is found to be the most economically feasible renewable resource in Ethiopia. As an indigenous resource, it helps not only to supplement the energy supply but also reduce foreign currency spending on fossil fuels.

In the case of geothermal energy, the return is fast (< 5 years) on account of high availability having a more than 90% load factor. The high load factor of geothermal means its energy supply is twice that of others of similar installed capacity. Considering its greater benefits, it is worthwhile to give sufficient attention to fulfil the suggested enablers.

A summary of constraints and possible remedies (options) for development of geothermal resources in Ethiopia are tabulated below.

TABLE 1: Constraints and Possible remedies

No.	Constraints	Possible remedy (Options)
1.	Geothermal not part of the National Energy Development Plans.	Integrate Geothermal in the National Energy Development Plans.
2.	Large upfront cost of Exploration and Development, likewise other energy resources.	Promote PPP, IPP, etc. • Participation of Financial institutions, bilateral donors and development agencies (e.g. UNDP, WB). Use the Opportunity of RMF/TAF (ARGeo). • Revolve revenues after initial developments.
3.	Limited budget for full fledged exploration.	Establish a mechanism to provide enough budgets.
4.	Lack of continuous and integrated work in exploration and development of the resource.	Establish a process/system for un-interrupted geothermal exploration and development activities.

PPP= Public Private Partnership; IPP= Independent Power Producer;
UNDP – United Nations Development Programme; WB – World Bank, RMF – Risk Mitigation Fund;
TAF- Transaction Advice Fund; ARGeo – African Rift Geothermal Development Facility

Currently, most of the suggested remedies are being implemented by the government of Ethiopia. The government is convinced that irrespective of future hydro developments, geothermal's contribution to energy security at times of drought could be critical if sufficient geothermal capacity can be brought on line

5. EXPECTED OUTCOME

The completion of the works proposed in the strategic plan is expected to have the following outcome and impact:

- The greater availability of reliable information on the geothermal resources of the country during the earlier stages of the projects would encourage power developers, public and/or private, to invest in the key industry of electricity generation and supply to a rapidly geographically expanding and growing market. From such investment would follow the following:
- Augmentation of power supply from hydropower plants, and improvement of the generation mix, for greater reliability of electricity supply.
- Diversification away from over-reliance on hydropower, to make more reliable and adequate electricity available to both urban and rural areas.
- Contributing to the replacement of diesel generating plants both within the national grid and outside it, as well as reducing the necessity for installing additional ones, and thus contributing to the reduction of green house gas emission and import dependence for fossil fuels.
- Contributing to the greater availability of electricity as an affordable, reliable and clean energy form to urban and rural households and reduction of environmental degradation, indoor pollution and loss of soil fertility arising from the high level of biomass fuel use.
- Supporting the improvement of access by the population to essential social services (health, education, clean water supply, information) for a betterment of the quality through more widespread supply of electricity to the facilities.
- Contributing to the more widespread use of electricity in productive economic activities, including in rural commerce and industry, thus supporting the increase of household incomes and the reduction of poverty.

- Supporting regional integration of national electricity systems, contributing to the generation of electricity export earnings and to regional economic cooperation and increasing integration.
- Creation of opportunities for remunerative employment and skill development for local populations in project areas during the exploration and resource development activities.
- Development of trained human resources, acquisition of equipment and machinery for further geothermal exploration and development in other potential sites thereby ensuring sustainability of capacities.
- Creation and cultivation of a collaborative regime in the East African Rift region that would enable the exchange of information and experiences and optimization in the use of the human, institutional and infrastructural resources available in the region.

ACKNOWLEDGMENTS

This paper is a summary of : (i) the country update presented in various national and international Geothermal conferences; (ii) ARGeo project document submitted to UNEP and the WB and; (iii) Recent Report on Strategic Plan of Geothermal Resource Exploration and Development prepared by the Geothermal staff of Geological Survey of Ethiopia and EEPCO (July 2008). I would like to acknowledge the organizers of the Short Course IV on Exploration for Geothermal Resources, UNU-GTP and KenGen, who invited me to present this paper and covered all my expenses.

REFERENCES

Ayele, A., Teklemariam, M. and Kebede, S., (2002): Geothermal Resources Exploration in the Abaya and Tulu Moye- Gedemsa Geothermal Prospects, Main Ethiopian rift. Compiled Report. .

Electroconsult (ELC), 1986: Geothermal Exploration Project- Ethiopian Lakes District, Exploitation of Langano-Aluto Geothermal Resources, feasibility report. ELC, Milano, Italy.

Kebede, S., 1986: Results of temperature gradient survey and geophysical review of Corbetti geothermal prospect, EIGS.

Cherinet, T. and Gebreegziabhier, Z., 1983: Geothermal geology of the Dofan and Fantale area. (Northern Ethiopian rift). Geothermal Exploration Project, EIGS.

GSE and EEPCO, July 2008: Project Pipeline Proposal on Ethiopian Geothermal Resources Exploration and Development in Ethiopia.

Teclu, A., 2002/2003: Geochemical studies of the Dofan Fantale Geothermal Prospect Areas. South Africa, Internal Report. GSE.

Teklemariam, M. and Beyene, K., 2005: Geothermal Exploration and Development in Ethiopia. Proceedings in the World Geothermal Congress, WGC 2005, Antalya, Turkey.

Teklemariam, M., 2009: Strategic plan for Geothermal Exploration and Development in Ethiopia, Presented at Short Cource III on Exploration for Geothermal Resources, Organized by and KenGen, at Lake Naivasha, Kenya, November 1 - November 22, 2009.

United Nations Development Programme (UNDP), 1973: Investigation of geothermal resources of Power development Geology, Geochemistry and Hydrogeology of hot springs of the east African Rift System within Ethiopia. DP/SF/UN 116-technical report, United Nations, New York, 275 pp.