

## Geothermal Development in the Assal Area, Djibouti

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**Keywords:** Djibouti, exploration, development, IPP, drilling

### ABSTRACT

Reykjavik Energy Invest (REI) along with investors intends to build a 50 MW<sub>e</sub> geothermal power plant with the possibility of an expansion of up 150 MW<sub>e</sub> in the Assal geothermal area in Djibouti. REI has the exclusive license from the Government of the Republic of Djibouti for geothermal utilization of the Assal area. REI and the Djibouti authorities have also signed head of terms project and power purchase agreements. A pre-feasibility study of the field was completed for REI in January 2008. The study included a surface exploration, cross-correlated with older drilling results and field data. A new conceptual model based on the interpretation of the data has been constructed and sites for exploration wells decided. The pre-feasibility study also includes an environmental management plan for the drilling of the exploration wells. Currently the project is in the feasibility phase which includes building of access roads and drill pads, installing a seawater supply system to provide drilling fluid, and the drilling of three deep deviated geothermal exploration wells. The preparation work will take place in the summer 2009 and the drilling of the exploration wells will start in late 2009. Once the power potential of the site has been assessed REI will start making preparation for the construction of the plant. It includes the conceptual design of the power plant, analyzing cooling possibilities for the operation, and the drilling of production wells to secure the designed capacity of the plant. While preparing for the construction REI will finalize the PA and PPA with the Djibouti Government, secure funding for the next phase, and complete an environmental impact assessment. The construction cost estimate for the 50 MW<sub>e</sub> geothermal plant is US\$ 170 million and the construction of the plant should be completed in 2013/2014.

### 1. INTRODUCTION

REI along with investors intend to build a 50 MW<sub>e</sub> geothermal power plant in the Assal Rift in Djibouti, East Africa (Figure 1). Djibouti is a republic which received its independence from France in 1977 and has an estimated population at 800,000. It has a strategic location because it is near the world's busiest shipping lanes, and is the terminus of rail traffic into Ethiopia. Djibouti is currently producing 50-60 MW with an old diesel driven Power Plant at a very high production cost. Whereas all the petroleum is imported the country is dependent on foreign supply for its electricity production. There is a high demand for stable and economical electricity in Djibouti and a geothermal power plant could boost the nation's economy by lowering the production tariff of electricity and relief it of foreign dependency on imported petroleum.

The Assal area in the Republic of Djibouti has attracted the interest of scientists as a potential area for the development

of geothermal power plant for production of electricity for the energy starving nation. The main exploration work was carried out in the 1970s and 1980s but has been dormant until REI signed an agreement with the Government of Djibouti on February 19<sup>th</sup> 2007 for a pre-feasibility study. Subsequently on April 10<sup>th</sup> 2008 the Government granted REI a concession to carry out a feasibility study in the same area. On the same date contracts were signed with the Government, clearing legal matters HOT Project Agreement and contract with the power company a HOT Power Purchasing Agreement.

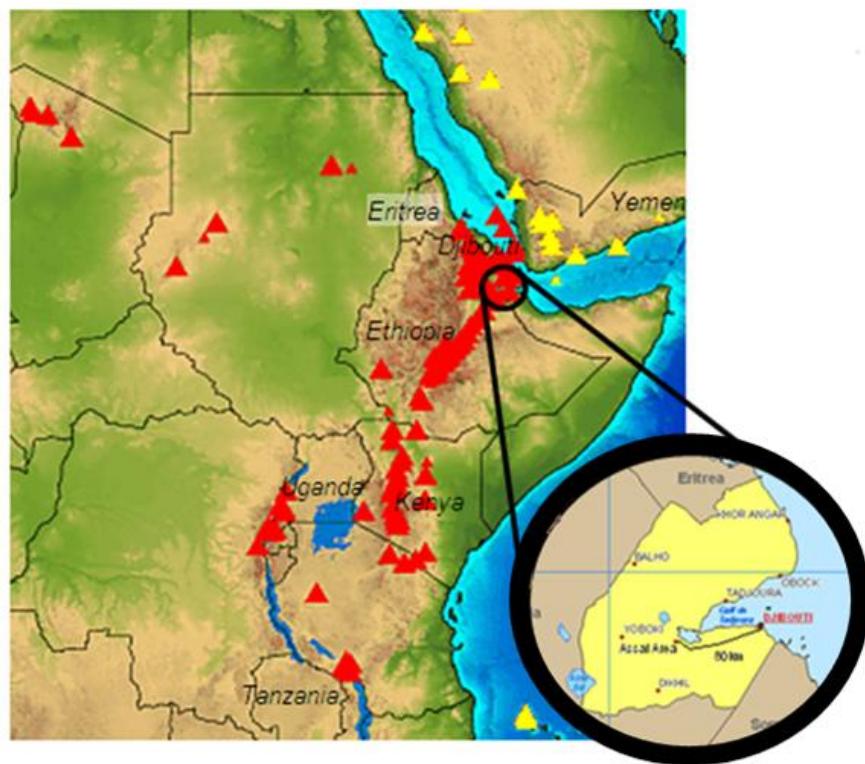
The future plan is to build up to 150 MW power plant with an initial stage of 50 MW. If the area can support and sustain a greater capacity the aim is to build extensions at such time as the market in Djibouti will be ready for additional power. It is estimated that the first stage of the power plant will be in operation in 2013/2014.

The project of building and operating a geothermal power plant is divided into four phases. The project is currently in the second phase and the task at hand is drilling of three to five exploration and appraisal wells, followed by a resource appraisal period, which will then be followed by the drilling of up to seven to nine additional production wells. Information attained through drilling the exploration wells and the second phase as a whole will be used for preparation and design of the power plant. Optimally REI's current activities should result in commissioning a 50 MW electric plant in few year times with a rough cost estimate for the electric plant is about US\$ 170 million.

### 2. PRE-FEASIBILITY PHASE

#### 2.1 Previous Studies

The first direct geothermal exploration work on the Assal Geothermal Prospect was carried out in the 1970s and 1980s under projects carried out in co-operation between the Government of Djibouti and United Nations Development Program (UNDP) (Battisteili et. al, 1990). These projects included the drilling of six exploration wells, down to 2105 m. The drilling confirmed the existence of a geothermal reservoir, with sub-surface temperatures reaching up to 360°C and maximum production of steam of 20 kg/s from a single well. The geothermal fluid is saline brine, making exploitation cumbersome (Battisteili et. al, 1990). In 1989-1990 a geothermal scaling/corrosion study was carried out on well Assal 3, with the objective to assess the effect scaling and corrosion and study possible ways to reduce the negative impact of the salinity (Virkir-Orkint, 1990). Furthermore TEM measurements were carried out in a part of the Assal region in order to add to the understanding of the sub-surface structures (Arnason et. al, 1995).



**Figure 1: The East African Rift and enlarged view of Djibouti.** Volcanoes with known or inferred Holocene Eruptions.  
Source: <http://www.volcano.si.edu/gyp/>.

## 2.2 Completion of the Pre-feasibility Study

REI has carried out and completed surface exploration and environmental studies to better understand and characterize geothermal reservoirs hosted in the Assal Rift volcanic area. The first phase of the pre-feasibility study was to accumulate all existing relevant data and evaluate its quality in the light of advances made in the decades since the initial work was carried out. Based on the findings a new reconnaissance program was prepared in order to complete a geothermal pre-feasibility study. For this endeavor Iceland GeoSurvey (ISOR) was contracted to undertake a comprehensive resistivity project and detailed geological mapping (Arnason et. al, 2008 and Khodayar 2007). The pre-feasibility program was completed based on the old and new field data the first conceptual model of the geothermal system prepared (Reykjavik Energy Invest, 2009). Furthermore, an environmental management plan (EMP) has been prepared to ensure that planned drilling activities, in the feasibility phase, will comply with domestic and international standards (Reykjavik Energy Invest, 2008).

## 2.3 Geophysical Studies

The main emphasis on the geophysical field work was to carry out a combined Transient Electro-Magnetic (TEM) and Magneto-Telluric (MT) resistivity survey. A total number of 102 and 106 MT and TEM soundings respectively were carried out and by combined 1D (layered earth model) interpretation by MT and TEM soundings made at the same location (Arnason et. al, 2008).

The regional geophysical survey, along with the older TEM measurement, gave a new and more detailed picture of the

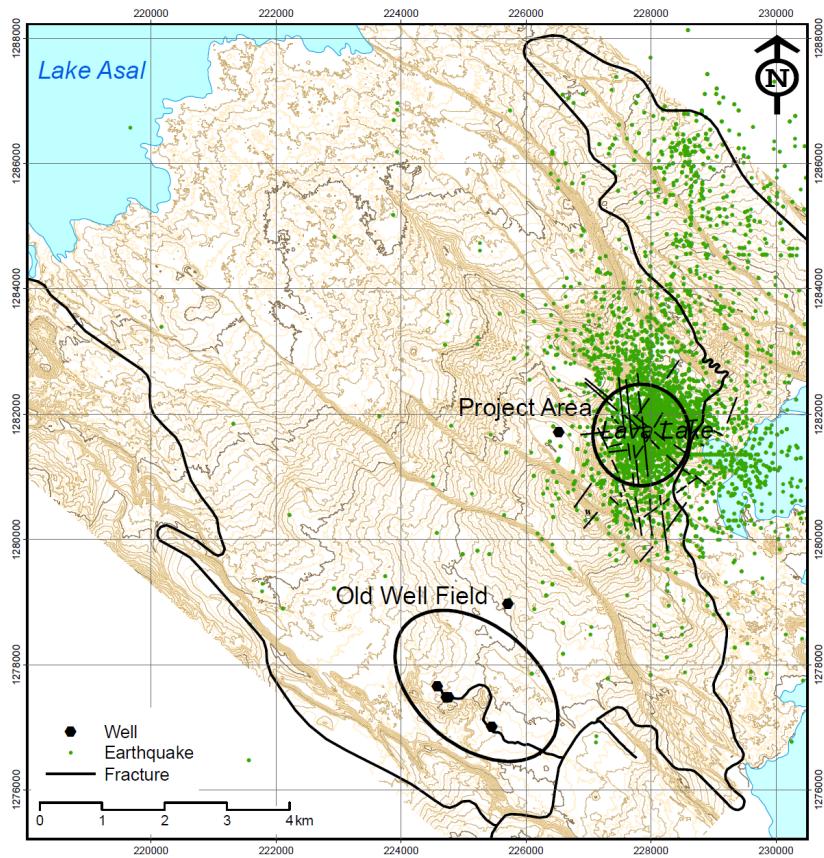
resistivity structure of the sub-surface stratigraphy. Several locations within the study area were identified as interesting anomalies.

## 2.4 Geological Mapping

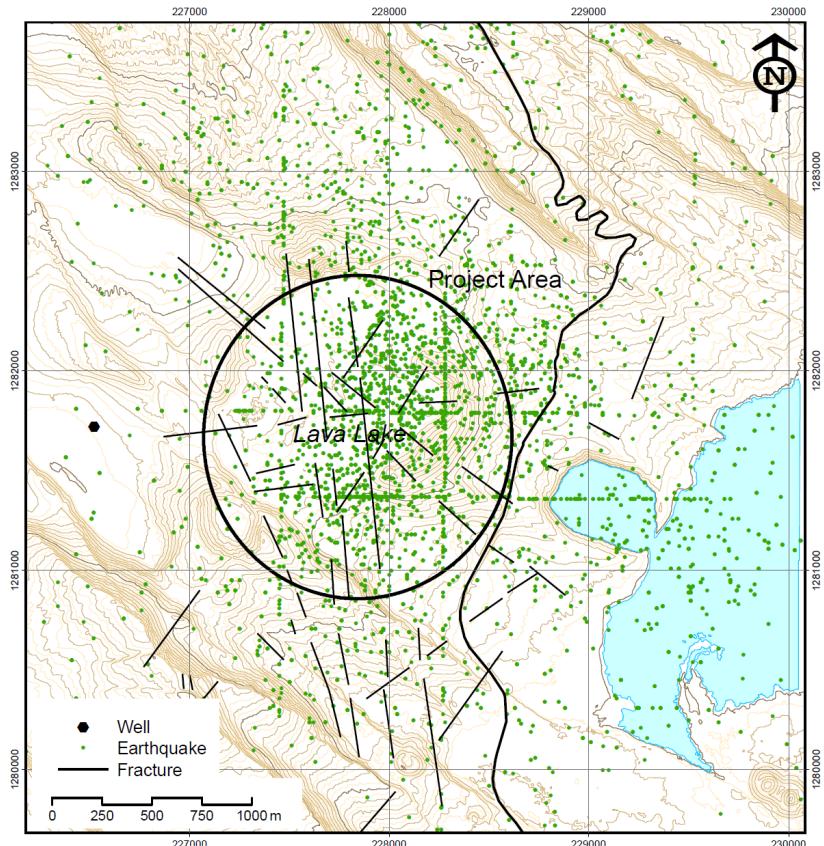
The Assal Rift is characterized by a diverging plate boundary that has accumulated substantial volume of basaltic magma. Microseismicity is persistent while large earthquakes are few. Last volcanic eruption took place in 1978, at Ardoukoba, southeast of Lake Assal (Figure 2). The eruption was a fissure eruption and lasted only a week.

The Assal Rift geology is characterized by flat lying lava flows, generally erupted through a series of vents on an open fissure. The active volcanic area is hosted within a graben type structure. Normal faults run from Gulf of Ghoubbet El Kharab in a NW direction towards Lake Assal (Figure 3). These graben faults have a cumulative vertical displacement in the range of few hundred-meters. Youngest rocks are found in central and lowest part of the rift. Formations get progressively older the farther one goes away from the rift.

The geological mapping has brought to light series of fault lines perpendicular to the graben faults (Khodayar, 2008). Some of these are transverse type while others are remnants from older spreading axes. These faults can be traced into the older rock formations. It is now believed that favourable geothermal targets, as well as surface manifestations, are controlled by intersection of these various fault lines. Many of these lineaments are also seen in geophysical studies (Arnason et al., 2008).



**Figure 2: Map of the Assal geothermal prospect. The dark green dots represent seismicity and the light green represents geothermal surface manifestations.**



**Figure 3: Model of geothermal activity in the Fiale area the intended project Area.**

## 2.5 Integration of Geological and Geophysical Mapping

The completed scientific program under the pre-feasibility phase has resulted in improved understanding of the Assal Geothermal Prospect. The integration of the pre-feasibility data, both old and new, has resulted in a new conceptual model of the area. The geological work shows intensely faulted young basaltic environment, progressively getting more active towards the centre of spreading. Several important geothermal targets have been located by the resistivity survey, one of them being the old wellfield which is situated in the older part of the Rift, apparently with little hydrostatic connection to other parts of the Assal area (Reykjavik Energy Invest, 2009). This is consistent with the high salinity of the brine found in the old wellfield. Other targets are located at the intersection of fault lineaments and in younger and more interconnected areas. These targets are expected to have lower level of salinity as they have better connection to recharge of seawater.

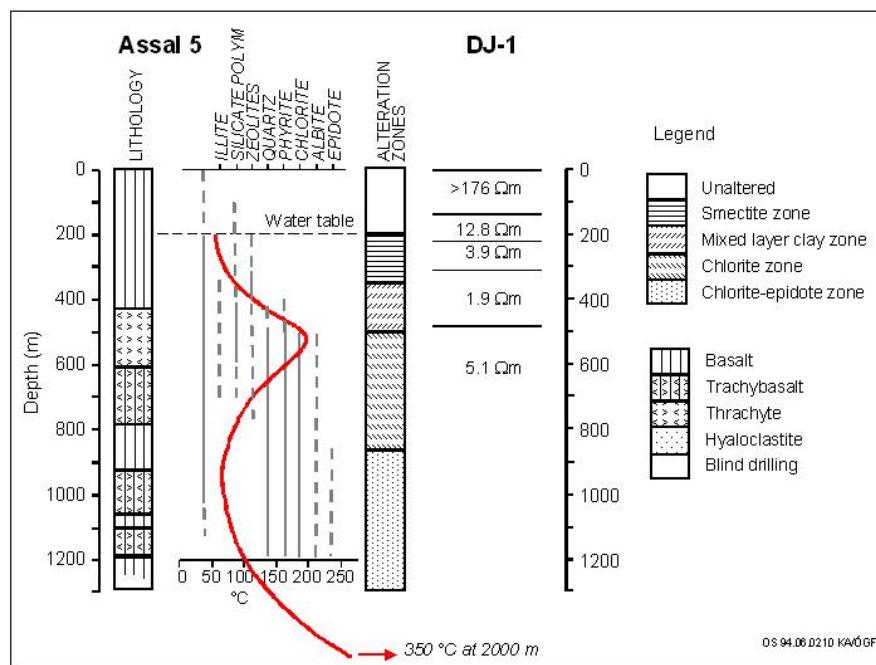
The old wellfield, tapped by existing wells 3 and 6, is considered proven resource by earlier drilling. For example, well 3 discharged high enthalpy steam equivalent to 10 MW electric at 10 bars wellhead pressure. When throttled to 20 bars, the 9 5/8" diameter well still was able to produce the equivalent of 5 MW electric. The fluid encountered at depth is very saline and of strong scaling potential. Extensive studies were undertaken on the fluid properties in 1989 (Virkir-Orkint, 1990). The high resource salinity is an indicator for stagnant fluids and tight reservoir boundaries (Arnason, 2008). This may restrict boundary fluid recharge and, thereby, the long term generating capacity of the sector. Due to unforeseen cost of designing, building and managing a comprehensive reinjection system in the old wellfield it was decided to divert the research focus to focus on the whole Assal area, between the sea and Lake Assal (Figure 2) (Reykjavik Energy Invest, 2009). One of the objectives was to attempt to identify a sub-area with more favorable fluid chemistry and boundary properties.

A new potential production sector has been identified, located in the Fiale area (Figure 3), with a focal point in Lava Lake, a circular depression filled with young lava flows, where maximum spreading takes place in the Rift and with intensive micro-earthquake activity. This area is the focus of the planned exploration-drilling project due to a set of observations that point towards a commercial resource. Firstly, coexistence of large and active faults, intersection of fault systems, a high resistivity anomaly underneath a low resistivity layer, lava production center, seismic and fumaroles activity. Secondly the brine is expected to have salinity close to that of seawater and therefore better suitable for utilization than the old wellfield. Finally the Lava Lake resistivity anomaly appears to be on the order of 4 km<sup>2</sup> at 1000 m depth and enlarges when going deeper. It should therefore prequalify as a resource that can support a minimum of 50 MW station, using a conservative 10 MW/km<sup>2</sup> generating capacity as a reference.

Well 5 of the former Assal drilling project (Battisteili 1990) is located within the Fiale area (Figure 3). It is unproductive and penetrates both cold and hot formations (Figure 4). This resource behavior suggests firstly that there are active flow channels of fresh seawater that recharge a deep reservoir. These faults should provide pressure support and more favorable fluid chemistry than observed in the old wellfield. Secondly the high temperature downhole confirms a large heat reserve.

## 2.6 Environmental Management Plan for the Feasibility Phase

An environmental management plan report for the feasibility phase has been completed. Its goal is to ensure that planned drilling activities comply with domestic and international standards (Reykjavik Energy Invest, 2008).



**Figure 4: Temperature profile, geology, thermal alteration and TEM based resistivity model for well 5 (modified from Arnason and Flovenz, 1995).**

As Lava Lake is a unique volcanic phenomenon, a special effort in diverting drilling activities to location outside the Lake has been made. The drill sites are carefully chosen to reach a specific drilling target, to be located where discharge brine can be disposed off, and where the disturbance on the pristine environment will be at minimum (Figure 3). Roads are mainly built on existing tracks. Well pads are located such that drilling targets are reached directionally (Reykjavik Energy Invest, 2008). Their visual impact, due to road construction and drilling activities, are kept at minimum. Productive wells can nevertheless be connected to future separator and power stations.

Environmental impact studies have, for the feasibility phase, mainly revolved around 3-4 new well pads and associated roads. Environmental impact characteristics were considered with respect to specific factors (e.g., air, water, landscape, ecosystems, health, and safety). The impact characteristics being direct, indirect, positive, negative, permanent, temporary, reversible, irreversible, synergistic, and cumulative. The impacts of the proposed project are mainly insignificant or moderate negative on the physical and biological environment. The impacts on the socio and cultural environment are generally positive or uncertain. The conclusion is therefore that the feasibility study should be classified as Category B project according to the World Bank's classification of projects (World Bank, Internet publication). Further environmental studies will be conducted for the full blown project.

### 3. FEASIBILITY PHASE

The immediate objective of the ongoing feasibility study is to evaluate the potential of a geothermal reservoir which exists at a shallow depth. The feasibility study will include building of access roads and drill pads, drilling of shallow water wells to provide seawater as a drilling fluid, installing a temporary seawater pipeline and drilling of three to five deep geothermal exploration wells. Following the drilling and thermal recovery of the wells they will be flow tested for a period of one to two months in order to evaluate the characteristics of the geothermal reservoir and to collect necessary information for the subsequent design work for a geothermal power plant if found feasible. Also included in the feasibility phase is the composition of an environmental management plan and the conceptual design for the power plant.

#### 3.1 Drilling

Based on the conceptual model from pre-feasibility study three well locations were determined and drilling targets were specified. The three geothermal wells are planned to be up to 2800 m deep and deviated. The proposed drill pads are shown as sites AA, AB and AC in figures 5, 6, and 7.

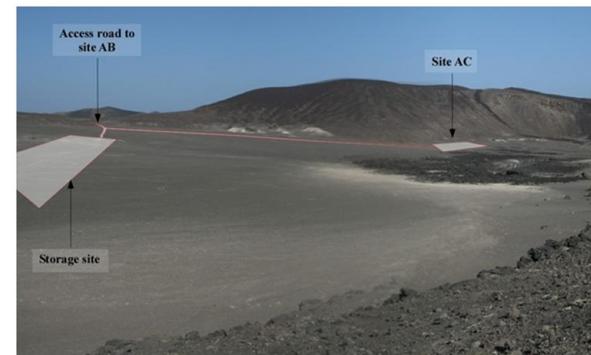
The Assal Area is expected to have highly saline geothermal fluid which REI intends to mitigate with a salinity management plan as proven at the Reykjanes Geothermal Power plant, in Iceland, and through the projects drilling plan (Albertsson, 2010). To prevent scaling within the wellbore and feedzone formations wellhead pressures will need to be maintained at 20 bars or higher, which will require the drilling of larger than usual diameter wells. The production section of the wells will be drilled at 12 1/4" diameter with 9 5/8" diameter perforated liner being utilized. They will also be drilled with aerated drilling fluids in order to maintain drilling fluid circulation to the surface and minimize formation permeability damage.



**Figure 5: Location of Site AA (Reykjavik Energy Invest, 2008).**



**Figure 6: Location of Site AB.. Access to Site AC can be seen through a pass on the centre right, a path leading there (Reykjavik Energy Invest, 2008).**



**Figure 7: Site AC(at the farther end of the plane). Well AS-5 is on the centre left of the photo (Reykjavik Energy Invest, 2008).**

The design of the exploration wells is to ensure the following: the safety of the well through the casing program (Table 1); maximum discharge by directional drilling; and high wellhead pressure through the wide drilling program. Directional drilling takes place in the second phase of the drilling and the bit is directed about 1° on every 30 m which are drilled (Figure 8). Once 800-1500 m depth is reached operational casing is set and cemented. Finally, in the third phase, the drilling takes place down to a working depth of 2000-2800 m and perforated liner is set at the bottom of the operational casing and it reaches to the bottom of the well. Table 2 shows the timeline for the phases of drilling and flow testing.

**Table 1: Drilling phases.**

Phase	Depth [m]	Drilling	Casing
Surface Drilling	60-90	Surface drilling	Surface casing
First phase	300-500	Drilling for anchor casing	Anchor casing
Second phase	800-1500	Drilling for production casing	Production casing
Third phase	2000-2800	Drilling for production zone	Perforated liner

**Table 2: The drilling and preparation of production wells.**

Action	Time Period	Well open/closed
Drilling	1-2 months	-
Thermal recovery	1-2 months	Closed/discharging
Flow testing	1-2 months	Open
Total	3 - 6 months	

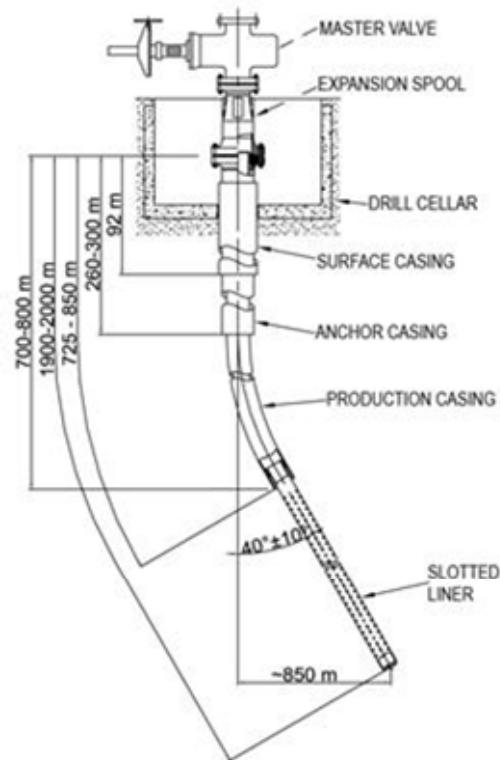
### 3.2 Testing Geothermal Wells

Testing of geothermal wells will be done through chemical monitoring, downhole measurements, and monitoring of water and steam flow. The monitoring plan has been prepared for the expected salinity in the geothermal fluid in Assal area.

After the rig moves off the well, well head discharge equipment will be installed, consisting of a lip pressure device, and a silencer were the flow of water at boiling temperature can be measured in a weir box. With the well head equipment in place the thermal and pressure recovery monitored by downhole measurements. When the well is ready it will be discharged and tested. During flow testing the monitoring of the downhole conditions will be continued, as well as the chemical recovery. The well head installation will enable continuous monitoring of discharge rate and the enthalpy of the discharge. Complete samples of brine and steam will be collected and analyzed and interpreted to determine the characteristics of the brine for utilization.

Due to the high scaling potential of the brine, scaling and corrosion tests will be carried out at one of the wells during the flow testing. The processes governing scaling in a discharging high-temperature well from saline geothermal reservoir are well known and the conditions where scaling starts have been established (Hardardottir et al., 2005). It is acknowledged that scaling is much more severe from saline systems than from dilute ones, and mitigating measures have to be taken to allow satisfactory operation of power production from such a resource. The scaling phases from saline brine in a discharging well can be summarized as follows:

- Sulfides – Commences at 35 – 45 bars
- Iron-silicates – Commences below 22 bars
- Amorphous silica – Commences at 5 bars



**Figure 8: The well is a drilled with directional drilling and has a deviation of 850m away from the vertical line.**

By proper well design and discharge management the scaling can be controlled to some extent and the disturbance reduced. By keeping well head pressure high enough, the precipitation of sulfides can be brought to the surface, were pipelines can be cleaned periodically in a controlled manner and minimum disturbance to the production. Silica scaling can be avoided by keeping the separation pressure and re-injection pressure above the silica saturation limit. The flow test will provide the needed information about the chemical behavior to enable the proper power plant design and reservoir management during production.

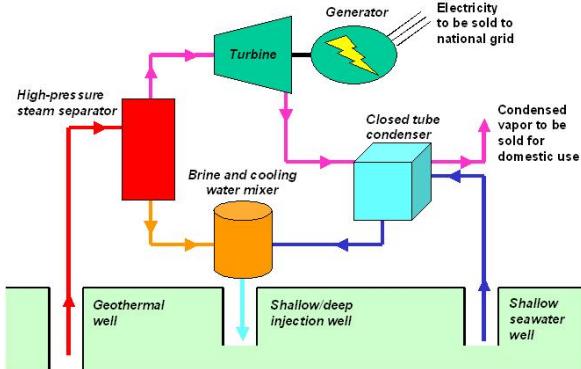
### 3.3 The Environmental Management Plan for the Power Plant

As the project approaches the construction phase a full scale environmental management plan will be completed for the construction and operation of the power plant. The intention is to do a social study on what has to be done to ensure positive social impact in the area and form a management plan to enforce that. In order to do that REI has made a Memorandum of Understanding with United Nations development Program on cooperation for this project. This project will be fulfilling a number of UNDP's Millennium Development Goals.

## 4. THE DEVELOPMENT PHASE

The intermediate goal is to commission a 50 MW plant in Djibouti. Once the capacity of the source has been confirmed with drilling, the project will proceed by continuing drilling production and re-injection wells in the area as well as having conceptual design done of the resource and the power plant. The development consists of access roads, service roads, production wells, water supply system, steam transmission pipes, steam separator stations, power house, cooling towers/units, steam exhaust stacks, a

groundwater supply system, water tanks, hot-water transmission pipe, quarrying, storage site, discharge system, injection areas and connection to the power grid.



**Figure 9: A conceptual design of a power plant that sells both electricity and condensed steam to the Djibouti market (Reykjavik Energy Invest, 2009).**

Figure 9 shows sketch of a conceptual power plant design, preferred by REI if Djibouti has market for condensed vapor. The design is principally the same as in Reykjanes, Iceland (Albertsson, 2010). Final design is subject to fluid chemistry and installation/operation cost plus of course Djibouti market prices of electricity and water. The construction time of the plant is estimated to be three to four years so operation can commence in 2013/2014.

## 5. CONCESSIONS AND CONTRACTS

REI has signed an agreement with the Government of Djibouti of exclusive license for geothermal utilization in the Assal area. The agreement provided REI with a concession to carry out a pre-feasibility study and will provide REI with a concession to carry out a feasibility study as well. Other contracts between REI and the Republic of Djibouti include a HOT Project Agreement (PA) and a contract with the power company of a HOT Power Purchasing Agreement (PPA).

## 6. THE BUSINESS MODEL AND FINANCING

When evaluating investment opportunities the main factor is the risk-return tradeoff where high levels of uncertainty (high risk) are associated with high potential returns. Geothermal power plants are of such nature that they require a large proportion of the cost to be spent prior to confirming the resource, where close to 1/3 of total project cost is the cost of drilling. This up-front cost causes geothermal power plants to have a different risk profile than other traditional power plants.

The cost of drilling is mainly financed with equity and the investors usually require a high ROE in a geothermal power plant. This increases the levelised energy cost. In order to go into financial closure about 60% of the needed energy has to be proven. Funding geothermal power plants has always been difficult and with the global financial crises it is even more so. Traditional power companies can finance geothermal plants largely with loans which keeps the WACC relatively low. New IPP projects, such as the one in Djibouti, use equity right in the beginning which causes the project to have a higher WACC than projects that are mainly funded with long-term loans.

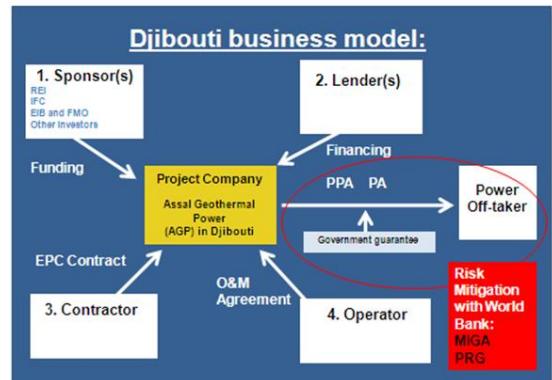
Geothermal harvesting worldwide would highly benefit if more attention would be brought to the financial aspect of geothermal harvesting. Both by focusing more on the finances at geothermal conferences as well as having more investors present.

The IPP business model for the Djibouti project can be seen in figure 10. REI signed a concession with the Republic of Djibouti for geothermal harvesting in the Assal Area. Since then REI has made a joint development agreement with International Finance Corporation (IFC) and has looked to other investors. It has been vital for the Djibouti project to have IFC, European Investment bank (EIB), and Nederlandse Financierings-Maatschappij (FMO) as shareholders. It would be considered very unlikely to sole finance the Djibouti project with private funding. This project requires developments banks to come into the early phases of the project.

The feasibility study has to be financed with equity. The long-term loans will come into the project at financial closer and in the Djibouti project the shareholders fully intend to come into the project by both increasing equity and by providing loans at financial closure.

The experience and knowledge of RE and Icelandic scientist has been used when analyzing the area and in assessing the resource. There results indicate very high likelihood of success. The experience of RE and Icelandic scientist will also be used in the designing, building and operation of the power plant during the lifetime of the contracts.

In addition the Djibouti project will be the first project to be approved by the ARGeo fund. The presence of ARGeo decreases the financial risk in the feasibility study and it has had a very positive effect on the investors' assessment of the project.



**Figure 10: The IPP business model for the Assal Geothermal Project.**

In order to decrease the financial risk for investors in the project, the intention is to purchase insurance, either from the World Bank (MIGA or PRG) or other third party in the open market.

The geothermal project in Djibouti is very economical for the nation. The current production cost in Djibouti, with old diesel machines, is 28 to 32 US cent/kwh while the estimate tariff from the geothermal plant is around 11 US cent/kwh. With the geothermal production Djibouti can save tens of millions of USD each year. It is vital for one of Africa's smallest countries, where GDP is low and

unemployment is high, to harvest its geothermal resources in order increase prosperity in the country while replacing diesel power plant with environmentally friendly energy.

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