Economic and Financial Appraisal of the Potential Geothermal Power Plant at Karkar

Task 1 Report (Revised):
Development of Preliminary Power Plant Concept

September 2012

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1 Introduction

The Armenia Renewable Resources and Energy Efficiency Fund (R2E2) asked Denzel Hankinson to conduct an economic and financial appraisal of the potential geothermal power plant at the Karkar geothermal site (the Karkar site). This work involves the development of a preliminary power plant concept (the conceptual plant) for the site based on previousfield investigation studies, and an analysis of the economic and financial viability of the conceptual plant.

The purpose of this report is to develop the conceptual plant and estimate the plant'stechnical specifications and performance characteristics. This involves four sub-tasks, which are as follows:

- Estimate the temperature and other key parameters at the Karkar site, which are essential to the assessment of electricity generationpotential.
- Identify the thermal cycle options based on the fluid parameters with maximum likelihood.
- Estimate the annual potential of the geothermal well(s) and maximum and minimum electricity generation per year based on the maximum likely key parameters of the resource potential.
- Assess the total capital and O&M cost (fixed and variable; major plant overhaul costs, make up well costs) of the potential geothermal power plant.

The remainder of the report is organized as follows

- Section 2 estimates the key parameters of the potential geothermal resource
- Section 3identifies potential thermal cycle options for the conceptual plant
- Section 4 quantifies the capital, operating costs and expected annual electricity generation of the different conceptual plant designs.

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2 Estimates of KeyParametersat the Karkar Site

This section provides estimates of the key parameters necessary for the development of a conceptual plant at the Karkar site. These parameters are as follows:

- **Resource temperature**. Resource temperature is essential for determining the amount of heat that can be provided to a power plant, and the optimal thermal cycle for the plant.
- **Mass flow rate from wells**. Mass flow rate of the thermal water, along with the resource temperature, is necessary to determine how much heat can be provided to a power plant built at the site.
- **Depth to resource**. Depth to the resource determines how deep the exploration and reinjection wells must be, which affects plant costs.
- **Size of resource area**. The extent of the geothermal resource area determines how large of a plant it can sustain.

There are additional parameters, such as total dissolved solids in the thermal water, whichwould be useful in the development of the conceptual plant. However, it was not possible to make reasonable estimates of these parameters based on the data in past studies and reports, so they are not discussed here or used in the development of the conceptual plant.

2.1 Results of Past Investigations of Geothermal Potential at the Karkar Site

The Karkar area has been investigated for geothermal potential for many years. The first survey was performed in 1932 – 1938. A more recent study—a three dimensional magnetotelluric (3D MT)survey—wasperformed in 2011. Many extensive reports have been written on the findings and much of the work is thorough and of good quality.[1]

While no geothermal system has been identified at the Karkar site, one 1000 m deep borehole drilled in the area shows high temperature gradients (over 90°C at 850 m depth), and three MT surveys from the area show a low resistivity layer at less than 1000 m depth. Models to explain the reason for the high temperature gradient in the borehole were developed in previous reports, and these models, as well as temperature estimates based on readings from geothermometers form the basis for our estimation of the key parameters for the site.

2.2 Estimation of the Temperature/Depth Distribution

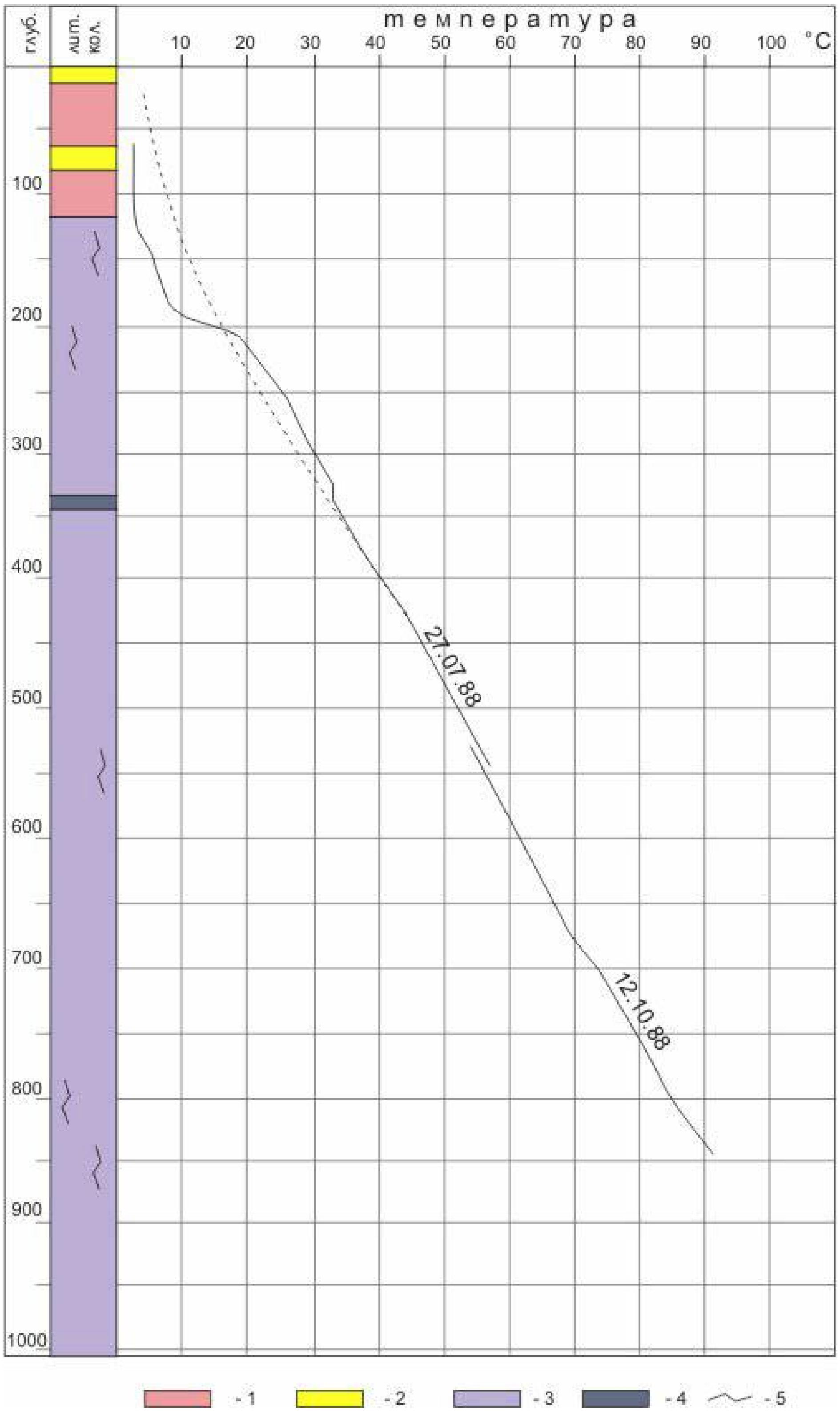
We estimated the temperature/depth distribution at the Karkar site based on conceptual models of the potential geothermal resource at the site, as well as the results of geochemical analyses conducted on spring water samples collected at the site.

[1] The reports that were provided to us by R2E2 can be found in Appendix A.

Conceptual models of the potential geothermal resource were developed in the 2012 report by Georisk Scientific Research Company and the University of South Florida.[2] In this report, temperature and depth data from exploration well B4 were used to produce a temperature model of the site. Figure 2.1 shows temperature and depth information from the borehole exploration and Figure 2.2 shows results of one of the temperature models used to estimate the temperature at greater depths.

Figure 2.1 Temperature and geological column in Borehole no. 4

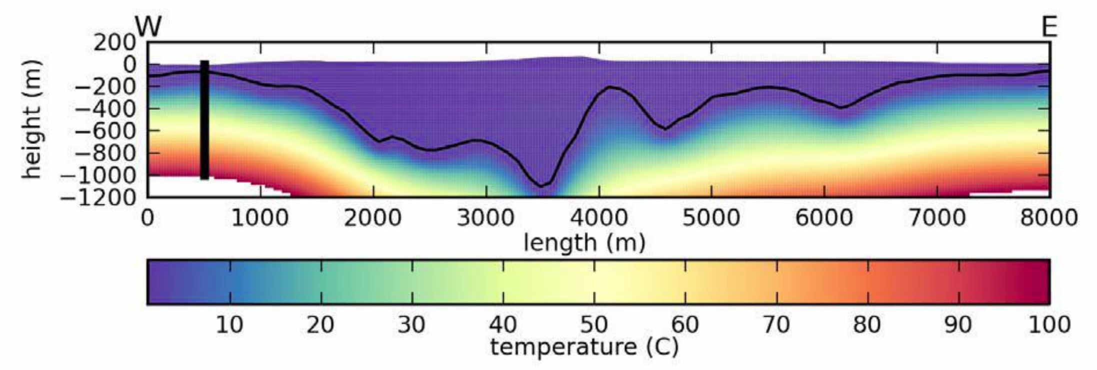
[2] See Appendix A



1 - basaltic andesite (3 4 Q –Q), 2 - alluvium-deluvium sediments, 3 - quartz monzonites, 4 - water-bearing zone, 5 - fractures.

Source: GEORISK Scientific Research Company 2008

Figure 2.2 Calculated Temperature Distributions



Source: GEORISK Scientific Research Company 2008

The results of the temperature model in Figure 2.1indicate that the temperature is expected to be less than 100°C down to 1000 m depth.The report in which this model was developed finds that it would be necessary to drill below 1000 m to achieve theminimum temperatures that could be used for power generation. The model assumes that the flanks of the pull-apart structure have higher temperatures than in the middle.

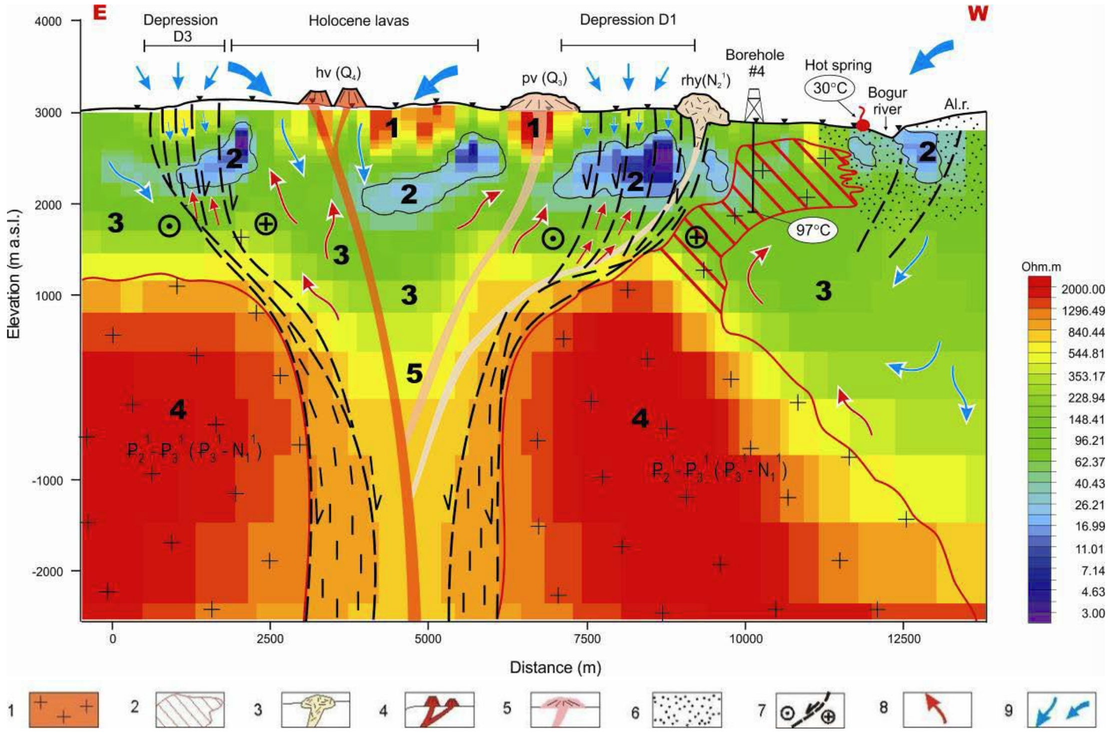
The inversion results of the MT surveys, which are from the 2011 Westerngecoreport,support the results of the temperature modeling in the Georisk and University of South Florida report.These results identified low resistive bodies that reach down to about 1000 m depth, with the largest ones located in the flanks of the pull-apart structure. Figure 2.3 and

We also used the results of the analysis of spring waters sampled at the Karkar site to estimate the temperature parameters of a conceptual plant at the Karkar site. This analysis was conducted by GEORISK Scientific Research Company, researchers from the University of Leeds and Western Geco Electromagnetics. In that analysis, chemical temperatureswere evaluated using Na/Mg/Ca, Na/K and Na/Li geothermometers. Potential temperatures were estimated as low as 20°C to as high as 566°C.

While these higher temperature estimates appear quite promising, it is important to note that the geothermal character of the water sampled for that study was very limited and, as a result, the reliability of the temperature estimates resulting from this analysis is low. Despite the fact that these estimates are somewhat unreliable, R2E2 requested that we also produce a conceptual plant design assuming that a high enthalpy resource existed at the site with a resource temperature of 300°C.

Figure 2.4 show two different model results based on the MT data, both of which identify low resistive bodies that are believed to indicate higher temperatures occur at relatively shallow depths.

Figure 2.3 Model Karkar A for a Depth of 5 km



1 – Dalidagh intrusion: Phases 1 and 2 together (Pg3 2 –N1 1) by the MT survey data; 2 – inferred distribution of Dalidagh Intrusion Phase 1 according to borehole data; 3 – rhyolites – Phase 3 of the Ddalidagh Intrusion (N2); 4 Pleistocene volcanoes in Karkar (Q13), 5 – Holocene volcanoes in Karkar (Q4), 6 – zone of hydrothermal silicification and alunitization; 7 – faults of the PambakSevan system; 8 – thermal mineralized waters; 9 – cold meteoric waters. 15 – structural units as layers of varying resistance according to the MT survey data.

Source: GEORISK Scientific Research Company 2008

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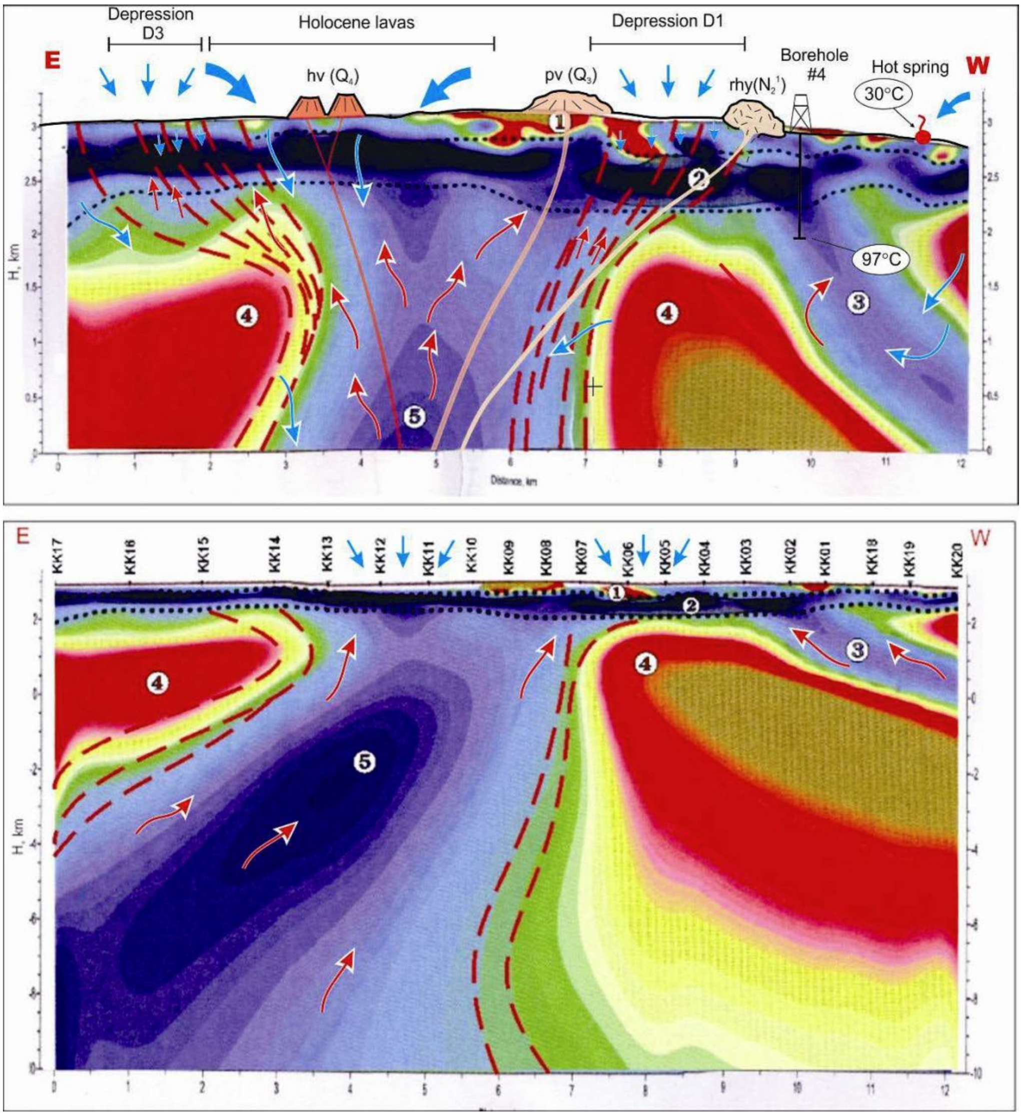
Figure 2.4 Two Dimensional Finite models of the Interpretation of the MT Survey in 2009



Note: model A is for the depth of 3.5 km, and model B is for the depth of 10 km, considering the interpretation of the 2D MT data by Models “Nord-West”-2009 and 2004, and assuming presence of low resistance values of 20-30 Ohm x m in the zone of Layer 5 (PDZ). Legend is the same as in Figure 2.3.

Source: GEORISK Scientific Research Company 2008

2.3 Key Parameters

The key parameters of resource temperature and depth, well mass flow and resource area were estimated as follows. The temperature/depth distribution was modeled based on the extrapolation of the well temperature profile at greater depth and the identification of a conductive layer in the MT surveys, as discussed above. We also used the results of geothermometer analyses conducted on spring water collected at the Karkar site to infer temperature estimates of the potential geothermal resource. Mass flow was estimated at the minimum range possible for economical use. The size of the resource areawas estimated from the results of the MT survey.

Table 2.1 presents a summary of the estimates of the key parameters for the site based on this analysis.

Table 2.1Key Parameters for the KarkarSite

Parameter	Unit	Report Value / Range	Estimated Value / Range	Comment
Resource temperature	°C	None	110 – 300°C	Based on the temperature in well B4 and the depth to the reservoir, as well as soil gas and spring water measurements
Depth to resource (i.e. estimated well depth)	m	Not known	1000-1250	Based on 3D MT data
Mass flow from well	kg/s	Not known	Minimum for economical use	Estimated at 25-50 l/s for the low temperature cases and 17-43 kg/s for the high temperature case*
Resource area	km^2	Not known	25	Based on the 3D MT data

Source: Reports provided by R2E2. See Appendix A for a full list.

*Note: low temperature mass flow estimates are expressed in l/s because the geothermal resource would be expected to produce liquid at these temperatures, while the high temperature mass flow estimates are expressed in kg/s because the resource would be expected to produce a combination of liquid and steam.

3 Development of the Conceptual Plant

This section provides an overview of the conceptual plant, which was designed based on the estimates of key resource parameters from Section 2. It specifies basic production and injection well designs, describes two potential binary-type thermal cycle design options and one Flash-type thermal cycle design option, and also provides a preliminary plant layout.

3.1 Basic Production and Injection Well Design

Based on the temperature, depth and flow rate parameters estimated in Section 2, the conceptual plant requires production wells that house downhole electrical submersible pumps (ESP). For the Binary cycle designs, the downhole ESPs will need to allow a production flow up to 50 kg/s of reservoir fluid and temperatures from 110-130 °C. The surface pressure of the fluid must be kept above 3 bar. For the Flash cycle design, downhole ESPs are not necessary.

The casing program proposed for the production wells is listed in Table 3.1. In the Binary cycle designs the anchor casing will house the downhole ESPs, which can be set down to 300 m. If more drawdown is expected, then the anchor casing will need to be deepened. In the Binary cycle designs a tube may be set from the pump to the surface for the transport of the reservoir fluid. The production casing will be telescopicto allow for the pumps.

The depth from the top of the reservoir to the geothermal resource is estimated to be about 1000 m, but it is assumed that an additional 250 m will be needed for a production interval. The production interval will be sealed off with a slotted liner to prevent collapse or caving during production.

Table 3.1 Proposed Production Well Program

Section	Depth (m)	Bit Diameter	Casing Diameter
Surface Casing	100	23"	18⅝"
Anchor Casing	350	17½"	13⅜"
Production Casing	300 - 1000	12¼"	9⅝"
Slotted Liner	950 - 1250	8½"	7"

The geothermal fluid will be returned to the reservoir by injection wells which are shown in Table 3.2. The production casing will be set all the way to the surface of the wells. A slotted liner may need to be set in the bottom for the injection interval, depending on rock conditions.

Table 3.2 Proposed Injection Well Program

Section	Depth (m)	Bit Diameter	Casing Diameter
Surface Casing	100	23"	18⅝"
Anchor Casing	400	17½"	13⅜"
Production Casing	1100	12¼"	9⅝"
Slotted Liner	1150-1250	8½"	7"

In the Binary cycle designs the energy used for pumping the reservoir fluid to the surface may affect the power supplied to the grid by the power plant,as the pumps have large electrical loads. However, due to the fact that the drawdown of the water level is unknown for the area, the expected parasitic load of the water pumps is unknown. We have assumeda production of 50 kg/s with a 100 m drawdown in the production wells, resulting in a pump parasitic load ofabout 70 kW per pump.

In the geothermal fluid, some dissolved chemicals may be present that can scale during utilization of the fluid. However, this would have to be further investigated when the first well is drilled.

3.2 Plant Generating Capacity

Given the uncertainty and margin for error in estimates of mass flow and reservoir size, the size of the conceptual plant is estimated based on existingbinaryand flash power plant sizes, rather than on a site-specific analysis. The gross capacity of the conceptual plant in the Binary cycle designs is assumed to be 8 MWe. The gross capacity of the conceptual plant in the Flash cycle design is 30 MWe. Due to the fact that these estimatesare based on benchmarks rather than real data, they are somewhat arbitrary. As described in Box 3.1, conventional methods for determining geothermal plant capacity often involve building a small plant and expanding it as additional information on the geothermal resource is gathered.

Box 3.1:Determining Geothermal Plant Capacity

Geothermal plant capacity is difficult to estimate before production has begun. Making accurate estimates of geothermal plant generating capacity prior to plant operation requires drilling several wells, discharging the wells and measuring how the geothermal resource reacts to discharging. However, this is usually impractical.

As an alternative, oftentimes plants are built small and expanded over time, as appropriate. Typically, once a resource has been confirmed, a moderately-sized power plant is constructed and the reaction of the resource to the operation of the plant is measured. These observations provide the basis for decisions whether or not to expand the existing plant.

3.3 Basic Design of Thermal Cycle Options

Three resource temperature estimatesare developed based on the data reviewed in Section 2. These consist of two low temperature estimates of 110° C and130° C as well as one high temperature estimate of 300° C.The low temperature estimates suggest two distinct thermal cycle options: Organic Rankine Cycle (ORC) and KalexCycle. ORC plants make use of organic fluids with boiling points at temperatures lower than water, which allows Rankine cycle heat recovery from low temperature heat sources. Kalex cycle plants utilize a variant of an ammonia water cycle Kalina cycle plant and are state of the art thermal cycles for electricity generation by low enthalpies. The high temperature estimate suggests a Flash cycle design, in which the steam from the geothermal fluid is used directly to generate power.

The decision to utilizean ORC or a Kalina cycle to make use of a potentially low temperatureresource may be debated, however when temperatures are high

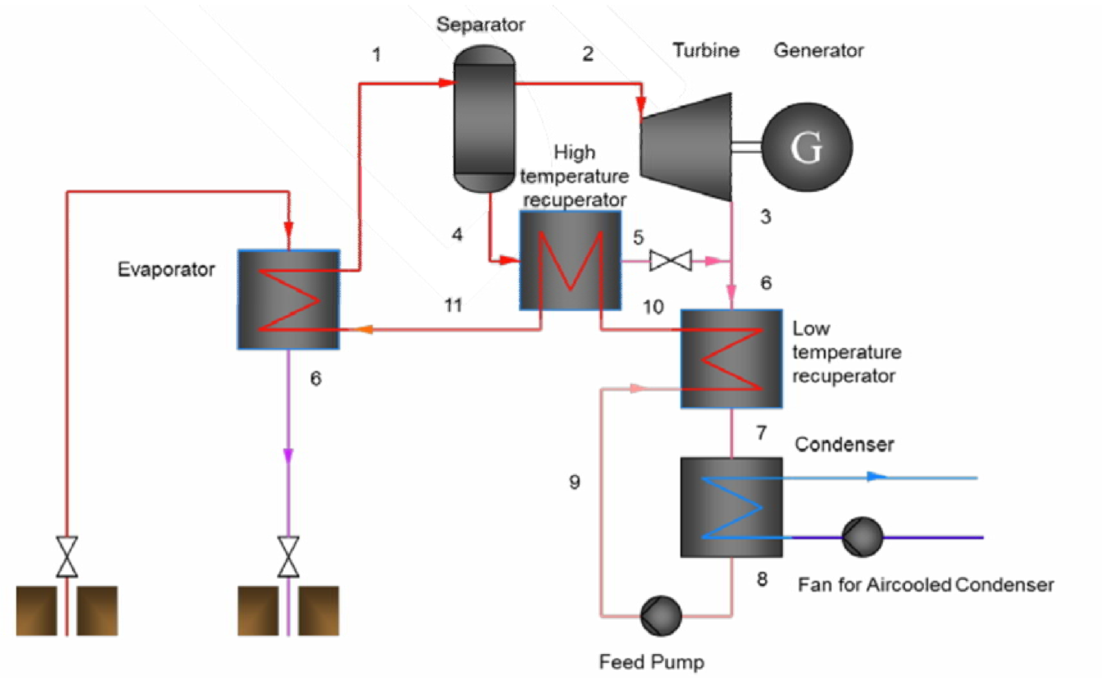
(160°C-185°C) the ORC cycle is believed to have an advantage. Furthermore, ORC power plants are the more conventional option: they have been in operation for substantially longer than Kalina Cycle power plants and there are significantly more in operation. On the other hand, Kalina cycle plants normally work better at temperatures lower than approximately 140°C. An ORC plant is therefore considered for the highest temperature estimate, even though 130°C is below the typical minimum resource temperature threshold for an ORC plant of 138°C.AKalina cycle is considered to address the lower temperature estimate.

3.3.1 Kalex Cycle Design

The Kalina/Kalex cycle circulates a mixture of water and ammonia within a closed loop between the evaporator and condenser as shown inFigure 3.1. Starting at the evaporator, the process fluid is heated and evaporated in the evaporator and exits the unit as Stream 1. The stream enters a separator that separates the ammonia rich vapor from the ammonia lean liquid. The vapor exits the separator as Stream 2 and enters the turbine, which produces electricity by impelling the generator (G). The vapor then leaves the turbine as Stream 3 and is mixed with the lean fluid of Stream 5. The liquid exiting the separator as Stream 4 enters the High Temperature Recuperator (HTR), which is a heat exchanger that recycles heat that would otherwise be wasted within the system. The liquid exits the heat exchanger as Stream 5 at a lower temperature before it is mixed with Stream 3. The mixed fluid (vapor and liquid) at Stream 6 enters the Low Temperature Recuperator (LTR), which serves a similar purpose as the HTR. The spent liquid exits the LTR as Stream 7 before entering the condenser, which condenses the fluid to liquid form as Stream 8. A pump circulates the liquid from Stream 8 at a higher pressure as Stream 9, before entering the LTR. Stream 10 and 11 are two steps in which the liquid is heated in the recuperators, before entering the evaporator again. The heat source for the evaporator is in this case the geothermal fluid provided by the wells.

The main characteristic differentiating the Kalina Cycle from the ORC is that the fluid, which is utilized in the closed cycle, is a mixture of water and ammonia. The evaporation temperature of the mixture changes with concentration of ammonia. Therefore, while passing through the boiler, the temperature profile of the working fluid can be better adapted to the temperature profile of the geothermal fluid. This reduces second law losses and results in higher second law efficiency of the working cycle. Another characteristic of the cycle is that with separation and mixing, the ratio of the ammonia and water mixture can be changed, changing condensation temperature, evaporation temperature and other properties of the fluid. This characteristic can be used to improve the efficiency of the cycle.

Figure 3.1: Kalina Cycle, a Modified Kalina Cycle Proposed for the Hot Water Low Enthalpy Reservoir at 110°C.

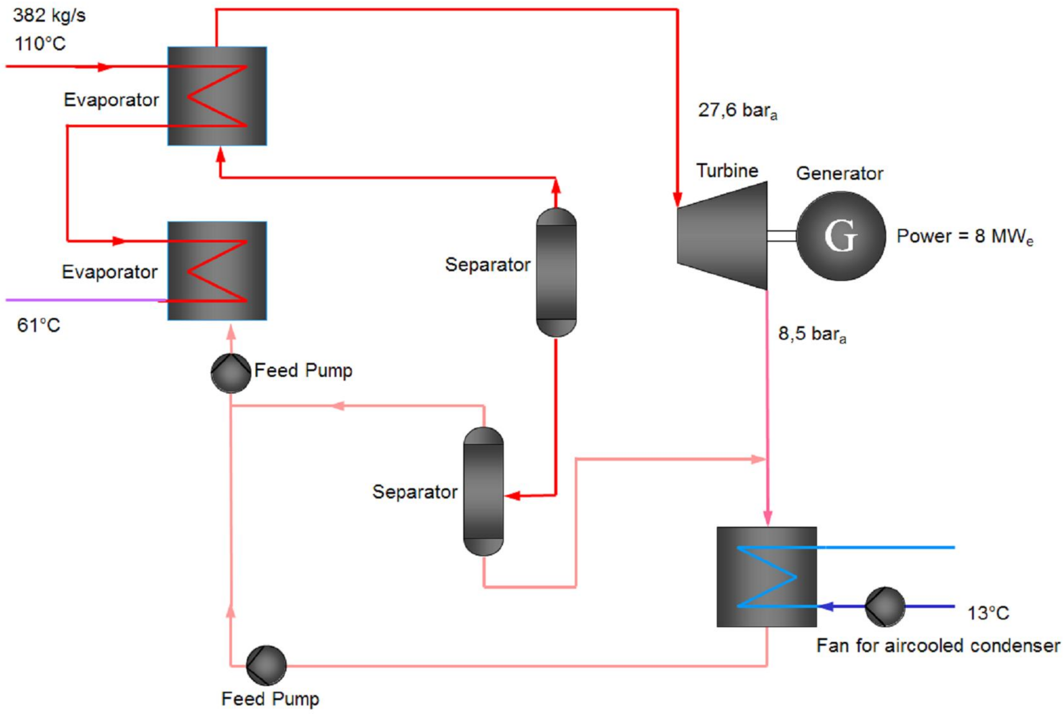


The Kalina technology has a short history of commercial operation in the geothermal sector. Kalina plants can be found in Iceland, Japan and Germany, and three of these plants are geothermal plants. Further Kalina plants are planned or under construction.

The Kalex cycle can be considered a modified Kalina cycle. It has the same advantages as the Kalina Cycle in terms of high second law efficiency due to the variable boiling point of the mixture with concentration. However, with respect to the working fluid, the difference of the characteristics of the Kalex Cycle and the Kalina Cycle is the thermal recuperation in the internal cycle. This is a definite theoretical advantage to the Kalina Cycle as a larger part of the thermal energy can be converted into electrical energy.

Today there are no up and running Kalex plants and it cannot be considered a proven technology, though it is state of the art. For this analysis a Kalex SG-16 cycle is chosen and a process flow diagram for the cycle at design conditions is presented in Figure 3.2.

Figure 3.2: Process Flow Diagram for the Kalex SG-16 cycle



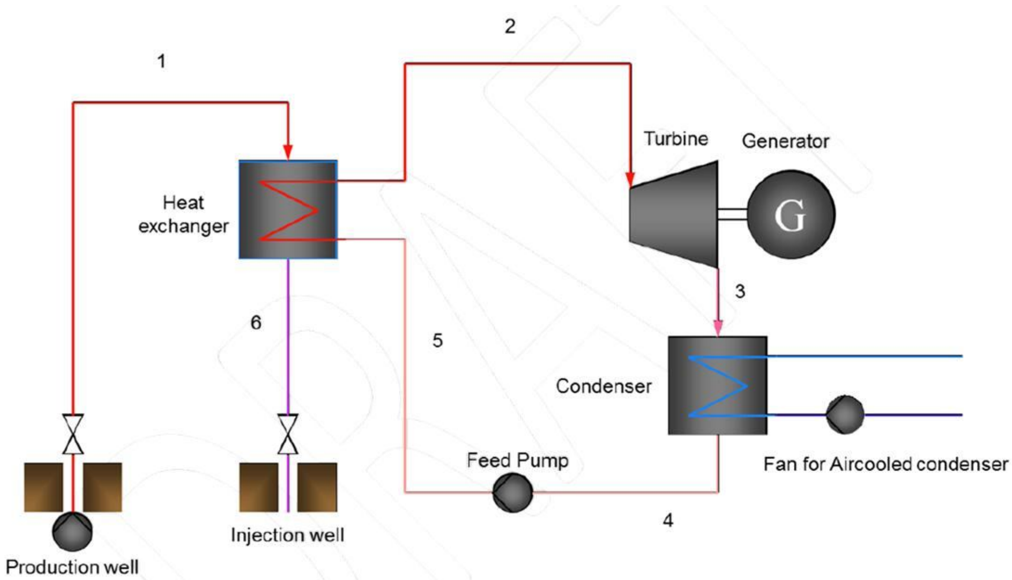
In order to generate 8 MWe gross in the Kalex cycle plant, 382 kg/s of the geothermal liquid is required. The geothermal liquid is cooled down to 61 °C before it is re-injected into the reservoir. The net output from the generator will be 6.4 MWe, as approximately 1.6 MWe are required for cooling pumps, feed pump and geothermal liquid pumps.

3.3.2 Organic Rankine Cycle (ORC) Design

A schematic diagram of an ORC plant is shown in Figure 3.3. Stream 1 shows the path of the reservoir fluid which is pumped up through the production wells. Generally, a well pump is needed as low-temperature geothermal resources are usually not self-flowing. The binary working fluid (normally isobutane or isopentane) is heated and evaporated in the heat exchanger and is piped to the turbine (Stream 2). The gas impels the turbine and electricity is generated in the generator (G) coupled to the turbine. The slightly superheated binary fluid exits the turbine at lower pressure as Stream 3 and enters the condenser where it condenses back into liquid form (Stream 4). A feed pump circulates the liquid at a higher pressure (Stream 5) before entering the heat exchanger and again repeating the process. The geothermal fluid is injected back into the reservoir (Stream 6) through re-injection wells.

Sometimes a recuperator is added in an ORC plant to increase the power cycle's efficiency. In this case, then the binary fluid is cooled before entering the condenser and preheated before entering the heat exchanger.

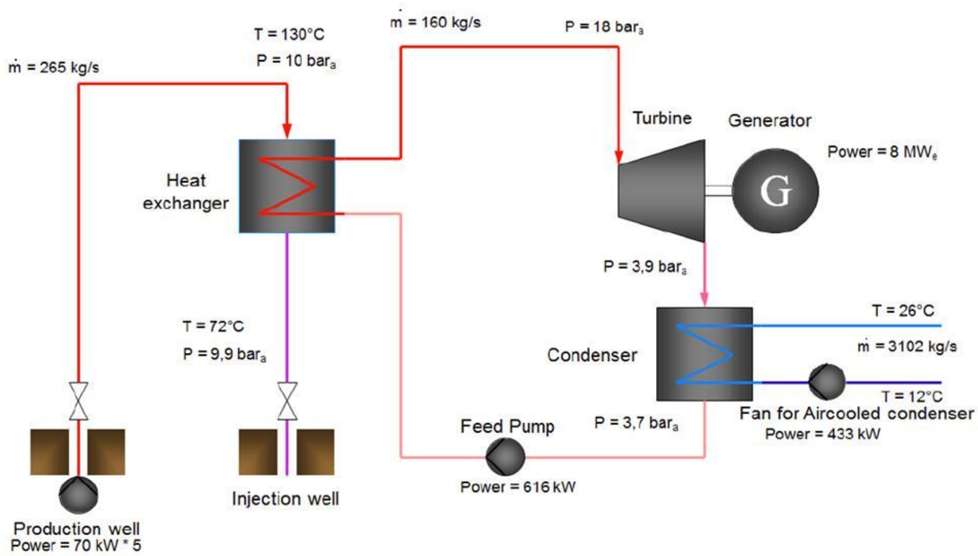
Figure 3.3: Organic Rankine Cycle, Proposed for the Hot Water Low Enthalpy reservoir at 130°C



The condenser requires cooling which may be provided by either water (wet cooling) or air (dry cooling). Even though air cooled condensers are more effective, wet cooling is often preferred, since the cost and foot print is smaller and the output not as dependent on ambient condition. Dry cooling may be the only option in areas of limited water resource, as is expected in this case.

The working fluid of an ORC is selected when preliminary results are obtained from the well flow tests. Given the temperature assumed in this report, isobutanewould likely be the best choice of binary fluid.A schematic diagram of an ORC process for the low enthalpy hot water reservoir at the site is shown in Figure 3.4.

Figure 3.4: Process Flow Diagram for the ORC

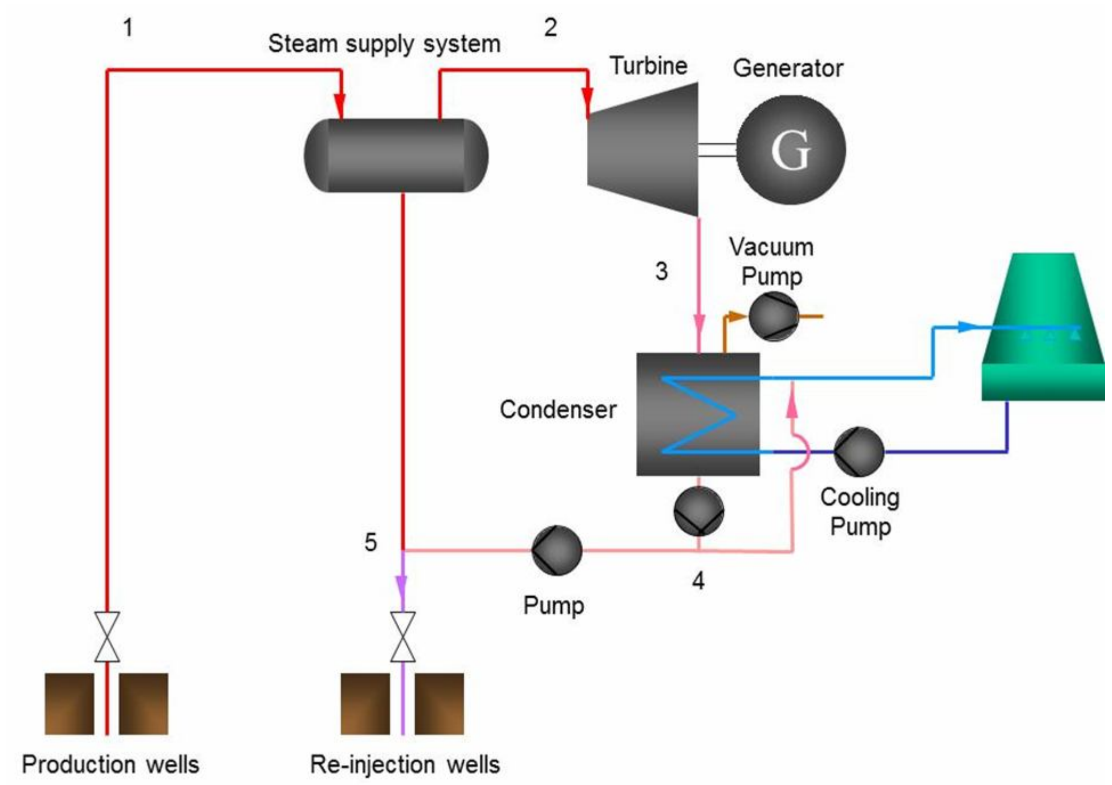


In order to generate 8 MW gross, 265 kg/s of geothermal liquid is required. The geothermal liquid is cooled down to 72 °C before it is re-injected into the reservoir. The net output from the generator will be 6.5 MW, as approximately 1.5 MW is required for cooling pumps, feed pump and geothermal liquid pumps.

3.3.3 Flash Cycle Design

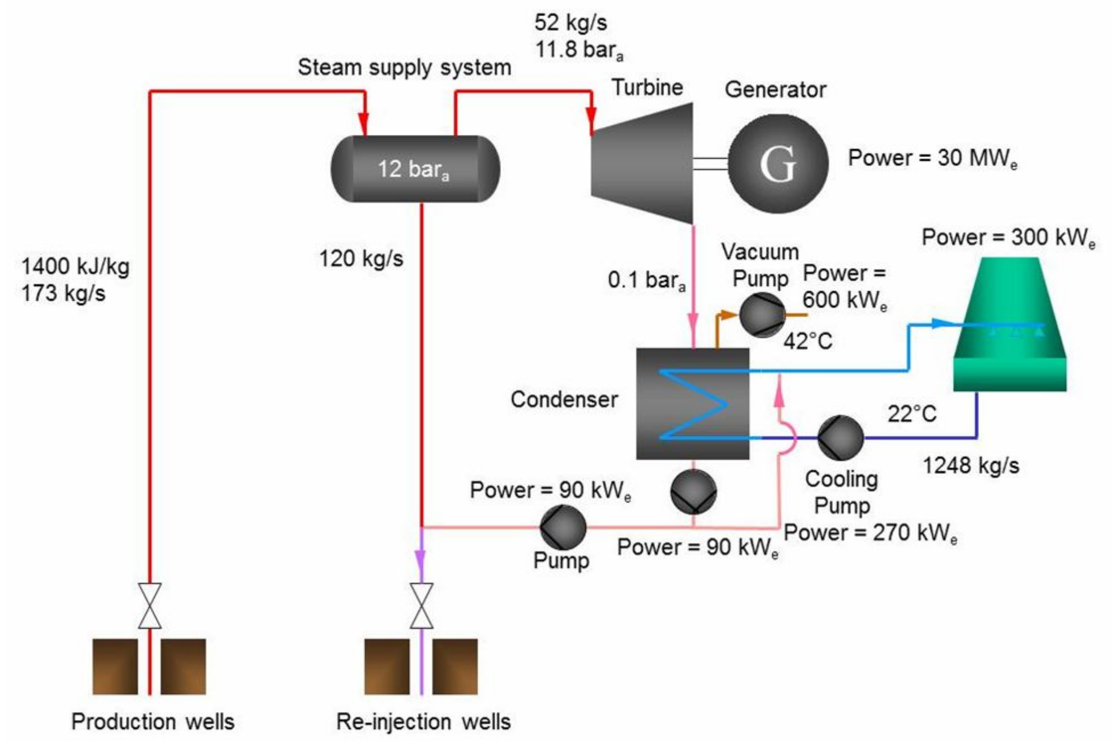
A schematic diagram of a Single Flash Cycle is shown inFigure 3.5.Stream 1 represents a mixture of steam and liquid, which is piped from the production wells to the steam separator where the fluid is separated from the steam. The liquid is disposed into the reservoir through re-injection wells as Stream 5. In Stream 2, the steam flows into the turbine and electrical power is generated in the generator coupled to the turbine. The steam goes as Stream 3 into a condenser where it is condensed at a low pressure. After going through the condenser, the fluid is in liquid phase as Stream 4 and a part of itis used as make up water for the cooling tower while the rest is pumped to the re-injection wells.

Figure 3.5: Flash Cycle, Proposed for the High Enthalpy reservoir at 300°C



A process flow diagram for the Flash cycle plant is shown below in Figure 3.6.

Figure 3.6: Process Flow Diagram for the Flash Cycle

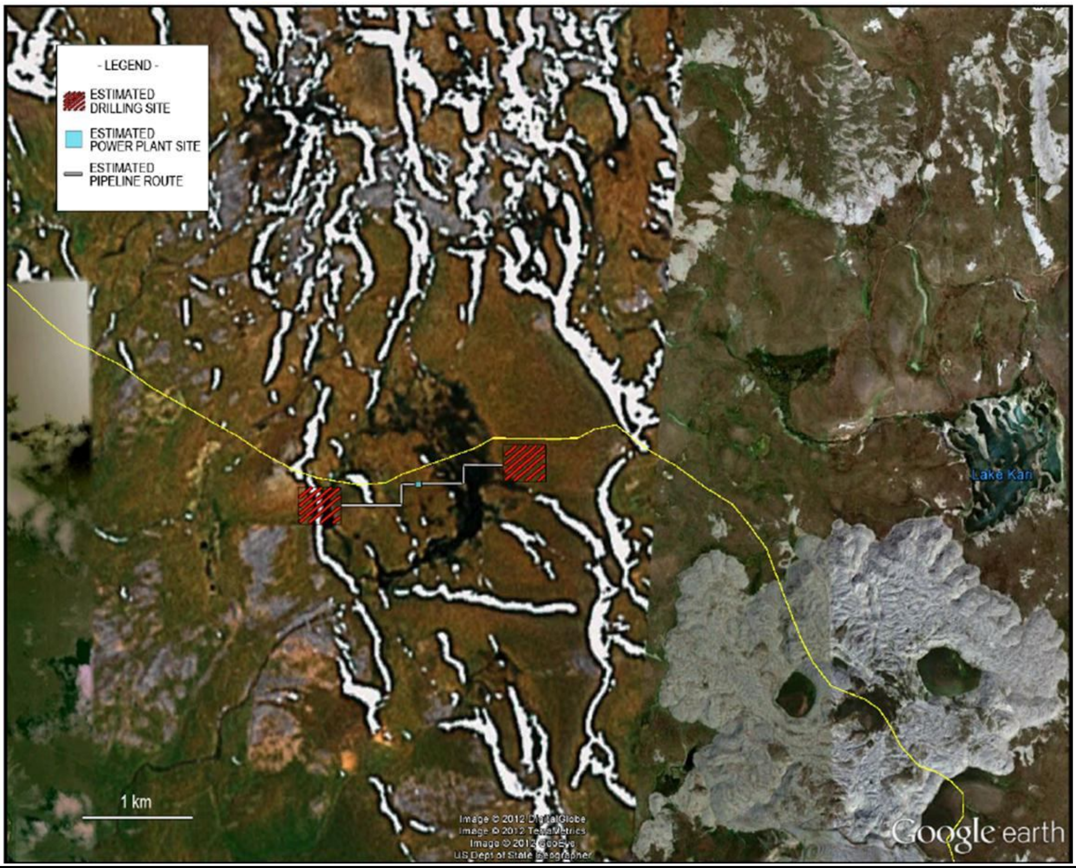


In order for the Flash cycle design to generate 30 MW gross, 4-10 production wells and three injection wells will be required. The net output from the generator will be 28.5 MW, as approximately 1.5 MWwill be required for a circulation pump, vacuum pumps, cooling pumps and cooling tower fans.

3.4 Conceptual Plant Layout

Figure 3.7shows a layout for the conceptual plant. The layout includes estimated drilling field, power plant and pipeline route locations. The plant is located close to the border between Armenia and Azerbaijan, which is indicated by the yellow line. It must be noted that this layout is very preliminary and the siting of each of these would depend on the success and analysis of further exploration wells.

Figure 3.7: Preliminary Layout of the Conceptual Plant


- LEGEND -
ESTIMATED DRILLING SITE
ESTIMATED POWER PLANT SITE
ESTIMATED PIPELINE ROUTE
Lake Kari
1 km
Image © 2012 DigitalGlobe
Image © 2012 TerraMetrics
Image © 2012 GeoEye
US Dept of State Geographer
Google earth

4 Annual Electricity Generation and Plant Cost Estimates

This section presents estimates of annual electricity generation from and the capital and operating costs of the conceptual plant. Estimates are made for each of the three conceptual plant designs described in Section 3.

4.1 Annual Electricity Generation Estimates

Annual electricity generation sent to the power grid from the plant depends on theinstalled capacity of plant, the plant's annual running time, the size of the on-site electrical load (parasitic load), and ambient temperature fluctuations, which affectthe plant's power output. These assumptions are presented below for each of the designs of the conceptual plant, followed by estimates of average annual electricity generation from each design.

Annual Running Time

A plant's annual running time is determined by planned and forced outages. The estimated annual downtimefor the conceptual plant due to maintenance and unscheduled stops is assumed to be approximately 7-10 days.Longer maintenance stops of approximately 21-28 daysare expected to be necessary every 3-5 years.[3] These estimated downtimes result in an operational efficiency of 95-97 percent. For the purposes of this report, it is assumed the operational efficiency will be 97 percent, since this would be a new plant with new equipment.

On-Site Parasitic Load

As mentioned above, the gross capacity of the Kalex cycle and ORC designs is assumed to be 8 MW, and the gross capacity of the Flash cycle plant is assumed to be 30 MW. For the Kalex cycle plant and the ORC plant,parasitic load is primarily due to the electricity consumption of the downhole ESPs, the binary fluid circulation pumps, the fans in the cooling tower and the cooling water circulation pumps. For the Flash cycle plant, parasitic load is primarily from the fluid circulation pump, vacuum pumps, cooling pumps and cooling tower fans. Adjusting for parasitic loads,plant net generating capacityis assumed to be 6.4 MW for the Kalex cycle design,6.5 MW for the ORC design and 28.5 MW for the Flash cycle design.

Effect of Ambient Temperature Fluctuations on Power Output

The ability of a power plant to reject heat into the environment determines its thermal efficiency, and therefore its power output. For air-cooled plants for which the heat sink is the ambient air (such as the conceptual plant presented in this report), ambient air temperature fluctuations affect plant power output. For each design of the conceptual plant, the effects of ambient temperatures on power output are estimated for three conditions: cold, design and hot. Interpolation is used to calculate power output for other available temperatures. The average annual power output is then multiplied by the assumed operational efficiency of the plant to estimate the gross annual average energy production.The effects of ambient

[3] It is possible more maintenance will be necessary if there are unforeseen difficulties with chemistry and gas in the steam.

temperatures on plant power output are shown for the ORC design in Figure 4.1, for the Kalexcycle design in Figure 4.2 and for the Flash cycle design in Figure 4.1.

Figure 4.1: Power Output Fluctuations Due to Ambient Temperature in the ORC

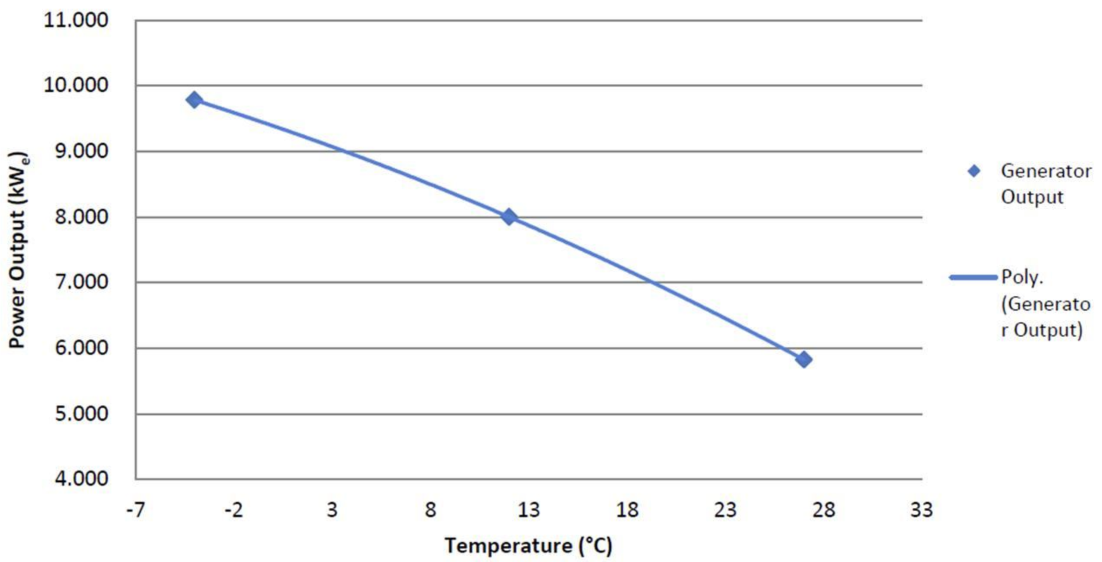


Figure 4.2: Power Output Fluctuations Due to Ambient Temperature in the Kalex SG-16 cycle

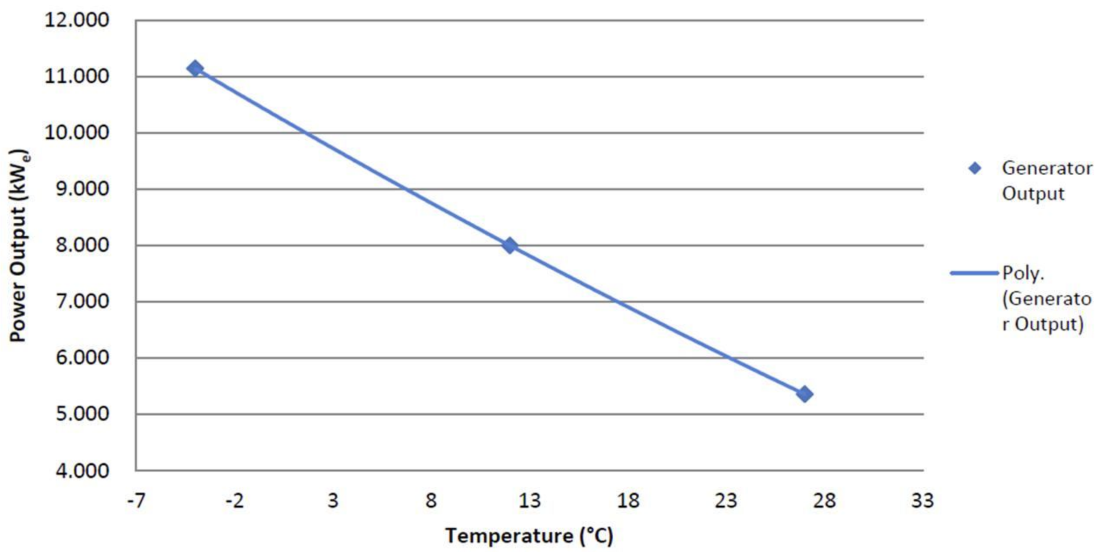
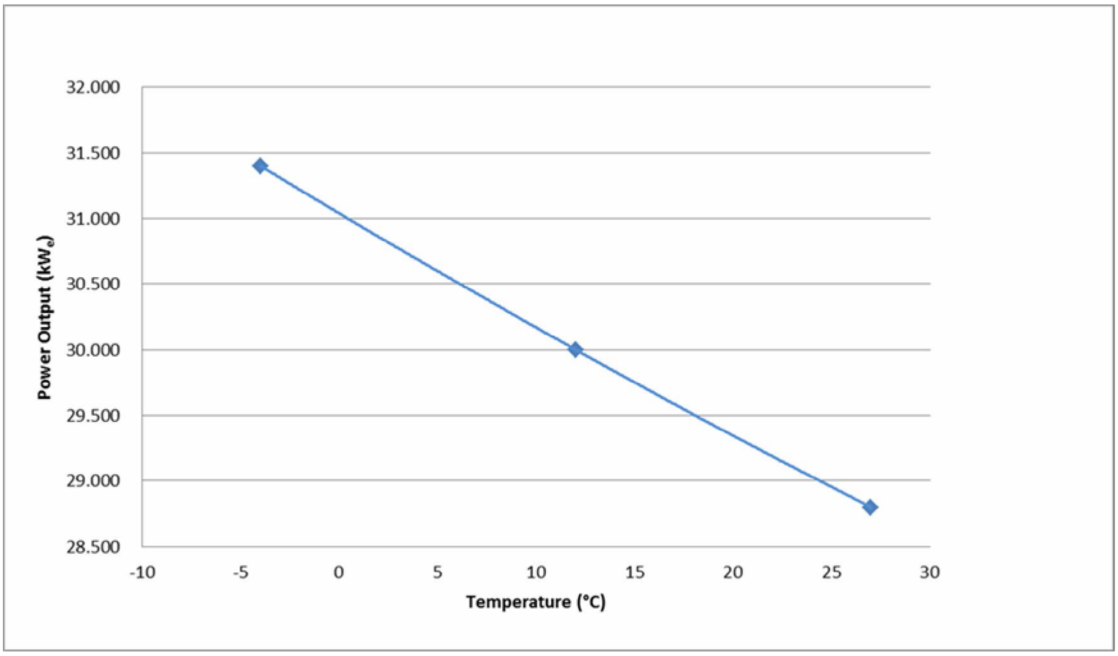


Figure 4.3: Power Output Fluctuations Due to Ambient Temperature in the Flash cycle design



Annual Average Energy Production

Annual average energy production estimates for the two designs of the conceptual plant are presented in Table 4.1. Under the assumptions about parasitic loads and ambient temperature effects presented above, the Kalex cycle design is estimated to have a capacity factor of approximately 84 percent, the ORC design is estimated to have a capacity factor of approximately 87 percent and the Flash cycle design is estimated to have a capacity factor of 96 percent.[4]

Table 4.1: Annual Average Energy Production

Thermal Cycle	Installed power gross (MW_e)	Installed power net (MW_e)	Operational efficiency	Annual average Energy Production Gross (MWh)	Annual average Energy Production Net (MWh)
KALEX SG-16	8	6.4	97%	60,100	47,000
ORC	8	6.5	97%	61,500	49,700
Flash	30	28.5	97%	251,300	239,700

4.2 Capital and O&M Cost Estimates

This section presents estimates of capital and O&M costs for each design of the conceptual plant. A range of capital cost estimates are presented for each design. These ranges affect the cost of generation and therefore will be incorporated into the economic and financial analyses.

[4] Capacity factor is calculated on a net basis, taking into account each design's net installed capacity and net energy production.

Accuracy of Cost Estimates

It is difficult to make accurate estimates of the cost of projects at the concept stage, and cost estimates at this stage generally have a large margin of error. There are a number of standards and classification systems that can are used to aid in making these estimates.For the purposes of this study, the AACE International Cost Estimate Classification System was used.[5]

Under this classification system, this project is a Class 5 or Concept Screening level estimate with a range of -50/-20 percent up to +30/+100 percent inaccuracies. With further research of the resource and design premises, this estimate wouldbecome more detailed and accurate.

Capital Cost Estimation Methodology

Equipment costs are based on experience gained from similar projects we have worked on in the past, and adjusted to account for changes in the costs of equipment since work on these projects was done. The methodology used for adjusting these past costs to reflect current costs is called the "multiple factor method."[6]Under this method, capital costs are based on actual prices and/or quotations and corrected in accordance with the following equation:

$$C_2 = C_1 \frac{i_2}{i_1} \times \left(\frac{q_2}{q_1}\right)^n$$

In the equation the number 1 indicates a past or known value and 2 a current or wanted value. C stands for cost, i for index, and q for quantity, capacity or size as applicable. N is the capacity-ratio exponent. The indexes are based on our prior experience and the Chemical Engineering Plant Cost Index (CEPCI) at the applicable date.

Capital Cost Estimates

Ranges for itemized capital cost estimate for the ORC,Kalexcycle and Flash cycle designs are presented in Table 4.2.The upper and lower bounds of the capital cost ranges for each design are dependent on the well costs, which are estimated for the upper and lower bound well productivity estimates,as described in Section 0. For the ORC design, the 25-50 l/s range of mass flow would require 5 to 10 doublets (pairs of production and injection wells). For the Kalex SG-16 design, it would require 8 to 15 doublets. For the Flash cycle design, three injection wells would be required, regardless of the number of production wells. For this design, 4-10 production wells would be required.

The total cost of design, project management, procurement and supervision is estimated as 20 percent of all other plant costs (exclusive of cost contingency), and itemized as "engineering" in Table 4.2. A cost contingency of 20 percent of non-engineering costs is also added.

Table 4.2: Capital Cost Estimates

[5] AACE International "AACE International Recommended Practice No. 17R-97: Cost Estimate Classification System," August 12, 1997

[6]Guthrie, K. M., & Grace, W. R. (1969, March 24). Capital Cost Estimating. Chemical Engineering , pp. 115-142. ; Helfrich, F., & Schubert, W. (1973). Ermittlung von Investitionskosten, Einfluss auf die Wirtschaftlichkeitsrechnung. Chemie-Ing.-Techn. 45.Jahrg. , 891-897; Perry, R. H., Green, D. W., & Maloney, J. O. (Eds.). (1997). Perry's Chemical Engineer's Handbook (Seventh ed.). New York: McGraw Hill.

Item	KALEX 110°C (Million US$)	ORC 130°C (Million US$)	FLASH 300°C (Million US$)
Surveying	0.5	0.5	0.5
Wells	43-75	29-52	25-39
Power Plant	27	22	48
Substation	0.5	0.5	2
Engineering	5.6	4.5	10
Contingency	5.6	4.5	10
TOTAL	**82-114**	**61-84**	**95.5-109.5**

A theoretical project schedule for the binary cycle plants is presented in Figure 4.4 and the schedule for the Flash cycle plant is presented in Figure 4.5. In addition to showing a theoretical project schedule, these figures demonstrate how project risk is highest at the early stages of the project when there is still significant uncertainty in the resource and total cost of the project. As project development proceeds and certainty in the estimates of resource characteristics and total costs increases, this risk decreases. However, the amount of money spent on the project in the early phases is low compared to the amount spent in later phases. The risk profile is roughly the inverse of the investment cost profile over the course of the project's development: risk decreases as project development proceeds while total investment cost increases.

Figure 4.4: Project Schedule – Binary cycle designs

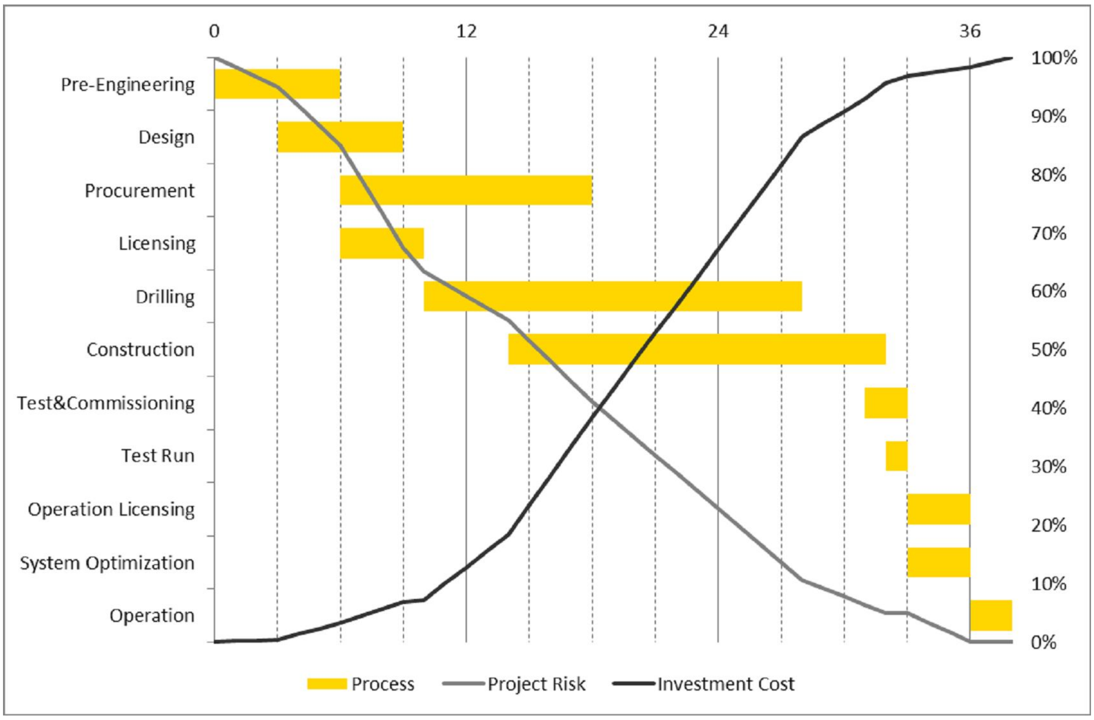
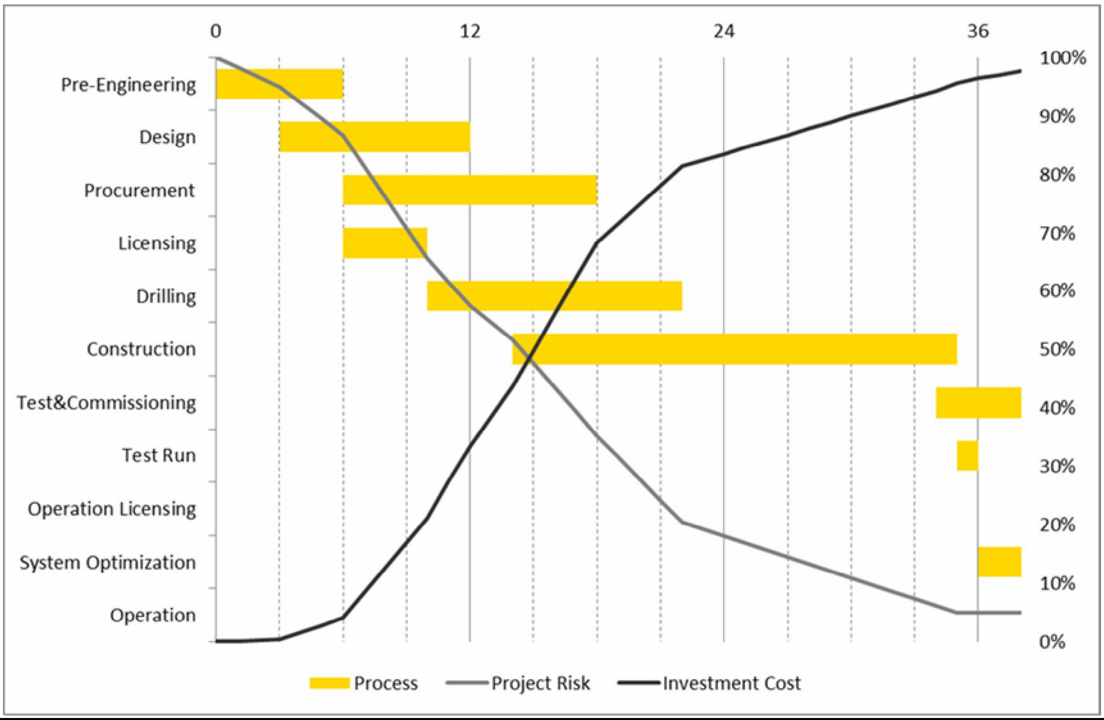


Figure 4.5: Project Schedule –Flash cycle design



The capital costeach design is presented in Table 4.3 as quarterly expenditures during the construction phase.Well drilling occurs in the 4th through 10th quarters of plant construction for the binary cycle plants, and the 4th through 8th quarters of plant construction for the Flash cycle plant.

Table 4.3: Quarterly Expenditures During Plant Construction

Quarter	**KALEX 110°C (Million US$)**	**ORC 130°C (Million US$)**	**FLASH 300°C (Million US$)**
1st	0.3	0.3	0.3
2nd	2.5	1.7	3.7
3rd	3.6	2.3	12
4th	5.8-9.4	3.7-6.3	16-19
5th	9.6-14.9	6.5-10.4	16-19
6th	12.5-17.9	9.4-13.1	18-21
7th	11.7-17	8.9-12.8	9.5-13
8th	11.7-17	8.9-12.8	5-6.5
9th	11.7-17	8.9-12.8	3
10th	6.8-8.7	5.7-6.8	3
11th	4.5	3.7	3
12th	1.5	1.00	3.5
13th	0	0	2
14th	0	0	0.5
TOTAL	***82-114***	***61-84***	***95.5-109.5***

Operating Costs

The operating costs of a geothermal power plant primarily consistof the following items:

- General overhead costs
- Supervision of machinery
- Materials for operation
- Additional drilling to maintain steam supply
- Maintenance, both work and material
- Monitoring of the geothermal field

The operational and maintenance cost is roughly estimated to be US$1 million per year for the ORC plant,US$1.3 million for the Kalex plant and US$2 million per year for the Flash cycle plant based on our experience with similar projects.

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Appendix A: List of Reports Reviewed for this Study

1. Geological field works, Magneto-telluric (MT) sounding of the Gridzor and Karkar geothermal fields. Armenia Geothermal Project GEF Grant # TF: 092563. Georisk Scientific Research Company, Yerevan, 2009.
2. Interpretation of MT Results: GT-CS – 2/2008. Renewable Resources and Energy Efficiency Fund of Armenia. Center of Geological Investigations of YSU LTD, Yerevan 2009
3. Magnetotelluric, gravity and soil gas survey, Karkar Geothermal field, Armenia. Operational Report, Volume 1 og 1. Prepared for Armenia Renewables and Energy Efficiency Fud (R2E2), by WesternGeco, Integrated EM Center of Excellence, Geosystem, Schlumberger ItaliananSpA, Milan, Italy. November 2011.
4. Magnetotelluric, gravity and soil gas survey, Karkar Geothermal field, Armenia., 3D Inversion Modellng Report Volume 1 og 1. Prepared for Armenia Renewables and Energy Efficiency Fud (R2E2), by WesternGeco, Integrated EM Center of Excellence, Geosystem, Schlumberger ItaliananSpA, Milan, Italy. November 2011.
5. Independent interpretation of the results of the 3D MT, gravity and CO2 survey conducted at the Karkar Site. Project GEF-CS-4/2008, Final report. Georisk Scientific Research Company and the University of South Florida. Yerevan, 2012.