Integrated Drilling Services for Geothermal Project Laguna Colorada

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Integrated Drilling Services, Bolivia, Laguna Colorada, Sol de Mañana, Drilling.

ABSTRACT

Laguna Colorada in the Sol de Manana Field is the first geothermal project in Bolivia. ENDE plans to drill 25 new wells in the field, yielding a total of 30 wells (including 5 existing wells), with anticipated production of 100 MW for a project life of 30 years. The project is applying a development model called integrated drilling services (IDS). In comparison to the separate contracting of discrete services, the IDS model has important economic, operational, and contractual advantages. This is why ENDE has chosen this approach to carry out one of the biggest geothermal projects in Latin America and one of the biggest IDS applications in the world.

1. Introduction

Bolivia has many potential geothermal fields with a variety of surface manifestations such as hot springs, fumaroles, and other secondary indications. Based on different studies carried out since the 1970s, one of the most promising areas for geothermal development in Bolivia is Laguna Colorada, where the local Sol de Mañana geothermal field is found.

According to the “Patriotic Agenda 2025” (Viceministerio de Electricidad y Energias Alternativas, 2014), Bolivia has formulated objectives to generate electricity through renewable energy such as hydraulic, wind, biomass, geothermal, and solar energy. In response, the government is prioritizing investment in renewable energy to diversify the energy mix of the country. The National Electricity Company (ENDE) is responsible for this and is developing geothermal energy production with the "LAGUNA COLORADA GEOTHERMAL POWER PLANT CONSTRUCTION 100 MW”. The main objective of this project is to generate 100 MW from the Sol de Mañana geothermal field and to supply electricity to the National Interconnected System (SIN) through the Sol de Mañana’s substation, as well as increasing the export of electricity. In addition, this project will benefit the energy mix because this is the first project in Bolivia that will generate electricity with geothermal energy. It will also provide electricity to nearby communities.

To produce 100 MW for at least 30 years, two 50-MW units will be built, and 25 geothermal wells will be drilled. This drilling operation will be conducted using a development model called integrated Drilling Services (IDS) (Schlumberger, 2019).

The scope of the works is to contract the integrated services for the drilling work of 25 deep geothermal wells, of which 16 are for the production of two-phase, water / steam fluid, and 9 are for the reinjection of separated geothermal water. Moreover, the integrated service will include workovers of 5 existing wells (SM1-1V, SM2-1V, SM3-1V, SM4-1V and SM5-1V), 4 production wells and 1 reinjection well. In order to perform this service, it is necessary that the Contractor supplies 2 drilling rigs with all the auxiliary and complementary services, 1 workover rig including the materials necessary to carry out the works.
It is estimated that the drilling should begin in the first quarter of 2020 and for an estimated operation period of 26 months in total to complete the drilling of the twenty-five (25) deep geothermal wells and 5 workover wells that have been planned. In Diagram 1, the number of wells that will be drilled by each drilling rig is shown.

2. Geothermal Field

2.1 Study Area

The Sol de Mañana geothermal field is located in the province of Sud Lípez, in the Potosí department, 20 km south of Laguna Colorada (Figure 1). The elevation of the area is approximately 4900 m above sea level (a.s.l.).

The Project has a concession area of approximately 1030 km^2 and an intervention area of approximately 40 km^2. The main communities near the project area are Quetena Chico and Quetena Grande, located 75 km to the northeast. In addition, there are small communities at Polques, Huayllajara, and Laguna Colorada.

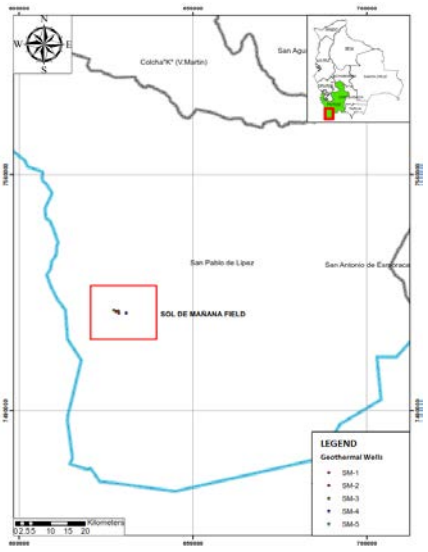


Figure 1. Location of the Laguna Colorada Geothermal Project and the Sol de Mañana field

3. Integrated Drilling Services (IDS)

IDS is an approach to drilling management in which all services and equipment and material procurement are integrated under one contract (Schlumberger, 2019). This model of a contract is technically and economically feasible for the geothermal concessions owners who usually lack all infrastructures for running a complicated drilling project. Instead of making contracts with 15-20 service providers, one can work with just a single contract. Project Management becomes similar and therefore more efficient, and contracting can apply simplifying clauses as "One Down All Down" (that is, if one piece of equipment fails or is interrupted for any reason, the remaining equipment will stop with no charge), to avoid additional costs for the Stakeholder or the Operator, mitigating NPT (non-productive time) impact. Using the IDS approach means only one Commence Date to start the official operation. This encourages the suppliers of various service to work as one team and helps ensure that all Subcontractors under the Contractor will be ready for the Spud Date or Commencement Date.

Further, the IDS approach can lead to improved well design, as well as better selection of rig equipment and technology. Based on terms and conditions, the experienced drilling company is responsible for problem solving, better drilling systems for different well sections, and good operational coordination which usually leads to drilling optimization and cost efficiency.

3.1 Drilling Plan

The assembly of the One Sheet Program allows grouping of different functions in the cycle of project execution, such as Mobilization, Civil Works, Drilling, Well-Testing Services, Facilities and Demobilization, together with project-management stages, such as Initiation; Planning; Execution; Monitoring and Control; and Closing.

In Diagram 1 and Table 1, the estimated plan for drilling 25 wells and workover for the 5 existing wells in Sol de Mañana Geothermal Field is specified. In the same table are presented the estimated drilling times according to the type of well, either producer or reinjector. The times of transfer between wells in the same platform (skidding) and the transfer to wells of different platforms (pad to pad) are not included, because this time may vary according to the type of Rig that is offered.

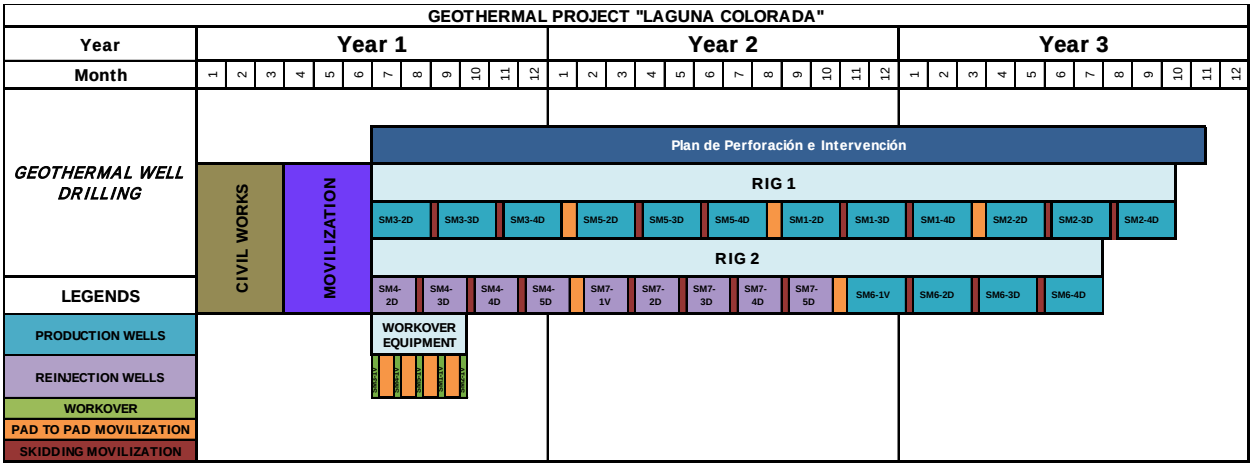


Diagram 1. Time line of drilling new wells and workover for existing wells

3.2 Well design

The existing wells (SM1-1V, SM2-1V, SM3-1V, SM4-V, and SM5-1V) and the 25 new wells to be drilled will be used in the implementation of the 100-MW geothermal power plant for 30 years.

Table 1. Time and quantity of the existing and new wells

	Drilling Time (Approx.)	RIG 1		RIG 2		TOTAL TIME
	Days (ea.)	Quantity	Time days	Quantity	Time days	
Production Wells	60	8	480	8	480	
Reinjection Wells	45	5	225	4	180	
Existing Wells that need Workover	7	3	21	2	14	
TOTAL WELLS		**16**		**14**		**30**
TOTAL TIME, days			**726**		**674**	**1.400**

Figure 2 (left) shows the wellbore design for Well SM1-1V (existing). The other production wells (SM2-1V, SM3-1V, and SM5-1V) have the same well design but have different casing depths. Figure 2 (right) shows the well design used for the reservoir model that will henceforth be referred to as the "Basic Design".

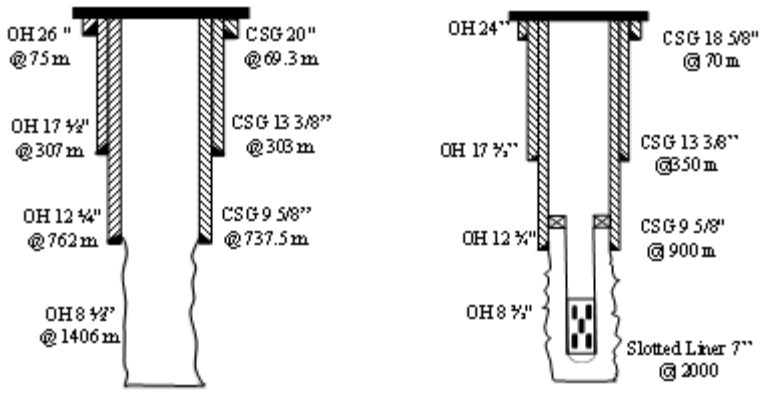


Figure 2. Existing well design (SM1-1V) (left) and Basic Design for new wells (right)

3.3 Required Services

3.3.1 Drilling Services and Auxiliaries

The drilling service must include the equipment detailed in Table 2, necessary for the drilling of deep geothermal wells.

It should be taken into account that the climatic conditions of the drilling site require that the equipment must be protected against extreme cold ("winterized") so that they are able to continue drilling without any interruption due to weather conditions.

Table 2. Technical specifications for drilling equipment

No	Types and Characteristics of Equipment	Requirements	
		Unit	Minimum Values
1	**MAST AND ACCESORIES, (Open Face Cantilever)**		
	Gross Nominal Capacity	M.T.	300
	Hook Load Capacity	M.T.	280
	Travelling block	M.T.	280
	Swivel head	M.T.	280
2	**SUBSTRUCTURE**		
	Pipe Setback capacity	M.T.	230
3	**DRAW WORKS**		
	Power (Consider the height effects over diesel motors performance)	HP	1200
4	**ROTARY TABLE**		
	Capacity	M.T.	340
	Rotary Table Opening	in	37½
5	**"TOP DRIVE", High Torque**		
	Capacity	M.T.	300
	Motor (Electrical)	≥ 1000 HP	
6	**EQUIPMENT WINTERIZATION**		
	Winterized (T_{amb} < – 15°C)	The drilling equipment must be adequate to operate continuously and safely in the weather conditions of the Sol de Mañana Geothermal Field.	

Particular Specifications:

-BOP and Choke Manifold: "closing, opening and pressing" test.

-Safety Valve: The Kelly valve installed in the lower part (Low Kelly Valve)

-Inclination Measurement: Wells inclination in their vertical part must not exceed 5°. The verticality control will be carried out by inclination measurement made at least every 100-200 m.

-Handling, calibration, control and measurement of the casing: Using rabbit (metallic accessory to calibrate and measure the length of casing)

-Non-destructive Inspection

3.3.2 Workover of existing wells

The scope of this section includes the services for the mechanical intervention of four (4) existing wells (SM1-1V, SM2-1V, SM3-1V and SM5-1V) with the objective of installing slotted liner in the fourth and last stage of the well and a minor intervention in one (1) existing well (SM4-1V).

The intervention of the wells includes the following operations:

(1) Well reconnaissance,

(2) Mechanical cleaning from the surface to the bottom of the well,

(3) Running and hanging of the slotted liner from the last well section of the 9 5/8" casing to the bottom of the well.

(4) Change and assembly of the new wellheads (SM1-1V, SM2-1V, SM3-1V, SM4-1V and SM5-1V).

Following is a description of the workover equipment needed:

Table 3. Technical specifications of the workover equipment

a) Mast		Unit	Recommended Value
MAST (Open Face Cantilever)	Nominal Gross Capacity	M.T. [Metric Ton]	110
b) Subestructure and other Equipment			
Capacity		M.T.	200
Set Back		M.T.	80
Motor	Power	HP	450
Drawwork	Power	HP	550
Rotary Table	Diameter	in	17 ½"
c) High Pressure Mud Circulation System			
High Pressure Mud Pump	Power	Hp	600
	Tipo	uni	Triplex
Pits Capacity	Installed	uni	3
	Capacity	Bbl	500
f) Complements	**Features**		
Winch	Two Equipment with 5,000 lbs capacity		
Air Compressor	Own and autonomous equipment for the pneumatic controls of the driller's console.		
Equipos de seguridad	Fire extinguishers, portable oxygen containers, etc.		

3.3.3 Drilling Muds

The Contractor is responsible for supplying and maintaining the characteristics of the drilling fluid, as well as for selecting and adding the necessary additives, which must be considered in its technical and economic proposal, in order to obtain and maintain the physical properties. Chemical additives are recommended according to the formations that are expected to be found and the activities implicit in the construction of the well, such as: mud conditioning for running casing, making drill-pipe connections, or conducting borehole logs.

The drilling-fluid program to be used for each stage must be prepared in advance and delivered to the ENDE Drilling Supervision, without this implying any responsibility in its application and operation for the Supervision.

During drilling in the 24 ", 17 ½" and 12 ¼ "stages, the Contractor must use a water-based drilling fluid prepared with sodium bentonite that has the ability to carry cuttings, to ensure efficient cleaning and control of well that allows to reach the programmed depth in each stage. Only in the case that geothermal water must be used (third stage of the well), the Contractor must use attapulgite for the preparation of the drilling fluid, with the necessary additives for an effective dilution.

For the 8 ½ "diameter stage, it is not permitted to use bentonite during drilling with water or with fluid under balance or controlled flow, so the Contractor must consider this restrictive condition for the preparation of the drilling fluid, including the supplying and dosing of appropriate chemical products that are required according to the mud design, but the Contractor can propose other additives to improve the characteristics of the drilling fluid according to its experience in

geothermal fields, with the objective of achieving a favorable balance of the air flow with the volume of water that allows the mud to act as support in the drag of the drilling cuttings towards the surface. In case the columns are unbalanced, the Contractor must use the most adequate technique to balance the columns and be able to continue with the drilling under balance in coordination with the air-service engineer and the ENDE Drilling Supervisor.

3.3.4 Cementing

The services of casing cementation and the placement of cement plugs are required to control the circulation losses of each of the deep geothermal wells that will be drilled.

Cementing services include the supply of: Personnel, Tools and Equipment, G or H cement, “A” cement, cementing and casing accessories, such as: shoes, collars, centralizers, cementing heads, etc.

The activities of the cementing services will be carried out simultaneously in two drilling sites.

Following is listed the detail of accessories and equipment needed for cementing:

- Pumping Unit for the two drilling sites (1 auto-transportable unit)
- Batch Mixer (one equipment for each rig)
- Auxiliary centrifugal pump (one equipment for each rig)
- Mixing-water preparation and storage tank (two equipments for each rig)
- Vertical pneumatic silos for cement storage, cement mixing and silica flour (one silo group for each rig)
- Cut, mixing and fluidized plant for dry cement, dry-mix cement and silica flour
- Air-supply compressor (two equipments for each rig)
- Transport equipment for pure cement or cement mixtures and bulk silica flour (two equipments)
- Circulation heads for casings (three equipments for each rig in several diameters)
- Cementing head for cement plugs (two equipments for each rig)
- Cementing head for casing cementation by the ´´Stand-In / Stinger´´ method (two equipments for each rig).
- Centralization
- Supply of cementing and casing accessories

3.3.5 Directional Drilling

The wells to be drilled are vertical and directional type, which can be used for the production or reinjection of the geothermal fluid. The directional drilling service is required to include the equipment, tools and personnel necessary to maintain drilling on two drilling pads simultaneously.

The following describes specific works required of the Contractor for directional drilling services:

- Execute the programs and directional designs of each well, in accordance with the drilling program of each well that the Contractor will deliver to the Supervision of ENDE, prior to the start of the activities of each well.

- Provide the necessary equipment and personnel to drill the directional section of each well, prior to starting the K.O.P. (kick-off point) in the vertical section of each well.

- The initial construction of the curve for the producing wells and reinjection wells will be carried out in the 12 ¼ "hole (this diameter may change in some wells depending on the result of the first drilled wells). PDM (Positive displacement motor) + MWD (measurement while drilling) will be used until reaching the angle of the curve and, with the approval of the ENDE Drilling Supervisor, until the end of the stage. For the next stage, the use of the single shot equipment for the directional control of the well has been estimated.

- The Contractor must perform other necessary analyzes, such as: anti-collision analysis due to the presence of nearby wells drilled in the same pad or in pads close to the well in drilling and torque and drag analysis for operations. In most of the pads, a vertical well has been drilled and it is planned to drill more than one directional well on each pad.

- The maximum angle of inclination with respect to the vertical for production wells and reinjection wells is between 20° and 40°.

Figures 4 show the directional proposals of the Production Wells (left) and the Reinjection Wells (right), respectively (wells SM-5A and SM-4A have been taken as reference).

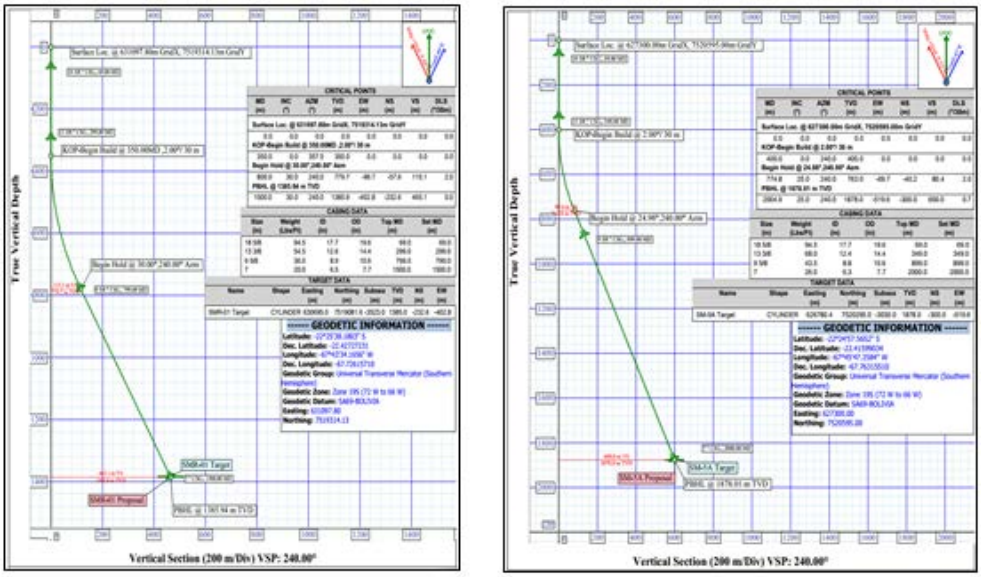


Figure 3. Profile View of Producer Well (left) and Profile View of Reinjection Well (right)

Specifications for Directional Drilling Equipment:

a) Directional BHA (bottom-hole assembly) for 12 ¼” hole:

- Bit 12 ¼”, PDM 8¼”, Float Sub 8”, Short and large Monel collar 8¼”, MWD system

b) Stabilized BHA 8 ½”:

-Bit 8 ½", near bit 8 ½", Drill String Stabilizers 8 ½", Float Sub 6¼”, UHBO 6¼” (universal bottom- hole orientation), Short and large Monel 6¼”, Drill Collar 6 ½”, Hydraulic Jar 8”, Single shot w/Thermal Protection, PDM 6 ¼”.

3.3.6 Wireline

During the drilling of each well, electric logging will be required for drilling process control in regard to the quality of the production pipeline cementation and geophysical logs for the formations characterization found in the interest area of the geothermal reservoir (from the geological point of view). In addition, a calibration log of the holes ("Caliper") will be made to estimate the volume of the well and other characteristics of the same prior to the cementation.

For the production pipes cementation control, a CBL (Cement Bond Log) will be run, for which a sonic tool will be used. The interpretation of this record will seek to obtain an assessment of the state of the cementation, and according to the result, corrective actions to be carried out in the process will be recommended or planned.

According to the design of the wells to be drilled, the "Caliper" logging will be made in the open hole of 12 ¼ "and the CBL will be made in the 9 5/8" pipe.

Required logs are listed below:

***Calibration Log–Caliper (BGT-borehole geometry tool) and Coupling for Production Pipes*:** To evaluate the effective diameter of the 12 ¼ " drilled holes, prior to the 9 5/8" casing running in the hole. The hole calibration logging will be taken with a four-arm probe and volume integrator with maximum opening up to 40" in diameter, including the continuous logging curve of hole deviation.

With this record you must have an estimate of the slurry volumes for the casing cementation, verify the directional parameters such as inclination and direction / azimuth and have the exact location of the 9 5/8" casing coupling.

Geophysical Well Logging: In the fourth stage of 8 ½ " diameter, in some wells, geophysical records will be taken to obtain more information about the formation of the reservoir area, especially focus on fractures and faults, inclinations of the geological structures and areas of hydrothermal alteration associated with the presence of characteristic minerals of geothermal reservoirs, in order to identify the permeable zones that allow the passage of hydrothermal fluids within the geothermal system and obtain information on the lithological characteristics of the geothermal reservoir.

Geophysical Logs to run are the following: Sonic Log, Density Log (DL), and Fullbore Formation Microimager (FMI).

***Special Logs and Services*:** Free-Point Indicator Tool (FPIT), Back off Service, Packer Run Service.

3.3.7 Under-Balanced Drilling

Air Drilling Services (under-balanced drilling) are required to drill the reservoir stratum in the fourth stage of the 8 ½ "diameter wells.

The service considers personnel, equipment, tools and the supply of additives for under-balanced drilling operations.

An under-balanced drilling program must be designed which must be supported by a model of the hydraulic conditions in the well, such simulation program must allow to evaluate the following conditions:

-If the conditions of under-balanced drilling can be achieved during drilling.

-The pressure drops, which must be within the ranges (lower and upper limit).

-If it gets adequate cleaning of the hole.

- Necessary work for the PDM.

***Equipment*:** Screw air compressor, booster compressor, safety slings, pumping system and additive mixer, pumping system and additive injection, flow meter (Daniel type), barton recorder, flow meter (Nuflo type), high-pressure line, rotary well head, banjo box, vertical atmospheric separator, isolation valve 10'' API 2000, manifold, spare parts, materials and accessories, warehouse, jet subs, control valve 10'' API 2000, diesel fuel tank, echometer and oximeter.

3.3.8 Drilling Parameters Control

The service includes the Control of the Drilling Parameters (Data Acquisition) during the drilling of the geothermal wells and during the Intervention of the Existing Wells. Taking into account that two (2) drilling rigs will be operated simultaneously, the service is required for each rig.

***Monitored Drilling Parameters*:** Well depth, inlet and outlet mud temperature, pump strokes, mud flow, drilling mud pump pressure, weight over bit and traveling block, velocity of rotary table (RPM) or top drive, torque of rotary table or top drive, rate of penetration (ROP), gas monitoring (CH_4, H_2S y CO_2), fluid level and volume in the hydraulic system tanks of the drilling equipment.

3.3.9 Well Geology

Macroscopic Analysis

During the well drilling, rig personnel will take a cutting sample for every five (5) meters drilled, with a minimum weight of 300 grams. Then the geologist's technical assistant must wash, dry and pack the sample in plastic containers previously labeled. With the help of a stereoscopic microscope, the well geologist will perform the analysis of the cuttings samples and thus determine the lithological column and the hydrothermal alteration conditions of the well.

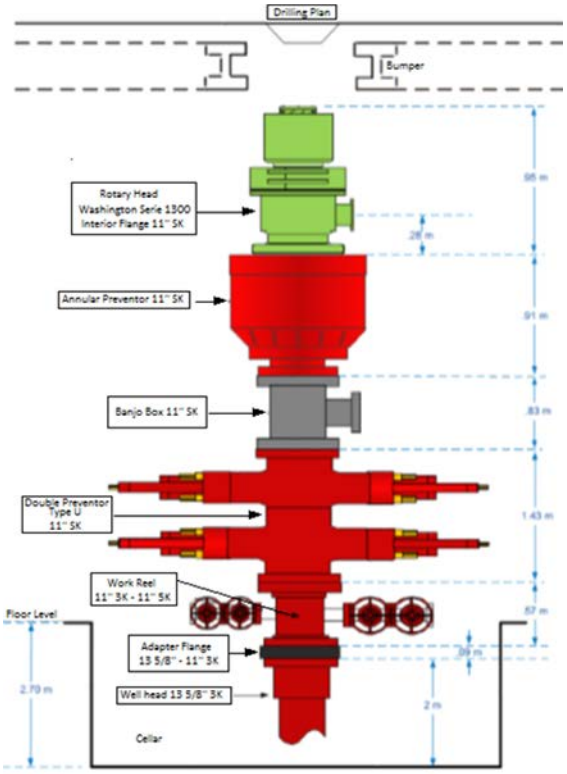


Figure 5. Well Head for Under Balanced Drilling

This analysis of the cutting and core samples will define the following main characteristics:

- Lithology and primary mineralogy

- Texture and structure

- Mineralogy of hydrothermal alteration

- Degree of hydrothermal alteration

- Recognition of hydrothermal facies (preliminary)

- Color, hardness, degree of consolidation

- Identification of fractures and fissures, fracture intensity, mineralogy in fractures

- Density, abrasivity, stability, content of despicable clays (approximate)

- During drilling, a continuous digital record will be taken with software STRATER or compatible.

Microscopic Analysis

In order to corroborate and extend the results of the macroscopic analysis and quantify the primary and allogenic mineralogical alteration of the intercepted lithological types, microscopic analysis of the cut samples approximately every 10 meters drilled will be available.

The analysis will be done using a polarized light microscope that will be included in the geology equipment for each rig.

The microscopic analysis of the cutting and core samples will define the following:

- Quantification of hydrothermal alteration minerals.

- Lithology and mineralogy.

- Primary and secondary textures, structure and complete description of the matrix and phenocrysts.

- Quantification of hydrothermal alteration minerals and alteration degree

- Determination of the limits of the hydrothermal facies and the stabilization temperature ranges of minerals correlated with the temperature ranges of formation measured in the well.

3.3.10 Drilling Waste Management

The main objective is that the mud and drilling waste be properly treated in such a way that the cuttings will be recovered for their final disposal in the authorized place that the Operator designates for it, and the residual liquid must be stabilized (primary treatment) before be reused to mix it in the mud circuit that is kept in circulation in the well and / or before its final disposal in a reinjection well.

It is expected that at the end of each well there will be no sludge residue, which should be understood that an efficient sludge management system is expected and that does not generate contamination on the drilling platforms. The Contractor can offer the system it deems most convenient to meet the stated objective.

***Cutting Treatment*:** The cuttings coming from the shakers, desander and desilter, should come out semi-dry from the shaker dryers, and will be collected in a cutting reception tank, from which-according to the rate at which it is being filled- it will proceed to extract them by means of a loader, later the discarded solids will be loaded to a dump truck that will transport them to the burial area in the place that the Operator has established for their collection. At the end of each well, the cuttings must be mixed with the land of the place, which will be complying with the parameters proposed by the Environmental Law No. 1333.

The water in the pit (fresh water + liquid from the cut-off receiving tank) will be re-pumped to the mud tanks for reuse and pumping to the well for drilling.

3.3.11 Liner Hanger 7” x 9 $^{5}/_{8}$”

In this section are the technical specifications for a complete service for the supply and installation of hangers for casing (liner) are defined, during the drilling of twenty-five (25) geothermal wells and in the intervention of four (4) existing wells. The remaining existing well, already has a liner. Table 4 shows the technical information corresponding to the Hanger and Liner (7'')

Table 4. Technical data for liner hanger

DESCRIPTION	TECHNICAL DATA
Liner Hanger and Setting Tool Features	
Hanger Diameter	7''
Hanger Type	Mechanical Double Slips
Slip Type	J – Slot Derecho (Right Hand)
Steel Grade	N–80 / L–80
Max. Anchorage	60 T.M.
Setting–tool	NC–50
Drift	6 ¼''
Liner Features	
Nominal Diameter	7''
Nominal Weight (Range)	26 lb/pie
Steel Grade	K–55
Anchorage Casing Features	
Nominal Diameter	$9\ ^{5}/_{8}$''
Nominal Weight (Range)	47 lb/pie
Steel Grade	N–80
Anchorage Conditions	
Hanger Nominal Diameter	7''
Max. Operational Temperature	280 °C
Max. Well Inclination	30°
Max. Depth of Anchorage Point	900 – 2000 m

3.3.12 Coring

According to the proposed drilling program drilling cores will be taken at different depths, or when, in an unscheduled manner, it is necessary and required by the Geology Supervisor. These cores will be cut with a length of nine (9) meters and a minimum of four meters (4 m) and 3 ½ "in diameter. The staff of the RIG will take appropriate measures so that the extraction of the witness does not cause any alteration or damage to it.

The drilling program foresees the taking of at least one core for each well, in the fourth stage of drilling (hole of 8 ½ ").

The cores will be cut mainly in areas of geothermal reservoir, therefore, it is very likely that the cutting operation will be carried out in conditions of total circulation loss.

3.3.13 Well Logging

The scope of this service is to perform all the measurements (pressure, temperature and flow logs) that are needed from the beginning of the drilling of a well to the thermal recovery after the completion of the same, as well as measurements and logs at the end of 4 existing wells intervention.

The following equipment must be available in field:

- KTB with ranges of 30 to 210 °C, 30 to 300 °C

- KPG with ranges of 0 to 210 bar, 0 to 350 bar

- Spheres for calibration of wells of different diameters and HWDP

- Several ranges Watches (3, 12, 24 hours)

- Wincher of 2.5 HP, 3000 cable meters with a diameter of 0.108", stainless steel, with tensiometer

- Amerada and Kuster (or equivalent) gauges

The following table shows the measure type to be carried out:

Table 5. Measures plan

Log/Test	Description
Thermometry	Thermal recovery logging at a specific point in the well to extrapolate the formation real temperature .
Dynamic Temperature Log	Identify loss zones
Injectivity test at several pumping rates	To determine injectivity rates
Fall – off of 20 max hours	Determine well skin and permeability
Pipes Calibration	Know the pipe physical condition, post injectivity test.
K–10 Electronic Measure	It is consider in the well recovery stage

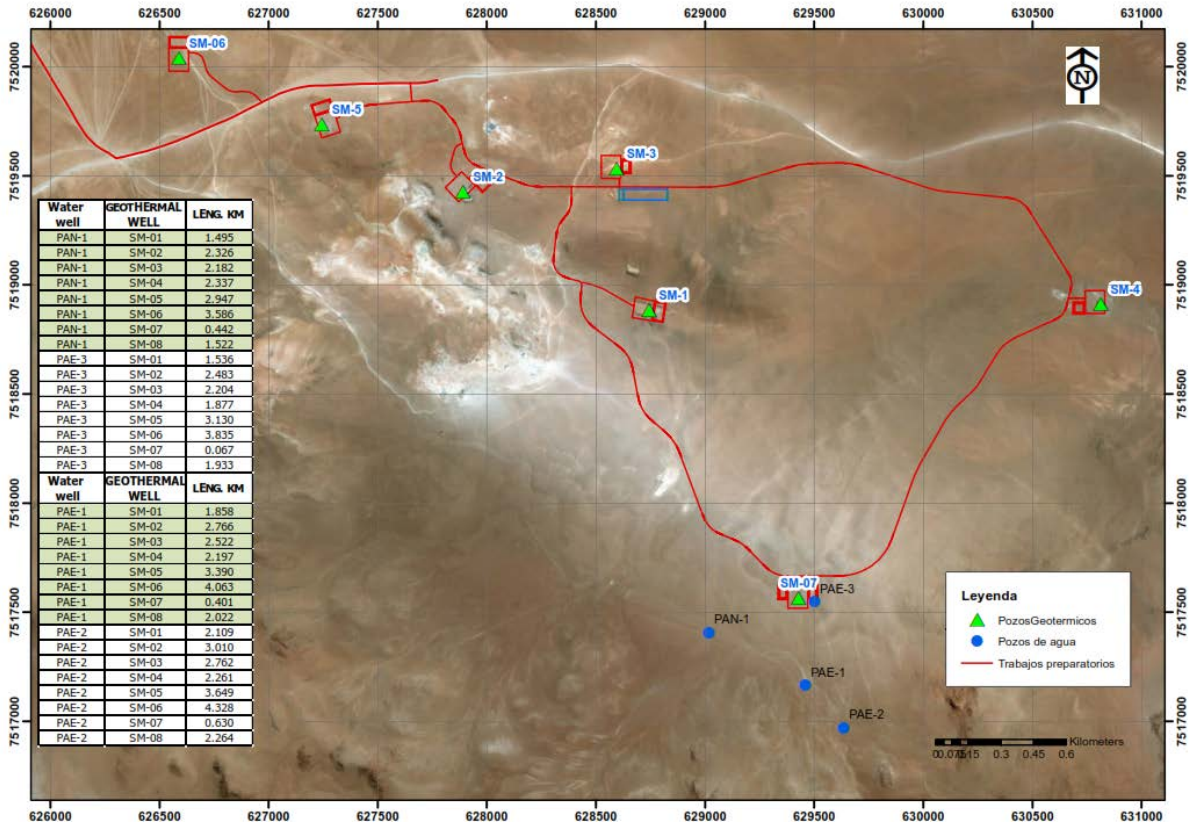
3.3.14 Water supply

The water can be supplied through: water wells (already existing), geothermal water and water springs.

***Water Wells*:** The project has five (5) fresh water wells located in the Sol de Mañana Field, which produce a flow of approximately 63.7 lt /s in total, as shown in the following table:

Table 6. Water Wells

WELL	EAST COORDENATE (m)	NORTH COORDENATE (m)	MEASURED FLOW (lt/s)
PAE–1	629457	7517164	7
PAE–2	629633	7516972	9.3
PAE–3	629499	7517550	14.2
PAN–1	629015	7517409	18.5
PAN–2	629140	7517770	14.7
		TOTAL	**63.7**



Water well	GEOTHERMAL WELL	LENG. KM
PAN-1	SM-01	1.495
PAN-1	SM-02	2.326
PAN-1	SM-03	2.182
PAN-1	SM-04	2.337
PAN-1	SM-05	2.947
PAN-1	SM-06	3.586
PAN-1	SM-07	0.442
PAN-1	SM-08	1.522
PAE-3	SM-01	1.536
PAE-3	SM-02	2.483
PAE-3	SM-03	2.204
PAE-3	SM-04	1.877
PAE-3	SM-05	3.130
PAE-3	SM-06	3.835
PAE-3	SM-07	0.067
PAE-3	SM-08	1.933
Water well	GEOTHERMAL WELL	LENG. KM
PAE-1	SM-01	1.858
PAE-1	SM-02	2.766
PAE-1	SM-03	2.522
PAE-1	SM-04	2.197
PAE-1	SM-05	3.390
PAE-1	SM-06	4.063
PAE-1	SM-07	0.401
PAE-1	SM-08	2.022
PAE-2	SM-01	2.109
PAE-2	SM-02	3.010
PAE-2	SM-03	2.762
PAE-2	SM-04	2.261
PAE-2	SM-05	3.649
PAE-2	SM-06	4.328
PAE-2	SM-07	0.630
PAE-2	SM-08	2.264

Figure 6. Location and distance between water wells and geothermal wells

***Water Springs*:** Always with the aim of ensuring the supply of fresh water for drilling, the Contractor is expected to include, the supply of at least two tank trucks with a capacity of 25-30 m3 to transport water from the near water springs to the project area. Furthermore will be built 1 pit approx. 5000 m3 in each pad to receive the operating water from sources.

The recognized water springs are: Silala, Pupusitas and Agüita Brava.

***Geothermal Water*:** It is foreseen that for the third and fourth stage drilling, geothermal water from the production tests of the drilled wells or wells that are open for other purposes will be used. For the use of geothermal water, the use of attapulguite is recommended for the drilling of the third stage of the wells, however, for the fourth stage polymeric materials should be used, such as CMC (Carboxymethylcellulose).

Geothermal water can be stored in the pits located on each platform or in the pit that facilitates pumping to the well where needed.

3.3.15 Fishing

The Fishing Service is required to include the equipment, tools, accessories and personnel necessary for fishing operations on two drilling platforms simultaneously.

Equipment list required for fishing operations is: Overshot (GOTCO type), filling jar, magnetic fishing, safety joint (Bowen type), taper tap, wash over, junk basket, lead impression block, spears for 5", others (Junk Mills, etc.)

3.3.16 Communication and Data Transmission

A telephone communication system, satellite internet and communication shall be installed with the Superintendent's office, Contractor's Drilling foreman, Drilling Supervisor Office and ENDE in each rig (4 lines per rig).

Likewise, telephone communication, satellite internet and communication with the offices of the Drilling Supervisor and ENDE must be installed in the base camp, in addition to the office of medical personnel (3 lines in base camp).

The minimum service speed requirement is 1024 Kbps, both for telephone and internet communication.

3.3.17 Main Camp and Catering

The Contractor shall provide in each drilling pad, accommodation for ENDE Supervision personnel, for the personnel themselves and for the personnel of their subcontractors who are working on the drilling pad.

The location of the base camp will be in the surroundings of the Sol de Mañana geothermal field. ENDE, in conjunction with the Contractor, will verify on the site the best location of the facilities of the base camp, trying not to affect the tourist areas of the site and maintain the necessary proximity to the water and electricity supply.

Since the base camp will be in the same geothermal field of Sol de Mañana, the Contractor must have a polyclinic and an ambulance to assist the staff with the respective medical personnel.

With regard to the polyclinic and ambulance, it is necessary to have medical personnel and a driver who must be available 24 hours a day.

With respect to the Dining Room on the drilling pad, the Contractor shall provide the feeding at the drilling site for its own personnel, for the personnel of its subcontractors and for the ENDE Supervision personnel. Cleaning and laundry service must perform daily, with transportation of the garbage to assigned places, and the water supply for the services. The place of disposal of the garbage, in an authorized dump, which will be defined by ENDE later.

3.3.18 Slotted Liner Service (7”)

The scope is the manufacturing services of slots / holes for 7" casing pipes to be used in the wells to be drilled in the Sol de Mañana Geothermal Field and in the four (4) existing wells.

Service Requirement:

- Perforation of 28 holes / meter of 50 mm in each tube, the holes in each tube will be made from 1.0 m from each end of the tube. The approximate length is 11.5 m each tube.

- The pipe specifications are: steel casing, 7" outside diameter, K-55 Steel type (API standard), 26 lbs/ft, wall thickness 0.362" (9.2 mm). The tubes are of the Seamless type with integral joint (pin and box) in each of their ends, the thread is semi-premium type.

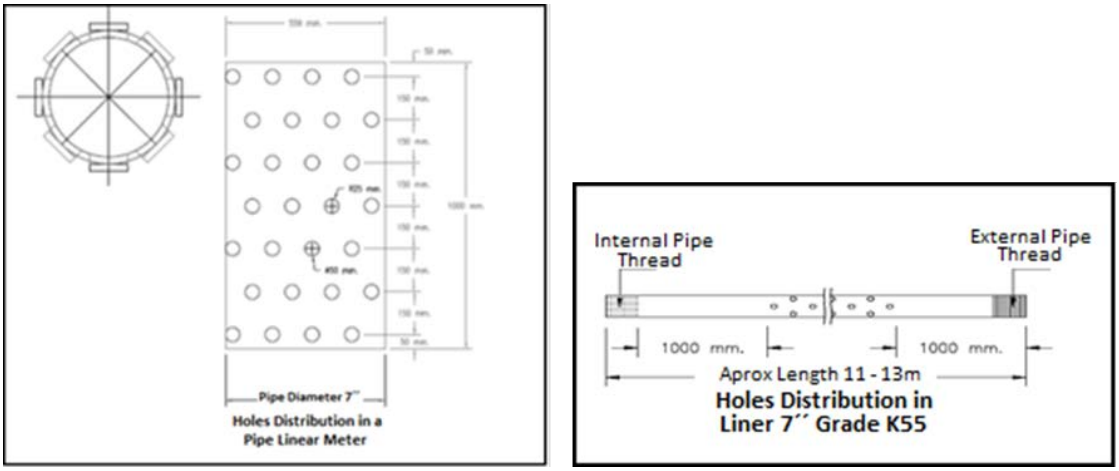


Figure 7. Slotted liner 7"

3.3.19 Casing running and Inspection

Service for casing and slotted liner running for the tubing in different sections of the well to be drilled and for liner running and installation in four (4) existing wells. Before each casing running, the contractor shall perform an inspection of all casing pipes that will be run in the wells for the different sections. This inspection shall comply with the visual inspection and non-destructive inspection required by the API 5 CT Standard. This services are summarized below:

-Inspection, running, cementing preparation for casing pipes of 18 5/8", 13 ⅜", 9 $^{5}/_{8}$".

-Inspection and running for Liner of 7", 26 lb/ft, K–55. Contractor must coordinate the liner hanger service inside the 9 5/8" Casing.

Equipment:

- Special equipment supply necessary for handling, transfer and elevation of the pipes from the "Rack" to the drilling floor, and their placement in a suitable position for the screwing.

-Equipment and materials (grease, "thread lock") necessary for the screwing and appropriate torque application to each pipe according to the technical specifications with the due precaution of not causing damage to the pipes.

-Cementing elements assembly (cementation head) or pipe preparation for cementing process, as appropriate, to deliver the well to the Cementing Contractor in conditions ready for operation.

3.3.20 Tubular Maintenance and Inspection (BHA, DP, etc.)

This Service consists on non-destructive inspections and repairs to tubulars (BHA elements, DP, PDM, etc.) according to API standards.

The inspections type to be done are:

- Inspection of drill pipe thread and body,

- Inspection of Drill Collar and Heavy Drilling Pipe (HWDP) thread and body,

- Inspection of subs, stabilizers, hole openers and reamers.

- Inspection of Drilling / Fishing Jars, PDM and shock absorbers.

- Threads Repairs (field re-facing or buffing).

- Hard banding Welding

Following are detailed the inspection requirements:

Body**:** Electromagnetism for leak detection, Pipe wear, Pipe thickness, Visual pipe inspection, Cross sectional area, Magnetic particle inspection (MPI)

Joint**:** Dimensional, Thread Magnetic particle inspection, API calibration

3.3.21 Assembly of Well Production Test Equipment

Single Well Production Test: Once the drilling of a producing well and its respective thermal recovery (30 days) have been completed, ENDE Supervision will give the Assembly Order of the test equipment. The Contractor will be responsible for the transfer, assembly, connections, supports installation, valves, silencers and all the materials and equipment required to perform the well test.

For this test is necessary a production well, reinjection well and the equipment (Service valves, weir box, silencer, pipes and accessories)

Multi-well Production Test**:** In this type of test will be involved four (4) production wells simultaneously, so the assembly process of the production test system explained above will be carried out simultaneously in four (4) different wells, as well as the installation of the reinjection pipe and connection between 2 or 4 reinjection wells. To begin the test is important to consider a 30 days Thermal recovery of the last drilled well of the pad.

3.3.22 Drilling Pad Maintenance and Clean Up

This activity contemplates all necessary operations to perform the maintenance of the platforms during the drilling operations.

It is considered that well pads should be maintained in a constant manner while preserving the initial conditions in which ENDE delivered (level, compaction, density and finishing conditions).

This activity includes:

- Mobilization of personnel, necessary equipment, etc.

- Provision, fuels management and all required material.

-All work that is necessary during the activity.

-The cleaning of the area or work area of activity waste.

3.3.23 Civil works

The Contractor must consider all the necessary technical aspects that guarantee the adequate execution of civil works and operations. Likewise, the design, verification, construction (equipment and personnel), material supply and operation are of their entire responsibility.

After the construction, they must clean the working area, complying with the legal, labor, environmental and safety regulations in force in Bolivia.

The required works are listed below:

- Pad Construction (7 pads)

- Rig Foundation Construction (One for each pad)

- Cellar Construction (25 cellars including 36” conductor pipe in a depth of 6 meters)

- Pits Construction (8 pits of 5000 m3 each)

- Pads Access Roads Maintenance

3.3.24 Integrated Service Management

The Contractor will perform the Integrated Services Management, with personnel of proven experience, the management must be carried out efficiently to achieve the objectives of the project for the drilling of 25 new wells and 5 workover in the existing wells.

The positions of the minimum personnel required for the Management of the Integrated Service are listed below:

1. Integrated services manager

2. Senior drilling and intervention engineer

3. Operations coordinator

4. Engineer or equivalent contracts specialist

5. Billing and cost control

6. HSE health, safety~~,~~ environment~~;~~

7. Logistics supervisor

8. Community relations

9. Civil works supervisor

10. Logging and well test engineer

11. Senior geologist

4. References

ENEL. “Proyecto Geotérmico Laguna Colorada Ampliación de Perforaciones Geotécnicas – Perforación del Pozo Sol de Mañana 5 (SM-5).” (1994b)

Schlumberger. "Integrated Drilling Services and Projects." Web site accessed 15 March 2019: https://www.slb.com/services/additional/integrated-oilfield-projects/integrated-drilling-services-projects.aspx. (2019)

JICA. “Asistencia Especial para la Implementación del Proyecto (SAPI) para el Proyecto de Construcción de la Planta Geotérmica Lagua Colorada (Fase 1 de la Primera Etapa).” (2015)