THE USE OF PORTABLE GEOTHERMAL WELLHEAD GENERATORS AS SMALL POWER PLANTS TO ACCELERATE GEOTHERMAL DEVELOPMENT AND POWER GENERATION IN KENYA

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ABSTRACT

Geothermal electricity is generated from geothermal energy. Technologies used to convert the geothermal energy to electricity include dry steam power plants, flash steam power plants, binary cycle power plants and lately wellhead generator units. Wellhead units can be connected to wells with output of up to 10-15 MW, with shorter steam lines compared to a central power plant which characteristically have long steam lines. They have modular construction, usually the turbo generator modules are factory assembled on a single sled. As matter of fact, the demand for electric power has been increasing due to economic and industrial growth therefore expanding the demand for small size geothermal power plants. Small size geothermal power plants are generally used for the following purposes: satisfaction of electricity demand in an isolated area, remote areas off-the national grid, power source during resource development, auxiliary or emergency power source for main geothermal generating plant and simplification of steam transmission lines. Wellhead power generator units are standardized. Special consideration is given to easy transportation, easy operation including start and stop, maintainability, high efficiency and high reliability. This paper defines the merits associated with portable wellhead generators, its effects to the electricity market with respect to Geothermal Development Company (GDC) agenda in Kenya, growth of small geothermal power projects around the world, the impact/significance of wellhead generators to; investors, off grid power for remote areas and use during geothermal exploitation stage. Geothermal portable wellhead generators can be applied to accelerate geothermal development and power generation in Kenya with immense opportunities for both the country and investors.

INTRODUCTION

Demand for electricity in Kenya is expected to increase rapidly due to; a growing rural and urban economy, expansion of rural electrification programme, the advent of county governments and Kenya's concerted efforts to be a medium sized economy by 2030. Therefore, securing stable energy supply, developing and establishing power plants that meet this demand is a priority for the Kenyan power sector if the economic growth is to be sustained in the future.

Kenya presents various attractive advantages for investment in power generation such as; dynamic electricity markets, abundant indigenous resources (e.g. hydro, wind, coal, solar and geothermal), and relatively low political risks.

Substantial opportunities for power generation exist both in large and small scales. However, opportunities for small scale power generation are more abundant from various sources. These sources include mini-hydro projects, solar, wind and small geothermal projects. The government interventions and initiatives have encouraged the application of small scale generation. Of particular interest are small scale geothermal projects which can be developed independently in remote areas or as part of a larger geothermal project in an early generation concept. Widespread use of small geothermal plants demonstrates the technological feasibility of small geothermal systems (Vimmerstedt, 1998).

In this paper, small geothermal power plant is defined as one with up to 20 megawatts (MWe) capacity.

Small geothermal power plants, which could be in the form of wellhead units, play an important role in the development of geothermal energy. Transmission of high temperature steam over long distances is a challenge, and hence the nearer the power plant the more effective the resource. The biggest challenge to the deployment of the wellhead units is their economic viability (Leeds et al 1979), when compared to a large central plant. However, the wellhead units possesses unique characteristics that make it very attractive for certain applications, these include; portability, re-usability, modest capital investment and rapid power production capability. The most promising applications of small geothermal plants include; onsite industrial use, electricity supply in remote areas, as a geothermal field development tool and peaking units for larger utilities.

ENERGY STATUS, FUTURE PROJECTION AND INTERVENTIONS IN KENYA

Energy Status in Kenya

Kenya energy mix consists of both renewable and non-renewable sources. The current electricity demand stands at 1,191 MW against an installed capacity of 1,429 MW. The generation capacities from the various sources are as shown in Table 1.

For a long time, Kenya has relied on hydro-electricity with perennial power outages forcing the government to invite emergency power producers who use thermal sources to generate electricity. This stop-gap measure not only lead to an increase in the cost of electricity, but also contributed in a major way to air pollution since it uses fossil fuel. The government therefore identified the country's untapped geothermal potential as the most suitable indigenous source of electricity.

Table 1. Kenya energy mix (SREP, 2011)

Item	Energy Source	Generation Capacity (%)
1.	Hydro	52.1
2.	Geothermal	13.2
3.	Baggase (Co-generation)	1.8
4.	Wind	0.4
5.	Thermal sources (Fossil)	32.5

Energy Demand Projections in Kenya

Going forward, the peak load is projected to increase to about 2,500 MW in the year 2015 and 15,000 MW in 2030 (SREP, 2011).

Accelerating power generation and distribution is at the core of the Kenya's government commitment in keeping with the Millennium Development Goals (MDG), to reduce by 50% the access to modern energy services, by 2015. Access to affordable energy is essential in achieving economic growth in Kenya. Hence the government has set-up the necessary policies, regulations and institutions to ensure increased electricity generation.

Similarly, The Vision 2030 (Kenya's long term development strategy that covers the period 2008 to 2030), considers energy as a significant enabler for economic acceleration in Kenya. Consequently, the government of Kenya through the Rural Electrification Master Plan is committed to ensure 100% countrywide connectivity through grid extensions and off-grid systems. However, to achieve all these developmental objectives there is a need to expand energy infrastructure and increase the supply of power to the grid.

In a view to address the ever increasing power demand, the government through the LCPDP (Least Cost Power Development Program) process, endeavors to expand the expansion and inclusion of renewable sources of energy in the national energy mix. The LCPDP planning process estimates future energy requirements and identifies suitable least cost sources of energy to meet the projected demand. Figure 1, shows a comparison of the cost of various renewable energy sources in Kenya. It is observed from the figure that geothermal sources generate energy at the least cost.

The amount of power generated from the various sources envisioned to meet the increasing demand in the country include; 5,000 MW from geothermal, 1,000 MW from hydro, 2,000 MW from wind, 3,600 MW from thermal, 2,000 MW from imports, 2,400 MW from coal and 3,000 MW from other sources (SREP, 2011).

Therefore going forward in the future, power generation from geothermal sources will play a major role in reducing the energy deficiency in the country.

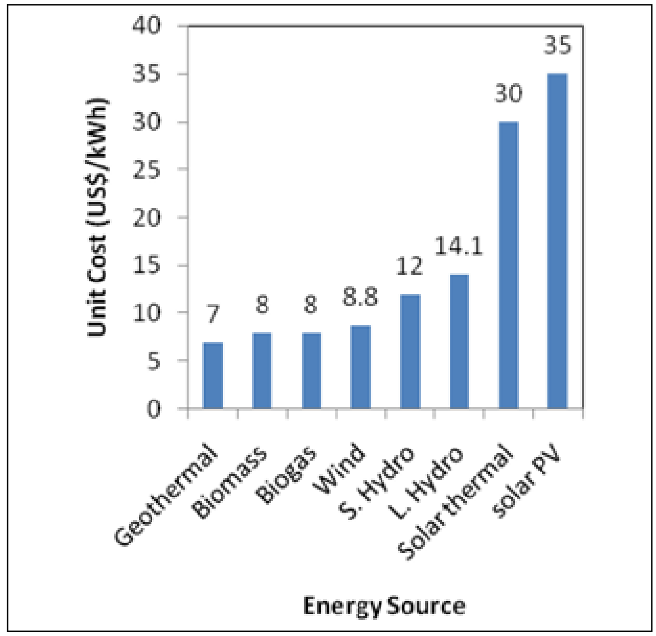

Figure 1. Comparison of generation cost for various renewable energy sources (SREP, 2011)

Geothermal Energy Interventions

The Sessional paper No. 4 of 2004 institutionally restructured the energy sector in Kenya. In the restructuring, GDC (Geothermal Development Company) was formed as a Special Purpose Vehicle to fast track the development of geothermal resources in the country and generate in excess of 5,000 MW of electricity from geothermal sources by the year 2030. Geothermal energy is an indigenous, abundant, reliable and environmentally- friendly source of energy.

The exploration and development of geothermal energy started as early as 1957 in Kenya. But this has so far yielded 209 MW only against a massive potential estimated at between 7,000 MW to 10,000 MW.

There are more than 14 geothermal sites in Kenya (Figure 2). The potential sites are spread along the Kenyan Rift. Other locations include: Homa Hills in Nyanza, Mwananyamala at the Coast and Nyambene Ridges. Currently only Olkaria has been developed, while Menengai is at the appraisal drilling stage.

Evidently, the speed of harnessing and developing geothermal resources in Kenya has been slow necessitating the creation of GDC.

GDC is expected to drill about 1,400 steam wells to provide steam for the generation of 5,000 MW of geothermal power by 2030.

To achieve the objective of developing geothermal energy, the government through GDC has started and progressing with the development 400 MW in the Menengai geothermal field to be completed in 2015 (SREP, 2011).

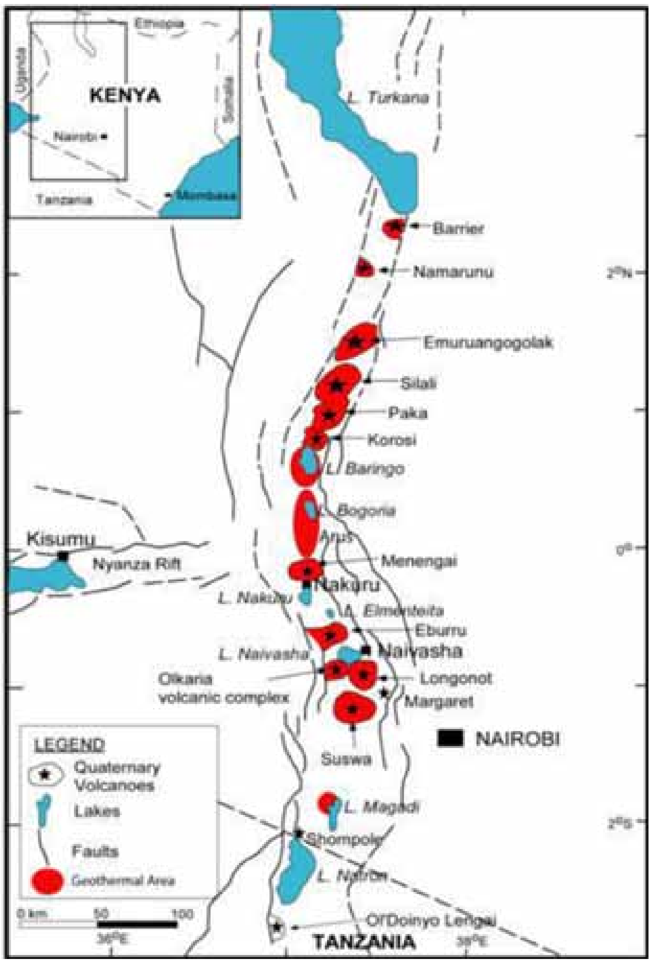

Figure 2. Geothermal Sites in Kenya

GDC currently has two rigs drilling at the Menengai field. Figure 3 shows one of the rigs on site, while Figure 4 shows the first exploration well in the Menengai field discharging vertically.

The expansion of the Olkaria field to accommodate a 280 MW power plant is underway.

The government's involvement in the development of geothermal energy is mainly to mitigate on the risks inherent in the early stages of geothermal development in the view of reducing the gestation period of the projects to about five years, and hence make it more attractive to investors.

Currently, funding for the geothermal projects in Kenya is sufficient since the government committed to finance the early stages of the projects.

The country can benefit immensely with accelerated power generation from ongoing geothermal projects through installation of wellhead generation units in an early generation concept.

Kenya geothermal industry offers competitive and attractive advantages for investment in power generation. These unique advantages include;

1. Dynamic electricity markets,
2. Abundant geothermal resources
3. Relatively low political risks
4. Government and institutional support
5. In-country expertise
6. Active geothermal development

Figure 3. A GDC rig at Menengai Geothermal Prospect, GDC 2011.

Figure 4. Well MW-01 in the Menengai geothermal field discharging vertically.

Characteristics that Make Portable Wellhead Generators Attractive

Geothermal wellhead generator unit possess special features that make it attractive for a small geothermal power plant application. These unique features could be the much needed interventions the power sub-sector in Kenya requires to mitigate some of the challenges that limit its development.

The challenges identified to retard electricity development in Kenya include the following:

1. Slow rate of capacity addition hence inadequate supply;
2. Over-reliance on hydropower
3. High cost of power
4. Weak transmission and distribution network
5. Long lead times in the development of power infrastructure
6. Low investments in power sector by private investors
7. High cost of rural electrification
8. Low countrywide electricity access and connectivity

The special features built into the portable wellhead generators include:

No Need for Power Source to Start

Portable wellhead generators can be started without any auxiliary power source except a battery for instrumentation.

The unit has steam turbine driven oil pump and mechanical-hydraulic control system. Therefore the unit can be installed without considering any electric network of the area.

Attracting Investment

The units enable developers, utilities and independent power producers to significantly shorten the time between exploration and revenue generation in geothermal projects and thereby accelerate the growth in the geothermal development in Kenya.

Optimal Energy Utilization

The independent wellhead power plant unit enables optimum power to be produced from each individual well regardless of their differing outputs and characteristics. The concept negates the needs of traditional power plants for well redundancy or an excess steam buffer to cater for well failures and allows all wells to be utilized. The wellhead generating unit is modular in design also makes it possible to generate electricity from remote wells that are outside the topographical reach of large traditional plants.

Rapid Deployment

Portable Wellhead generator modular design, based on standard manufactured components, allows for significantly reduced lead times and early power online. Today, manufacturers can deliver power online within 12 months of ordering the portable modular wellhead power plant and thereafter rapid deployment, at a rate of one modular portable wellhead unit plant per month, can be achieved (GEG website: www.geg.no/news).

Lower Risk

With modular flexibility, the wellhead turbine power plant is delivered in standard containers and each module is ready made at the factory allowing for quick installation. It is designed to operate independently for each well, but can be organized in power farms to provide a similar power output to large traditional geothermal power plants. In the event of a well failure, the module is designed to be decommissioned, transported and redeployed on a second well, maximizing the return on investment. Equally importantly, the failed well can be returned to its original state thus preserving the environment.

Reduced Cost per Megawatt

The unit modular design like C64 from the Green Energy Group can generate over 6.4 MW (based on standard manufactured components; this enables a highly competitive capital price and allows for easy maintenance and access to spare parts. By focusing on the characteristics of each well independently, this module is able to adjust turbines to achieve a high level of power output efficiency, driving down electricity production costs.

Advance Control and Maintenance

Wellhead power generating units also deploy an advanced control system providing real-time operational data, allowing for early remediation action and preventative maintenance thus avoiding unnecessary downtime and associated costs.

Huge Investment Opportunity

Wellhead generators provides a big opportunity to power developers, utilities and independent power producers to significantly cut capital costs and shorten the time between exploration and revenue generation in geothermal projects. The wellhead generator can be used to test the geothermal field and in effect benefit from data already gathered.

TECHNOLOGIES FOR SMALL POWER PLANTS

Majority of small geothermal power plants currently in use are either binary or flash, although some are a hybrid of both. Both flash steam and binary technologies have their own proponents and each has its own set of advantages and disadvantages.

Flash Steam Plants

Flash steam plants are used where the geothermal resource produces high temperature hot-water or a two-phase fluid.

In the flash steam plant (either single or double flash) the hot-water or two-phase flow from the well is directed to a steam separator where the steam is separated from the water phase and directed to drive the turbine. In double flash system, the steam is flashed from the remaining hot-fluid of the first stage, separated and fed into a dual-inlet turbine.

This technology is competitive and economical for deployment in many locations and can be developed with capacities of between 10 to 50 MW (Meyers, 2002). A modular approach is also possible with this technology where standardized units are installed.

The flash steam systems can either be condensing or non-condensing. In a non-condensing flash system, as shown in Figure 5, the steam is separated from the geothermal discharge and fed through a conventional axial flow steam turbine which exhausts directly to the atmosphere. This plant is the simplest and the cheapest in capital cost of all geothermal cycles. The condensing flash system, shown in Figure 6, is a thermodynamic improvement on the non-condensing design. Instead of discharging the steam from the turbine to the atmosphere it is discharged to a condensing chamber that is maintained at a very low absolute pressure- typically about 0.12 bar-a. Because of the greater pressure drop across a condensing turbine more power is generated compared to atmospheric exhaust.

Non-condensing turbines are less efficient than condensing turbines. They demand about 12 tons of steam per Mega-watt-hour (MWh), compared to around 8 tons per MWh required for condensing turbines. But when used for testing new wells they are very attractive in an economic sense (Hiriart, 2003).

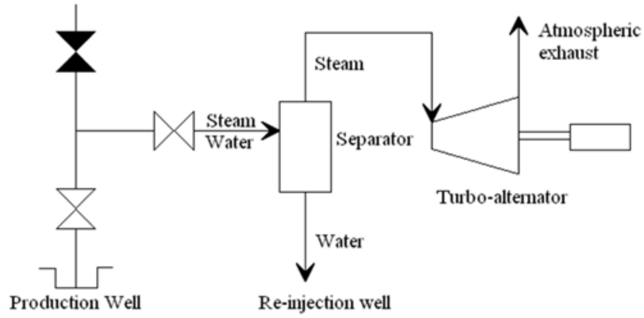

Figure 5. Atmospheric exhaust cycle simplified schematic

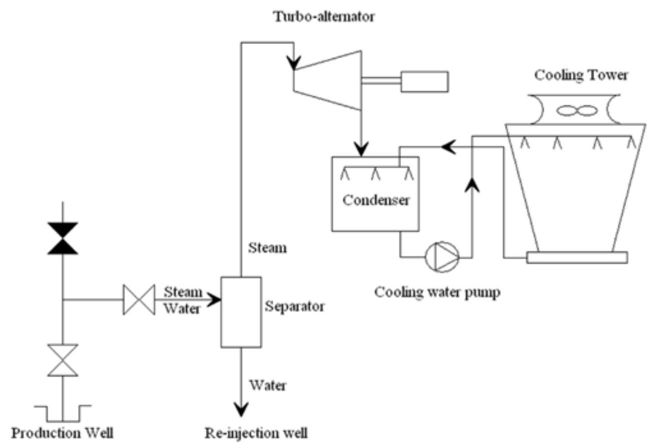

Figure 6. Condensing cycle simplified schematic

Examples of small flash plants can be found in, Japan, Mexico and Guadalupe.

In Japan, a small flash facility was installed at the Kirishima International Hotel in Beppu, Kyusha in 1983. The 100 kW non-condensing unit operates on the output of two production wells and has an inlet temperature of 127°C at 2.45 bars (Bloomquist, 2005).

In Mexico, a 5-MW wellhead non-condensing turbine (Los Azufres Unit 8) was used to test the behavior of the Los Azufres geothermal reservoir. This plant was later moved to the Los Humeros geothermal field (Hiriart, 2003). This example demonstrates the significance of wellhead units in geothermal development.

Binary Plants

The binary cycle plant is used with low and medium enthalpy resources.

In a binary plant, shown in Figure 7, the thermal energy of the geothermal fluid is transferred to a secondary working fluid via a heat exchanger for use in a conventional Rankine Cycle or Kalina Cycle. The vaporized working fluid, e.g. isopentane, propane, Freon or ammonia drives the turbine before being condensed and returned to the heat exchanger in a closed loop. Cooling is generally provided through the use of air coolers.

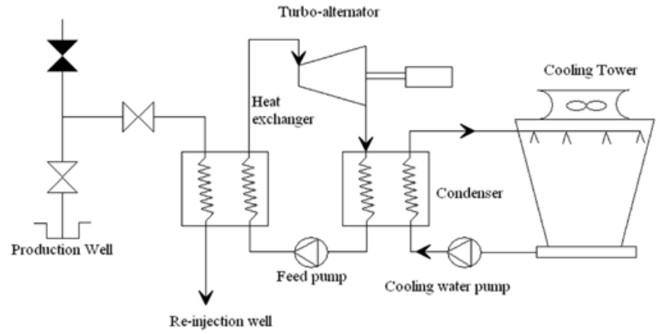

Figure 7. Binary cycle simplified schematic

Geothermal binary plants are widely used and the technology is very feasible. Normally modular configuration and systems are applied to achieve higher plant availability factors of over 98% (Meyers, 2002).

EXISTING SMALL GEOTHERMAL POWER PLANTS

Amedee Geothermal Venture Binary Power Plant (Lund and Boyd, 1999)

Amedee Geothermal Venture binary plant, located in northern California near Susanville, became operational in 1988. The plant consists of two units of 1-MW each with a total net output of 1.5 MW. The resource temperature is 219˚F (104˚C), and well depth of 850 ft (260 m) with a maximum flow rate of 3,200 gpm (205 l/s). The plant uses R-114 working fluid and cooling ponds for makeup water. The units were designed by Barber-Nichols Engineering Company of Arvada, Colorado. They have an availability is 90% and the system is remotely monitored by telephone line. Geothermal fluids from two wells are used to operate the plant, and surface discharge is used to dispose of the spent fluid. This is possible because the geothermal fluids have a very low salinity and a composition the same as area hot spring water.

Tarawera Binary Plants, Kawerau, New Zealand (Lund and Boyd, 1999)

They were commissioned in late 1989 and officially opened in early 1990 after a record short construction time of 15 months. The two ORMAT energy convertors (OEC) receive waste water from Kawerau 21 flash plant at about (172˚C) and 8 bar. Heat rejection from the plant is by a forced draft air condenser situated above the OEC units. Each unit has a gross output of 1.3 MW; a total of 2.6 MW, of which about 13% is used by auxiliaries, pumps, fans, etc., giving approximately 2.2 MW available for the Bay of Plenty Power Board (BOP) grid. The monitoring system allows unattended operation that ensures that unscheduled outages can be quickly reported. The plant performance is also monitored by the manufacturers in Israel, who provide weekly reports directly to the BOP offices in Whakatane. Tilson, et al., (1990) reported no deposition in the heat exchangers and, with little maintenance required, load factors for the first six months of operation were over 90%, with 96.6% availability. The unit average output was about 1,800 MWh per month for the initial operation.

2 MW Nominal Geothermal Power Plant, Lake Naivasha, Kenya

Geothermal Development Associates (GDA) designed, assembled and installed a 2 MW nominal geothermal steam turbine generator and related power plant auxiliary components at the Oserian flower-growing facility near Lake Naivasha in Kenya.

GDA shipped the plant to Kenya in June 2007. The time from contract signature to readiness for shipment of the plant was 10 months. The plant was commissioned in November 2007. The complete geothermal power generation system (turbine generator set, gearbox, oil lubrication system and electrical control system) was manufactured and assembled in the U.S. The plant is now operational.

Eburru Wellhead Geothermal Pilot Power Plant, Kenya

Geothermal Development Associates (GDA) has also been contracted for the design, supply, and commissioning of a wellhead geothermal pilot power plant at Eburru geothermal field in Kenya. The equipment supplied will include a 2.5 MW steam turbine generator set complete with auxiliary systems and controls. The contract was signed on October 2009. The construction of the plant started in early 2011 and completed within the same year. The plant is waiting commissioning. The Eburru geothermal field is along the flanks of the Ol Doinyo Eburru Volcano and is situated 11 km northwest of Lake Naivasha.

The trend with the small geothermal plants discussed above is the short time the power plant takes to come online. This is the greatest advantage of wellhead generators, which allows them to be deployed rapidly.

THE IMPACT AND SIGNIFICANCE OF APPLICATION OF PORTABLE WELL HEAD GENERATORS TO THE INTEGRATION OF SMALL GEOTHERMAL POWER GENERATION IN KENYA

The period after which geothermal projects in Kenya are expected to start generating electricity can be reduced further to two or three years by installing wellhead generators on the already drilled productive wells. This strategy will not only generate power for project implementation by providing power to the drilling operation, but also provide opportunities for other direct uses.

Early Generation for Geothermal Development

Geothermal sites in Kenya are found in remote locations; off-grid (Outside national power network) and hence diesel generators are used to provide power to the drilling rigs. For instance, Menengai wells 03 and 04 have used diesel to power the drilling rig, base camp and associate equipment of over Kenya shillings 100 million (USD 1.2 million) which is about 25% of the total cost of drilling the well. Menengai well 01 and 04 can produce over 10 MW peak loads for our 2000 horsepower rigs is 1.5 MW. By connecting these wells to wellhead generators producing over 10 MW, we can save over a quarter of drilling and base camp facility costs. Moreover, procurement and logistics period required before obtaining the diesel fuel will be eliminated hence reducing the drilling period significantly. This is notwithstanding the fact that diesel generators require maintenance periodically. Oil filters; oil and fuel filters alongside labor required for maintenance are eliminated by use wellhead generators.

Since the use of diesel will completely be eliminated by the portable wellhead generators, the use of geothermal energy amount to use of green energy which environmental friendly, cheaper and clean.

Drilling, design and construction of a traditional geothermal power plant can take up to 7 years to complete (Green Energy Group website: www.geg.no/product-sheet). This involves the need for big capital injections while at the same time not being able to cater for the short term needs of energy. Well head manufacturers like Toshiba and Green Energy Group have developed a standardized module system which is in mass production today. The production capacity of each module is up to 15 MW and can be put together to produce a larger scale power station. It takes one year from module construction to it being installed and operational. The considerable time before power production can take place lies in the amount of wells that need to be drilled.

The portable geothermal units can be installed in the Menengai geothermal field especially to displace the diesel being currently used to run the rigs, compressors and auxiliary equipment in the field. The two already producing wells (well MW-01 and MW-04) can be harnessed to generate over 10 MW as well tests are ongoing. As more wells are drilled in the field, the number of wellhead plants can be increased to supply electricity to the grid. This is practical as the Menengai field is close to Nakuru town which will provide a ready market.

The same concept can either be applied to existing geothermal fields like Olkaria, where more wells are being drilled for expansion or new fields like Korosi-Paka-Silali block, as part of the geothermal field development program.

By implementing this concept, the subsequent early generation programs will benefit from the experiences of the first implementation and the reuse of the portable wellhead units.

Integration of Small Power Plants with Agribusiness and Tourism

The integration of small geothermal power projects with agribusiness and tourism is rapidly growing in popularity. This trend is a result of advancements in the generation of electricity from low to moderate temperature geothermal resources (100°C-150°C) and the economic advantage that full use of the resource provides.

Opportunities for integration of small geothermal plants with other direct uses exist in the Kenyan Rift where most of the viable geothermal sites are found, i.e.,, Nakuru, Baringo and Turkana counties.

The use of wellhead type generation coupled with agribusiness systems e.g. agriculture crop dehydration, greenhouses, milk processing and aquaculture in these remote regions of the Kenya will not only support the above processes but also supply power off grid. In addition, the infrastructure built in the process of developing the geothermal resources will promote tourism activities in these regions. Consequently, there will be a need to provide power off-grid and using the geothermal fluid for tourism activities like outdoor bathing, warm swimming pools and water heating for sauna baths. Table 2 summarizes some of the integrated direct uses of geothermal fluid from the small power plants.

Table 2. Opportunities for integrated geothermal power generation and direct uses in Kenya

Item	Area (county)	Type of integrated direct use
1	Nakuru	• Crop dehydration; maize, onions, wheat • Greenhouse use • Milk and pyrethrum processing
2	Baringo	• Crop dehydration; tomatoes, onions • Greenhouse uses • Tourism applications; swimming pools, outdoor bathing and heating of sauna baths
3	Turkana	• Fish drying • Greenhouse uses • Tourism applications; swimming pools, outdoor bathing and heating of sauna baths

The integration of small power production with agribusiness projects and off grid power supply in remote Kenya by use of portable wellhead turbine power generators can significantly improve the economic viability of using lower temperature geothermal fluids and can result in a much higher overall "fuel use efficiency" than can be achieved with stand-alone power or direct use projects.

Investment Opportunities

By embracing the early generation concept, the geothermal industry in Kenya will provide a great investment opportunity to the private sector. The portable wellhead technology will enable power developers, utilities and independent power producers to significantly reduce capital costs since this is no need for steam lines to connect many wells to the power plant as is the case in traditional power plants. The reduced time between exploration and revenue generation in geothermal projects will accelerate the growth in the geothermal development in Kenya. The investor can generate power from a single or more wells and generate revenue to invest in other fields being drilled. More significantly the government would have shielded the investor from the high risk initial stages of the field development and proved the existence of the resource, and hence enables the investor to concentrate on power generation.

CONCLUSION

Geothermal portable wellhead generator set is completely assembled on a common base then shipped to the site. Therefore installation and adjustment work are minimal. Pursuant to immense benefits related to their lower cost of installation, this would provide an economical alternative to the rather expensive conventional power plants in Kenya. Kenya which is a developing economy and having installed electricity capacity of only 1,330 MW in the whole country will benefit from the use of these units, especially during the resource development phase of geothermal energy and supply of electricity to off grid and remote areas of the Great Rift Valley where up to 10,000 MW of geothermal potential exists.

EDITOR'S NOTE

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